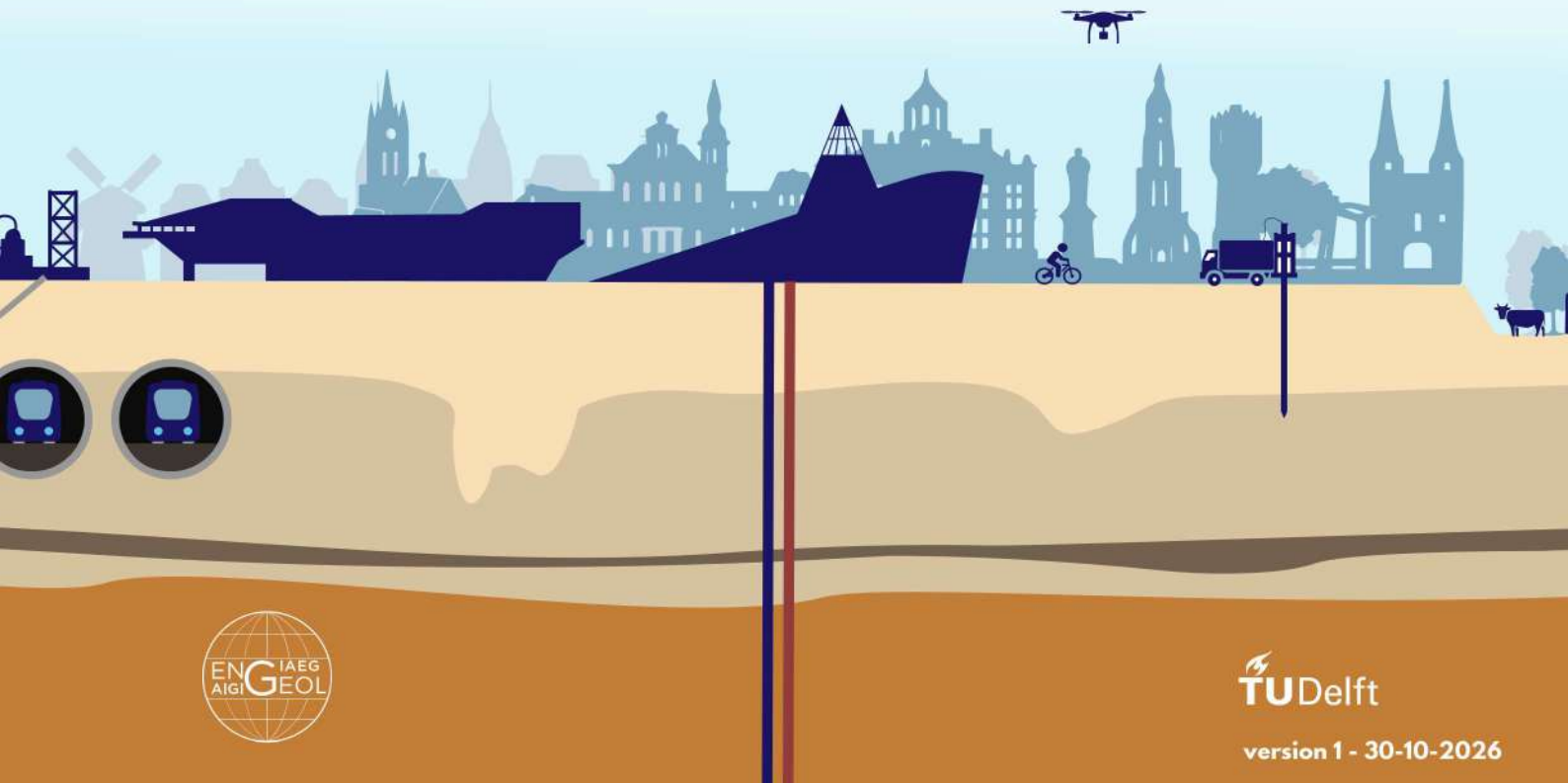
Dominique Ngan-Tillard, Leon van Paassen, Denise Maljers

IAEG 2026 Engineering Geology in a Rapidly Changing World

Book of Abstracts of the XV World Congress of the International Association for Engineering Geology and the Environment

30 Oct. - 6 Nov. 2026 | Delft, The Netherlands



TU Delft

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Welcoming Message



It is a great pleasure to host the **XV IAEG World Congress 2026**, in Delft, the Netherlands, between 30 Oct and 6 Nov 2026.

The congress, titled **Engineering Geology in a Rapidly Changing World**, focuses on cutting-edge research on the fundamentals of Engineering Geology. It showcases best practices in the domain, and demonstrates the pivotal role of engineering geology in a world struggling with unprecedented challenges.

The world is changing rapidly: cities are expanding, climates are shifting, natural hazards are intensifying, and human impacts continue to grow. At the same time, engineering geologists have access to powerful new tools and knowledge that can transform ground-related challenges into opportunities and help build a safer, more sustainable future.
Whether you are presenting a paper, pitching a poster or attending as a regular delegate, explore how innovation, research, and education are shaping the future of engineering geology and take part in this dynamic exchange of ideas.

The IAEG 2026 Book of Abstracts contains 555 accepted abstracts. 250 of them are associated to a paper published by TU Delft OPEN Publishing in The Evolving Scholar| IAEG 2026 and will be part of the Proceedings of the 15th IAEG World Congress IAEG 2026: Engineering Geology in a Rapidly Changing World, 30 October to 6 November 2026, Delft University of Technology, The Netherlands. You can already click on **dois** in the abstract footers and inspect your paper or discover articles authored by others.

Thank you for your participation in the XV IAEG World Congress 2026 and to the collective efforts that will shape the future of Engineering Geology.

Special thanks to:
- the IAEG 2026 authors, reviewers, chairs and co-chairs
- the sponsors and exhibitors

for helping make the IAEG 2026 Congress truly memorable.

The IAEG 2026 editorial board
Dominique Ngan-Tillard, Leon van Paassen, Denise Maljers

Editorial support:
Coco Man, abstract bookmaker
Sophie Ngan, Nikolaos Antoniadis, and Annemieke van Ast: design of the book illustations

Congress themes in detail

The XV IAEG World Congress 2026 brings together expertise, experience, and groundbreaking ideas from across the globe, reflecting the full diversity of engineering geology and its associated disciplines. The Congress showcases themes that are shaping the future of the profession, from traditional engineering geology and major infrastructure projects to sustainability, climate change adaptation and mitigation, and emerging technological approaches.





1. Innovation in Ground Modelling

From Site Investigation to Ground Models.
Showcase of new Engineering Geology tools for (sub)surface investigation and modelling. Emphasis on new technology for geotechnical property determination, 3D modelling, and in situ monitoring. Special attention to challenging environments: offshore, onshore, cities, nature reserves, mountains and outer space.

2. Low Lying, Coastal, Soft Soil Countries

Engineering Geology for a sustainable future in densely populated low lying, coastal, deltaic, and soft soil countries. Priority on subsidence, coastal erosion, and flood protection, including water management.





3. Geohazards

Engineering Geology and managing natural and man-made geohazards through identification, monitoring, modelling, prevention, mitigation, and adaptation. Focus on landslides, earthquakes, volcanoes, tsunamis, karst subsidence, droughts, erosion, and flooding. Special attention to cascading multi-hazards.

4. Engineering Geology in the Energy Transition

Role of Engineering Geology in CO_2 sequestration, energy storage, geothermal energy, wind energy, hydropower, and nuclear energy.



5. Use of the (sub)surface



Emphasis on successes, failures, and forensic analyses in geotechnical engineering. Special attention to challenging environments and prestigious projects. Engineering Geology focus on mining ores, rare earths and aggregates, induced geohazards, (post)mining risk management, resilient infrastructure, dredging and compensation for nature, building-with nature and smart bio-geomaterials.

6. Environmental Engineering



Engineering Geology for a virtuous clean water cycle and circularity in waste management. Focus areas include landfills, tailings dams, desalination, contaminant transport and treatment, innovative microplastic removal techniques, and sludge recycling.



7. Engineering Geology for preservation of heritage

Highlight of Engineering Geology techniques for the characterization and preservation of geological, archaeological and industrial sites combined with policy and management. Special attention to building stones and ancient mines.

8. EG in the Digital transition and AI revolution



Focus on 3D geo-mapping, learning from big data sets, Artificial Intelligence, and Virtual and Augmented Reality in Engineering Geology.



9. Boosting Engineering Geology

Added value of Engineering Geology. The **B**ulletin **o**f **E**ngineering **G**eology and the Environment: past, present, future. Innovations in Education and training in Engineering Geology. The **Y**oung **E**ngineering **G**eologists (YEG) and **W**omen in **E**ngineering **G**eology (WEG).

10. Special sessions

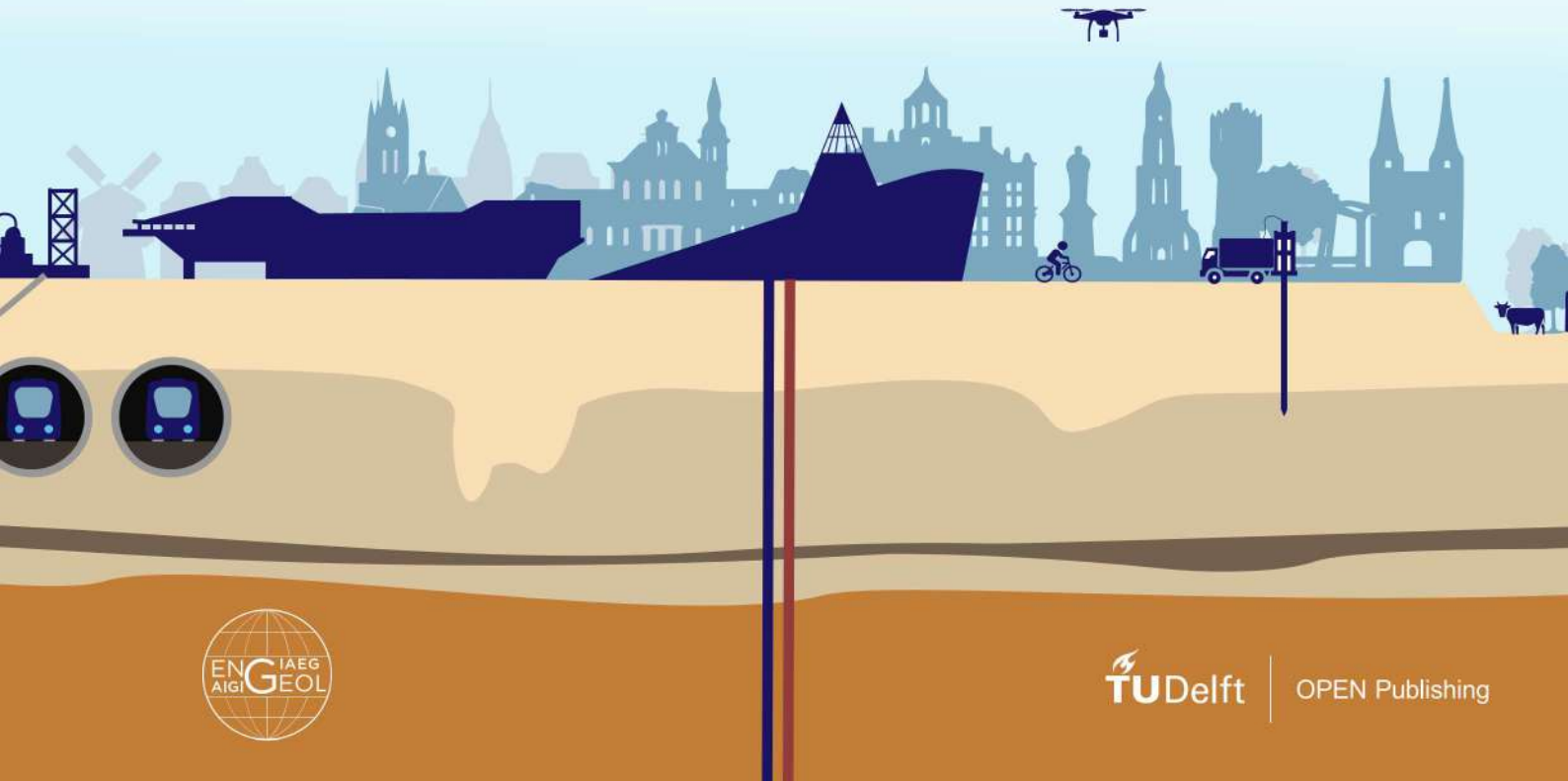


Special highlights on prestigious projects and technological advances in Europe, China, and beyond, as well as the special community session, Facing the Unthinkable: Science and Responsibility after the Nepal-China Border Cascading Disaster, which brought together participants for solidarity, reflection, and scientific exchange.

1. Innovation in Ground Modelling



From Site Investigation to Ground Models.
Showcase of new Engineering Geology tools for (sub)surface investigation and modelling. Emphasis on new technology for geotechnical property determination, 3D modelling, and in situ monitoring. Special attention to challenging environments: offshore, onshore, cities, nature reserves, mountains and outer space.



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On the General Engineering-Geological Classification of Geological Processes and Phenomena

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[2] President of Georgian Society for Soil Mechanics and Geotechnical Engineering, Tbilisi, Georgia
[3] Founder and Chairman of Supervisory Board of Geoengineering Ltd, Tbilisi, Georgia

Abstract

As science evolves, it becomes essential to assess past theoretical and practical achievements to guide future research—particularly in the advancing field of engineering geodynamics, a core area of engineering geology. Engineering geodynamics is a field focused on the formation and evolution of natural and human-induced geological processes, especially in relation to construction and land use. Its aim is the rational use of geological environments and the prevention of hazardous events. Advancing this field requires a general classification of geological processes and phenomena that addresses practical engineering needs: Universality – it should encompass all currently known geological processes and events, whether natural or anthropogenic (particularly those related to construction, resource development, and land use); Clear conceptual definitions – especially for terms such as "geological process" and "geological phenomenon"; Distinction between formation and development conditions – taking into account contributing factors and their causes; Practical usability – the classification must be simple and convenient to apply in addressing both theoretical and real-world engineering problems; The new classification should serve as a methodological foundation for studying geo-ecological problems caused by the activation of geological processes and phenomena related to global warming, and for developing preventive strategies; It should act as the primary guide for creating regional, specific, and specialized classifications of geological processes and phenomena; The concepts and terminology used in the classification must be clearly defined and accurately reflect objective reality. This work aims to present a new general engineering-geological classification of geological processes and phenomena, based on comparative analysis, objective reasoning, and sound methodology.

Keywords: Engineering geodynamics, Geological processes, Classification system, Geohazards, Geo-environmental modeling

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A Novel Approach for 3D Subsurface Modelling of the Subsiding Coastal Green Heart Area, the Netherlands

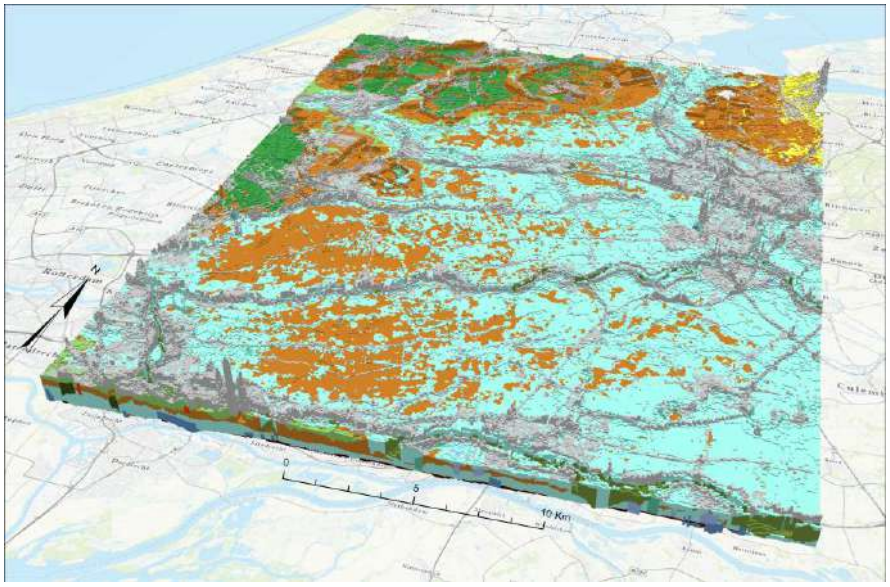
Reinder Reindersma[1], Jan Stafleu[1], Romée Kars[1], Anuska Kaliar[1], Chris Heerema[1], Bart Meijninger[1], Tessa Witteman[1], Kay Koster[1]

[1] TNO Geological Survey of the Netherlands, Utrecht, Netherlands

Abstract

Land subsidence in densely populated coastal areas is a major hazard, especially in view of global sea-level rise. It poses the threat of flooding and groundwater salinization, it inflicts damage to the built-environment and has negative impacts on ecosystems. To mitigate land subsidence processes, a thorough understanding of its drivers is required. A critical element for this is a full understanding of the coastal subsurface. Knowing the architecture of subsurface coastal features, their lithological composition, and characteristics such as permeability and organic matter content, aid in understanding spatial patterns of land subsidence. For this purpose, in recent decades, research advancements within the field of human-induced subsidence focused on the development of 3D subsurface models of unconsolidated sediments. We present a workflow for the development of a 3D geological subsurface model custom made for land subsidence analysis of the Green Heart area in the coastal plain of the Netherlands. The presented workflow and model is a special customization of an existing workflow for GeoTOP, a high-resolution 3D voxel model of the Netherlands. The Green Heart area is characterized by several meters thick peat beds and severely affected by human-induced land subsidence. To mitigate subsidence, a thorough understanding of the spatial distribution of subsidence processes and rates is required. The presented workflow encompasses the automated stratigraphical interpretation of thousands of boreholes and Cone Penetration Tests, the manual mapping of soft soil layers, layer-based and voxel-based interpolation using kriging procedures, and implementation of peat void ratio and organic matter content as parameters of the voxels. With this, the model is deployable for further land subsidence analysis.

Keywords: 3D modelling, peat, Cone Penetration Test, Borehole, Land subsidence



3D lithostratigraphy of the Green Heart area

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Evaluation of anthropogenic transformation of urbanized areas based on archival topographic maps and its impact on modeling of geological structure

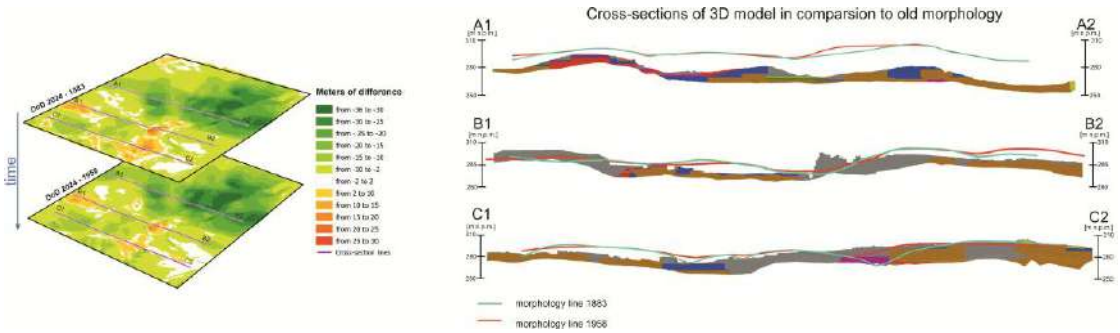
Adam Popławski[1], Aneta Horbowicz[1], Szymon Zaręba[1]

[1] PGI-NRI, Warsaw, Poland

Abstract

Urban areas with a long industrial history, such as the region around Bytom (Poland), have undergone significant terrain transformations, both natural and anthropogenic. Despite the availability of modern elevation data, the long-term evolution of landforms in such areas remains poorly understood due to limited integration of historical topographic information. This project aims to reconstruct and analyze changes in land surface morphology over time using a combination of modern and archival data. The hypothesis is that archival topographic maps, when integrated with modern 3D ground modeling techniques, can significantly improve the understanding of terrain evolution and reveal the extent of anthropogenic impact. A 3D geological model was developed using data from the Engineering-Geological Database (BDGI), and a series of archival digital elevation models (ADEMs) were generated from historical maps. Present-day and archival geomorphon maps were compared to identify morphological changes. Additionally, DEMs of difference were computed to quantify changes and locate areas with high surface uncertainty. Cross-sectional profiles were established to visualize surface evolution. The final 3D model was enhanced by integrating historical morphological features to better reflect urban terrain transformations. This approach demonstrates the importance of using archival maps in 3D ground modeling and provides insight into the spatial extent of anthropogenic changes, offering valuable input for urban planning and environmental assessment in post-industrial regions.

Keywords: urban geology, 3D modelling, engineering geology, anthropogenic transformations, geomorphology



Cross-sections of 3D model in comparsion to old morphology

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Geological-engineering regionalization in Poland

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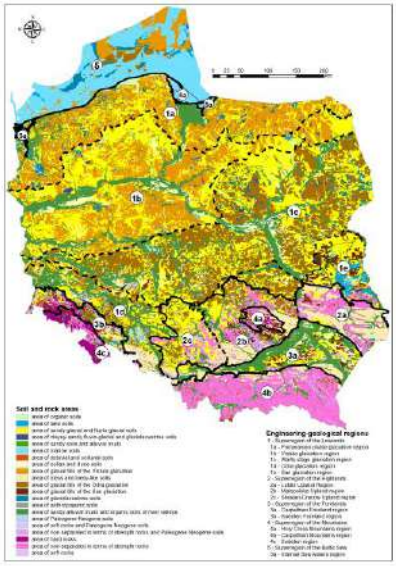
[1] Polish Geological Institute - National Research Institute, Warsaw, Poland

Abstract

The aim of the poster is to present geological-engineering regionalization in Poland, including on offshore and onshore. Geological-engineering regions were distinguished for the purposes of determining and assessing geological-engineering conditions in the scope of investment planning and land use. Regions were described as homogeneous parts of the geological environment, separated on the basis of a specific criterion - features of the geological environment. Geological-engineering regionalization consisted in identifying units with specific boundaries, distribution and characteristics. Geological-engineering units were separated on the basis of one feature or a set of specific features. As a result of the conducted analyses, geological-engineering units of various orders were distinguished, depending on the adopted division criterion. The higher the level of the engineering-geological unit, the greater the diversity of geological profiles in its individual parts, which means lower geological homogeneity, more uncertain assessments of engineering-geological conditions and forecasts of changes (Kowalski, 1978). In Poland, engineering-geological regions were distinguished, which are characterized by a common style of geological structure. The regions were grouped into superregions, areas characterized by a similar style of geological structure. Based on the criterion defined in this way and on the proposals of Glazer and Malinowski (Glazer, Malinowski, 1991) and Majer, Sokołowska, Frankowski (Majer, Sokołowska, Frankowski (ed.) at all 2018), 14 engineering-geological regions were distinguished and described in Poland.

Keywords: geological-engineering regions in Poland, geological-engineering conditions, soils and rocks occurring in Poland, geological risk, geohazards



Geological-engineering regions in Poland

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Engineering-Geological Map of Poland at 1:50,000 Scale (MgiP50k) - a Simple but Modern Approach to Engineering-Geological Cartography.

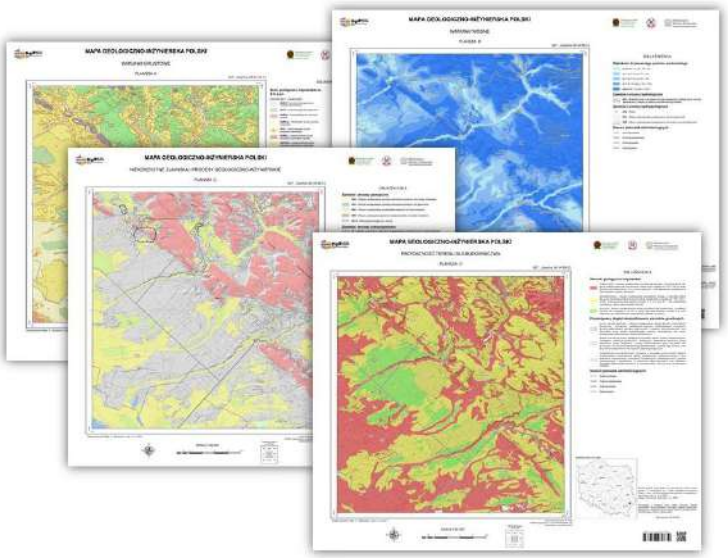
Krzysztof Majer[1], Edyta Majer[1], Anna Stawicka[1], Adam Popławski[1]

[1] Polish Geological Institute - NRI, Warsaw, Poland

Abstract

The Engineering-Geological Map of Poland at a scale of 1:50,000 (MgiP50k) is one of the key projects undertaken by the Polish Geological Survey. This map complements the series of systematic geological maps of Poland at a scale of 1:50,000 and contributes to the enhancement of digital resources within the Central Geological Database (CBDG). The MgiP50k project is being developed progressively using a map sheet system. Each sheet includes four thematic charts illustrating geological and geomorphological conditions, groundwater conditions, adverse engineering-geological processes, and land suitability for construction purposes. The map is compiled using authoritative source data and standardized national databases. All digital products and traditional layouts associated with MgiP50k are publicly accessible and free to use. The development process for each sheet is fully automated and based on advanced GIS software and geostatistical analysis methods. This significantly reduces human intervention in the analytical workflow, ensuring both efficiency and objectivity. As such, MgiP50k represents a modern and streamlined approach to engineering-geological mapping. The process of creating the four-chart map sheet is based on modern GIS software and geostatistical analysis techniques, and it is fully automated. As a result, human influence on the analytical process is kept to a minimum, making the approach both modern and efficient. This presentation/poster outlines the methodology applied in the creation of MgiP50k map sheet charts. The abstract has been prepared as part of a project financed by the National Fund for Environmental Protection and Water Management, as a task of the Polish Geological Survey.

Keywords: engineering-geological cartography, geological-engineering conditions, geo-risk, geo-hazard



example of charts of MgiP50k sheet

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Applying Engineering Geological Models in Tailings Dam Projects

Wenzhu Hou[1]

[1] BGC Engineering Inc., Calgary, AB, Canada

Abstract

This paper discusses practical applications of the Engineering Geological Model (EGM) in a tailings dam project located in a tropical area with complex geology. Three-dimensional (3D) digital models were developed to address spatial and temporal technical challenges, integrate multidisciplinary data, and communicate uncertainties. Key engineering geological aspects presented in this paper include surficial and bedrock geology, tropical weathering, structural geology, hydrogeology, and material parameters. Emphasis is placed on the roles of the EGM at each stage of a tailings facility's lifecycle, the challenges encountered during the realisation and delivery of the EGM, and practical solutions to these challenges. This paper aims to demonstrate best practices for applying EGMs in tailings dam projects and to provide new insights for geoscientists and geotechnical engineers tackling similar challenges in complex geological environments.

Keywords: Engineering Geological Model, 3D Digital Modelling, Tailings Dam Project

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Ground Model in Eurocode 7, Country Perspectives

Matthew Baldwin[1], Hakan Garin[2], Kees-Jan Made, van der[3], Philippe Reiffsteck[4], Jordy Vries, de[3], Robert Wudtke[5]

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[2] GeoVerkstan Sverige AB, Kungsbacka, Sweden
[3] Wiertsema & Partners b.v., Tolbert, Netherlands
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Abstract

The second generation of Eurocode 7 introduces a refined and systematic framework for the development of Ground Models (GMs) in geotechnical design. This guideline establishes the Ground Model as a fundamental, site-specific representation of geological, geotechnical, hydrogeological, and seismic conditions based on factual data and derived values. The GM serves not only as a schematic and interpretative tool for understanding subsurface conditions, but also as a foundation for risk assessment and decision-making across all phases of a geotechnical project. It evolves progressively with input from desk studies, site inspections, field and laboratory investigations, and monitoring data. This document outlines procedures for defining the zone of influence (ZOI), determining the complexity of the model in relation to geotechnical categories, managing uncertainties, and linking the GM to the geotechnical design model (GDM). Emphasis is placed on the incorporation of seismic and environmental considerations, the representation of derived ground properties, and the importance of iterative updates to reduce uncertainty and ensure reliability. This guideline aims to standardize GM practices across Europe and support the implementation of EN 1997-1:2024 and EN 1997-2:2024, promoting safer and more sustainable geotechnical structures. In the article we will expand on the ground model in the first phase of a project and differences between the countries of the authors based on the concept national annexes that are now being drawn up.

Keywords: ground model, country perspectives, eurocode 7

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Evaluating the Propagation of Geological Uncertainty from Ground Model to Geotechnical Analysis

Tobias Peterstorfer[1], Johannes Leo[1], Franz Tschuchnigg[1]

[1] Institute of Soil Mechanics, Foundation Engineering and Computational Geotechnics, Graz University of Technology, Graz, Austria

Abstract

Engineering geological ground models integrate information from field investigations, laboratory tests, and geological interpretation. However, due to the sparsity and imperfection of these input data and the natural variability of geomaterials, ground models inherently contain uncertainty. One important aspect is addressed as geological uncertainty, which relates to unknown stratigraphic boundaries and the spatial arrangement of geotechnical units. While established metrics for geological uncertainty quantification, e.g., information entropy, can highlight regions with ambiguous geological classifications, they provide limited insight into how this uncertainty may affect the geotechnical system performance downstream. To address the propagation of geological uncertainty in complex boundary value problems, this study applies a Monte Carlo simulation framework that couples stochastic ground modeling with geomechanical finite element analyses. The approach is hierarchical: first, a probabilistic ground model is defined based on the geological scenario; then, an ensemble of observation-consistent realizations is generated; finally, each realization serves as input to a deterministic geomechanical analysis using standard commercial finite element codes. The resulting ensemble statistics from the geotechnical analyses provide insight into how geological uncertainty propagates to geomechanical response variability, supporting transparent uncertainty communication, risk assessment and decision-making.

Keywords: stochastic stratigraphic modeling, consolidation settlements, geomechanical response variability, finite element method

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Rapid Geotechnical Assessments Using Interactive Methods

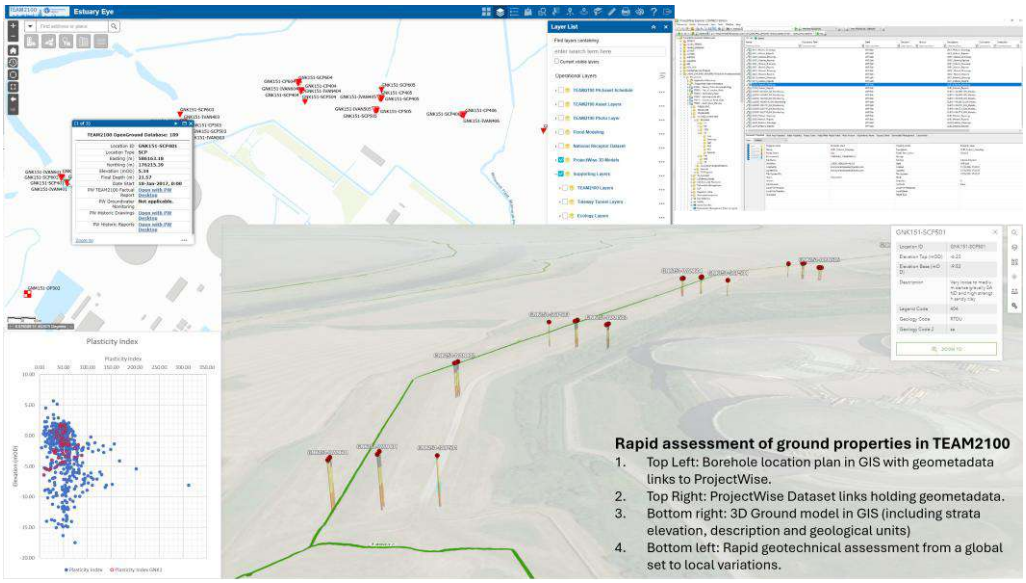
Eraclis Anastassiades[1, 2], Danniel Culli[3, 4], Liz Rivers[5]

[1] Jacobs, Bristol, United Kingdom
[2] Geological Society of London, London, United Kingdom
[3] TRC Companies, London, United Kingdom
[4] Royal Geographical Society, London, United Kingdom
[5] Institution of Civil Engineers, London, United Kingdom

Abstract

The Thames Estuary Asset Management 2100 programme (TEAM2100) was the Environment Agency's largest to inform engineering solutions was recognised as a fundamental mitigation measure to reduce the risk of data "loss". During the programme, a Geotechnical Database Management Team (GDMT) was created with the task of managing the TEAM2100 geotechnical data. Specifications were developed from the current Association of Geotechnical and Geoenvironmental Specialists (AGS) standards and British Geological Survey (BGS) (1:50,000) geological mapping, to enable the development of a programme-wide ground model, defined as a structured and standardised geotechnical dataset, interpreted by the TEAM2100 geotechnical design teams, and supported by standardised data plots. These plots have enabled the rapid identification of trends and variations in ground conditions across the estuary-wide dataset. Selected geological data were made available as interactive layers in the TEAM2100 GIS web-based mapping platform, identifying all available boreholes in plan view, including key metadata such as corresponding Ground Investigation Reports and historic drawings, and in a 3D environment. This level of granularity provided an opportunity to use readily available geotechnical data for a variety of purposes such as strategic decisions, geotechnical assessments and even asset inspections. This paper will describe the management of geotechnical data across this major flood risk management programme and the development of a ground model and various geotechnical assessment tools, presented across various platforms, suitable for engineering purposes and strategic decision-making..

Keywords: Ground modelling, Soft soils estuarine deposits, Geotechnical assessments, Software Integration,



Rapid assessment of ground properties in TEAM2100

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Bridging the Gap Between 3D Digital Mapping and Geomechanical Analysis of Fractured Rock Slopes

Niccolò Menegoni[1], Daniele Giordan[2], stefania corvo[1], Mattia Bonazzi[1], Aurora Petagine[1], Matteo Foletti[1], Enrico Arese[3], Cesare Perotti[1], Matteo Maino[1]

[1] Dipartimento di Scienze della Terra e dell'Ambiente, Università di Pavia, Pavia, Italy
[2] Consiglio Nazionale delle Ricerche (CNR), Istituto di Ricerca per la Protezione Idrogeologica (IRPI), Torino, Italy
[3] 4 Freelance, Dott. Geol. Enrico Arese, Racconigi, Italy

Abstract

Digitization of rock outcrops (e.g., LiDAR, SfM, SLAM) and fractures (e.g., DSE, CloudCompare) has advanced significantly in recent years. However, disciplines such as engineering geology, geomechanics, hydrogeology, and structural geology still face two major limitations:

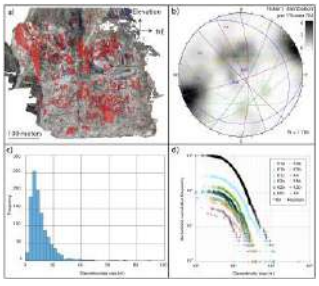
1. Data collection and processing methods are often based on outdated techniques (e.g., Markland, 1976; ISRM, 1981; ASTM D5878-19, 2019), which use manual measurements and qualitative indices (e.g., RQD, RMR, GSI), introducing significant subjectivity in the interpretation of results.

2. Despite the increasing use of digital methods, standardized and statistically robust workflows for analyzing fractured rock masses are still lacking.

To address these issues, we propose an open-source workflow integrating UAV-based photogrammetry with Digital Outcrop Models, processed in CloudCompare software with DICE (Discontinuity Intensity Calculator and Estimator) and ROKA (ROck slope Kinematic Analysis) algorithms. The workflow was applied to a steep granite slope near Mt. Montorfano (Southern Alps, Italy). Manual fracture mapping in CloudCompare generated a robust dataset of structures—including faults, fractures, and dikes—affecting slope stability. DICE enabled quantitative analysis of fracture intensity (P21, P32) and intersection density (I20, I30). Spatial analysis revealed an increase in fracture damage approaching the main faults, best modeled by an oscillatory trend. ROKA identified critical discontinuities prone to planar sliding, flexural toppling, and wedge sliding, offering improvements over traditional methods (e.g., Markland Test).

This integrated and open-source approach provides quantitative and detailed characterizations of fractured slopes, supporting the creation of 3D maps that are essential for reliable, data-driven slope zoning and the design of effective mitigation strategies.

Keywords: rock mass, fracture intensity, kinematic analysis, point cloud, 3D models



(a) 3D model representing the analyzed rock slope where manually mapped discontinuities are depicted as colored disks. (b) Stereographic projection (equiangular, lower hemisphere, isodensity calculated for 1% of the area) representing the pole density of the discontinuity planes and the average planes of the recognized discontinuity sets. (c) Histogram of the discontinuity size of the entire discontinuity datsets (bins size 2.5 m) showing a modal size of 5 - 7.5 m. Note that three discontinuity size values above 100 m are truncated for a better represent the discontinuity size distribution: the truncated values are 103.5, 112.6 and 512.1 m. (d) Log-log plot showing the discontinuity size distribution of the entire dataset and all the different discontinuity sets.

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Rock slope stability and Block volume estimation analyzing 3D Digital Outcrop Model with innovative algorithms

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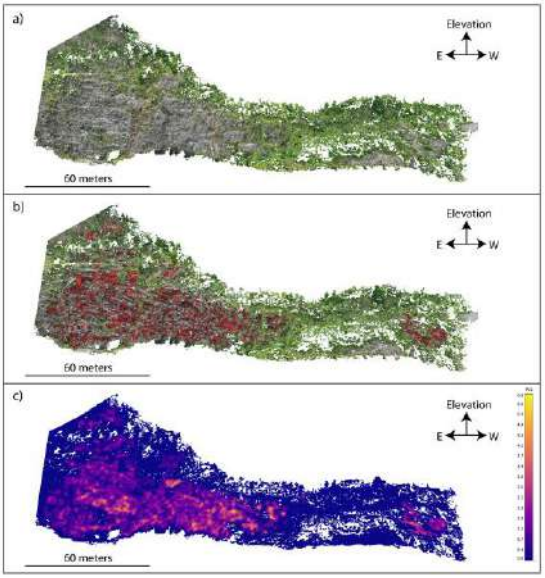
Abstract

Recent advancements in photogrammetry and Structure from Motion (SfM) algorithms have significantly improved the geomechanical characterization of rock masses. Miniaturized sensors and Remotely Piloted Aircraft Systems have made SfM more efficient, safer, and more cost-effective for rock slope studies. Additionally, the growth in computational power and specialized software has improved 3D data extraction, particularly for discontinuity network characterization. However, the absence of validated and standardized digital workflows still limits the comprehensive analysis of large 3D datasets. Traditional methods, such as the Markland Test, often fail to fully exploit the detailed geometric and spatial data now available.

To address these limitations, we present an innovative, integrated workflow designed to improve both the robustness and effectiveness of identifying, analyzing, and prioritizing critical features within fractured rock slopes. This workflow has been applied to the Molassana quarry within the SkyMetro project for the new Genoa metropolitan line.

This integrated approach demonstrates the potential of merging traditional geological interpretation with advanced digital tools, providing a more comprehensive, data-driven framework for rock slope stability assessment, particularly valuable for planning large-scale infrastructure projects.

Keywords: Rock block volume, 3D models, Fractures, Rock slope, Infrastructures



(a) 3D point cloud of the analyzed rock slope, (b) 3D discontinuity planes mapped onto the point cloud and (c) discontinuity areal intensity (P21) calculated using the DICE software

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The reconstruction of 3D Engineering Geological Model at urban scale: a case study in Chieti's city (Abruzzo, Italy)

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Abstract

3D Engineering Geological Model enables the visualization of the volumetric distribution of the subsurface geometries and the variation of the lithotype properties with an accuracy directly related to the spatial resolution of the geo-lithological data available. A three-dimensional model on the NW flank of Chieti's Hill, a city situated in Central Italy, was reconstructed using interpolation techniques applied to the following data: (1) the Digital Terrain Model (1 m cell size), (2) geological maps at different scales drawn of the Chieti city center (i.e. 1:5,000 scale from the Seismic Microzonation studies, 1:50,000 Sheet 361, Chieti, from the CARG project), (3) a grid of 18 cross sections and (5) a large dataset of boreholes data. The geological maps enabled the definition of geometrical constraints of the outcropping units. However, the 3D reconstruction at metric scale needed to adjust the geological maps at lower resolution through an iterative process. The new geological map, updated in light of the new available field investigations and geognostic surveys data, was produced in a GIS environment by verifying the geometric congruence of the newly drawn stratigraphic limits. Nonetheless, the highly anthropized area made this task tough due to the lack of geological outcrop data. The model proposed by this study is the first sound representation of the geological bodies with metric precision obtained through a recursive activity of field work and geognostic surveys correlation based on geometrical constraints.

Keywords: 3D Engineering Geological Modelling, Chieti city center, Highly anthropized areas

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A Sub-Zonal Markov Random Field Framework for Regional Stratigraphic Modelling in Heterogeneous Basins

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Abstract

Regional geological models are critical for reliable seismic-hazard and infrastructure assessments, yet traditional deterministic methods often fail to capture the complexity and uncertainty of subsurface conditions. To address this challenge, this study presents a high-resolution, regional-scale 3D geological random field modelling approach. The Taipei Basin is selected as the study area to investigate this issue due to its geological heterogeneity, shaped by complex depositional history, and its abundance of borehole data suitable for Markov Random Field (MRF) parameter calibration. First, a lithological composition map was obtained by calculating the soil-type probabilities within the top 30 m of the ground surface and then interpolating across the study area. Based on this map, the study area was subsequently subdivided into several geological sub-zones, with each zone exhibiting similar lithological- compositions and spatial correlations. The MRF method was then applied to simulate thousands of geological realisations for each sub-zone, while Bayesian analysis is used to calibrate spatial correlation parameters during the simulation process. From the resulting series of sub-zone simulations, marginal probability functions of soil types near the sub-zone boundaries were derived. These were used to update soil types near the boundaries for all realisations using Monte Carlo simulations. By combining the sub-zone models through this process, a high-resolution geological model that reflects local geological variability at a regional scale is achieved. This sub-zonal approach enhances the applicability of MRF modelling in geologically complex basins by balancing local accuracy with regional coherence, while also quantifying the associated geological modelling uncertainty.

Keywords: Regional geological models, Markov random field, Stratigraphic modelling, Uncertainty quantification, Taipei Basin

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Bridging Cell-Based Subsurface Modelling and BIM: A Lightweight IFC4x3 Conversion Approach

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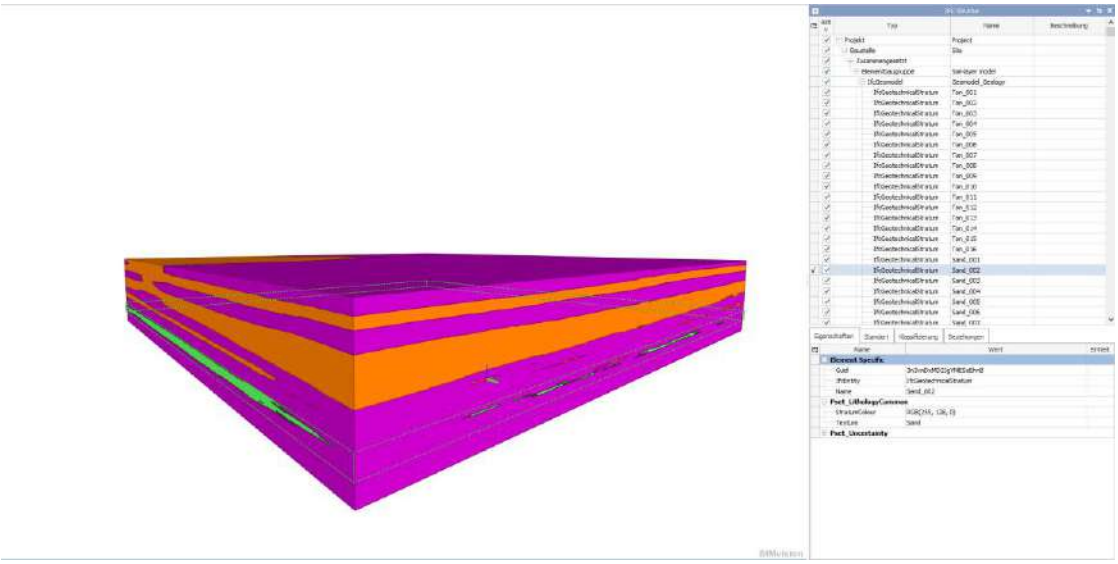
Abstract

Building Information Modelling (BIM) and Industry Foundation Classes (IFC) provide a standardized environment for interdisciplinary data exchange; however, integrating cell-based subsurface models remains challenging in practice. This paper proposes a lightweight IFC4x3 workflow for cell-based, simulation-derived subsurface models, integrating facies cleaning, connectivity-based unit partitioning, and boundary-shell extraction with optional mesh decimation. The resulting connected lithological bodies are exported as compact tessellated IFC geometry and mapped to IFC4x3 geotechnical entities to enable object-level interrogation. A synthetic benchmark based on a million-scale indicator lithofacies grid demonstrates that the approach produces a compact, interoperable IFC model while preserving global volumetric characteristics, enabling routine loading, querying, and coordination in standard BIM viewers. The proposed workflow bridges the gap between large-scale voxel-based scientific models and practical BIM-based exchange of high-resolution subsurface lithology.

Keywords: BIM, Subsoil Modeling, Geotechnical Information Modeling, IFC4x3, Geostatistics



IFC4x3 subsurface lithology model generated using the proposed pipeline showing the sand unit Sand2 within the stratified subsurface and its associated properties; sand units are shown in orange, while clay units are shown in purple.

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Early-Stage Dynamic 3D Ground Modelling to Improve Offshore Wind Farm Site Investigation and Future Data Integration

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Abstract

Expansion of global offshore wind targets has significantly increased demands for geotechnical data. This increased demand presents a significant challenge, as early-stage offshore wind site investigations typically operate with limited understanding of subsurface ground conditions. Consequently, developing a reliable visual three-dimensional (3D) ground model has become crucial for enhancing site understanding, optimising investigation efficiency, and improving associated timelines and costs. This paper presents a comprehensive approach to how early-stage 3D ground models built within Leapfrog® software enhances pre-investigation site understanding and serve as a dynamic tool for offshore site investigation campaigns. The 3D ground model is based on multi-disciplinary data integration combining geological context and seismic data to establish a baseline understanding prior surveys. The visual and comprehensive 3D environment enables both technical and non-technical stakeholders to understand offshore seafloor and sub-seafloor ground conditions and geohazards, particularly valuable in complex geological formations. During offshore site operations, the model enables "live" dynamic updates through progressive integration of acquired data, allowing real-time refinement and optimises ground characterisation of upcoming investigation locations. The framework can be leveraged by available in-situ testing data through spatial interpolation algorithms to predict hypothetical geotechnical parameters, allowing investigation improvement and constraining uncertainties. This paper explores the development of a dynamic 3D ground modelling tool as pre-investigation planning aid and real-time assistance during site operations to enhance site characterisation efficiency and evolving understanding of ground conditions. The implications of the data management for maintaining dynamic, updatable integrated ground models are also discussed.

Keywords: 3D, Ground Modelling, Site investigation, Offshore

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3D ground modelling improving offshore data integration in complex post-glacial soils; case studies of the North Sea

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Abstract

The expansion of offshore wind development across Europe has significantly increased demand for ground modelling and geotechnical characterisation, particularly in complex glacial and post-glacial soils of the North Sea. Understanding seafloor and subsurface ground conditions in these geologically complex regions requires sophisticated workflows for effective ground risk assessment, highlighting the need to optimize the cost-to-understanding ratio in site characterisation.

This paper presents an integrated approach using an advanced three-dimensional (3D) ground modelling software, Leapfrog®, for a large offshore wind farm development in the North Sea, correlating geophysical and geotechnical data. The common methodology employed to define a site is built across an initial geological model guided by seismic interpretation then refined by geostatistical approaches incorporating geotechnical sampling and in-situ testing to identify soil lithological variations. The 3D modelling approach presented in this paper aims to enhance this methodology by capturing complex interbedded marine soils and paleo-incisions created by repeated Quaternary Sea level fluctuations, which are often un-accounted for. The use of 3D modelling can enhance the extrapolation of geotechnical properties across the development area by capturing geological characteristics and constraints.

The 3D modelling environment enhances ground condition understanding through visualisation of geological and geotechnical relationships and remains accessible to both technical and non-technical stakeholders, facilitating robust interpretation during data integration. The presented data integration approach utilizing 3D software represents a significant improvement in how we assess offshore sites, giving essential tools to help manage ever increasing volumes of data in wind farm development sites while addressing the inherent uncertainties in subsurface conditions.

This study examines the principal challenges identified during project and demonstrate solutions developed to address these constraints.

Keywords: 3D, Ground Modelling, Quaternary, North Sea, Integration

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Managing Subsurface Data Using Blender: A Multi-Method 3D Investigation of the East Montebello Fault in Los Angeles, CA

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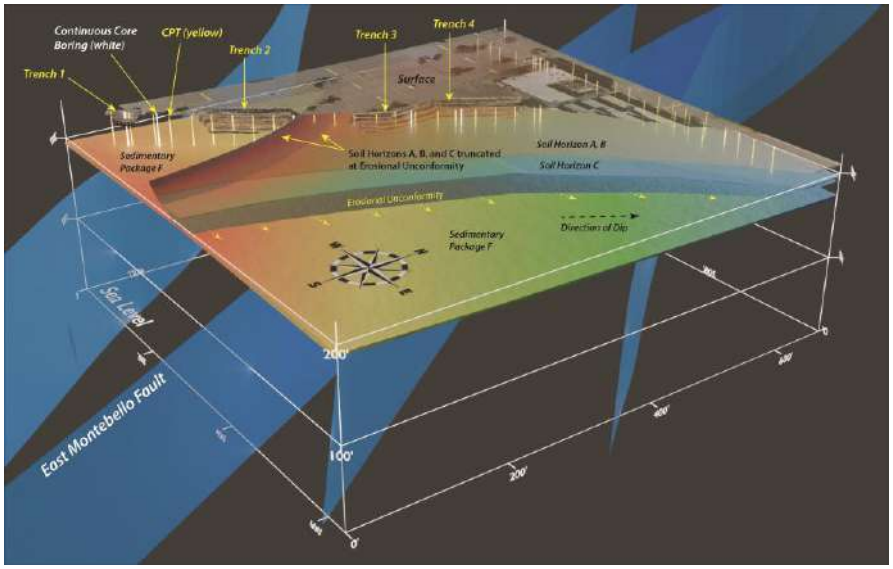
Abstract

This work presents a comprehensive 3-dimensional (3-D) fault investigation of a site along the East Montebello Fault (EMF) in the City of Rosemead, Los Angeles County, California. A multi-method exploration approach was employed to assess the geologic environment and test for the presence of Holocene faulting. Field data were collected through 46 cone penetrometer tests (CPT), eight geotechnical borings, four geologic trenches, geophysical surveys, and drone-derived elevation data, supplemented with published geologic maps. This diverse dataset provided a robust foundation for developing an integrated visualization and analysis of subsurface conditions.

The CPT data provided insight into lateral variations in stratigraphy and soil properties, while the borings allowed for vertical correlation of soil horizons and calibration of CPT responses. Trenching offered direct visual evidence of stratigraphic continuity or disruption. All data were synthesized into a 3-D geologic model using Blender, an open-source 3-D modeling platform with GIS integration. The model ensured internal consistency between datasets and facilitated precise visualization and interpretation of subsurface stratigraphy.

The 3-D model enabled correlation of multiple soil horizons across the site, demonstrating lateral continuity and supporting the conclusion that no Holocene faulting is present on the property, despite its location along the trend of the active EMF. This investigation underscores the value of integrating advanced subsurface exploration techniques with 3-D geologic modeling in fault studies. The resulting model offers a powerful tool for seismic hazard assessment, land-use planning, and engineering geology applications in densely developed urban environments.

Keywords: 3-D geologic modeling, Fault investigation, Urban geology, Subsurface visualization, Geologic trenching



3-Dimensional Model Showing Data Integration and Subsurface Modeling of a Site Along the East Montebello Fault in Los Angeles, CA

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A 3D Geomechanical Model Optimized by InSAR-Based Data Assimilation: The Bologna, Italy, Case Study

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Abstract

Anthropogenic (differential) land subsidence has affected the Bologna metropolitan area in Italy since the 1960s due to intensive groundwater extraction for civil and industrial purposes. Displacement rates have exceeded 100mm/year, resulting in cumulative land subsidence of more than 3m in the north-western portion of the city. This has led to structural damage and problems for the watercourse drainage system. From 2010 to 2016, land subsidence resumed, as pumping rates necessitated by climate change-induced droughts over the last decade, increased. However, predicting land subsidence evolution in Bologna for the next decades is challenging since the heterogeneity of the Bologna alluvial fan. To address uncertainty, we developed a 3D-geomechanical model that assimilates InSAR observations using Bayesian-based approach. It operates on a geostatistical aquifer system based on 3D facies simulations, with the multi-zone multi-depth transition probability models conditioned on borehole stratigraphy. The 88km² study area is characterized using 175 boreholes, which underpin stochastic hydrofacies simulations and corresponding stacks of preliminary geomechanical realizations. Four main lithologies are used to characterize the subsurface structure, with correlation lengths ranging from hundred to thousand meters in shallower and deeper depth ranges, respectively. The workflow aims at forecasting land subsidence in complex aquifer systems and supports the design of mitigation strategies for urban areas threatened by ongoing ground deformation. This work is funded by the European Union-Next Generation EU, component M4C2, in the framework of the Research Projects of Significant National Interest 2022 National Recovery and Resilience Plan Call, project SubRISK+ (www.subrisk.eu; grant id. P20222NW3E), 2023-2026 (CUP B53D23033400001).

Keywords: Land Subsidence, Data Assimilation, Geomechanical Modelling, Stochastic Hydrofacies, InSAR

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2D/3D Engineering Geological Modeling of Deep Foundation in Parts of Rivers State, Nigeria

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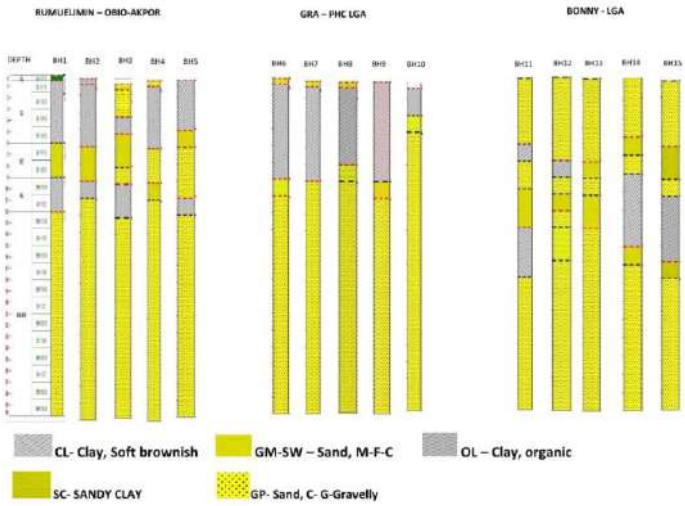
Abstract

Inadequate understanding of subsurface conditions in Rivers State has necessitated the development of 2D/3D engineering geological model for improved visualization of its complex stratigraphy. This study integrates geotechnical investigations, both field and laboratory data into modeling Software such as Groundwater Modeling System (GMS), Logplot8 and Surfer 20. Fifteen borehole each to the depth of 30m, where drilled in Obio-Akpor, Port Harcourt and Bonny Local government areas. Obio-Akpor exhibits four stratigraphic layers: soft brownish clay (CL), underlain by loose sandy-clay (SC), followed by stiff greyish clay (CL), and medium to coarse milky sand (SP-GP). Port Harcourt comprises three layers: (SP) at the top, soft-stiff brownish (CL) below, and (SP) to the borehole's depth. Bonny has five stratigraphic layers including: (SM) from the top, underlain by (CL), (SC) layer, followed by (SM-SC) and (SC), underlain by (SP) mixtures to the end of the borehole. Standard Penetration Test (SPT) results indicated generally dense sandy Formations, with corrected N-Values of 19, 21, & 50 for the three locations. The static water level averaged 20.3m, with measured moisture content of 20.3%, liquid limit of 99%, plastic limit of 41% and plasticity index of 34%. Pile bearing capacity analysis for a 0.4m diameter pile yielding 5708.04KN in Rumuelimini, 2782.76KN in Port Harcourt and 2808.45KN in Bonny. The integration of geotechnical properties in engineering geological models enhanced the understanding of subsurface heterogeneity, supporting safer structural design and risk informed construction. These models provide essential insights for sustainable infrastructure development in geologically complex environments across Rivers State.

Keywords: 2D/3D Engineering Geological Model , Deep Foundation , Geotechnical Investigation , Ground Water Modeling System , Golden Software Surfer 20



"Figure Showing the Stratigraphic sections of layers at each location"

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3D Geological Modeling and Engineering Geological Characterization of Shallow Subsurface Soil and Rock of Addis Ababa, Ethiopia

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Abstract

Geotechnical and seismological engineering studies in urban settings require a comprehensive understanding of the shallow subsurface soil and rock conditions. Even though a large amount of geological and geotechnical data is available from government and private, companies and is conducted for various purposes, the geological and geotechnical modeling of the shallow subsurface of Addis Ababa city has not yet been studied. This study aims at the construction of a 3D geological model as well as providing awareness of the engineering characteristics of shallow subsurface soil and rock in the city. The 3D geological model was constructed by using more than 1500 geotechnical boreholes data, well-drilling data, and geological maps. The well-known geostatistics inverse-distance weighting interpolation method was applied to visualize the spatial distribution and geological variation of the shallow subsurface. Due to the complex nature of geological formation, vertical and lateral variation of the geological profile horizons-solid command has been selected via the Groundwater Modeling System (GMS) graphical user interface software. Because of the heterogeneity, the geotechnical properties vary vary from place to place due to the uneven nature of subsurface formations observed in the study areas. The constructed model ascertains the thickness, extent, and 3D distribution of the important geological units of the city. This study is the first in its kind, and contributes to the understanding of the variability of subsurface conditions, and provides a reference for developing a geo-database. The findings could be useful for further research on subsurface conditions in the city for various geotechnical and seismological engineering applications.

Keywords: 3D geological modelling , Addis Ababa, Inverse-distance weighting, Horizons-solid

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Engineering Geological 3D Modelling Based on Photogrammetry and Field Investigations during Tunnel Excavation

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Abstract

A 3D geological model represents a digital database of geological data, enabling an integrated overview of collected information and its use in further analyses. This paper presents engineering geological 3D models developed along the alignment of the tunnels on the new Divača–Koper railway line. The model is based on the integrated use of photogrammetric surveys of excavation surfaces, detailed engineering geological mapping, and data from field investigations carried out during construction, including boreholes, piles, geotechnical anchors, and probe drilling. Photogrammetric data represented a key input for the development of the engineering geological 3D model. Photogrammetric surveys were performed at different excavation stages, enabling the generation of high-resolution, georeferenced 3D models of excavation faces, tunnel sidewalls, and portal areas. These models provided a continuous spatial record of lithological variations, structural elements, and engineering geological units along the tunnel alignment. Although geotechnical monitoring data were not directly used as model inputs, they contributed indirectly to the validation and refinement of geological interpretations. Furthermore, the developed 3D models represent an important basis for the interpretation and prediction of geological conditions for the planned construction of parallel tunnel tubes along the same alignment and can be integrated into building information modelling (BIM)-based tunnel models.

Keywords: geological 3D modelling, tunnel, photogrammetry, geological mapping, flysch

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Development Suitability on Mountainous Region in Kundasang, Malaysia

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Abstract

In line with Malaysia's rapid advancement and urbanization, mountainous areas particularly those prone to active soil movement and landslides are no longer excluded from development and have increasingly become focal zones for infrastructure and urban expansion. This study aims to determine appropriate development suitability approach based on the physical and environmental characteristic of the area. Terrain mapping approach is implemented to provide a comprehensive conceptual evaluation for determining development suitability levels in mountainous region. Whereas, a landslide susceptibility assessment was conducted using the Susceptibility method (Information Value method) to quantify the influence of slope instability towards development suitability. The results were further correlated with elements at risk, particularly building materials and structural types, in order to identify the dominant construction materials and evaluate whether the existing structural systems are suitable and resilient under landslide-prone conditions. This approach is applied to Kundasang area in Sabah, Malaysia due to the topographic factor of hilly terrain, growing population and tourism demands. The findings of the study indicate that only 6.41% of the study area is classified suitable (Class I) for development and urban growth, reflecting the limited presence of stable terrain within this mountainous and landslide-prone environment. In contrast, the remaining 92.39% falls within the moderately suitable (Class II), less suitable (Class III) and unsuitable (Class IV) categories. Hence, this approach has demonstrated a reliable interpretation of development suitability in mountainous areas by incorporating key terrain and landslide-related factors, while also evaluating building materials and structural characteristics, thereby supporting sustainable, structurally resilient, and well-planned development.

Keywords: Mountainous region, Development suitability, Terrain mapping assessment, GIS-based Analysis, Building material adaptation



Development on hilly topography of the study area, Kundasang, Sabah

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An Open-Source Workflow for Creating Soft-Soil Engineering Geological Models and Making Them Accessible in BIM

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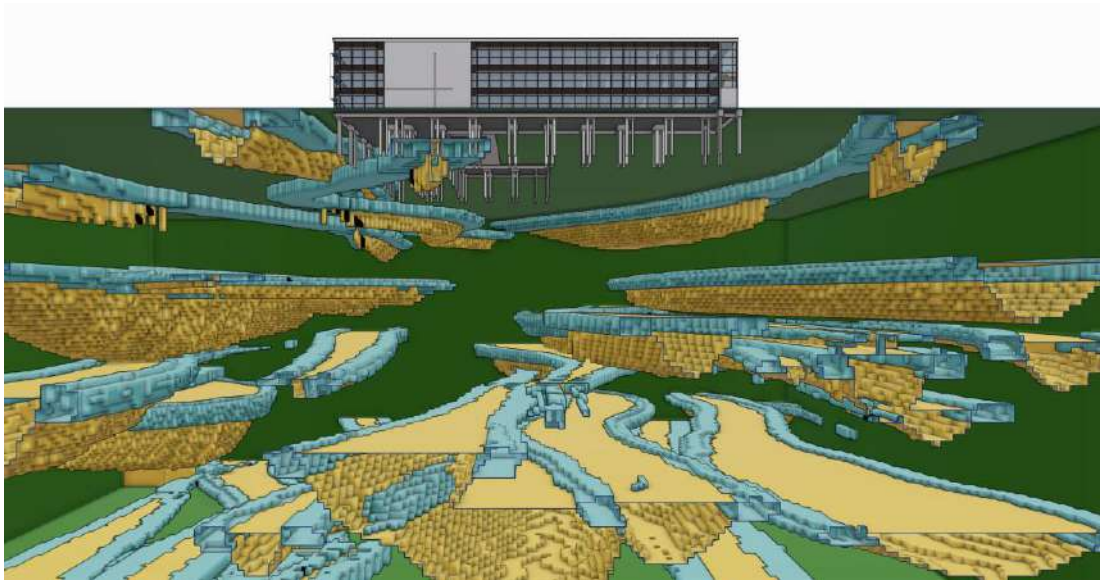
Abstract

This contribution presents a reproducible workflow for developing a soft-soil Engineering Geological Model (EGM) for coastal–deltaic and fluvial settings, consistent with IAEG C25 guidelines, using open-source software: 1) GemPy is used for 3D structural geomodelling and geostatistical interpolation of engineering parameters. 2) Speckle makes the EGM accessible through its API and connectors to common CAD/BIM software and visualizes it in context with relevant 3D GIS and BIM data. The workflow is demonstrated for a site near the EYE museum in Amsterdam using the public low-resolution GeoTOP lithological model and CPT data from the Dutch Registry of the Subsurface (BRO). Using GemPy, first the lithostratigraphic information from GeoTOP is used to construct a 3D geological voxel model that embeds regional stratigraphy and a conceptual model of the local coastal–deltaic setting. Subsequently, CPT parameters (cone resistance, friction ratio, pore pressure) are interpolated within these geological units with sequential gaussian simulation. This results in a stochastic parameter model that captures lateral and vertical variability, including palaeochannel-scale heterogeneity, within geological units. This combination of structural geomodelling and stochastic parameter simulation implements the EGM principle of integrating conceptual and observational components, makes full use of available geological and geotechnical data, and allows straightforward updating as new data become available. Publishing the EGM to Speckle makes it directly usable for designers, contractors, clients and regulators, improving communication and supporting risk-based decision making. The exclusive use of open-source tools reduces vendor lock-in, enhances transparency and provides flexibility for project-specific requirements.

Keywords: Soft-Soils, BIM, Open-Source, Geostatistics, Deltas



Soft-soil EMG in context with a BIM model.

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Advancing 3D Subsurface Modeling for Emerging Societal Needs

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Abstract

The Geological Survey of the Netherlands (TNO-GDN) is renewing its national 3D subsurface modeling efforts to better respond to changing societal demands, new technical possibilities, and stricter requirements for data quality and accessibility. Since the early 2000s, 3D geomodeling has become an essential complement to traditional geological mapping. GDN currently maintains four nationwide subsurface models, three of which are part of the Dutch Key Registry of the Subsurface (BRO), making their use mandatory for government organizations. This has increased both their impact and the need for frequent updates, robust quality control, and broader applicability.

The renewal program aims to improve not only individual models but also their integration into a unified geological layer model. This future model should serve multiple applications, including groundwater, geo-energy, geotechnics, and spatial planning. A central concept in this transition is the development of subsurface models as part of broader information chains, linking data acquisition, storage, interpretation, modeling, dissemination, and end use. These chains support better cooperation between data providers, modelers, and decision-makers.

To achieve this, GDN is expanding its use of diverse data sources and advanced techniques, including machine learning to extract information from legacy reports, seismic data, and cone penetration tests. It is also exploring new modeling approaches such as stratigraphic forward modeling and implicit modeling to improve speed, detail, and representation of geological complexity. Additional efforts focus on uncertainty visualization, outlier detection, and better handling of sparse data. Together, these innovations are intended to create more flexible, up-to-date, and application-oriented subsurface models that support societal challenges such as climate adaptation, energy transition, land subsidence, and critical raw materials exploration.

Keywords: geomodelling, 3D

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An Integrated Framework for Digital Rock Mass Characterization

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Abstract

Heterogeneity, anisotropy, and excavation-induced changes in rock masses require engineering designs to incorporate geological observations and evolving mechanical conditions. This study proposes an integrated framework linking digital site investigation, spatial parameter fields, active reinforcement, and adaptive design. Remote mapping and point cloud interpretation are combined with drilling, geophysical investigation, and portable mechanical testing to characterize intact rock properties and discontinuity geometry. These data support three-dimensional geological modelling and direction-dependent rock mass quality assessment. Stress and seepage analyses inform the spatial representation of mechanical and hydraulic parameters. Reinforcement demand is quantified as the additional minimum principal stress required to satisfy a prescribed stability criterion, providing a mechanical basis for estimating prestress requirements and determining reinforcement layout and timing. Pre-excavation prestressing and rapid post-excavation anchoring are incorporated to limit unloading-induced deformation and damage. Engineering examples from the Xiaowan dam foundation, the Zongo II abutment slope, and tunnels along the Lanzhou–Chongqing railway illustrate design considerations associated with excavation unloading, slope stabilization, and asymmetric deformation in layered rock. During staged excavation, newly exposed geological features and supplementary measurements provide data for updating parameter fields, while monitoring feedback guides revisions to excavation and support schemes. The framework connects digital rock mass characterization with mechanically defined reinforcement demand and iterative design revision, providing a methodological basis for adapting rock engineering decisions to evolving site conditions.

Keywords: Digital rock mass characterization, Rock mass anisotropy, Active reinforcement, Confining stress, Adaptive design

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Overall Geological Screening of Danish Waters for Offshore Wind

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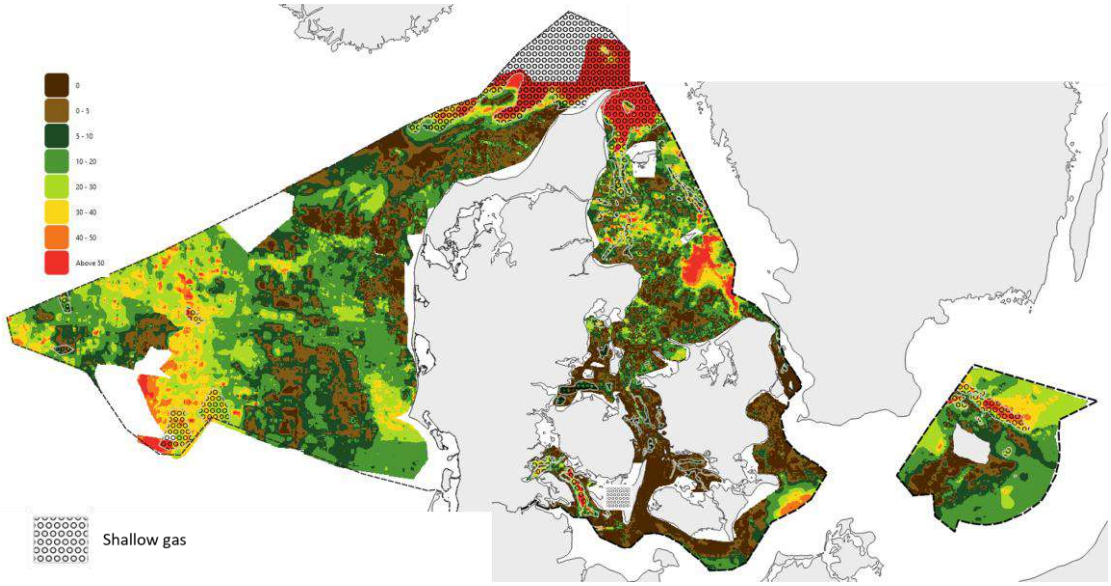
Abstract

Offshore wind is crucial in the further development of green and sustainable energy in Denmark. Construction of marine infrastructure involves detailed geophysical, geological and geotechnical investigations. But prior to wind farm site selections, overall mapping and understanding of the shallow geology is necessary for an initial assessment of the geological risks in different areas. Therefore, GEUS has been conducting a geological screening of the Danish waters for the Danish Energy Agency. The work has been part of the project "Screening and Environmental mapping of the offshore Wind potential in Denmark" providing a sensitivity mapping of nature-, environmental- and other interests as well as assessment of potential cumulative effects from large-scale offshore wind development together with an overall evaluation of the technical potential. The geological screening has included an overview of existing data and data gaps, acquisition of new data, area-specific conceptual geological models and mapping of key geological units with importance for the planning of future wind farm sites and subsequently turbine locations and foundation design. To improve the geological knowledgebase of the Danish waters, GEUS has acquired c. 7.800 km UHRS single- and multichannel sparker seismic, sub-bottom profiler, side scan and multibeam data as well as 168 vibrocores to support the seismic interpretation. The mapping of the shallow geology of the Danish waters has been performed using all the newly acquired data supplemented with selected available existing data. We present here the results of the geological mapping that will support the long-term planning of offshore wind farms in Denmark.

Keywords: UHRS seismic, Geological mapping, offshore wind, Holocene, Late glacial



Thickness of unconsolidated sediments in meters

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Effect of swell-shrink on shear strength of expansive clays from the Canadian Prairies

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Abstract

Geological origin and seasonal weather govern the behavior of expansive clays in the Canadian Prairies. A typical glacio-lacustrine expansive clay deposit (up to 30 m deep) underlies the city of Regina in Saskatchewan, Canada. The deposit developed in the proglacial Regina Lake (fine particles settled during the Wisconsinan) from extensively eroded (alternate scraping, deposition, overburdening, and reworking of materials) glacial drift of the Quaternary period. Likewise, the area is characterized as Dfb (warm summers and continental climate) according to the Köppen climate classification system. The extreme seasonal weather variations include temperature that ranges from -14.7°C in January to 18.9°C in July and precipitation with 60% occurring between June and August while the remainder of the eight months is relatively dry. The interaction of geology and climate results in volume changes (swelling due to raining and shrinkage upon evaporation) that, in turn, causes possible strain softening (loss of cohesion) in the expansive clay. The main objective of this research is to develop a clear understating of the effect of swell-shrink on shear strength of the native expansive clay. Laboratory investigations will be conducted on high quality undisturbed samples retrieved from selected test pits. Shear strength parameters, determined under saturated and unsaturated conditions, will be correlated with the swell-shrink curve and the water retention curve. These results will be studied in conjunction with soil microstructure assessments, based on scanning electron microscopy of the clay under critical stages of saturation and volume change.

Keywords: Expansive clay, Swell-shrink, Saturation degree, Laboratory investigation, Soil microstructure

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Characterizing the Deformation of Lumpy Fills Using Micro-CT Scanning

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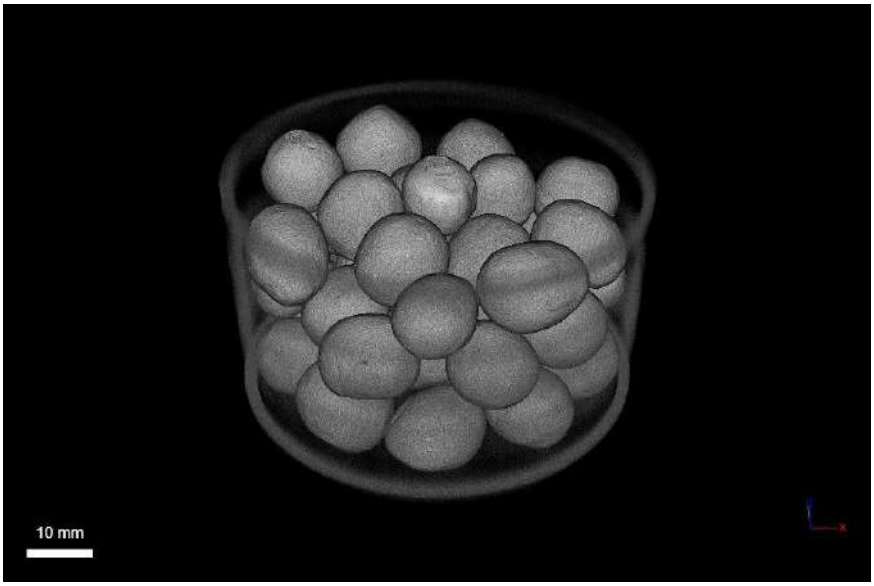
Abstract

This study explores the challenges of using stiff clays in land reclamation projects, focusing on how the soil behaves when deposited as large clay lumps that form a double porosity system, complicating settlement predictions. Through a combination of field data (like CPTs and settlement plates) and laboratory experiments using oedometer tests and micro-CT scanning, the research uncovers significant variability in fill behavior and limitations in existing settlement models. The results of oedometer tests on clay balls about 10 mm diameter with air in the macro-voids demonstrated that lumpy fills show larger amounts of deformation, and that the consolidation behavior is highly dependent on the ratio between the stress level and the undrained shear strength (Su) (or pre-consolidation stress) of the clay lumps prior to excavation. At stress levels below about 0.5 Su there is very limited deformation, at stress levels between 0.5 and 4 Su the deformation is dominated by closure of the macro-voids between the clay lumps, while at stress levels above 4 Su the consolidation behavior of lumpy fills is similar to homogenous clay layers, despite showing slightly lower compressibility. Filling the voids between the clay balls with water causes rapid deformation due to softening and/or wetting collapse. These findings advance understanding of lumpy fill deformation and suggest improved modeling methods and early-stage design strategies to reduce risks and uncertainties related to the settlement prediction in reclamation projects.

Keywords: Dredging, Clay, Beneficial Use of Sediments, Reclamation, Consolidation



CT-scan of an oedometer ring filled with a stack of clay balls

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Characterization of Intrinsic Properties of Sand Using CT-Scan Image Analysis

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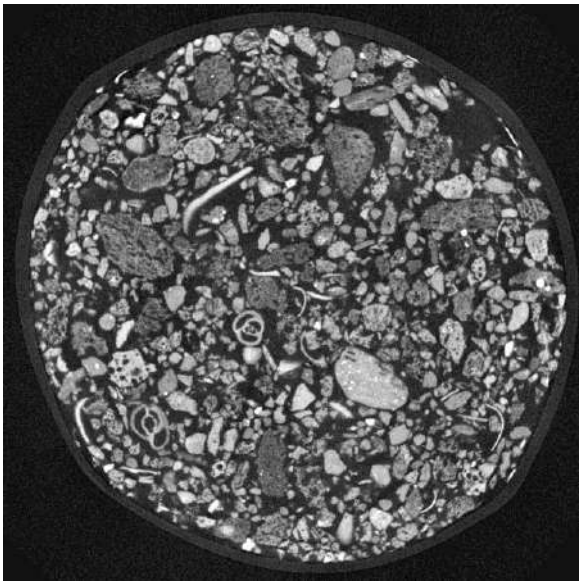
Abstract

Sand is the most commonly used material in construction industry. The intrinsic properties of sand, like grain size distribution, grain shape, texture, and mineralogy significantly affect the material behavior when used in construction. Current commonly-used testing methods on sands include sieving or laser diffraction for grain size distribution, carbonate content by acid digestion, X-ray diffraction for mineralogy, and (2D) optical microscopy for grain shape analysis. CT-scanning and image analysis can be provide a rapid and attractive alternative to obtain these intrinsic properties. Dried stacks of sands with different grain characteristics were scanned and image processing algorithms were developed to determine grain size distribution, dry density, (3D) particle shape distribution and particle density. Where particle density could be linked to mineral type. The results illustrate to what extent CT-scanning can be used as a method to determine the intrinsic properties of sand and if so whether a standardized scanning and interpretation procedure can be developed that can be used and accepted by industry practice.

Keywords: Sand , Mineralogy, Texture, Image processing, Computed Tomography



CT-scan of volcanic sand

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Occurence and Behaviour of Dutch Expansive Clays

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Abstract

Since the dry period of 2018, problems such as building damage related to the shrinkage and swelling of clay in the Netherlands have become more pronounced. This article describes the results of an ongoing research programme into the characteristics, composition, and shrink–swell behaviour of Dutch clays (marine as well as fluviatile) from several locations throughout the country, investigated under laboratory conditions. The reported results form part of a larger study on the risks and prevention and mitigation measures associated with the occurrence of expansive clays in the Netherlands.

All clay samples analysed to date from the 12 investigated locations contain significant quantities of swelling clay minerals and exhibit shrink–swell tendencies. Swell stress and strain were measured and used to determine the heave index (CH). In addition to the observation of extreme swelling pressures exceeding 1200 kPa, these tests yielded promising results in the sense that reliable values were obtained that appear to be primarily related to intrinsic clay properties and to be relatively independent of the specific testing conditions and initial state of the samples. Another index we have determined, the shrink swell index (ISS) did not yield promising results, since it appears to be overly dependent on only one specific test result, namely the shrink test. For both parameters more research is needed to be able to make a definitive decision about the applicability of these parameters for characterizing Dutch clays.

Keywords: Swelling clay, Damage, Laboratory reserach, Suction, Expansion



Damage to laboratory equipment due to Dutch swelling clay

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CT Scanning of Collapsible Soils: Proof of Concept

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Abstract

To address concern over the collapsibility of silty sands (usually referred to as collapsible soils) in a building project, it is necessary to successfully and quickly identify these in a ground investigation. Oedometer tests are often difficult to undertake on good undisturbed samples. Collapsible soils are characterised by an open pore structure, thus it may be possible to identify potentially collapsible layers by characterising their structure to facilitate the concept design and develop the GI strategy for more refined design and analysis. Computerised Tomography (CT) is a technique developed for medical uses that is now being adapted for geological purposes, e.g. creating 3D representations of fossils, characterising porosity of various soft sediments. It has not previously been applied to collapsible soils.

We report initial data to assess the usefulness of micro-CT scanning as a technique for identifying and characterising collapsible soils as an additional tool for the design team. We scanned three samples with a range of previously determined collapsibility both dry and wet after loading for two hours with a 150 kPa weight. The results presented show which structural features can be picked up by micro-CT scanning and how they change after wetting in these samples.

Keywords: collapsible soils, techniques, CT scanning



Effects of building on collapsible soils - hospital building, Luanda, Angola

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The Soil Classification Based on Laboratory Testing and CPTU Data of Quaternary Deposits in the Levan Area

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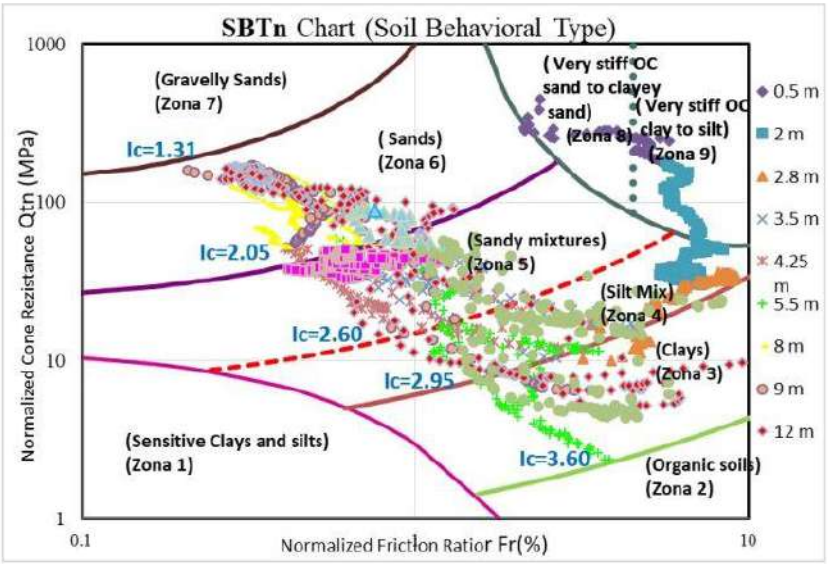
Abstract

This paper presents the results obtained from laboratory testing and the Cone Penetration Test (CPT) conducted on Quaternary deposits in the Levan area, which forms part of the Pre-Adriatic Depression. These soils are characterized by weak geotechnical properties, making them generally unsuitable as a foundation for engineering structures without appropriate treatment. The geotechnical investigation involved conventional borehole sampling, in-situ testing, and laboratory analyses for soil classification. In-situ testing within the soft soils, sandy soils, and silty clays was performed using the Piezo-cone penetration test (CPTU). Laboratory tests focused on determining the physical properties of the soils. The thickness of the soil layers identified by both methods was based on field descriptions recorded during borehole drilling. Soil classification was carried out using the Unified Soil Classification System (USCS) based on laboratory results and soil behavior type (SBT) charts derived from CPTU data, as proposed by Robertson (2009) [1] and updated by Mayne (2014) [2].

A comparison of the results obtained from both methods indicates a good correlation between the SBT derived from CPTU data and the USCS classification based on laboratory testing. However, it was observed that the silt content indicated by CPTU tends to be slightly higher than that determined through laboratory analyses, from the surface down to the investigated depth.

Keywords: Soils , CPTU, Laboratory testing, Borehole, USCS



Soil classification according to SBTn Chart.

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Bridging Soil and Rock: Evaluating Weathered Bedrock with Structural Prominence

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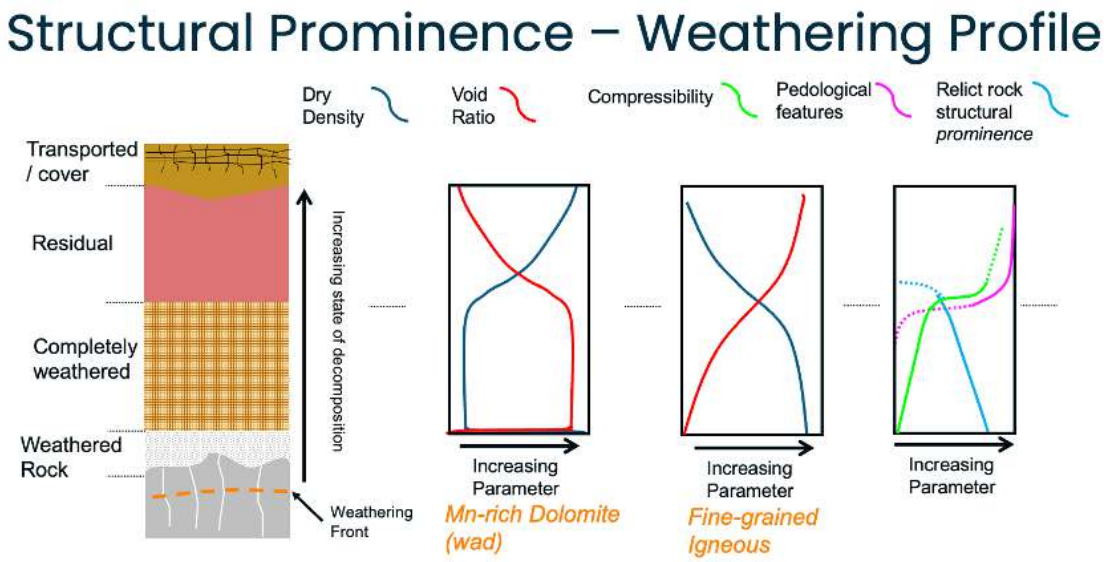
Abstract

Weathered bedrock profiles pose persistent challenges in geotechnical classification due to their transitional nature between soil and intact rock. This study introduces structural prominence, a novel parameter quantifying the persistence of relict rock structure, as a means to better evaluate compressibility and mechanical response in completely weathered rock and residual soil. Fieldwork focused on weathered profiles developed in diabase, andesite, and dolomite under subtropical South African conditions. Samples were analysed using a multi-tiered approach combining traditional geotechnical testing (particle size distribution, Atterberg limits, permeability, oedometer testing) with chemical analysis (XRF, XRD) and high-resolution X-ray Computed Tomography (XRCT). XRCT enabled the 3D visualisation of internal fabric, revealing that even in materials classified as soils, relict structural features significantly influence mechanical behaviour. Results show that as chemical weathering intensifies, structural prominence declines, correlating with increased compressibility. Samples with higher structural prominence exhibited elevated stiffness despite high porosity, highlighting the mechanical influence of relict structure beyond conventional indicators like dry density or void ratio. Elemental depletion indices correlated well with compressibility trends, offering a more precise indicator of weathering progression. Structural prominence thus bridges the gap between descriptive weathering classifications and quantitative design parameters. It enhances delineation of the soil–rock interface and informs predictions of settlement and strength. This integrative framework linking visual, mechanical, and chemical data offers geotechnical practitioners a scalable tool to reduce uncertainty and improve design reliability in weathered bedrock profiles

Keywords: Structural Prominence, Chemical Decomposition, Weathering profile



Conceptual weathering profiles illustrating the relationship between dry density, void ratio, compressibility, pedological development, and structural prominence.

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Heating induced variation in soil strength and its mapping using infrared spectroscopy.

Om Prasad Dhakal[1], Lukáš Brodský[1], Marco Loche[1, 2], Gianvito Scaringi[1]

[1] Charles University, Prague, Czech Republic
[2] Czech Academy of Sciences, Prague, Czech Republic

Abstract

Temperature-dependent changes in residual shear strength are important for slope stability, landslide reactivation, and thermally loaded geotechnical structures. Although this response is controlled by mineral composition, there is no clear method for extending laboratory results to larger areas. This study combines temperature-controlled ring shear testing with short-wave infrared (SWIR) spectroscopy for eight mixtures of quartz-rich sand, kaolin, and bentonite. The specimens were tested at normal stresses of 50, 100, and 150 kPa and subjected to heating-cooling cycles between 20 and 80 °C. Sand and kaolin rich mixtures showed little change, whereas mixtures containing at least 50% bentonite showed clear heating-induced strengthening. For pure bentonite, the residual friction angle increased from 6.18° to 9.02°, corresponding to $\Delta\phi r=+2.84°$. The SWIR spectra distinguished clay-bearing from clay-free mixtures using the absorption feature near 2209 nm and differentiated high-activity from low-activity clays using the feature near 1912 nm. Partial least-squares regression was then used to relate the spectra to residual friction angle. Finally, the spectral data were interpolated across a sand–kaolin–bentonite ternary space and combined with the laboratory results to map $\Delta\phi r$. The study provides a first step toward mapping mineral-dependent thermal changes in soil strength.

Keywords: Residual shear strength, Thermo-mechanical coupling, Mineral mapping, Infrared spectroscopy, Soil strength mapping

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Engineering Characterization of Soil Properties and Embankment Using Finite Element Analysis in Relation to Infrastructural Development

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Abstract

Embankments construction in a soft soil with high groundwater level shows excessive settlement and requires long duration to dissipate excess pore pressure which often involves a number of geotechnical and engineering geology issues especially that related to settlement. Excessive post-construction settlement may be total or differential leading to serious problems to all parties on the project. However, the undesirable characteristics associated with soft soils such as inadequate bearing capacity and large displacement, which can occur a long time made embankment construction over soft ground a challenging task. The focus of the present study is to analyses in order to provide a theoretical model suitable for the production of settlement in the compressible soil layers underlined the newly proposed embankment. Prior to this, a review through the collation of soil data available from the soil investigation reports carried out before desktop study ensued in order for relevant information pertaining to the subsoil condition. In general, a considerably accurate assessment in the rate of settlement of soil is a very important factor in ensuring the achievement of structurally sound building and or infrastructural work on soft ground without the development of excessive post construction settlement. Thus a model was carried out using the PLAXIS finite element 2D program by setting the relevant borehole results, evaluation of the laboratory results of the consolidated settlement and control parameters. This would allow post-construction settlement be predicted during pre-construction stage be determined. This is greatly useful for the design engineer in taken a satisfactory solution subsequently.

Keywords: Embankment, Sand, Peat, Clay, Modulus of Elasticity, PLAXIS finite Element, settlement



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Residual Granitic Soils: Geotechnical Properties Variability to Use in Low-Volume Roads

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Abstract

Low-volume roads (LVR) are more than 90% of roads in the world used in people, materials and crop production mobility. Also, these roads are necessary for people to access education and health services. Several conferences were developed since 1970's to generate specific design criteria, evaluate materials, construction and management practice to verify the best performance of these kind of roads. In Uruguay, Low-volume roads are more than 75 % of roads in the country. It is very common used residual soils generated by weathering processes in pavements as sub-base and base layers. In this paper granitic residual soils are analyzed as LVR material. The samples were collected in different quarries in the same granitic complex to understand how soil could have or not a similar behavior. Soils are classified as sand to gravels with silt and poor or well graduate (SP, SM, and GP-GM) in SUCS and CBR values have differences between the quarries as well as in the same quarry. In this research, weathered granitic soils show geomechanical properties variability which makes it necessary when identified in the field to generate blended soils with homogeneous composition and isotropic geotechnical properties.

Keywords: granitic residual soil, geotechnical properties, Low-volume Roads

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Physicochemical Characterization of Tropical Soils in the Central Region of the Greater Metropolitan Area (Costa Rica)

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Abstract

In tropical regions influenced by high temperatures and humidity, the development of highly weathered soils poses significant challenges from an engineering standpoint, due to their particular and complex properties (compared to soils from temperate latitudes). Therefore, the identification and characterization of their chemical and mineralogical properties can contribute to a better understanding of their geotechnical behavior and its relationship with associated problems. In this study, two residual tropical soil profiles resulting from the chemical weathering of pyroclastic deposits (ashes) and clastic sedimentary rocks (sandstones) were characterized, both located in the central sector of the Greater Metropolitan Area of Costa Rica, where approximately 50% of the population currently lives within only 4% of the national territory, representing the area with the greatest urban growth and development in the country. The methodology included the determination of physical, chemical, and mineralogical properties through specialized tests and methodologies more suitable for this type of soil. The results indicate that soils derived from pyroclastic materials correspond to elastic silts with very high plasticity (MH), LL > 95%, with potentially collapsible and expansive behavior, and a mineralogy dominated by halloysite, Ca-montmorillonite, kaolinite, quartz, magnetite, hematite, goethite, among others. Conversely, soils derived from sedimentary rocks are classified as sandy silts of low plasticity (ML), LL < 50%, with mineralogical phases including quartz, Ca-albite, magnetite, K-feldspars, kaolinite, vermiculite, halloysite, hematite, among others. The accumulation of iron oxides allowed these soils to be classified as true laterites.

Keywords: Tropical soils, Chemical-mineralogical analysis, Laboratory testing, Mechanical behavior, Urban planning

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Complexities in coupled processes in clay soils: evaluating the residual shear strength

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Abstract

Despite being a key parameter controlling the behaviour of reactivated landslides in clay-rich soils, the residual shear strength remains insufficiently understood. Usually evaluated in shear boxes or ring-shear devices, it displays nonlinear dependencies on temperature and pore fluid composition, as well as time- and rate-dependent effects. In addition, sample preparation procedures can significantly condition its evaluation. In this contribution, recent experimental results are presented, framed within the international literature, and experimental workflows are discussed. Coupled and non-linear responses upon changes in temperature and rate of shearing are identified, including strengthening upon heating under slow, drained shearing, and an opposite response under rapid shearing. Clay mineral type and abundance are shown to control the soil's thermal sensitivity. Modelling approaches to account for a temperature-dependent residual shear strength are presented, and challenges associated with objective evaluations of the residual shear strength and its upscaling to field conditions are discussed.

Keywords: residual shear strength, clay, temperature, rate effect, landslide

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The Trinity Water-Discontinuity-Clay minerals (WDC)

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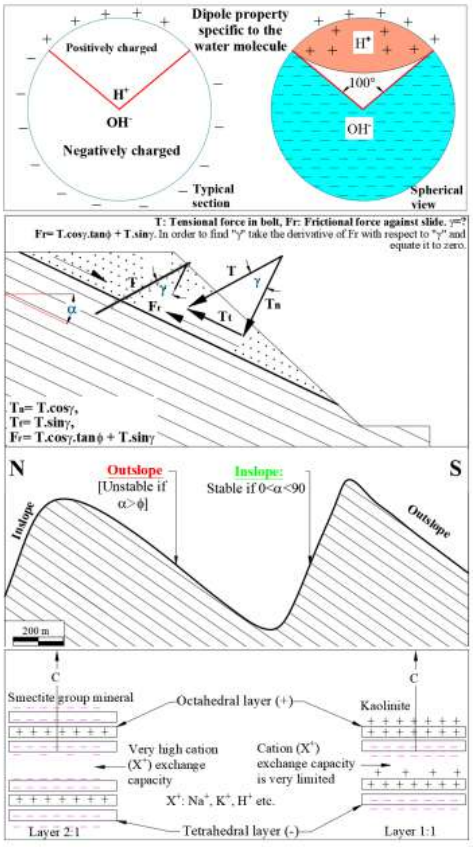
Abstract

The trinity "WDC" is the main cause of all geotechnical problems. The water molecule is bipolar (+/-). It covers the particles regardless of the surface charges, significantly reducing the shear strength. In particular, in stratified units containing clay mineral infill, the shear strength approaches zero upon wetting. Consequently, slides become inevitable where bedding/layering is outslope. Slope stability problems are dependent on the main discontinuity attitude and the presence of water and clay minerals. Over 90% of the slope failures occur in stratified units where beddings are outslope. In case of inslope, the presence of water and clay wouldn't be effective. In crystalline rocks, the natural/cut slopes do not fail. Clay as a size term is beyond the scope of the manuscript. Such as clay soil of quartz and/or calcite is nonplastic. The shear strength of clay minerals becomes zero upon wetting. The hydraulic permeability (K, m/s) of clay soil, composed of calcite and/or quartz, is 10-6 or greater. Whereas the K value of a layer of clay minerals of the smectite group is below 10-8. More importantly, smectite clay minerals are highly plastic, while calcite/quartz clay is non-plastic. Liquefaction occurs in the silt and sand layers, where bounded (D) by the clay mineral layer (C) from the bottom and top, especially in the first upper mantle with a thickness of 20 m, where saturated (W). Liquefaction does not occur in layers of silt and sand where bounded by layers of calcite/quartz.

Keywords: Water, Discontinuity, Clay, Geotechnics, Stability



The outline of the trinity water, discontinuity, and clay.

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Computation of Total Settlement in Sensitive Soils Using the Cone Penetration Test: Case Reviews From the Niger Delta

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Abstract

Sensitive soils of the Niger Delta present significant challenges to geotechnical design due to their high compressibility, low shear strength, and susceptibility to excessive settlement. Accurate prediction of total settlement is therefore critical for the safe and economical design of foundations in this region. This study investigates the computation of total settlement in sensitive soils using data obtained from the Cone Penetration Test (CPT), with emphasis on case reviews from selected sites within the Niger Delta. CPT-derived parameters, including cone resistance and sleeve friction, were used to estimate soil compressibility characteristics and stratigraphic profiles. Empirical and semi-empirical correlations were applied to compute immediate, primary consolidation, and secondary settlement components. The results from CPT-based settlement predictions were compared with observed field performance and available laboratory consolidation data to assess their reliability. Findings indicate that CPT provides a rapid and effective means of characterizing sensitive deltaic soils, with settlement estimates showing reasonable agreement with measured values when appropriate correlations are employed. The study highlights the advantages and limitations of CPT-based methods in sensitive soil environments and underscores the need for localized calibration of correlations. Overall, the research demonstrates that CPT is a valuable tool for settlement analysis in the Niger Delta, contributing to improved foundation design and risk mitigation in sensitive soil terrains.

Keywords: Consolidation, Settlement, CPT, Niger Delta, Compressibility

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Dynamic Behaviour of Mechanical Capping: Equilibrium-Based Analysis and MPM Modelling

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Abstract

Mechanical capping is applied to create access on land reclamation projects where soft fine-grained sediments such as clay and silt are used as fill material. Although widely implemented in practice, the underlying physics governing the displacement of the capping material and underlying soft sediments during placement, and the resulting equilibrium conditions remain insufficiently understood. This study investigates the dynamic behaviour of a single lump of capping material placed on soft soil using two complementary approaches: a dynamic equilibrium-based analytical formulation and a dynamic simulation using the Material Point Method (MPM). The analytical model describes cap penetration through a force--inertia balance for which the cap is idealized as a rigid block of material that only moves vertically. The resulting Ordinary Differential Equation (ODE) is solved numerically to obtain time-dependent sink profiles and steady--state depths. The MPM simulations incorporate large deformation behaviour and a Mohr–Coulomb constitutive model for the soft sediment. Comparison of both approaches shows good agreement in steady-state sink depth, while dynamic responses differ due to the simplified energy dissipation mechanisms in the analytical model. A parametric study shows that the final penetration depth is mostly influenced by the density of the cap material, whereas initial plunging height only affects the dynamic behavior. The combined analytical–numerical assessment provides improved insight into the mechanisms governing the placement of capping material on soft soils and offers a foundation for more reliable design and execution of capping operations in very soft soil environments

Keywords: Soft sediments, Material Point Method, Mechanical Capping

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Effects of Grain Crushing on the Geotechnical Properties of Soils with Varying Mineralogy.

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Abstract

Grain crushing during construction activities alters soil grading by generating additional fines, thereby modifying the geotechnical behaviour of foundation soils. This study quantified these changes in two sandy clays and three lateritic soils with varying mineralogical compositions. These samples, which contain a significant proportion of granular particles, were characterized by X-ray diffractometry and tested for Atterberg limits, linear shrinkage, free swell index, activity, compaction, and permeability before and after grain crushing. Statistical analyses using paired t-tests and Cohen's d were employed to evaluate the significance and effect size of the observed changes. Quartz, kaolinite, and mica were the dominant minerals in the soils, while two samples contained significant amounts of smectites. Results showed significant increases in plasticity index (up to 10 %), linear shrinkage (up to 16 %), free swell index, and optimum moisture content, all with large effect sizes. Maximum dry density decreased by 6 –9 %, while permeability was reduced by up to one order of magnitude; however, the reduction in permeability was not statistically significant despite showing a large effect. Irrespective of mineralogical composition, the increase in fine particles due to grain crushing led to higher compressibility and swell potential, with implications for reduced shear strength and bearing capacity of soils subjected to construction-induced stresses.

Keywords: Grainsize, Soil mineralogy, Compaction, Activity

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Three-Dimensional Microstructure and Structural Representative Volume Element of the Intact and Remolded Loess

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Abstract

On the Loess Plateau of China, the number of projects involving the excavation of mountains and the filling of valleys to create new land is rising. The loess excavated from the mountain is directly used as building material. After being filled into the valley and remolded, it serves as the foundation for overlying structures. However, significant differences in mechanical behavior exist between intact and remolded loess, leading to various issues such as differential settlement. Understanding the microstructure of loess is essential for improving our comprehension of its macro-level hydrological and mechanical behavior. Due to the inherent limitation of the conventional methods (e.g., scanning electron microscopy and mercury intrusion porosimetry) for microstructure investigation, an in-depth understanding of the three-dimensional (3D) microstructural differences between intact and remolded loess remains elusive. To address this gap, this study employs advanced X-ray micro-computed tomography (micro-CT) to investigate the 3D microstructure of both intact and remolded loess from two typical man-made new land creation projects. The three-dimensional microstructures are segmented into a series of cubes of varying dimensions to identify the structure's representative volume element (RVE) and assess the uniformity of both loess types. The pore network of the RVE is quantitatively analyzed to characterize the microstructure. The results reveal significant disparities between the microstructure of intact and remolded loess, particularly in terms of uniformity, pore size distribution, and pore connectivity. Remolded loess exhibits a denser structure with poorer pore connectivity and greater heterogeneity compared to intact loess. These microstructural differences are attributed to the distinct formation processes of the two types of loess.

Keywords: three-dimensional microstructure, micro-CT, representative volume element, intact loess, remolded loess

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Whether the Spherical Fines With Rolling Resistance Can Replace the Real-Shaped Fines in Geotechnical Granular Mixtures

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Abstract

Taking particle shapes into consideration is an inevitable trend in simulating geotechnical granular matters. However, the computational costs involving irregular shapes are considerable, especially for granular mixtures with abundant particles. To improve computational efficiency, the shapes of some particles, e.g., fine particles, are simplified, yet the simplification may distort simulation results. This short communication investigates the substitution effect of simplified particles with rolling resistance on real-shaped fine particles. This is achieved by simulating confined compaction tests of mixture models with different fine particles. The contact parameters in models were calibrated and the reliabilities of models were verified by a series of physical tests. The results show that the macroscopic deformation and mesoscopic particle motions in simplified models with rolling resistance are perfectly close to those in the models with real-shaped fines, especially when the size ratio exceeds 8. Due to the different sources of rolling resistance, however, applying rolling resistance inevitably causes a difference in kinetic energy.

Keywords: Granular mixture, Geotechnical particle, Discrete element method, Shape simplification, Rolling resistance

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Geotechnical and Hydraulic Properties of Aeolian Kalahari Sands in Botswana

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Abstract

The Kalahari sands of aeolian origin cover three-quarters of Botswana, extending from the southwest to the northeast, with increased thickness on the western parts. The sandy soils originated mainly from Karoo Supergroup and Ghanzi Group sandstones and have been reworked by wind since deposition, resulting in high quartz content. The sands are fine-grained, subrounded, poorly sorted, and display a collapsible fabric. The poor sorting also renders them susceptible to erosion. It is challenging to maximize strength by compaction due to the resistance and hardness of the quartz grains in these sands and their subrounded particle shape results in reduced shear strength. Notable plasticity is achieved from the minus 0.075 mm fraction, despite conventional testing (on minus 0.425 mm) classifying them as non-plastic. The inherent plasticity and low natural moisture content yield significant suction strengths. Their fine composition lowers permeability, resulting in poor drainage and reduced groundwater potential, particularly in the western Botswana with a semi-arid environment. When utilizing these sands in construction dry compaction with high-energy equipment is a possible solution especially due to the water scarcity in large parts of Botswana. Settlement and hydrocompaction of these collapsible soils may result in structural damage and land degradation.

Keywords: Kalahari sands, aeolian, engineering properties

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Hydration-Induced Swelling of High-Speed Railway Subgrades on Red-Bed Mudstone and Deformation Control Using a Pile–Slab System

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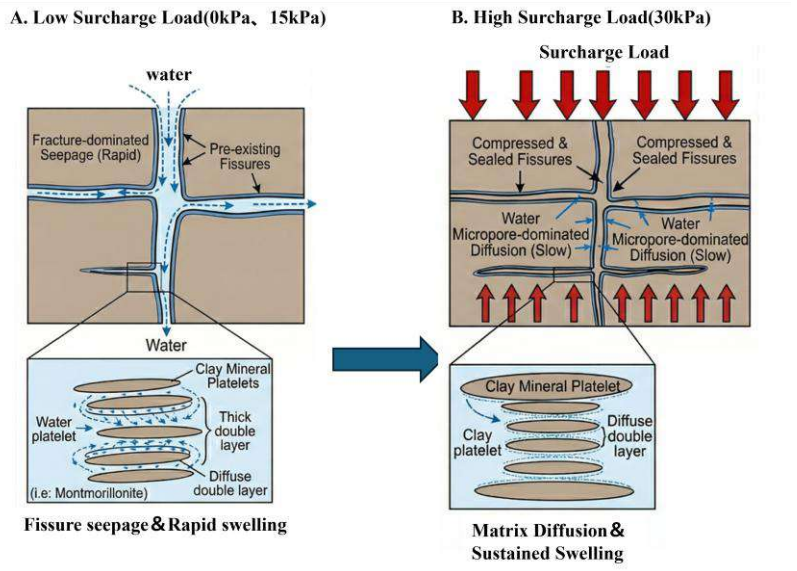
Abstract

Rainfall infiltration-induced long-term heave of high-speed railway subgrades founded on red-bed mudstone threatens the geometric stability and serviceability of ballastless tracks in the Sichuan Basin. To investigate swelling behavior and deformation-control mechanisms, field soaking tests under different surcharge conditions were conducted, and a sequential stress–humidity coupled numerical model incorporating excavation unloading and subsequent hydration was established. Results show that the swelling process comprises rapid, slow, and stabilized stages. The rapid stage contributes approximately 60% of total deformation under zero surcharge but decreases to 21% at 30 kPa. Increasing surcharge restricts fracture opening and seepage pathways, thereby delaying water migration and hydration. Numerical results indicate that unloading rebound is more pronounced near subgrade edges, whereas hydration-induced swelling concentrates in the central zone and dominates long-term heave. Maximum heave decreases exponentially with increasing surcharge; raising the surcharge from 0 to 30 kPa reduces maximum heave by 82.72%, while further loading yields limited additional improvement. A surcharge of 30–35 kPa is therefore recommended to balance deformation-control efficiency and engineering economy. A combined reinforcement scheme using a thickened base slab and pile–slab system further reduces maximum vertical displacement from 5.20 mm to 1.76 mm and effectively suppresses differential heave. These findings clarify the nonlinear hydro-mechanical response of red-bed mudstone and provide a basis for deformation prediction and control of high-speed railway subgrades in red-bed regions.

Keywords: Red-bed mudstone, High-speed railway, subgrade, Stress-humidity coupling, Hydration-induced swelling



Conceptual model of the transition from fracture-dominated seepage to micropore-dominated diffusion in mudstone under external confinement.

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Preparation of a 3D Model of the Calp Limestone in Dublin City Centre

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Abstract

The Carboniferous Lucan Formation, locally known as Calp dominates the bedrock geology of Dublin. The Calp Limestone was deposited during the Dinantian Epoch (approximately 325 to 363 million years ago) of the Carboniferous Period. Geological Survey Ireland (GSI) describes the Calp Limestone as an interbedded sequence of dark grey massive limestones, shaley limestones and massive mudstones and cherts. It was deposited in a basinal and ramp environment in deep water with limited fauna. Glacial deposits, up to 30 m thick, in Dublin City Centre (the study area) overlie and obscure bedrock, limiting structural information in Calp Limestone. The aim of this work was to create a geological model of the Calp Limestone of Dublin City Centre. This was achieved through the analysis and digitalisation of available ground investigation data, supplemented where possible with additional information such as in-house Arup ground investigation reports. The project utilised modern modelling tools and benefited from guidance and reviews by experienced ground engineering experts. The resulting model includes information on the composition and depth of weathering, of the Calp Limestone.

Keywords: Urban, Geology, Ground Model, Ground Investigation,



Core Boxes of Calp Limestone

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Evaluation Methods for Loosened Rockmass Confirmed at the Damsite in Japan

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Abstract

The foundation bedrock of the dam requires consolidated hard rock. At the planned dam construction site, the development of sheeting joints causes loosened rockmass on the surface, and problematic state of the bedrock for dam construction is distributed on the surface. A common method for evaluating loosened rock uses joint aperture as an index. In this area, however, it was difficult to correlate outcrop observations with borehole data. To address this, the author correlated borehole core data with borehole camera observations, clarified the limitations of borehole-derived information, and proposed a method for evaluating loosened rockmasses. During dam construction, simple geophysical surveys were conducted on excavation surfaces, enabling the identification of the distribution and condition of subsurface joints. As a result, it was possible to confirm that loosened zones had been removed and that a competent rockmass suitable for dam foundations had been secured.

Keywords: loosened rockmass, sheeting joints, borehole data, physical exploration

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A Review of Weathering Classifications for Geological and Engineering Documentation

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Abstract

Work on classifying weathering and creating a model profile flourished in the 1960s and 1970s. During this period, the first attempts to classify and describe weathering appear. On the basis of the description of weathered rocks, the first weathering profiles were created, which, depending on the type of rock described and its occurrence, differ, among other things, in the number of separated zones. The basis for the separation of zones was the description and characterization of the weathering rock (mainly color), the presence of fragments of bedrock and relict structure. In 1981, a model weathering profile was published in British Standards (BS 5930:1981). The posted weathering profile distinguished six characteristic zones (fresh rock, zone of slightly weathered rock, moderately weathered rock, very weathered rock, completely weathered rock and zone of residual soil). The weathering profile separating the six characteristic zones is present in ISO guides, manuals and standards. The PN-EN ISO 14689 standard, adopted for use in Poland, provides rules for the description and classification of weathering. It includes a model weathering profile that separates six characteristic zones (0-5; 0- fresh rock, 5- residual soil). The standard recommends classifying weathering based on a qualitative assessment of the physical properties of weathered soils, such as color change, the appearance of fractures and cracks, the presence of residual soil and corestones. It recommends using the terms; soil, rock-soil and rock to describe weathered soils. This indicates that the weathered material described in the profile can be treated as either rock or soil.

Keywords: weathering profile, GEOLOGICAL AND ENGINEERING DOCUMENTATION, weathering

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Permeability Depth-Relation of Rock Mass: Based on Laboratory Measurements and Geophysical Logging

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Abstract

It is crucial to estimate the permeability-depth relation for CCS, geothermal project, or nuclear waste disposal. However, no geophysical logging or other in-situ testing can obtain the permeability-depth relation continuously. We proposed a simple approach to evaluate the permeability-depth relation using laboratory tests of intact rock (permeability) and fractures (hydraulic apertures) under confining stress. The contribution of intact rock and fractures to equivalent permeability of rock mass can be estimated. If the porosity-depth logging is available, the permeability-depth relation can also be estimated via permeability-porosity function based on laboratory test, if the contribution from fractures are negligible. The permeability-depth relations of one geothermal site (slate formation) and one CCS site (weakly cemented sedimentary rock with little fractures) were evaluated and illustrated to show how the proposed approach works.

Keywords: Permeability, Stress dependent, geothermal project, CCS, Nuclear waste disposal

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Dynamic Evolution of Connectivity in Multi-Cluster Fracture Networks: A Novel Quantitative Framework for Engineering Geology Applications

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Abstract

Complex fracture networks in geological formations typically consist of multiple clusters whose connectivity evolution significantly impacts rock mass stability and fluid flow behavior. This study presents a comprehensive framework for quantifying and understanding the dynamic evolution of connectivity in multi-cluster fracture networks, with direct applications to engineering geology practice.

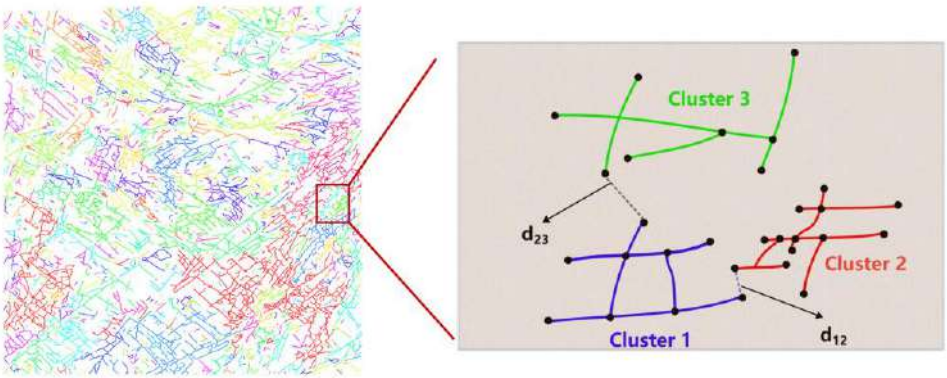
We developed a novel connectivity metric (Ct) that accounts for individual fracture cluster contributions and their hydraulic interactions through the rock matrix. This dimensionless metric considers cluster sizes, spatial distributions, and hydraulic conductance between clusters, providing a more realistic assessment than traditional percolation-based approaches that focus only on spanning clusters.

Our investigation encompasses two critical scenarios: (1) natural fracture network degradation through sealing processes, analyzed using 80 real outcrop maps from global locations, and (2) dynamic fracture network evolution during hydraulic fracturing, simulated using coupled Discrete Element-Lattice Boltzmann Method (DEM-LBM) with realistic discrete fracture networks.

Key findings reveal that fracture sealing has profound impacts on connectivity, with only 5% of sealed fractures reducing overall network connectivity by approximately 20%. During hydraulic fracturing, natural fractures significantly influence fracture initiation, propagation patterns, and final network connectivity. The process creates multi-cluster systems where fracture strength heterogeneity determines the final network configuration.

The proposed framework enables quantitative assessment of connectivity evolution under various geological and engineering conditions, providing essential insights for slope stability analysis, groundwater flow prediction, and unconventional reservoir development. This methodology bridges the gap between qualitative fracture network observations and quantitative engineering design requirements.

Keywords: Fracture networks, Connectivity quantification, Connectivity evolution, Multi-cluster systems, Engineering geology



Demonstration of complex fracture networks composed of multiple clusters and connectivity quantification

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New Engineering Classification of Weak, Fault Rocks

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Abstract

"Weak rocks" is a term employed in geotechnical engineering, soil and rock mechanics, and engineering geology to distinguish a group of rocks that are transitional materials between hard rocks and soils. The most common rock mass classification systems have been developed around hard rocks and do not fully apply to the characterization of weak rocks. Fault carbonate rocks of weak origin present unique properties that cannot be fully accounted for using these systems. Therefore, a new classification scheme is needed to accurately predict their mechanical properties. Based on the (limited) literature data, in-situ investigation and laboratory testing results using novel methodologies, the present study aims to introduce a new engineering classification system that addresses the unique properties of such geomaterials. Weak, fault rocks are classified into four main types: Parent rocks, Welded breccias, Unwelded breccias, and Matrix material. A methodology to estimate the Uniaxial Compressive Strength (UCSi) of each fault rock type is proposed herein. The results indicate that the uniaxial compressive strength of the welded/unwelded breccias is a function of the corresponding strength of their components (fragments and matrix) and the matrix ratio (the percentage of matrix in a given volume). The Hoek-Brown failure criterion is modified to take into consideration: (a) the different intact rock strength that should be used, based on the classification of the fault rocks, and (b) a re-calibrated Geological Strength Index (GSIFR) and Disturbance Factor (DFR), which were introduced to better capture the decay of weak rock mass strength.

Keywords: Carbonate fault rocks, Mechanical properties, Uniaxial Compressive Strength, Classification System, Modified Hoek-Brown criterion

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Estimation of Strength Properties and Elastic Modulus in Jurassic Sandstones of Tampico-Misantla Basin in México.

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Abstract

We present the results of 32 triaxial and 4 uniaxial compressional tests conducted in samples of the Cahuasas formation, a Jurassic sedimentary unit located in the Tampico-Misantla Basin (TMB) in México. The Jurassic units of TMB are increasingly recognized as potential unconventional reservoirs, geological carbon storage sites for CCUS projects and subsurface energy storage. The samples were obtained from cores drilled in sandstone and siltstone facies located at 2400 and 4000 meters in depth, in exploration oil wells. Mechanical properties include compressive strength, Young Modulus, Poisson ratio and brittleness index. Experiments were performed on dry cylindrical specimens under confining pressures of 0, 20, 30, 40, 60, and 90 MPa at the Laboratorio de Física de Rocas (LAFIR), Instituto de Geociencias, UNAM. The results suggest that mineralogical composition, rock fabric, and macroscopic fractures have influence on the mechanical behavior of samples. The compressional strength increased with confinement in all cases, reaching 481 MPa in sandstones whereas Young Modulus increased to 25 GPa in siltstone facies. In addition, nine fatigue experiments were conducted using sinusoidal cyclic loading in triaxial and uniaxial conditions revealing that the elastic modulus varies as a function of cycle amplitude and damage accumulation, with magnitudes comparable with the dynamic modulus estimated with log data. This study contributes to the ongoing geomechanical characterization of the Jurassic units of the Tampico- Misantla Basin, reinforcing their potential for CCUS projects and highlighting their suitability for unconventional reservoir development in support of long-term energy transition strategies.

Keywords: Geomechanics, Rock Mechanics, CCUS, Unconventional reservoirs, compresional test

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Could the Hydro-Mechanical Behavior of Rock Joints Be Evaluated Using the JRC? Viewpoints Based on Joint Aperture Measurements of 3D-Printed Joints

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Abstract

This study critically examines whether the joint roughness coefficient (JRC) provides a sufficient basis for predicting the hydro-mechanical behavior of smooth to slightly rough rock joints. To address this, we employed high-resolution 3D printing to fabricate rock joint specimens with controlled surface roughness (JRC = 3.5–5.8), including both matched and mismatched configurations. Specimens were designed to isolate the effects of surface configuration by producing joints with identical JRC values but distinct asperity geometries. Mechanical and hydraulic apertures (E and e) were measured under varying normal stresses and analyzed using a semi-logarithmic closure model to characterize stress-dependent behavior. The results demonstrate that while the JRC remains a reasonable predictor for mismatched joints, its predictive capacity for matched joints is limited within the tested roughness range, as aperture variability is more strongly governed by surface geometry and the degree of matedness. This decoupling of roughness magnitude, asperity morphology, and matedness effects underscores the need to move beyond reliance on JRC alone for modeling coupled hydro-mechanical behavior. In addition to presenting a reproducible laboratory method for generating joint profiles with controlled roughness, this work highlights the limitations of using JRC as a stand-alone parameter and emphasizes the importance of integrating surface configuration and joint matedness into future predictive models of stress-dependent aperture evolution in rock joints.

Keywords: Mechanical/hydraulic aperture, 3D-printed joints, Joint roughness coefficient (JRC), Matched/mismatched joint, Stress dependence

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Assessment of deformation modulus by empirical methods in Nepal Himalaya

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Abstract

The deformation modulus plays vital role in the design of rock engineering projects. Estimation of deformation modulus of rock mass can be done either by in-situ measurement or by using existing empirical relationship. It is not easy to carried out in-situ test in the contest of the Nepal Himalaya due to time consuming, expensive and operation difficulties. In contrast, estimation of deformation modulus by empirical method is very simple, easy, less time consuming and economical. Due to this reason, most of the project of the Nepal Himalaya uses empirical method to estimate deformation modulus instead of in-suit measurement. Having large number of existing empirical relationship for determining deformation modulus values, the question rise, which empirical relationship provides the most reliable estimation in the Nepal Himalaya. Hence this paper has review, compare, performance of existing empirical equations derived from various rock mass classification system such as RMR, Q and GSI on Nepal Himalayan terrain. For the purpose of the study, the data obtained from 23.62 km of Headrace tunnel of ten hydropower projects has been analysed. The Em values were calculated using the existing empirical equations based on the RMR, Q and GSI. The estimated values of Em by various equations is compare with trend of variation with respect to rock mass quality of study area, respectively. The relationships between Em with RMR, Q and GSI were obtained via simple regression analysis using geometric average Em. The relationships generated in this study indicated significant correlations for the Nepal Himalaya.

Keywords: Deformation modulus, Rock mass classification, Empirical relationships, In-situ measurements, Relationship

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Mechanical Characterization of Some Gneisses From Southeast Brazil

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Abstract

A comprehensive laboratory testing programme was conducted on four distinct gneiss types from different dam foundation sites, to determine their physical and mechanical properties. These properties included dry and saturated unit weight, effective porosity, uniaxial compressive strength (UCS), elastic modulus, wave velocities (Vp and Vs) and abrasiveness. Sound rock specimens from all four lithotypes were prepared in accordance with the International Society for Rock Mechanics' (ISRM) recommendations. The elastic moduli were determined using an impulse excitation technique with a Sonelastic system to establish both static and dynamic elastic moduli. Rock abrasiveness was assessed using a Cerchar abrasiveness tester. The results revealed considerable variation among the tested rock types. Mean UCS values ranged from 94 to 143 MPa, while the dynamic elastic modulus varied from 51 to 77 GPa. Primary wave velocities (Vp) ranged from 4,709 to 5,598 m/s, while secondary wave velocities (Vs) ranged from 3,641 to 4,274 m/s. The abrasiveness of the four lithotypes was found to range from low to moderate. These findings demonstrate that despite macroscopic similarities in texture and mineralogy, there are significant variations in the mechanical properties of the gneiss types. These data will directly influence the engineering design of solutions specific to each dam foundation site.

Keywords: Strength, Deformability, Abrasiveness, Wave velocity



Textural aspects of the three samples tested for the study.

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Assessment of Lithological Layers for a Shallow Foundation Using Integration Investigation at Igbobi Boys College, Yaba, Lagos, South-Western, Nigeria

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Abstract

The study area is located at Igbobi Boys College, Yaba is a suburb of Lagos State. It lies within latitude 6°31'44.5"N, longitude 3°22'12.4"E, and latitude 6°31’47.4”, longitude 3°22’12.9”. The investigation was to determine the number of lithological layers, their thicknesses, and to determine the competency of each layer for the shallow foundation of the proposed structure. The cone penetrometer test indicated one lithological layer between 0 - 4.75 m depth, indicating loose becoming medium dense sand, from the ground surface to depths between -0.25m and -2.5m, relative density as shown by end resistance, qc, values rising from figures as low as 10kgf/cm2 near the ground surface to values as high as 130kgf/cm2 at the base of the zone. The Vertical Electrical Sounding Resistivity method reveal that the first geo-electric layers represent the topsoil with resistivity and thickness values that vary between 52 – 410Ωm and 0.9 – 1.6 m, respectively. This layer constitutes sand and correlates well with the CPT results, showing an increase in cone resistance with depth. The 2-D resistivity results delineated the topsoil as a competent layer composed of sand with resistivity and thickness values that vary between 120 - 500Ωm and 5 – 10 m. The sand is the layer of interest as it has the best mechanical properties for hosting structures; and the sand exhibits good engineering properties of moderate to high shear strength and consolidation characteristics considered a medium within which shallow foundations may be placed to safely support moderate superstructure bearing pressures.

Keywords: Cone penetrometer test, 2D resistivity, CST, Shallow Foundation, Pressure bulb

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Engineering Geological Models for Design of Excavations in Structurally Controlled Rock Masses

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Abstract

The most important component of an Engineering Geological Model (EGM) for rock engineering is typically the structural geology. This is perhaps an important differentiator when compared with EGMs developed for soil engineering. The engineering end use and project objectives must be clearly defined early in the design process. These decisions determine how the model will be built. However, there are common themes. In most rock engineering projects, the in-situ and induced stresses are less than the intact strength, and behaviour of the rock is therefore dominantly controlled by shear along discontinuities. While this is widely acknowledged in the literature, it is not often well applied in practice. Accordingly, when geological structures dictate mechanisms of rock mass deformation, structure must be considered in detail and explicitly at the scale of interest. Only then can rock mass behaviour and stability mechanisms be properly understood, and appropriate engineering measures designed, when required, to enhance the natural state. Using examples and case studies this paper describes the use of EGMs for rock engineering design. In particular, the paper demonstrates how geological structure can be incorporated into an EGM and the overall design process. Without explicit reference to the controlling geological structure, design analyses are unable to simulate the rock mechanical responses and associated failure mechanisms of discontinuous rock masses. In most circumstances appropriate modelling of structure is fundamental to reliable design in rock.

Keywords: Rock Engineering, Engineering Geological Models, Rock Mass Models, Rock Mechanics, Characterisation

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Analysis of the Deformation of a High and Steep Rock Slope Affected by Two Sets of Closely Spaced Persistent Discontinuities

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Abstract

In this paper we describe the results of a preliminary analysis in static conditions of the deformation affecting the upper portion of a high mountain slope composed of carbonate rocks in the Sibillini Mountains (Central Apennines, Italy). The rock mass structure is featured by closely spaced bedding joints and regularly spaced and persistent shear joints (small faults), both dipping into the rock mass. The shear joints dip at approximately 75°, whereas the bedding joints are almost sub-horizontal. At the outcrops of the shear joints, deformations have produced long gaping fractures parallel to the slope crest and obsequent scarps. These observations, together with the rock mass structure, suggest that a large-scale flexural toppling is active. Deformations likely accelerated during the high magnitude earthquakes (Mw 6.5-7) that have periodically affected the region. The final aim of the study is to assess if the deformation mechanism under static conditions could evolve into a large-scale failure after seismic events, with catastrophic consequences for the downslope valley. Considering the structural characteristics of the rock mass, 2D static numerical analyses have been carried out with a non-commercial finite element code (FELIX), which incorporates a constitutive model suited for the analysis of anisotropic equivalent continua. The model accounts for strength and deformability features of the discontinuity sets and the rock they comprise. Preliminary results are discussed as a first step toward subsequent dynamic analysis.

Keywords: rock slope, finite elements, flexural toppling, Central Apennine

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Rockburst-Inspired Controlled Spontaneous Fragmentation of Hard Rock via Ultra-High Frequency Particle Impact

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Abstract

Harnessing rockburst—the spontaneous fragmentation of high strain-energy hard rock—is a promising strategy for efficiently breaking hard rock in the high in-situ stress environments of the deep earth. However, safely controlling this spontaneous process remains a formidable challenge. Here, we demonstrate a method that uses an ultrasonic vibration field to actuate small-scale steel particles, generating ultra-high-frequency point-load impacts on extremely hard rock (unconfined compressive strength, UCS > 150 MPa). These repeated, high-stress impacts rapidly initiate localized damage, which triggers a cascading release of the rock's intrinsic strain energy and leads to spontaneous fragmentation. Crucially, the process remains highly controllable: the rapid attenuation of the ultra-high-frequency action and the small localized influencing area confine the damage zone, ensuring safe and efficient spontaneous operation. Quantitatively, using our proposed Relative Comprehensive Damage Rate (RCDR) index, our findings indicate a 161.7% increase in rock fragmentation efficiency at 80 MPa confining pressure compared to the unconfined case, without any increase in external energy input. Our work thus demonstrates a strategy to safely harness the immense stored energy within deep rock, transforming a geological hazard into a highly efficient excavation tool.

Keywords: Ultra-high-frequency particle impact, Confining pressure, Hard rock, Spontaneous fragmentation, Controllable characteristic

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Kinematic Analysis of the Slopes of the Mutirão Quarry, in Seropédica, Rio de Janeiro, Brazil

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Abstract

* Kinematic analysis is one of the methods employed in rock mass stability studies. A detailed analysis was conducted on the slopes of Mutirão Quarry, a decommissioned unit in Seropédica, Rio de Janeiro. The site is used as a "training outcrop" for practical training of geology students at the Federal Rural University of Rio de Janeiro. The rock mass consists of Neoproterozoic orthogneisses with low-angle dip banding, which does not influence slope stability. For this study, 204 discontinuity measurements collected between 2023 and 2025 were used, and ten slope segments were defined and analyzed and the results were compared to field observations for validation. Structural analysis indicated four main discontinuity families, and kinematic analysis indicated higher probability of planar sliding and toppling (flexural and direct). However, the analysis revealed a significant discrepancy in wedge failure assessment; the software indicated significant failure probability percentages that were not confirmed in the field. This occurs because the last version of the program does not apply lateral limits to wedges, treating laterally limited planar failures as if they were actual wedges. However, for other processes, the analysis showed high adherence to observed reality.

Keywords: Kinematic analysis, rock mass, slopes, discontinuities



Geomechanical mapping training at Pedreira Mutirão in Seropédica, Rio de Janeiro (BR)

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A New Portable Device for Classifying Rock Weathering Using the Slaking Method

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Abstract

The degree of weathering of rock materials can be determined using various methods, such as visual identification, chemical analysis, and mechanical testing. However, each of these methods has its drawbacks. For example, whereas visual identification requires the researcher's experience, chemical analysis and mechanical testing require laboratory work. The operating principle of the device developed in this study was based on a jar slake test. When the degraded rock material is placed in the device tube, it induces turbidity in the water, allowing determination of the rock degradation level based on the turbidity level. Water turbidity was measured using infrared sensors to avoid the effects of sunlight. The classification system follows the ISRM (1981) guidelines. Field tests on andesite, basalt, and granite outcrops demonstrated that the device accurately assessed materials with weathering grades of 3–6.

Keywords: Jar Slake Test, Rock Weathering Classification, Slaking, Turbidity

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The Effect of Ring Thickness on the Circumferential Direct Tensile Strength of Rocks: Based on Experiments and DEM Numerical Simulations.

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Abstract

This study proposes a novel testing method for directly measuring the tensile strength of rocks using ring-shaped specimens. By applying uniform radial tensile stress on the inner surface of the ring specimen using a flexible loading method, the specimen splits in a direction perpendicular to the applied tensile load. The research primarily focuses on investigating the effect of specimen size on the tensile strength of rocks. The outer diameters of the specimens are 90mm, 100mm, and 110mm, with a fixed inner diameter of 80mm and a fixed height of 20mm. Acoustic Emission (AE) monitoring technology is employed to capture the fracture process during the tensile tests, and the distribution of RA-AF values reveals various types of tensile-shear composite cracks generated during the fracture process. Furthermore, Particle Flow Code (PFC) simulations are used to model the failure of the ring-shaped specimen under tensile loading, providing deeper insights into crack propagation and stress distribution. The results indicate that the tensile strength increases with the specimen size, and specimens with greater thickness exhibit higher tensile strength. Additionally, the PFC simulation results correlate well with the experimental data, validating the effectiveness of the proposed direct testing method. This method offers a practical and convenient alternative for measuring the tensile strength of rocks and is of significant importance for rock mechanics and material property testing in civil and geotechnical engineering.

Keywords: Tensile strength of rock, acoustic emission

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Feasibility Study of Surface Weathering Index (SWI) for Quantitative Assessment of Tropical Granite

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Abstract

Accurate characterization of granite weathering is essential for engineering geological assessment and preliminary site investigation in tropical environments, where intense weathering processes progressively weaken near-surface rock masses. Conventional field classification methods rely primarily on visual description and single-parameter mechanical indicators, which often result in uncertainty in transitional weathering grades. A quantitative and continuous framework is therefore required to improve objectivity and consistency in weathering evaluation. This study develops a Surface Weathering Index (SWI), a non-destructive framework integrating surface mechanical stiffness, digital colorimetric parameters, and mineralogical indicators to quantify weathering severity. Twenty-four granite specimens representing ISRM Grades I–VI were examined. Mechanical stiffness was determined using the Knocking Ball Test to obtain the dynamic elastic modulus, while surface color variation was quantified using the CIELAB color space. Mineralogical trends were identified through X-ray fluorescence (XRF) analysis. All parameters were normalized and combined using a weighted formulation optimized through regression analysis. Results indicate that mechanical stiffness serves as the primary control on weathering progression, while colorimetric and mineralogical components enhance sensitivity in early and transitional stages. The optimised weighting configuration (0.05: 0.85: 0.10 for color, geomechanical, and mineralogical components, respectively) achieves $R^2 = 0.9937$ against mechanical reference data. A practical geomechanical weighting range of 0.65-0.85 maintains strong agreement ($R^2 > 0.90$) across lithological variations. As a surface-based method, the SWI provides a consistent and field-applicable tool for quantitative weathering assessment, particularly for preliminary site investigation of cut slopes, tunnels, and excavations in tropical granitic terrains.

Keywords: Granitic Rock, Elastic Modulus, Colorimetric analysis, Weathering classification, Tropical weathering

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Static versus Dynamic Elastic Moduli in Gneiss: A Comparative Study for Geotechnical Characterization

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Abstract

This study aimed to compare analysis of elastic modulus values obtained using dynamic (Ed) and static (Est) methods on four gneiss samples to assess the applicability of non-destructive techniques for geotechnical projects such as slope stability analysis in mining operations. The dynamic methods employed were the Impulse Excitation Technique (IET) and the Ultrasonic Pulse Velocity (UPV) while static reference values were obtained from uniaxial compressive strength (UCS) tests. Physical index tests (density and porosity) were also performed. The results indicated that the dynamic moduli overestimated stiffness compared to UCS results. The UPV-derived dynamic modulus (EdUPV) was on average 47% higher than EstUCS, whereas the static modulus estimated from IET (EstIET) showed the closest agreement, being only 12% higher on average. The sample with the lowest porosity and highest density exhibited the greatest stiffness. The IET method provided estimates reasonably close to the reference UCS modulus, offering a rapid, non-destructive alternative for field applications. The findings contribute to optimizing geotechnical investigations in challenging environments.

Keywords: Elastic Modulus, Impulse Excitation Technique (IET), Non-destructive Testing, Slope Stability, Ultrasonic Pulse Velocity (UPV)

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Borehole Exploration of Qatar's Subsurface: Physical and Mechanical Characteristics of Rocks and Soils

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Abstract

This study provides an integrated geotechnical characterisation of an area in Qatar using two 25 m-deep rotary core boreholes. Quaternary deposits overlie Simsima Limestone to a depth of roughly 14 m below the existing ground level. The limestone layers are underlain by the sediments of Rus Formation. In-situ tests included SPTs in superficial materials and continuous coring through carbonate rocks, with index and mechanical testing (gradations, moisture content, Atterberg limits, point-load indices, and unconfined compressive strength with modulus determinations) on recovered samples. Results show that intact strengths range from single-digit values up to more than 70 MPa, core recovery varies from 33 % to 100 %, and the Rus Formation exhibits higher moisture contents and lower densities compared with lithologies of Simsima Limestone. The heterogeneity of strength and stiffness highlights the importance of linking stratigraphy with rock mass condition rather than assuming uniform properties. The findings provide parameters that can be extended to other areas, and illustrate how variability in carbonate sequences controls settlement predictions, bearing capacity estimates, and excavation support design.

Keywords: Borehole exploration, Simsima Limestone, Rus Formation, geotechnical properties

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Mechanism of Strength Attenuation in Gypsum Rock under Water-Rock Interaction

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Abstract

In response to the strength attenuation phenomenon of the Cretaceous Guankou Formation gypsum rock widely distributed in the southern suburbs of Chengdu, this study investigates the mechanism of strength attenuation in gypsum rock under water-rock interaction. Based on summarizing the variation patterns of gypsum rock parameters during a 35-day immersion process, methods such as hand specimen identification, X-ray diffraction whole-rock quantitative analysis, and thin section identification were employed for in-depth analysis. The results indicate that factors including mineral composition, structural characteristics, and immersion duration significantly influence the strength attenuation of gypsum rock, with its failure mode transitioning from brittle to plastic failure. At the microscopic level, the mechanism of strength attenuation in gypsum rock is primarily manifested in the dissolution of mineral components, structural erosion, and weakening of structural connections. Macroscopically, it is characterized by softening, disintegration, reduced strength, and increased deformation of gypsum rock. The structural degradation of gypsum rock can be described using parameters such as the softening coefficient and structural damage coefficient. With prolonged immersion time, the softening coefficient of gypsum rock gradually decreases, while the damage coefficient progressively increases.

Keywords: Gypsum rock, Strength attenuation mechanism, Water-rock interaction, Salt-bearing stratum, Rock structure

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Field Assessment of Rockfill Density Using a Water Replacement Method in Test Pit: A Case Study

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Abstract

Rockfill is widely used to enhance the mechanical stability and drainage performance of tailings storage facilities (TSFs). In rockfill construction, performance is primarily governed by method-based control, while material properties and in-situ density measurements are used to verify placement consistency and benchmark field conditions against design assumptions, particularly when rockfill is implemented for the first time. This paper presents a field case study of rockfill density assessment using the water replacement method at large-scale tailing facilities at the Oyu Tolgoi mine, Mongolia. The field test results indicate that gravel content is the primary factor controlling dry density, whereas moisture content has a negligible influence on the achieved density. The study demonstrates that the water replacement method is a practical and effective field technique for determining rockfill density in large-scale tailings' applications.

Keywords: Rockfill density, Field test, Tailing dam, Rockfill compaction,



Test pit excavation

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Stochastic 3D Discrete Fracture Network Modeling from Sparse Outcrop Data: A Methodological Framework

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Abstract

Rock joint characterization is essential for geohazard assessment and underground structure design. However, outcrop-based surveys often lack spatial coverage due to restricted accessibility. This study probabilistically extends sparse outcrop data to construct a three-dimensional Discrete Fracture Network (DFN) and evaluates its structural fidelity. Using joint orientation, spacing, and trace-length data measured at 14 granitic sites, we generated approximately 700 fractures per site within a 20 m cubic domain using dfnWorks. Fracture radii followed a truncated power-law distribution (0.5–10 m), and orientations were modeled with Fisher distributions, distinguishing major joint sets (kappa = 30) from background joints (kappa = 1). Furthermore, the generation proportions for each set were determined using field-calculated volumetric fracture intensity (P32). Visual assessments using density contour plots and rose diagrams demonstrated strong structural consistency. Quantitatively, reproduced joint-set orientations agreed with field measurements with a mean angular difference within 5°. Notably, Sites 4, 8, and 10 exhibited identical joint-set mean orientations in the field and DFN results. These results indicate that stochastic DFN modeling effectively mitigates spatial biases inherent in limited outcrop data, securing reliable characterization of fracture network characteristics. This study was conducted as part of the project "Development of long-term environmental change prediction technology for high-level radioactive waste disposal sites (RS-2024-00419276)" funded by the Korean Ministry of Trade, Industry and Energy and supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) under the subproject titled ‘Development of monitoring and operational technique for site characterization factors in national/site scale (RS-2024-00419806)’.

Keywords: Discrete Fracture Network (DFN), Stochastic modeling, Joint characterization, Model validation, Outcrop survey

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Physical and Mechanical Characterization of Anisotropic Rocks

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Abstract

Pre-Ordovician metamorphic rocks of the Schist-Greywacke Complex (SGC) or Dúrico-Beirão Supergroup outcrop in Northern and Central Portugal (Central Iberian Zone). Low to medium-grade metamorphic rocks form the rock masses where large structures have been built. Two locations were selected where intense site geological investigation was carried out for the construction of two large concrete dams. One is located in the Douro Group and the other in the Beiras Group. In both sites, the rocks correspond to centimeter-thick alternations of metagreywackes and slates, dark grey when intact (W1) to brownish when weathered (W3). Weathering is more intense along the foliation planes, which are predominantly subvertical. This fact influenced the number and quality of specimens collected, cut, and prepared in the sizes and shapes required for laboratory testing. Nevertheless, about 100 tests were performed for each site, following ISRM and ASTM standards. These included non-destructive and destructive tests to determine: the porosity and density of the rocks; the ultrasonic pulse velocity; the resistance to point load, the uniaxial compressive strength, and the tensile strength. Approximately 20 specimens were used for each test due to the intense anisotropy (tectonic deformation) of the rocks. Both the predominant lithologies in each sample specimen and the foliation show a significant influence on the results. Porosity (essentially due to tectonic compaction) is much higher for samples from the Beiras Group than for those from the Douro Group, with correspondingly lower specific gravities. The mechanical properties for the Beiras Group are also generically weaker than for Douro Group.

Keywords: Tectonic background, Anisotropic rocks, Physical properties, Mechanical properties

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Bedding-Perpendicular Fracture and Mechanical Mechanism of Soft-Hard Interbedded Rock Mass

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Abstract

Bedding-perpendicular joints (BPJs) developed in soft-hard interbedded strata are a common and significant type of discontinuity in sedimentary strata. Their development affects the mechanical and hydraulic properties of rock masses and is closely related to geological structure evolution and resource exploitation. This paper analysed how depositional environment, lithology, geometric conditions of strata, and geological setting influenced BPJ development. It also systematically revealed the scale evolution mechanism of BPJs through three development stages: initiation, in-layer propagation, and cross-layer propagation. The results show that BPJ spacing is heterogeneous and follows a dynamic distribution function that changes with different development stages. Higher depositional energy during diagenesis correlates with greater joint spacing. Thicker hard layers lead to larger joint spacing and wider apertures. The dominant strike of BPJs typically forms a small angle with the tectonic stress direction. However, interface morphology heterogeneity, contrasts in elastic modulus, and material inhomogeneity may cause changes in the local stress field, thereby affecting this pattern. Joint initiation is controlled by weak zones or areas of stress concentration within the rock layer. Joint propagation follows the principle of minimal energy and its path depends on the homogeneity of the rock layers. Interface bond strength and soft-layer thickness influence cross-layer propagation. Higher bond strength and thinner soft layers are easy to form large-scale cross-layer joints. In contrast, lower bond strength and thicker soft layers cause joints to deviate along the interface. This work will provide an important foundation for a comprehensive understanding of BPJs.

Keywords: Soft-hard interbedded strata, Bedding-perpendicular joints, Fracture mechanism, Heterogeneous development , Scale evolution

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Disintegration Mechanism and Mode Transformation of Red-Bed Mudstone Under the Coupling of Multiple Factors Based on a Novel Disintegration Apparatus

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Abstract

To investigate the disintegration mechanism of red-bed mudstone in the upper reaches of the Yellow River region, a series of laboratory tests was conducted on the basis of a novel disintegration apparatus and testing method, thereby controlling the clay mineral content, initial moisture content, water pressure, and temperature. The disintegration behaviors of high-clay-mineral-content mudstone (HCM) and low-clay-mineral-content mudstone (LCM) were explored by analyzing indices such as the instantaneous mass-loss ratio, instantaneous mass-loss rate, final mass-loss ratio, and other features. It was found that the clay mineral content and initial moisture content significantly affect evolutionary processes and the final state of unsaturated red-bed mudstone; the and values of unsaturated HCM initially increase and then reach a maximum, after which they decrease with increasing initial moisture content. The instantaneous mass-loss ratio and final mass-loss ratio of unsaturated LCM decrease monotonically with increasing initial moisture content. Water pressure and temperature did not influence the final state but altered the evolutionary process of unsaturated red-bed mudstone, as the final mass-loss ratio of saturated mudstone was minimally affected by water pressure and temperature. The red-bed mudstone can be categorized into three modes: complete erosion, partial fragmentation, and surficial spalling, which will mutually transform affected by clay mineral content and initial moisture content. The disintegration mechanism was analyzed by considering the coupling of multiple factors, such as clay mineral content, initial moisture content, water pressure and temperature. The results indicated that the clay mineral content and the initial moisture content are the fundamental factor and controlling factor during disintegration, respectively. Water pressure and temperature are the disturbance factors during disintegration.

Keywords: red-bed mudstone, disintegration, clay minerals, water pressure, moisture content

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Laboratory Experiments and Engineering Applications of the Stress Relief-Recovery Test

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Abstract

Geotechnical engineering hazards are directly related to the stress state of the surrounding rock, making accurate stress data essential. However, due to the heterogeneity and anisotropy of rock masses, conventional stress testing methods are often difficult to apply in engineering practice. This study proposes a stress relief-recovery test for determining two-dimensional stress components on the rock surface. First, strain gauges are attached to the rock surface where stress measurement is required, and the readings are set to zero. Then, a borehole is drilled to extract the core with the attached strain gauges, and the deformation after stress relief is measured. Finally, the extracted core is reloaded until the strain gauge readings return to zero, and the restored stress at this point is used to estimate the in-situ stress. Laboratory simulation tests validated the accuracy of the proposed method, and field application in a tunnel showed an average error of 14.25%. The study demonstrates that the stress relief-recovery test does not require obtaining the elastic parameters of the rock compared to the conventional stress relief method, and is in good agreement with theoretical solutions of in-situ stress, making it a simple and practical approach for stress measurement in surrounding rock.

Keywords: Surrounding rock stress, Stress relief, Stress recovery, In-situ measurement

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Visualizing the Transition from Stick-Slip to Stable Sliding in Rock Fractures

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Abstract

In subsurface engineering, excavation-induced unloading can trigger a wide spectrum of frictional slip behaviors along rock fractures, ranging from unstable stick-slip to stable sliding. Although the stiffness-based stability criteria provide a theoretical framework for predicting these transitions, direct experimental evidence of how deformation evolves spatially during progressive unloading remains limited. Here, we performed a series of stepped-unloading friction experiments on smooth fractures in heterogeneous granite and homogeneous polycarbonate to reproduce the progressive transition from unstable stick-slip through transitional slip to stable sliding. Full-field shear strain was quantified using digital image correlation, enabling direct visualization of the spatiotemporal evolution of fracture deformation. The results show that unstable stick-slip is characterized by a persistent and highly localized shear strain hotspot near one edge of the fracture, indicating repeated slip nucleation from a dominant asperity region. As unloading progresses, the localized deformation of the polycarbonate fracture gradually weakens and reorganizes into multiple discrete strain concentrations, revealing a transition toward more diffuse deformation during frictional stabilization. The granite fracture exhibits the same overall trend but with substantially greater spatial heterogeneity, where multiple competing strain concentrations develop and persist, inhibiting the formation of a single coherent shear zone. These observations demonstrate that frictional stabilization during stepped-unloading is accompanied by a distinct spatial redistribution of deformation. The study provides direct experimental evidence linking frictional stability to the evolution of full-field deformation and highlights the critical role of lithological heterogeneity in governing slip localization and stabilization during excavation-induced unloading.

Keywords: Digital image correlation, Dynamic shear rupture, Shear strain localization, Frictional sliding stability

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Rock Mass Classification from In-Roof Imaging: A Sydney Sandstone Tunnel Case Study

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Abstract

Rock mass classification is a key input to tunnel and underground mine support design, excavation sequencing, advance length, cost control and construction scheduling. In current tunnelling and mining practice, roof support decisions are commonly based on face mapping, although roof conditions can differ from those exposed at the advancing face. This mismatch can lead to under-supported ground, with safety risks, or over-supported ground, with avoidable cost and program impacts. This study evaluates whether in-roof borehole imaging can provide a direct basis for roof rock mass classification.

Real construction data from a tunnel excavated in Hawkesbury Sandstone within the Sydney Basin were analysed. The broader dataset included more than 400 face maps, where previous comparison between predicted and mapped ground conditions showed low classification accuracy of 34.9% and 41.2% in two main drives of the tunnel. In-roof boreholes drilled, from about 4 m up to about 7 m into the roof were classified using adapted Endoscopic Rock Mass Factor (ERMF), Roof Fall Risk Index and modified Pells approaches, then compared with rock mass classes from face maps in the same areas.

The results show that endoscopic roof data can produce rock mass classes comparable with face mapping, with the ERMF method achieving the highest exact agreement and capturing poorer ground classes that other approaches missed. More importantly, in-roof imaging identifies roof discontinuities and local defects not visible at the face. Future work should define the required borehole density for different geological settings and integrate rock strength measurements into endoscope-based classification.

Keywords: Rock mass classification, face mapping, in-roof borehole imaging, endoscopic imaging, borescope imaging

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Estimation of Groundwater Seepage Velocity on Slopes by Continuous Electrical Resistance Tomography Method

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Abstract

Groundwater is the main cause of slope instability and sliding. The pore water pressure caused by groundwater infiltration reduces the effective stress on the ground material. Conventional groundwater level monitoring is limited to a single location, making it impossible to predict infiltration flow rate during the groundwater transport process. Monitoring groundwater flow rate is challenging. It is limited by the accuracy and precision of the instruments and is often expensive to carry out in situ monitoring. In this study, we used a large-scale sandbox model to simulate the seepage generated in the ground during rainfall on a slope. We evaluated the seepage flow rate by continuously and precisely monitoring the water level and using the continuous Electrical Resistance Tomography method. The method is feasible and can provide information about groundwater seepage velocity after several experiments.

Keywords: Groundwater, Seepage, Landslide, Continuous Electrical Resistance Tomography Method

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Comparative Analysis of Load Transfer Mechanism and Strain Distributions in Compression-Type and Composite-Type Anchors Based on Full-Scale Field Test

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Abstract

Ground anchor systems enhance structural stability by mobilizing tensile forces through high-strength steel tendons anchored in grouted bodies within competent ground. These systems resist earth pressure, uplift, and lateral loads, and are widely applied in retaining walls, slope stabilization, and excavation support. Their performance depends on ground conditions, tendon–grout interaction, and anchor configuration. Recent efforts focus on improving load transfer, reducing displacement, and increasing durability for use in complex subsurface environments.

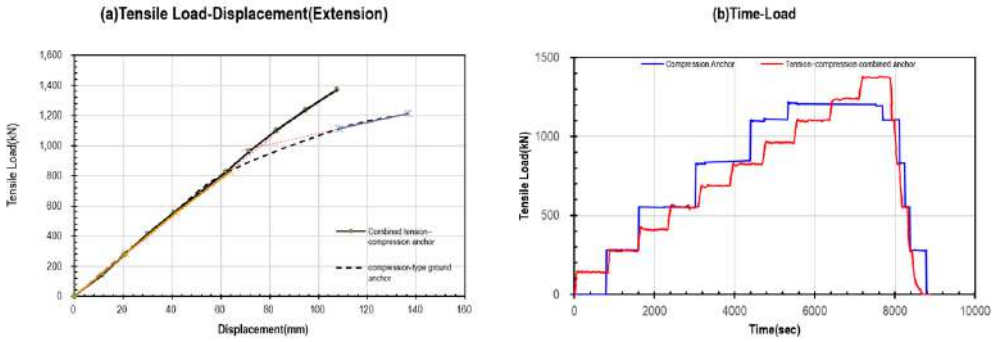
Conventional tension-type anchors, while widely used for their constructability and reliability, often suffer from grout cracking and progressive failure due to load concentration at the start of the fixed zone.

Compression-type anchors were developed to improve this problem, but the tensile force of the anchor is concentrated at the anchor mounting end, causing cracks to form at the stress-concentrated area, resulting in load loss.

This study developed a novel composite anchor concept that distributes concentrated loads generated by the anchor by placing a tensile member at the end of the anchor body, which is subject to compression. This anchor system effectively alleviates the load concentration at the tip and minimizes the loss of tensile strength, thereby improving the maintainability of the anchor's load management.

Field pullout tests were conducted to evaluate and compare the structural performance of 140-ton capacity compression-type and composite-type anchors installed in weathered gneiss ground. Results demonstrated that the composite-type anchor achieved higher load capacity (1373.4 kN) with lower displacement (107.46 mm) and exhibited superior load distribution and structural stability without yielding or ultimate failure, compared to the compression-type anchor. The study confirms that the newly developed composite anchor effectively combines the advantages of both tension and compression mechanisms and holds significant potential for permanent ground reinforcement applications across various soil conditions.

Keywords: ground anchor, composite anchor, field pullout test, composite anchor, tension-type anchor



(a) Comparison of tensile load–displacement behavior between compression-type and composite-type anchors (b) Time–load histories of compression-type and composite-type anchors during field tensile testing

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When Do Boreholes in Unconsolidated Sand Formations Fail?

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Abstract

Subsurface groundwater resources are essential for both Aquifer Thermal Energy Storage (ATES) systems and potable water supply. These systems rely on wells to access aquifers, yet rising demand for subsurface space and declining global water tables require innovative approaches to reach deeper and more challenging formations. One workable solution is the local expansion of the boreholes' diameter at depth. This permits higher design flow rates, potentially reduces clogging, and improves cost-efficiency. However, it also raises new concerns regarding borehole stability. Previous experimental and theoretical analysis has shed light on the critical role of dilation, providing explanation as to why a borehole can remain stable even when drilled in a formation with little to no cohesion. Nonetheless, the conditions that lead to borehole failure remain insufficiently understood. Therefore, the logical follow-up question is: when do boreholes in sand fail? To address this, the problem is investigated by means of Discrete Element Analysis (DEM), allowing for the proper representation of the discontinuous nature of borehole collapse mechanisms in unconsolidated sands. The aim of this study is to identify conditions when borehole fails, and to quantify related stress conditions. These insights enables the exploration of more complex well designs. In this contribution the outcomes of the DEM study are presented

Keywords: ATES, Borehole failure, Unconsolidated sand, DEM

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Integrating Satellite Reflectance and Field Measurements to Predict Moisture Content Profiles in Bare-Soil Conditions

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Abstract

Landslides triggered by rainfall infiltration pose significant geotechnical hazards, yet predictive modeling remains limited by the lack of scalable, high-resolution soil moisture data. This study develops a machine learning-based Hydro/Spectral (H/S) model to predict volumetric water content (VWC) at multiple soil depths using Sentinel-2 multispectral imagery and in-situ soil temperature measurements from ten Kentucky Mesonet stations. Over 500 cloud-free images were processed within 160 m × 160 m bare-soil buffers, an area of interest significantly finer than the kilometer-scale resolutions typical of most satellite-based soil moisture predictions. For each image, statistical descriptors such as skewness, variance, and covariance eigenvalues were extracted from reflectance data in visible, near-infrared, and shortwave infrared bands. These features were paired with daily in-situ measurements to train and validate multiple regression models. Random Forest outperformed other models, achieving the highest R^2 and lowest RMSE across all depths. Soil temperature and spectral indices such as the Normalized Difference Soil Index (NDSI) were identified as key predictors. Results demonstrate that reflectance and climate data can predict shallow soil moisture with moderate accuracy at fine spatial scales. This approach supports the development of scalable, non-invasive tools for monitoring unsaturated soil conditions and improving slope stability assessments under changing climate conditions.

Keywords: volumetric moisture content, remote sensing, machine learning, surface reflectance, soil

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Integrated Geophysical Investigation of Aquifers in Glacial Burried Valleys. Case study from Central Poland.

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Abstract

This study focuses on the integrated use of geophysical methods to characterize local aquifers hosted in sand and gravel filling of burried tunel valley. The area presented is located in central Poland near Sierpc town. The area is geologically complex due to the presence of highly variable glacial sediments, which complicate subsurface investigations. The location and general geometry of buried valleys in the study area had been previously recognized based on borehole logs, water well records, and early archival geophysical surveys. However, these earlier datasets provided only a simplified picture of the subsurface conditions. In this project, we reprocessed selected archival geophysical data, which led to the identification of a more complex internal structure of the buried valleys than previously assumed. The revised interpretation suggested significant variability in valley shape, depth, sedimentary infill and much narrower valley. To refine the geological model, we carried out an additional shallow seismic survey. This new dataset allowed for more detailed imaging of aquifer boundaries and improved our understanding of the internal stratigraphy and geometry of water-bearing units. Our results enhanced the knowledge of this locally important aquifer system. In the context of climate change and increasing stress on water resources, accurate characterization of such groundwater reservoirs is crucial for effective regional water management.

Keywords: Aquifer, Engeenering Geophysics, Glacial Sediments, Burried Valleys, Water Resource Management

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LiDAR for Rapid Geomorphological Assessment, Examples in Relict Periglacial and Landslide Landsystems

David Giles[1]

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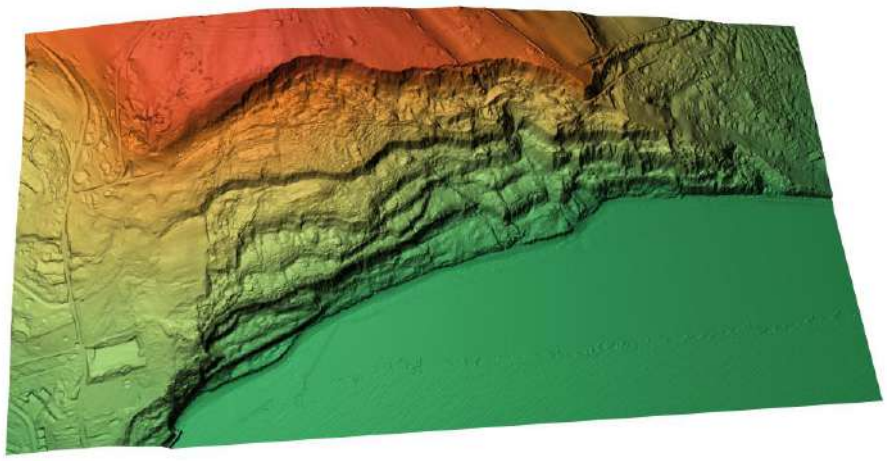
Abstract

Areas of relict periglacial landforms, including landslides, cambering, valley bulge and associated gulls are often challenging to delineate from ground mapping alone. This submission presents the advances in ground model assessment offered by airborne LiDAR (laser scanning) data sets for engineering geomorphology. High resolution digital elevation models derived from the LiDAR imagery can be utilized to interpret and visualize the on-ground geomorphology. The available LiDAR imagery is described, and examples of their use presented from classic case study sites.

Keywords: LiDAR, Periglacial, Geohazard, Landslide, Visualisation



Shaded relief models of the Black Ven - Spittles landslip complex, Lyme Regis, Dorset, UK. Benches displaying bedding controlled failures can be seen along with fault control slowing the lateral expansion of the landslide complex.

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Advanced Geotechnical QA/QC of Drill Core Data to Optimize Hydrofracking Analysis

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Abstract

The LKAB Kiirunavaara iron ore mine is seismically active and mining operations are progressing downwards. A project for exploring the effect of the hydraulic fracturing technique as a seismic hazard mitigating tool is evaluated. The underground trials went on between 2019 to early 2023.

This subproject, initiated in October 2024, aimed to refine the geotechnical, lithological and structural models at Kiirunavaara mine, and improve the knowledge regarding alteration, by the application of QA/QC routines. In LKAB, geotechnical QA/QC is mainly conducted by evaluating comparative geotechnical parameters one vs another, and correlation with structures. The project consisted of over 110 drill cores, drilled in two production areas between 2019 – 2022. During this time, logging routines have been developed and expanded, and logging was performed by many different geologists.

The project aim was to get a complete and consistent geological and geotechnical datasets, which would enable a deeper analysis of hydraulic fracturing and also provide a better understanding of the deposit and facilitate damage analyses.

The project involved extensive core handling as the cores had been stored under unfavourable conditions. Updated QA/QC methods were employed to identify errors in the geotechnical and geological datasets, initiate necessary corrections and re-logging resulting in consistency and reliability of the datasets for lithological, structural and geotechnical analysis.

A comprehensive drill core analysis program was conducted, including re-logging for rock mass classification, geochemical sampling, and geotechnical testing (UCS, Triaxial, Brazilian). Comparing data before and after QA/QC has shown improvement in the geotechnical model.

This multidisciplinary project (including: geotechnical and structural geologists, miners and mine seismologist) advanced the geological and geotechnical understanding of the Kiirunavaara deposit, supported improved modelling, and highlighted the significance of integrating rigorous QA/QC protocols and updated methodologies in resource evaluation.

Keywords: QA/QC, drill core, hydraulic fracturing, geotechnical logging, geotechnical modelling

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Field Hydraulic Conductivity Test in Clayey Soils: Evaluation Aquifer Recharge Challenges

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Abstract

Climate change is altering rainfall patterns, leading to greater intensity and shorter duration of events. This generates significant surface runoff, causes flooding, and decreases natural aquifer recharge. Consequently, methods for artificial aquifer recharge must be evaluated, as groundwater extraction continues while natural infiltration declines. Baseline conditions must be investigated to evaluate phreatic levels, recharge areas, hydrogeochemistry, and isotopes, among other parameters. In Uruguay, the Raigón Aquifer is a vital groundwater resource utilized for agricultural and industrial activities, as well as drinking water. The Libertad Clay, an aquitard composed of clayey and silty-clayey soils, overlies the Raigón Aquifer. Regional piezometric levels indicate that recharge occurs through the Libertad Clay where its thickness ranges between 20 m and 35 m. In this study, field and laboratory tests were conducted to measure the hydraulic conductivity (HC) of the Libertad Clay and determined whether recharge through this aquitard is viable. In the field, 3 m deep wells were constructed for infiltration testing, and soil samples were collected every 0.5 m for laboratory classification and HC testing. Laboratory HC values were lower than 10-9 m/s, whereas field infiltration rates ranged from 10-6 m/s to 10-7 m/s. As a results field infiltration rates were 100 to 1,000 times higher than laboratory measurements, finding that field testing provides a more representative evaluation of the hydraulic behavior of the Libertad Clay for aquifer recharge. Ongoing complementary research aims to identify the specific processes driving this recharge to inform future managed aquifer recharge strategies.

Keywords: Libertad Clay, aquifer recharge, hydraulic conductivity, field test

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The stiffness of weathered clays and mudstones: Back-analyses of an earthwork trial

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Abstract

This paper presents back-analyses from an instrumented embankment trial, founded on weathered clays and mudstones. The trial was undertaken during construction of the High-Speed Two (HS2) railway between London and the West Midlands. The Charmouth Mudstone Formation (Lias Group) outcrop in this part of central England was formed ~183-199 Ma ago and subsequently experienced glacial and periglacial weathering. It has a gradational weathering profile that transitions from clay-like properties to rock-like properties at greater depth. The ground profile beneath the trial embankment was examined using borehole logging, downhole geophysics and the excavation of samples for laboratory testing. Piezometers and extensometers were installed beneath the embankment prior to construction and monitored during and after construction. They measured and logged changes in porewater pressure and ground deformation beneath the embankment. Simple back-analyses were undertaken to interpret the engineering properties of the ground profile beneath the embankment. These included interpretations of stiffness degradation at small strains and the pore water pressure response to changes in total stress. The results provided an insight into the changing engineering properties of the weathered mudstone profile with depth. This can be used to inform the design and construction of earthworks and other structures in outcrops of weathered mudstone.

Keywords: Mudstones, Weathering, Earthworks, Stiffness, Porewater pressure

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Engineering Geologic Investigation for Planning Tejon Ranch Mountain Village, a 140 km2 Proposed Resort Community in Kern County, Southern California

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Abstract

This paper describes an engineering geologic site characterization case study to assist the Tejon Mountain Village planning team with sustainable land planning by developing a geological constraints map for the 14,000-hectare planning area. The investigation assessed active surface fault rupture, landslide, sackungen, subsidence, liquefaction and debris flow hazards, their potential impacts on development, and alternative mitigation measures. A geologic map for the site was compiled from existing data, supplemented with data collected during this field investigation. The investigation utilized Landsat imagery and stereo aerial photographs; geologic field mapping; and a subsurface investigation consisting of core drilling, cone penetration probes, and fault trenching. The project is bisected by the Garlock fault, a 250-km fault with a slip rate of 5-7 mm/yr, generating 3-7 m left-lateral displacements about every 1000 years. Numerous landslides were mapped within the project. The steep granitic slopes also experience sackungen-style deformation with slope-parallel troughs and upslope-facing scarps from slow gravitational deformation. Mud and debris flows are actively building fan topography at the base of the slopes, sediments that are susceptible to hydroconsolidation, and soil erosion has increased due to historic cattle grazing. The geohazard constraints map became the basis for the site planning and the mitigation alternatives served to develop the environmental impact assessment. The appropriate type of sustainable mitigation depends not only on the geological conditions within a specific area, but also on the grading, design and type of structure that is planned. But any mitigation analysis first requires a comprehensive engineering geologic site characterization.

Keywords: Development Planning, Sustainable Development, Geohazards, Fault Studies



Typical landforms within the proposed Tejon Ranch Mountain Village planned community.

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Muon Imaging in Engineering Geology: New Applications of Cosmic Ray Technology

Tommaso Beni[1], Diletta Borselli[2, 3], Lorenzo Bonechi[3], Debora Brocchini[4], Silvia Guideri[4], Sandro Gonzi[3, 2], Tommaso Carlà[1], Giovanni Gigli[1], Luca Lombardi[1], Massimiliano Nocentini[5], Vitaliano Ciulli[2, 3], Raffaello D'Alessandro[2, 3], Nicola Casagli[1]

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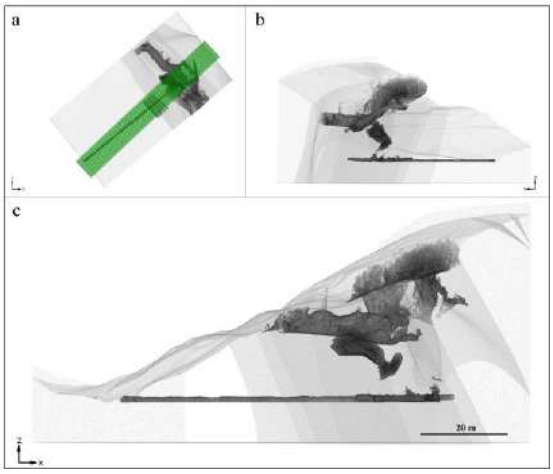
Abstract

This study investigates muon imaging (muography) as a non-invasive method for engineering geological surveys, integrated with advanced geomatic techniques to identify and characterize subsurface voids. Muography exploits the natural flux of cosmic ray muons, high-energy charged particles produced in the upper layers of the Earth's atmosphere through interactions between primary cosmic rays and atmospheric molecules. Muons have a high penetrating power, allowing them to traverse hundreds of meters of rock, with energy attenuation depending on the density and thickness of the material crossed. By analyzing variations in muon flux after passing through the studied target, internal density anomalies can be inferred, enabling detection and three-dimensional mapping of cavities. This passive imaging approach is analogous to X-ray radiography but applied at geological scales. The case study concerns the Temperino mine, within the Archaeological and Mining Park of San Silvestro (Italy), historically exploited for skarn minerals from the Etruscan era to the 20th century. The rock mass hosts a complex network of natural and anthropogenic voids, posing hazards including roof collapse, sidewall instability and surface subsidence. Muon transmission measurements acquired with a muon tracker inside the mine were integrated with high-resolution point clouds and geological models to reconstruct cavity geometry and surrounding rock volumes (Figure 1). This enabled preliminary numerical simulations of stress and strain to evaluate stability conditions. The study also discusses advantages and limitations of muography. Future applications in engineering geology are considered, such as tunnel monitoring, rock mass imaging and the sustainable management of mining sites.

Keywords: Muon imaging, Muography, Stability assessment, Undeground mining sites, Non-invasive surveys



Three-dimensional model obtained from the integration of geomatic and muographic surveys for engineering geological applications: a) orthogonal view of the case study with the sections analyzed for numerical modeling (highlighted by green lines); b) and c) lateral views of the rock mass showing all identified cavities and transparent geological contacts.

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Correct Interpretation of Inclinometer Measurements Even at Great Depths. Several Years of Experience Acquired with a Robotic Inclinometer System

Danilo Godone[1], Paolo Allasia[1], Daniele Giordan[1], Davide Notti[1], Diego Guenzi[1], Mohanad Ellaithy[1], Niccolò Dematteis[1]

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Abstract

The measurement of horizontal deformations in the subsoil remains a fundamentally important data point in both the field of geo-risks and the sector of large-scale works. In both sectors, this measurement represents a key element for planning, mitigation or informed coexistence with the phenomenon. The measurement still most widely used in this sector is the inclinometer, which is generally performed with manual operator-assisted systems or automatically using IPI. To overcome the limitations of these systems, an alternative system was developed years ago that robotized manual measurement, replacing the operator with an automatic electromechanical system. This system enabled reaching an exceptional depth of 250 m with a single probe and double readings (0/180°), while also highlighting critical issues related to inclinometer measurements that are well-known at both the scientific and practical levels. Daily (or higher) measurements acquired, combined with high precision in vertical positioning, have clarified aspects related to accuracy and the main acquisition and interpretation errors. These analyses improve the quality of geo-engineering interpretation of the phenomenon by reducing the presence of apparent deformations that are often difficult to explain and sometimes low compatible with the observed process. Correct evaluation of the measurement, especially in the case of extremely small values, is of fundamental importance to avoid apparent movements that can also be amplified by integral processing, with consequent criticalities and reliability of the monitoring itself

Keywords: Underground deformations, Landslides, Monitoring, Robotic system

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Cradle-Induced Variability in Ultrasonic Pulse Velocity Measurements: A Comparative Study of Support Materials

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[2] Vale S.A, Belo Horizonte, MG, Brazil

Abstract

The propagation velocity of elastic waves, including compressional (Vp) and shear (Vs) waves, is a fundamental parameter for characterizing the physical and mechanical properties of rocks. Conducted by an all-women team—including undergraduate and master's students and the advisor—this study evaluates the influence of different support materials on ultrasonic wave velocity measurements (Vp and Vs) in gneiss specimens through a research initiative that combines scientific investigation and experimental training, promoting education and participation in Engineering Geology. Tests were performed using transducers with central frequencies of 250 kHz for Vp and 40 kHz for Vs. Five gneiss specimens were analyzed using six support materials: wood, 3D-printed PLA, expanded polystyrene, polyurethane foam dry, polyurethane foam saturated, and low-carbon steel. Results showed that P-wave velocities (Vp) exhibited low dispersion and high repeatability across supports, indicating minimal sensitivity to contact conditions. In contrast, S-wave velocities (Vs) were highly sensitive to support characteristics, showing greater variation and dispersion. Flexible polyurethane foam in saturated condition induced a Vs variation of approximately 32% relative to the mean, whereas carbon steel produced the highest dispersion, nearly 41%. These findings indicate that shear wave propagation is strongly affected by contact imperfections, coupling heterogeneity, and acoustic impedance mismatch at the specimen–cradle interface. Standardizing support materials is therefore critical for ensuring consistent and reliable Vs measurements and improving laboratory reproducibility.

Keywords: Ultrasonic testing, Acoustic impedance, Support materials

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Fault Hierarchy–guided Evaluation and Weighted Integration of Multi-Source Remote Sensing Methods for Fault Identification

Keke Zhu[1, 2], Zan Wang[1, 2], Shengwen Qi[1, 2], Songfeng Guo[1, 2], Yongchao Li[1, 2], Xiao Lu[1, 2], Yidong Xiao[1, 2]

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Abstract

Faults represent critical structural units governing regional tectonic frameworks and geomorphic evolution. Despite the growing adoption of multi-source remote sensing data fusion for fault identification, conventional evaluation methods predominantly employ uniform metrics, thereby overlooking scale-dependent variances and their distinct tectonic implications. This study introduces a hierarchical reference fault system and develops a scale-bias factor to systematically investigate the impact of hierarchical logic throughout the "evaluation-weighting-overlay" workflow. Key findings demonstrate that: (1) hierarchical evaluation reveals the differential responses of identification algorithms to various fault scales, providing a more holistic perspective for performance analysis; (2) hierarchical weighting effectively capitalizes on method-specific advantages across different scales, facilitating targeted weight allocation and enhancing the accuracy of structural representation; and (3) a comparison of results reveals that significant improvements in location, morphology and continuity of faults can be achieved even with minor variations in weight values. The "hierarchical evaluation-weighted overlay" approach demonstrates significant practical value for fault identification from remote sensing images.

Keywords: Fault identification, Multi-source remote sensing, Hierarchical evaluation, Scale-bias factor, Weighted overlay

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Non-Invasive Seismic Subsoil Imaging for Practical Applications

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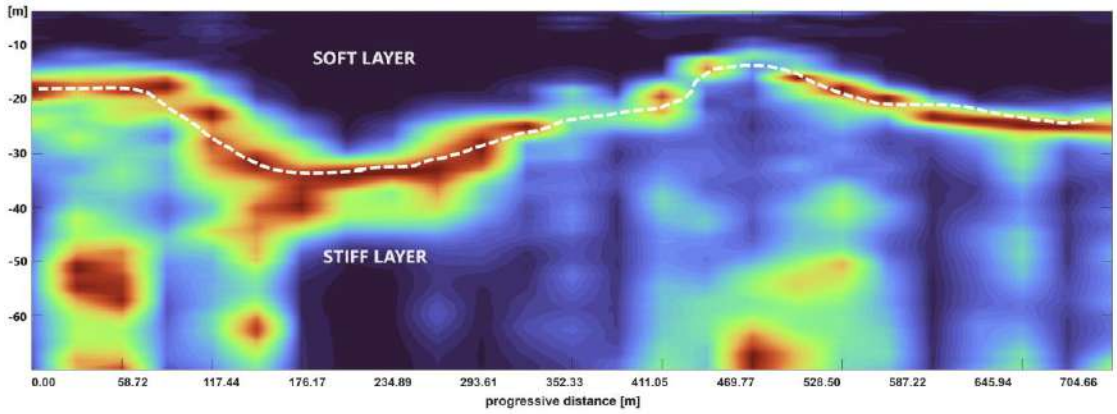
Abstract

The microtremor Horizontal-to-Vertical Spectral ratio (HVSR or simply H/V) technique is a well-known geophysical method, expected to provide the resonance frequencies of soft sedimentary layers overlying stiffer layers. A few minutes recording of ambient microtremors by means of a tri-axial seismometer are enough to show characteristic spectral patterns, varying from site to site, according to the local geological features. From the resonance equation f = V/4H, it can be seen that the resonance frequency (d) of a layer is inversely proportional to its thickness (H) and that when one knows or can assume a 'characteristic' seismic wave propagation velocity (V) for the sedimentary layer, the resonance frequencies can be converted into thicknesses of resonating layers, thus allowing to image the ground.

We show a number of notable examples of bedrock mapping, landslide mapping and other seismic reflectors mapping performed by means of sequencies of short and very short H/V recordings collected in 2D or 3D configurations. We will show the effect of the assumptions on the seismic wave propagation velocity (V) and we will clearly state the benefits and the limitations of the technique and specifically the cases when it cannot be applied, and what one should do in those cases.

The hope is that the presented approach will be used by the engineering geological community for expedite subsoil imaging at different scale, with a clear idea of its benefits and limitations.

Keywords: Seismic methods, subsoil imaging, HVSR, passive seismic

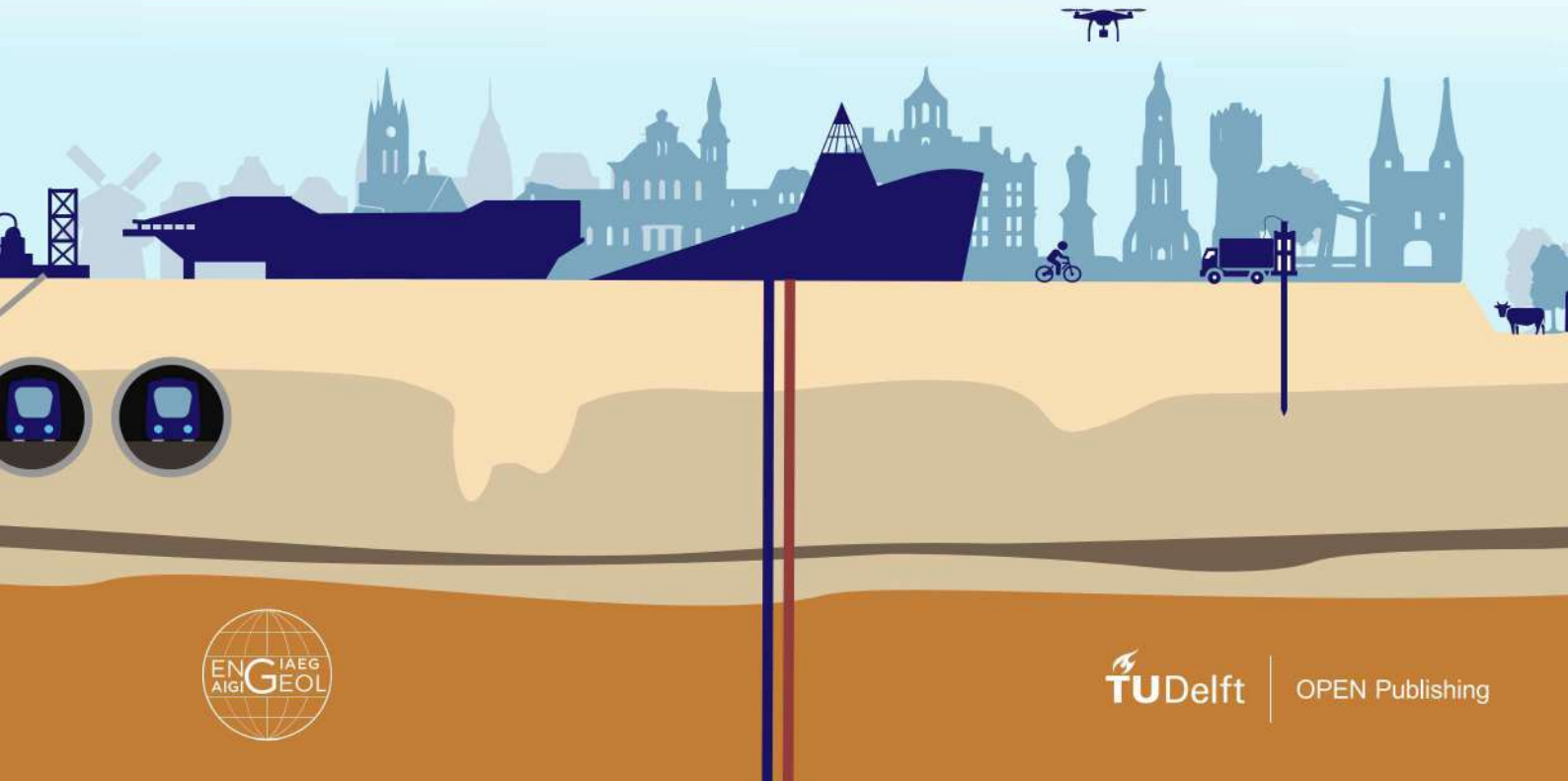


Example of subsoil imaging by means of single-station passive methods

2. Low Lying, Coastal, Soft Soil Countries



Engineering Geology for a sustainable future in densely populated low lying, coastal, deltaic, and soft soil countries. Priority on subsidence, coastal erosion, and flood protection, including water management.



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Vertical Land Motion Monitoring of Expansive Clay with High-Precision Extensometers in the Groningen Coastal Plain of the Netherlands

Laura Becerra Silva[1, 2], Kay Koster[1], Vincent Soustelle[1], Pietro Teatini[2], John Blackman[3], John Leeman[3], Thibault Candela[1]

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Abstract

Vertical land motion in the clay-rich coastal plain of Groningen (the Netherlands) is believed to be a prime contributor to damage inflicted to buildings and infrastructure. Nevertheless, the driving processes responsible for vertical land motion in this clay area have been poorly investigated. Therefore, we designed a vertical land motion monitoring set-up near the town of Ezinge to determine long term trends and daily to seasonal fluctuations in land surface elevation. High precision extensometers were deployed with anchors at three different depths within the clayey coastal sequence, with piezometers installed at corresponding depths. This set-up allows to link changes in groundwater heads at different depths to vertical land motion. In addition, we make use of open access data of precipitation and temperature to explain the observed motion. Here, we present the extensometer set-up and the first monitoring results. The results show that phreatic water level changes respond relatively fast on changes in precipitation, resulting in vertical land motions of up to 1 mm/day within the upper 2 meter of the clay soil. These are superimposed on seasonal fluctuations, which have been observed to be more than 5 mm. .

Keywords: land subsidence, Vertical land motion, Clay, Extensometer, Soil

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Modelling seasonal shrink-swell and saturated zone deformation of clay underneath buildings on shallow foundations

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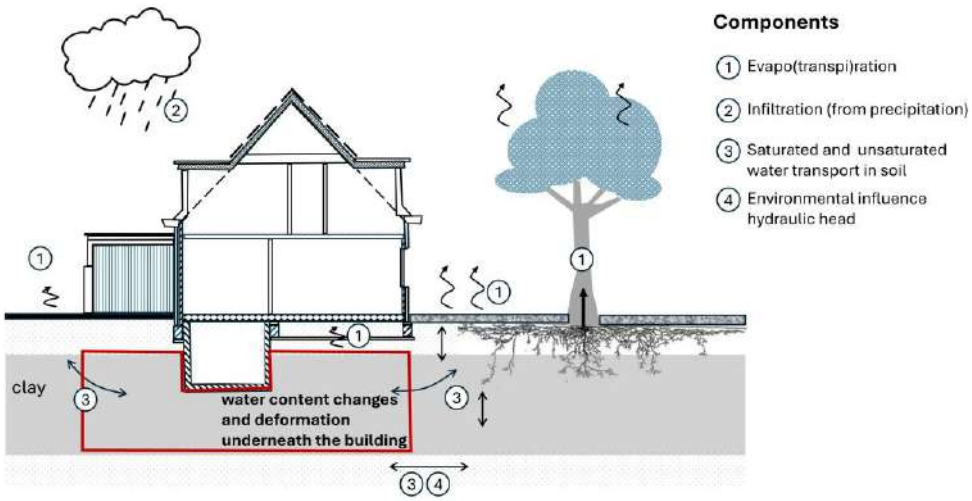
[1] Deltares, Utrecht, Netherlands

Abstract

Increased damage reporting for residential buildings in the Netherlands following recent droughts, incentivized applied laboratory, field and modelling investigation of the role of seasonal deformation of clay underneath buildings on shallow foundations. Here, a mathematical model is presented which simulates water transport, water content changes and deformation in the saturated and unsaturated zone at the building scale. The model provides a process-based framework to improve understanding of hydro-mechanical soil-foundation interaction in clay-rich settings, and to clarify factors that contribute to damage risk. Water loss and gain from evapotranspiration and rainfall drive the model and are applied adjacent to the building. Effects extend underneath the building and the (phreatic) water table movements are simulated rather than imposed. Shrink-swell and saturated zone deformation is modelled as a reversible process. A unique feature of the formulation lies in the extension of the van Genuchten retention model toward stress-dependent behavior, establishing formal continuity between unsaturated retention physics and the saturated compressibility framework conventionally employed in geotechnical practice. This allows exploring effects of the weight of the building. Laboratory-determined retention, hydraulic conductivity and shrinkage curves are used to model the differential vertical movements.

Keywords: foundation damage, differential settlement, clay, shrink-swell, risk factors



Conceptual depiction of the model. The model consists of an arbitrary soil profile underneath and adjacent to a residential building which includes clay (indicated in grey). Focus of the model are water content changes and (vertical) deformation of the clay underneath the building (within the red perimeter) via the indicated component processes and conditions: (1) water loss through evapotranspiration; (2) water replenishment from precipitation; (3) water transport in the soil, where the latter may also be influenced by the hydraulic head underneath the clay (4).

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Monitoring subsidence and building vulnerability in Como, Italy: 30 years of InSAR

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[2] Università degli Studi dell'Insubria, Como, Italy
[3] Istituto Nazionale di Geofisica e Vulcanologia, sezione di Napoli Osservatorio Vesuviano, Naples, Italy

Abstract

Urban areas built on alluvial and lacustrine deposits in low-lying, coastal, and delta regions are increasingly exposed to geohazards such as subsidence, driven by both natural processes and human activity, and further intensified by climate change. This study presents a synthesis of 30 years (1993–2023) of satellite-based ground deformation monitoring in the city of Como (Northern Italy), integrating multi-sensor Interferometric Synthetic Aperture Radar (InSAR) data with building damage surveys conducted in 2019 and geological–stratigraphic data. The analysis adopts a multi-scale and multi-temporal approach, combining long-term C-band observations (ERS-1/2, Envisat, Sentinel-1) with high-resolution X-band Cosmo-SkyMed data at the building scale. The investigation reveals prolonged deformation patterns in specific sectors of the city, correlated with known fill areas, historical drainage basins, and low-lying zones. Damaged buildings are predominantly concentrated in the historic city centre, where cumulative vertical displacements exceeded 10 mm in the years leading up to 2019, thus suggesting the presence of measurable pre-failure signals. This work highlights the value of long-term, satellite-based deformation monitoring as a practical decision-support tool for engineering geologists and urban planners in geologically sensitive urban environments. We also discuss implications for early-warning systems, urban resilience planning, and future monitoring strategies.

Keywords: InSAR, subsidence, building damage, urban resilience, Como

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State-of-the-Art Overview of Understanding Combined Resource Extraction and Groundwater Management Induced Subsidence in the Netherlands

Thibault Candela[1], Peter Fokker[1], Suresh Palanisamy Vadivel[1], Maarten Pluymaekers[1], Manon Verberne[1], Aris Lourens[1], Joana E. Martins[1], Joost Roholl[1], Sander Osinga[1], Brecht Wassing[1], Frans Aben[1], Jan Stafleu[1], Bart Davids[1], Leon Gonzales Acosta[1], Kay Koster[1]

[1] TNO Geological Survey of the Netherlands, Utrecht, Netherlands

Abstract

The Netherlands has a long tradition of human subsurface activities. The extraction of hydrocarbons and salt from kilometer depths takes place since almost a century, whereas shallow groundwater management keeping groundwater levels at artificial lows has been practiced for millennia. Both of these processes contribute to land subsidence, in recent times locally amplified by urbanization and land use change. It is generally acknowledged that the effects of subsidence results in damage to the built environment and increase flood risks, especially in soft soil coastal areas. In recent decades, the effects of both deep resource extraction, and shallow groundwater and soil related subsidence, have been investigated separately. However, new research insights revealed that in coastal areas where deep mining occurs alongside with artificially lowering groundwater levels, the effects of subsidence are cumulative and influence each other. As a result, disentangling deep and shallow subsidence, unravelling their drivers, and determining interferences of deep and shallow processes, has become a prime topic of interest for TNO Geological Survey of the Netherlands. Here, we present a state-of-the-art overview of previously made research advances on both deep and shallow subsidence. We showcase recent progression, as well as our novel combined approach between data, models, and observations.

Keywords: land subsidence, mining, groundwater, hydrocarbon, salt

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Deformations and Damage of Linear Infrastructure Caused by Peatland Subsidence – Mechanism and Case Histories

Arjan Venmans[1], Jelle van der Zon[2], Henk Kooi[1], Agnes van Uitert[3]

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[2] Royal HaskoningDHV, Delft, Netherlands
[3] ProRail, Utrecht, Netherlands

Abstract

Peatlands are found worldwide in waterlogged areas. Widespread exploitation of peatlands for agriculture and urban development had and still has large subsidence impacts. The first stage of exploitation usually is lowering of the natural water table. This triggers a cyclic process of peat oxidation, subsidence and further groundwater table lowering. Many peatlands in the Netherlands show subsidence rates of 5-10 mm/year today, even centuries after the start of exploitation. The construction of embankments for infrastructure in peatlands initially causes compression and creep of the peat. The subsidence rate decreases in time. Ultimately, the subsidence rate of the embankment will decrease to values less than the subsidence rate of the surrounding peatland, because the embankment effectively blocks oxidation of the underlying peat. The resulting differential subsidence between surrounding peatland and embankment may cause deformations and damage to the infrastructure supported by the embankment. This mechanism of differential subsidence has not yet been addressed in the literature. The paper describes the geological background of peatland subsidence, the deformation and damage mechanism, contributing site factors and climatic controls. Climate change will intensify the impact of the mechanism, because increasing temperature and longer dry periods will increase drawdown of the water table and accelerate subsidence. Two case histories in the Netherlands are presented, including deformation measurements in a railway embankment, and their relation with the precipitation deficit. Also, a preliminary numerical analysis of the deformation mechanism is presented. Finally, the paper suggests some solutions for mitigating the impact of differential subsidence on infrastructure.

Keywords: peatlands, differential subsidence, railways, deformations, climate change mitigation

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Case study of the joint application of field and InSAR ground deformation monitoring for a solar pond perimeter dike in Jordan

Oscar Mooijman[1], Rammah Al-Ja'afreh[2], Hanno Maljaars[3], Pieter Bas Leezenberg[3]

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[2] APC, Amman, Jordan
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Abstract

Since 2011, annual InSAR-based ground deformation monitoring is combined with terrestrial survey data to assess ground deformations of dikes around solar evaporation ponds in the Dead Sea valley, Jordan.

During the yearly InSAR evaluation for 2023, a new settlement anomaly appeared in Dike 18, the perimeter dike for solar pond SP0A. Over a few weeks, settlement rates increased about 5-fold. Field monitoring was intensified, and an extra InSAR processing and interpretation took place. Additional field monitoring results indicated horizontal deformations of Dike 18 in the area of the settlement anomaly.

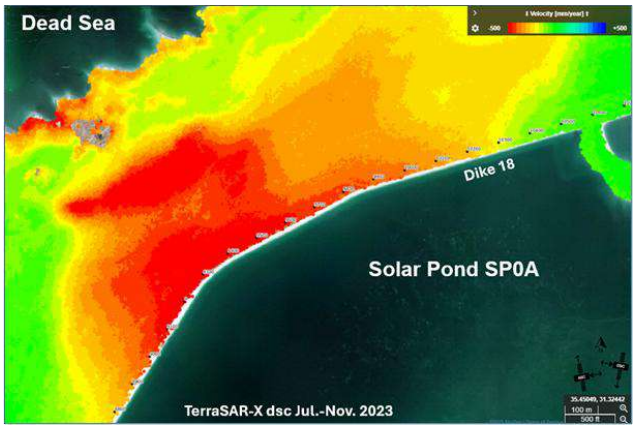
The potential of InSAR to visualize horizontal deformations was already known. As it can be assumed that horizontal deformations mainly develop perpendicular to the dike alignment, oriented decomposition can be performed. Oriented decomposition and terrestrial survey results showed a good match in parts of Dike 18 that are oriented favourably with respect to the Line of Sight of the SAR satellites.

Initial results showed horizontal movements to recede over time. At a later stage, continued and improved field monitoring showed horizontal deformations to increase again. This was confirmed by additional oriented decomposition.

InSAR and field measurements show that vertical and horizontal deformations are related. The root cause of the settlement anomaly probably lies in deep subsurface processes that are triggered by the decline of the Dead Sea water level. This decline will continue, and there are no means to prevent these processes from occurring. Further increase of horizontal deformations of Dike 18 is expected.

Dike 18 will be strengthened soon, as part of an already initiated larger project aiming to extend the operational lifetime of solar pond SP0A. The possible effects of future horizontal deformations on Dike 18 are integrated in the further design of this project.

Keywords: InSAR, Oriented decomposition, Settlements, Horizontal deformations



Settlement anomaly in TerraSAR-X InSAR data

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Assessing Drought-Induced Subsidence Disruptions in the Dutch Railway Network

Gina Alexandra Torres-Alves[1], Andrés Martínez[1], Thibault Candela[2]

[1] TNO, Delft, Netherlands
[2] TNO, Utrecht, Netherlands

Abstract

The Netherlands is projected to experience drier summers due to climate change, characterized by increased evaporation from hotter temperatures. More frequent and intense drought have already contributed to substantial ground subsidence and embankment instability in the country. This trend towards drier summers can significantly impact critical infrastructure like railway networks and threaten their performance and reliability. This study presents a methodology that integrates InSAR data, climate observations, future climate scenarios from the Royal Dutch Meteorological Institute (KNMI'23), and operational subsidence thresholds established by ProRail, to assess drought-induced disruptions in railway infrastructure. A vine-copula approach is used to investigate the dependence between consecutive dry days (CDD), temperature, and vertical subsidence for selected railway segments between Amsterdam and Alkmaar. Results show a strong dependence between long dry periods and subsidence, highlighting the importance of combining climate projections and ground subsidence data to provide valuable insights for informed maintenance planning at network level. Moreover, this work can be extended to applications beyond the railway sector, supporting the growing need for adaptive asset management strategies in the face of increasing climate-related infrastructure vulnerabilities.

Keywords: Railway infrastructure, Subsidense, Drought, Climate change,

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A Spatial Screening Approach for Subsidence of River Dikes Using InSAR and Subsurface Data

Ece Özer[1], Manon Verberne[2], Chris Heerema[2], Kay Koster[2]

[1] TNO Reliable Structures, Delft, Netherlands
[2] TNO Geological Survey of the Netherlands, Utrecht, Netherlands

Abstract

It is undisputed that in view of climate change the thousands of kilometers of dikes in the Netherlands are one of the country's most critical flood protection infrastructures. The Dutch coastal and river dikes are designed to withstand rising sea levels, storm surges, as well as extreme peak river discharges. In addition to these hydraulic loads, however, dikes are also affected by land subsidence processes that cause local to regional reductions in crest elevation, potentially compromising flood safety. This study aims to develop a spatial model that red-flags dike sections susceptible to subsidence, thereby supporting national and regional authorities in prioritizing monitoring programs and reinforcement strategies. A detailed 3D geological understanding of the natural subsurface underneath the dikes is conducted, as soil type governs spatial patterns of subsidence. To explain spatial variability in subsidence rates, observed surface deformations derived from Interferometric Synthetic Aperture Radar (InSAR) is integrated with a 3D geological subsurface model and Cone Penetration Test data. Results demonstrate a clear correlation between the presence of shallow peat and clay beds underneath dikes and increased subsidence rates, whilst sandy subsurface corresponds to more stable behavior. This integrated spatial analysis provides a robust basis for a red-flag model, contributing to proactive risk management of the Netherlands' most vital infrastructures in the light of climate change.

Keywords: dikes, land subsidence, InSAR, Cone Penetration Test, 3D model

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Spatial Land Subsidence Variations Due to Urbanization

Valentina Maoret[1, 2], Thibault Candela[2], Pietro Teatini[3], Kay Koster[4], Ylona van Dinther[1], Jan Diederik van Wees[2, 1], Caludia Zoccarato[3]

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Abstract

Human-induced land subsidence in coastal areas is a pressing issue worldwide. Subsidence can occur due to different subsurface activities at various depths, such as hydrocarbon extraction, salt mining, and groundwater withdrawal. In coastal urban areas, the built environment itself, however, also influences subsidence processes, adding complexity to the phenomenon. Additionally, differential settlement inflicts damage to buildings and infrastructure, leading to high costs and hazardous situations. We aim to resolve the unknown effects of urbanization on land subsidence. To this end, we analyze how land subsidence varies between urban and rural areas in the coastal plain of the Netherlands. We quantify the effect of the presence of buildings and anthropogenically brought-up soil on subsidence rates, and we investigate how building characteristics and soil properties affect each other. In our approach, we combine Interferometric Synthetic Aperture Radar (InSAR) data with geological subsurface information. We divide the persistent scatterers between the ones inside and outside the building footprints, as well as inside and outside urbanized areas as a whole, to analyze the difference in subsidence rates. Preliminary results reveal that subsidence rates of buildings strongly relate to foundation type and construction date, whereas rates of the non-building areas are influenced by the cumulative thickness of soft coastal soil.

Keywords: Subsidence, Coastal cities, Urbanization, InSAR

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Stratigraphic and Sensitivity Influence on Soft Soil Behavior in the Holocene Deposits of the Eastern Izumo Plain, Japan

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Abstract

Low-lying coastal and deltaic plains underlain by thick Holocene sediments, are prone to subsidence, differential settlement, geotechnical instability, and flooding. In such environments, stratigraphic variation significantly influences the compressibility and sensitivity of soft sediments. The eastern Izumo Plain in SW Japan has thick Holocene sediment deposited by both fluvial and marine processes during estuarine infilling. This research integrates geotechnical analysis with sedimentological interpretation to comprehend how it affects the mechanical behavior and sensitivity of marine clays. A 20.7 m borehole core was collected from nearby the shore of Lake Shinji and analyzed to assess the relationship between sedimentary facies and geotechnical behavior. Visual logging and grain size analysis revealed a transition from sandy-silty delta front deposits (above 10 m) to soft, clay-rich prodelta deposits (below 10 m). Laboratory tests showed significant differences in compressibility and index properties between the facies due to contrast in depositional environment and sedimentation rate. For the deeper clay layer (below 10 m), unconfined compressive strength (UCS) testing revealed high sensitivity values indicating structural bonds formed by post-depositional processes. Although these sensitive clays are not classified as quick clays, they are susceptible to strength loss under loading, excavation or seismic disturbance. The results show a strong correlation between depositional environment and engineering behavior in deltaic systems. Stratigraphic interpretation is essential for identifying zones susceptible to differential settlement and potential structure failure in developing urban lowlands. This integrated approach provides a valuable framework for infrastructure planning and hazard mitigation in deltaic soft soil regions worldwide.

Keywords: Izumo Plain, Soft marine clay, Compressibility, Sensitivity

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The Untapped Potential of Geotechnical and Geological Data for Coastal Land Subsidence Research

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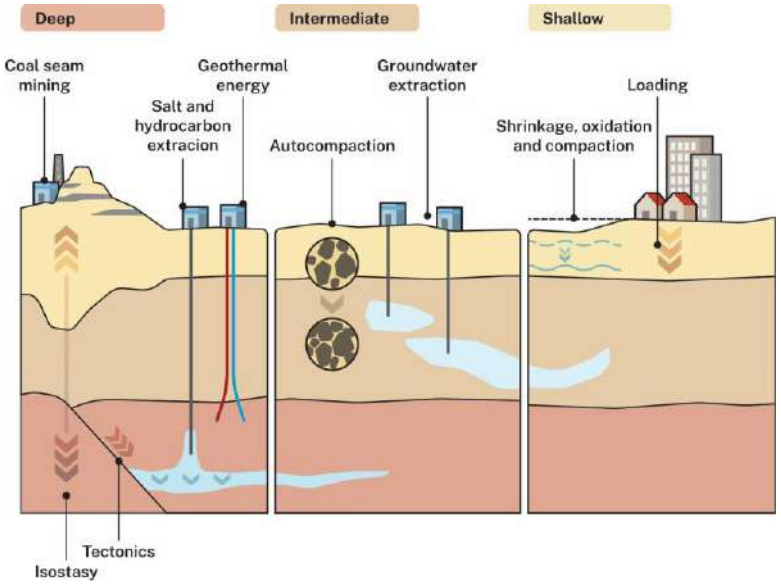
Abstract

Land subsidence in coastal lowlands arises from multiple processes at various depths, including oxidation of organic layers, clay shrinkage, and compaction of soft soils; at larger depths compaction due to extraction of groundwater, hydrocarbons or salt. Subsidence monitoring relies on various techniques, like levelling, GNSS, and InSAR. However, the monitoring data which are used in many subsidence studies offer limited information on the depth or geological origin of displacements. Standard geotechnical and geological data, such as sediment cores, Cone Penetration Tests, and extensometer measurements, have potential to fill this gap, and they are underused in subsidence research. In this contribution, we explore the data usage and the methodological approach in coastal subsidence studies. We demonstrate how geological and geotechnical data can support subsidence investigations by deploying them for geological modelling, improving subsurface parameterization, and how they aid in the interpretation of spatial and temporal variability in vertical land motions. Despite challenges such as data heterogeneity, limited spatial coverage, and limited cross-disciplinary integration, these a priori available datasets offer significant opportunities for advancing land subsidence research. Their broader use can enhance the ability to disentangle depth-dependent drivers, constrain predictive models, and guide effective mitigation strategies in subsiding coastal areas.

Keywords: Subsidence, Modelling, Cone Penetration Tests, Geological data, Disentanglement



This figure shows the most common subsidence processes. What geological data is important and/or poses a challenge differs per subsidence cause. Often in one location, multiple subsidence processes contribute to the total subsidence. Image by Nik Trabucho Alexandre (TNO - Geological Survey of The Netherlands).

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Unravelling shallow subsurface deformation processes in organic-rich coastal plains

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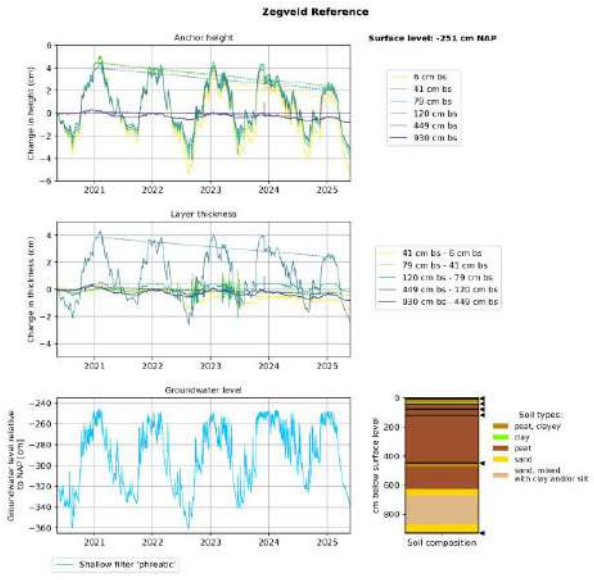
Abstract

Many low-lying coastal plains worldwide contain abundant organic facies, often peat, in the Holocene subsurface. These facies are very susceptible to soil deformation processes, some of which leading to irreversible land subsidence. Most important irreversible processes are oxidation of organic matter, shrinkage and compaction. Reversible soil deformation processes are shrinkage and swell and poro-elastic deformation.

In cultivated areas, soil deformation processes leading to land subsidence are often driven, and accelerated, by human activities such as drainage for agriculture and loading of the subsurface. To reduce land subsidence, the first step is to identify the relative contribution of soil deformation processes to total subsidence. Next, measures may be developed and applied.

At various locations in the Dutch coastal plain, extensometers specifically designed for soft organic facies are used to measure vertical movement of multiple levels in the Holocene subsurface at high temporal resolution. Resulting multiyear timeseries are used to quantify the amount of irreversible and reversible deformation over time for different soil intervals, which subsequently may be linked to soil deformation processes. Results demonstrate a large variability in the relative contribution of deformation processes to total subsidence as well as in long term subsidence rates, due to spatially variable geological and hydrological circumstances. This calls for site-specific measures to reduce land subsidence. Moreover, because of this spatial variability, spatially explicit mapping approaches, e.g. models, are needed to predict deformation behaviour in soft soil sequences.

Keywords: Peat soils, Land subsidence, Soft soil deformation, Extensometer,



Extensometer timeseries of vertical movement of different anchor levels and soil intervals, at a location near Zegveld in the western Dutch peatland area. At the bottom the phreatic groundwater table dynamics and the subsurface composition at the same location.

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A Synergistic PCA–ICA InSAR-based methodology for the understanding of multi-drivers' land subsidence in Emilia-Romagna region, Italy

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Abstract

Land subsidence results from complex natural and human-induced processes, making it challenging to disentangle their contributing factors. To tackle this issue, we integrate satellite-based Earth observation data—specifically Interferometric Synthetic Aperture Radar (InSAR) datasets from the Copernicus European Ground Motion Service (2018-2022)—with geological, hydrological, and anthropogenic information from regional and global sources. A synergistic InSAR-based ground displacement time series analysis, including Principal Component Analysis (PCA) and Independent Component Analysis (ICA), was used to identify spatial and temporal hotspots of ground displacement in the Emilia-Romagna region in Italy. The approach innovates in detecting land subsidence hotspots, to unraveling the multi-drivers' land subsidence. Ground displacement hotspots in the Emilia-Romagna region exhibit diverse temporal trends, including linear, non-linear, and seasonal behaviours. The results identify a major land subsidence hotspot in the Bologna area, with rates exceeding −30 mm/year and affecting an area of approximately 130 km². Both natural factors, and human activities including groundwater withdrawal, were investigated. These findings support the development of targeted mitigation and adaptation strategies, while the proposed methodology is transferable and can be applied to other regions.

Keywords: Land subsidence, InSAR, time series analysis, Copernicus European Ground Motion Service, Emilia Romagna region

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New Prediction Maps for the Netherlands Show Land Subsidence Due to Water Management

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Abstract

Large parts of the Netherlands are experiencing subsidence due to processes occurring in the shallow subsurface. Subsidence rates range from 1 to 10 mm per year. One of the primary drivers of subsidence in rural areas is water management, specifically the drainage of peat and clay soils. For a low-lying country like the Netherlands, subsidence will further complicate water management and causes damage to buildings and infrastructure. Additionally, subsidence in peatlands is associated with CO_2 emissions. National predictive maps of land subsidence in the Netherlands have been produced in the past to quantify the impacts of water management scenarios. These maps are widely used to support regional and national spatial planning and policymaking. This widespread application motivates continued improvement of the maps and the underlying models. The versions presented in this contribution are based on a new calculation scheme for land subsidence and incorporate enhanced and improved input data. With the increasing availability of subsidence measurements—for example, from extensometers and InSAR-based analyses—we now have the opportunity to compare model outcomes with real-world observations. Finally, previous water management scenarios have been expanded to include potential mitigation measures. These include decisions aimed at reducing land subsidence within the policy framework of "soil- and water system-based spatial planning." Conversely, we also examine what forms of water management are necessary to meet various existing and proposed policy objectives and subsidence reduction targets.

Keywords: subsidence, peatlands, mitigation, modelling, scenarios

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Understanding Ground Instability in Mexico City: A Multidisciplinary Study of Land Subsidence, Fracturing, Faulting, and Seismic Response

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Abstract

Ground instability in Mexico City results from the interaction between basin architecture, groundwater exploitation, and seismic site effects. While the shallow lacustrine deposits (<50 m) and the deep basin geometry have been extensively investigated, the three-dimensional geological architecture of the upper 400 m remains poorly constrained despite its critical role in controlling groundwater flow, differential compaction, land subsidence, ground fracturing, and seismic amplification. This study presents a multidisciplinary assessment of the upper basin fill by integrating geological, hydrogeological, geophysical, geodetic, and seismological datasets. A database of 586 groundwater production wells, including 348 lithological logs, was compiled to characterize the stratigraphic architecture of the upper 400 m. These data were interpreted together with 332 Vertical Electrical Soundings (VES), benchmark subsidence records, documented ground fractures, regional fault systems, published InSAR observations, and recent seismic site-response studies. Preliminary results reveal pronounced lateral and vertical heterogeneity associated with the transition from volcanic piedmont to lacustrine environments. Lithological correlations and geophysical evidence indicate that volcanic bodies, volcaniclastic deposits, buried structural discontinuities, and variable sediment thicknesses compartmentalize the basin and strongly influence groundwater circulation and deformation patterns. These geological contrasts spatially coincide with zones of differential subsidence, concentrated ground fracturing, and significant variations in seismic response. The resulting Geological–Hydrogeological–Geophysical conceptual model provides a regional framework for understanding ground instability and supports improved geological hazard assessment, urban planning, and resilience strategies for Risk Management in the Mexico City Metropolitan Area.

Keywords: Land Subsidence, Lacustrine sediments, Mexico City, Deformation, Geological Risk

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Integrating Subsidence Dynamics and Saltwater Intrusion in the Mekong Delta: A Numerical Modeling Approach for Sustainable Groundwater Management

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Abstract

In recent years, the Vietnamese Mekong Delta is increasingly threatened by the dual impact of land subsidence and groundwater salinity intrusion, both intensified by excessive groundwater extraction. Previous studies have reported land subsidence rates of up to 6 cm/year, while groundwater salinity intrusion is projected to penetrate aquifers to depths of up to 150 meters. The combined effects of these two processes are creating stress in agricultural productivity due to the lack of freshwater and could potentially lead to the drowning of the large delta system by the end of this century. Although existing studies underscore the region's vulnerability to combined human and climate forces, they typically treat groundwater salinity and extraction-induced subsidence in isolation. To address this gap, we aim to create a novel 3D numerical model that couples groundwater salinity with extraction-induced land subsidence, integrating 3D hydrogeological and 1D geomechanical models within a single framework. This innovative coupled modeling approach has not been applied before at the scale of a large delta system, and it will fill up the critical research need by providing a system-scale tool for extraction-based land subsidence and groundwater salinity interaction, ultimately enhancing our understanding and the adaptive management of the groundwater system.

Keywords: Land Subsidence, groundwater salinity, coupled model, drowning delta, numerical modeling

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Anthropogenic Controls on Urban Ground Deformation: Insights From GPR Surveys in Querétaro, Mexico

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Abstract

Ground-penetrating radar (GPR) is a non-invasive, high-resolution geophysical method widely used to detect shallow subsurface anomalies in urban and geological settings. This study focuses on monitoring geohazards, including localized subsidence, ground fissures, and structural damage, in the northwestern sector of Querétaro City, Mexico, an area undergoing rapid urban development. In 2023, four GPR surveys were conducted at 2 study sites (BQBN and DLLA) with reported surface deformation, using a 200 MHz antenna. Radargram interpretation revealed shallow reflectors and vertical displacements within the first 3 meters, often associated with poorly compacted anthropogenic fill and reworked volcanic materials. These anomalies indicate that surface deformation is primarily related to human-induced processes—such as inadequate compaction, heterogeneous fill, water infiltration, and traffic-induced loads—rather than deep-seated faults or regional subsidence. The effectiveness of GPR in identifying subsurface discontinuities and material contrasts underscores its value as a diagnostic and monitoring tool in urban environments affected by geohazards. Unmanned Aerial Vehicle (UAV)-based photogrammetry was used as a complementary method to provide high-resolution surface models and enhance spatial analysis of deformation patterns. However, geological fieldwork revealed that the area is characterized by nearby faults, volcanic materials, and interbedded competent and easily erodible materials. These features suggest latent susceptibility to settlement processes, although such effects were not directly observed at the study sites.

Keywords: Urbanization, Ground fractures, Geohazard, GPR, Queretaro



Ground Penetrating Radar (GPR) profile acquired with a 200 MHz antenna at a study sites in NW Querétaro City, México (named DLLA site). The radargram displays vertical reflectors discontinuities suggesting localized deformation zones. The DLLA site shows antropogenic deformation caused by traffic induced stress and inadequate soil compaction. These results highlight the diagnostic capability of GPR and other tools, such as remote sensing and field observations, for identifying subsurface disturbances in rapidly urbanized environments.

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Analyzing faults, fracture connectivity, and groundwater dynamics in San Miguel de Allende, Mexico

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Abstract

Groundwater is the main source of supply in the city of San Miguel de Allende, Guanajuato, in Mexico, where the presence of structural faults and earth fissures significantly influences aquifer dynamics. This study aims to investigate the relationships among the geometric and topological configurations of fracturing systems, regional fault structures, and groundwater flow within the local aquifer system. The analysis incorporates lithological characterization, well distribution, and piezometric data to elucidate the basin's hydrogeological dynamics. The aquifer is predominantly composed of granular materials, and its extraction patterns exhibit spatial and vertical variations controlled by geological and structural conditions. Faults and fractures may act as preferential conduits or hydraulic barriers, modifying hydraulic gradients. Intensive extraction increases the effective stress in unconsolidated materials, generating deformation and surface fracturing when the elastic limits are exceeded. These processes alter groundwater flow, intensify land subsidence, and favor localized drainage. Three fractures have been identified in the northeastern sector of the San Miguel de Allende area. The results show a spatial and hydrodynamic relationship between fractures and aquifer dynamics, highlighting their role in the system's mechanical response under groundwater overexploitation.

Keywords: Groundwater exploitation, Regional faulting, Earth Fissures, Land Subsidence, Mexico

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Evolution of Geotechnical Properties of Dredged Sediment During Ripening

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Abstract

Dredged material from ports and waterways is increasingly being used as building material for habitat restoration and dike construction. This beneficial reuse requires a ripening process—a natural transformation that dries and oxidizes the reduced, waterlogged sediment or pre-treated (partially dewatered) material into a well-aerated, soil-like material. This study investigated the geotechnical changes in mechanically dewatered dredged sediment from the Elbe River near Hamburg. The material was placed into nine stockpiles (SP, 1,000-2,200 m3) with varying turning frequencies (none, 2×/year, 4×/year; with an excavator) and vegetation management (removed before turning or not). Analyses included Proctor compaction tests, Coefficient of Linear Extensibility (COLE), surface crack formation, and tensile strength measurements. Significant changes in geotechnical properties were observed during ripening. COLE values significantly decreased in all stockpiles to below 0.14, indicating progressively decreasing shrink–swell behavior (Fig. 1, left). Proctor density in the control stockpile (SP4, not turned) increased by 13.64% (from 1.10 g/cm3 to 1.25 g/cm3) (Fig. 1, middle), and higher turning frequencies led to greater compactibility. After 2 years of ripening, the highest tensile strength was found in the control stockpile (no turning). Stockpiles that were turned frequently showed a low tensile strength, whereas those turned only twice per year had a higher tensile strength, still increasing over time (Fig. 1, right). These results show that ripening improves dike-relevant geotechnical properties, but management effects are property-specific and should be optimized according to the target engineering function.

Keywords: Dredged sediment, Soil ripening , Geotechnical properties , Proctor compaction , Shrinkage and cracking behaviour

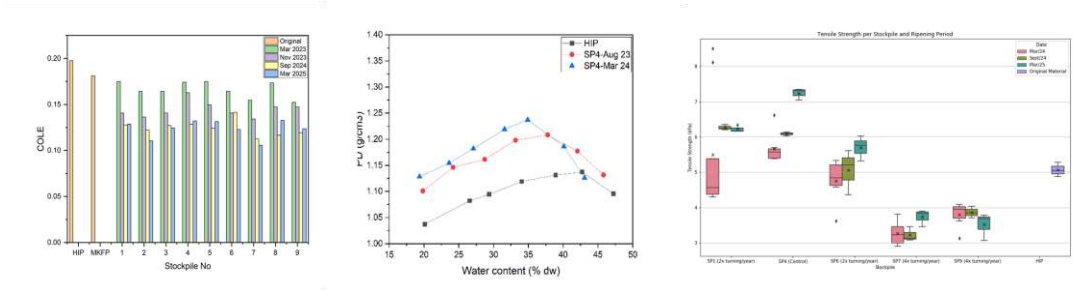

Fig. 1. Development of COLE (left) and Proctor curves (middle), and tensile strength (left) over time of sediment ripening. SP4 = stockpile 4 (control), Box = 25th to 75th percentile, line = median, cross = average. HIP = high intensity press material (pre-ripening original, partially dewatered dredged sediment).

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Coupling Natural Compaction and Groundwater Withdrawal-Related Subsidence in Deltaic Areas

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Abstract

Land subsidence in deltaic regions results from a complex interaction between natural and anthropogenic processes across multiple depth domains. Two primary drivers are the compaction of aquifer systems following groundwater withdrawals and shallow natural auto-compaction of compressible sediments.

In the Vietnamese Mekong Delta, these processes have been investigated individually using two separate numerical models. 1) a 3D hydrogeological model, developed in iMOD, simulates the geomechanical response of the 500-meter-thick multi-aquifer system due to groundwater pumping. The large model dimensions result in an oversimplification of the shallow aquitard unit, largely consisting of low-permeability and compressible sediments. 2) the second model, developed in NATSUB3D, aims to quantify auto-compaction of the shallow Holocene stratigraphy during delta progradation, i.e. sediment deposition and compaction of the upper 10 to 30-meter-thick sedimentary sequence under its own load. While these models serve their individual research purposes, they are not coupled, thereby limiting our capacity to simulate and investigate dynamic process interactions across the two depth domains.

We aim to bridge this knowledge gap of depth-dependent subsidence process interactions by coupling the two existing models into an integrated, process-based framework. We propose and test four approaches based on different iterative procedures with various degrees of coupling. This coupling will allow us to simulate and quantify geomechanical processes that delta-scale studies have previously under- or overestimated. This will support longer-term, 3D projections of land subsidence across different depth domains. This is the first coupled modelling approach, showcased for the Mekong Delta, and will be transferable to other vulnerable deltas.

Keywords: Land subsidence, Groundwater extraction, Natural compaction, Aquifer system compaction, Numerical modelling

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Non-Linear Long-Term InSAR-Derived Land Subsidence in River Deltas: The Mekong Delta, Vietnam, Case Study

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Abstract

Aquifer overexploitation is a dominant cause of accelerated subsidence in river deltas, often exceeding sea-level rise. While climate-induced sea-level rise is a global phenomenon, subsidence is a local process, both natural and human-induced, with the highest rates mainly linked to human activity. Despite severe impacts, including flooding, saltwater intrusion, and land loss, subsidence remains understudied in many deltas worldwide. Although InSAR enables large-scale subsidence monitoring, most studies cover short periods, assume purely vertical land motion, and apply linear regressions, thus introducing significant uncertainties over longer periods.

The low-lying Vietnamese Mekong Delta faces accelerating subsidence trends, threatening its socio-economic stability. As no comprehensive, open-source, in-situ geodetic network exists in the delta, InSAR provides the most effective tool for large-scale subsidence assessment. In this study, we present a long-term (2015-2024) InSAR-retrieved subsidence analysis of the entire Vietnamese Mekong Delta, using over 750 ESA-Copernicus Sentinel-1 radar images from ascending and descending tracks. We performed PS and SBAS InSAR to achieve high spatial and temporal resolution and to detect non-linear land deformation trends throughout the entire delta.

We identified nearly one million coherent scatterers, revealing stable, decelerating, and accelerating subsidence patterns. Delta-wide subsidence exceeded earlier estimates, with hotspots reaching up to 8 cm/year at present. This is the first near-decade-long consistent InSAR analysis of the Mekong Delta, offering critical insight into its non-linear spatio-temporal subsidence dynamics and informing process-based modelling and mitigation planning. Our findings also highlight the urgent need for a ground-based reference network to strengthen subsidence monitoring in this vulnerable area.

Keywords: Land subsidence, InSAR, Mekong Delta, Aquifer overexploitation, Relative sea-level rise

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Geotechnical and hydrogeological conditions of subsidence sites detected by InSAR of Sentinel-1 images from 2015 to 2020 in the area of Barcelona.

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Abstract

Sentinel-1 InSAR processing for the area of Barcelona during 2015-2020 was conducted to monitor ground deformation associated with the dewatering of a construction site for road tunnels beneath Glòries square. These data revealed the existence of 56 additional sites with significant subsidence across the city and its surroundings, including the Llobregat river lower valley and delta, and the Vallès graben between the cities of Rubí and La Llagosta. These subsiding locations generally exhibited displacement rates ranging from 1 to 10 cm·yr^{-1}. In order to explain the observed ground settlements, geotechnical logs, piezometric data, land use, construction works history, and field observations of damage in infrastructures were reviewed. The proposed subsidence mechanisms include the compaction of old landfills, landslides in steep terrain, recent construction of railway embankments, as well as the consolidation of thick clay layers. Despite the limited availability of data, fine-grained soils and anthropogenic fill materials were described for 35 sites and subsidence was correlated with groundwater withdrawals in 3 sites. The results of this analysis show the potential of InSAR data as an efficient ground monitoring tool for hazard management.

Keywords: InSAR, Sentinel-1, Subsidence, Barcelona area

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Experimental and Geomechanical Modelling Investigation on a Saltmarsh Restoration Project in the Venice Lagoon

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Abstract

The Venice Lagoon, once home to 250 km² of salt marshes, has lost more than 80 percent due to hydraulic works, erosion, subsidence, and sea-level rise. Among many restoration and reconstruction projects, only a few exhibit the characteristics of long-term survival once nourishment is completed. A key aspect for this to happen is their ability to accrete, that is, to maintain the elevation of their surface relative to the mean sea (typically +20-50 cm). Reconstructions supposedly target this range. Our work specifically addresses two relevant geomechanical processes that have been neglected: autocompaction of the conveyed sediments and the compaction that their weight generates in pre-existing deposits. To quantify the effects of these phenomena and develop effective, innovative, and scientifically based design methodologies, we surveyed the topography of a salt marsh reconstruction and installed five monitoring stations for shallow compaction and five for deep compaction to obtain precise information on the evolution of the infill. After determining the soil stratigraphy in situ by coring, it was possible to construct and validate a 3D geomechanical numerical model that simulates the future evolution of the re-nourished area and quantify soil deformation by investigating which pre-existing layers were most affected. Ultimately, the methodology can be used to help predict the amount of sediment required to ensure the long-term survival as a re-created salt marsh.

Keywords: saltmarsh, modelling, compaction, investigation

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Stratified Behavior of Soft Soils in a Subsiding Urban Basin: A Case Study From Molino-Tezonco, Mexico City

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Abstract

Mexico City experiences one of the highest subsidence rates globally, reaching 30-40 cm/year; furthermore, the zone is considered seismically active. In 2017, the 7.1 magnitude earthquake caused significant damage in Mexico City, particularly in a zone named Molino-Tezonco, Iztapalapa, likely amplified by lacustrine soils. Underscoring the critical need for a detailed geomechanical characterization of the region's soft lacustrine soils. This study aims to enhance the relevance of considering the geological characteristics of clayey sediments to assess their mechanical behavior. We present the results of consolidated-undrained (CU) triaxial compression tests conducted on fine-grained cohesive samples recovered from a 52-meter borehole at the site. Consolidation pressures tested ranged from 50 to 500 kPa. Significant differences in the stress-deformation curves allowed us to demonstrate that clayey sequences are heterogeneous and to establish a mechanical stratigraphy. Results show stiffness depends not only on confinement pressure related to depth, but also strongly on mineralogical composition, and exhibits high sensitivity to water content changes, leading to significant reductions in strength. Samples with well-crystallized clays, such as smectites with cemented microstructures, displayed an increase in strength. Grain size distribution is also a determining parameter; slight variations in clay or sand content produce contrasting mechanical behavior. This detailed study of the clayey sequences demonstrates that a reliable assessment of seismic response in the lacustrine sediments of Mexico City requires the consideration of geological factors, especially with the presence of volcanic materials within a lacustrine environment, in addition to conventional plasticity-based classifications. The results highlight the necessity for comprehensive geomechanical characterization to improve predictions of subsidence, deformation, and failure mechanisms in static conditions and in earthquake-prone soft soil environments.

Keywords: Lacustrine clays, Land Subsidence, Mexico City, Trisxial testing, Soil mineralogy

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Machine Learning-Based Hazard and Risk Assessment of Subsidence-Related CO2 Emissions in Dutch Peatlands

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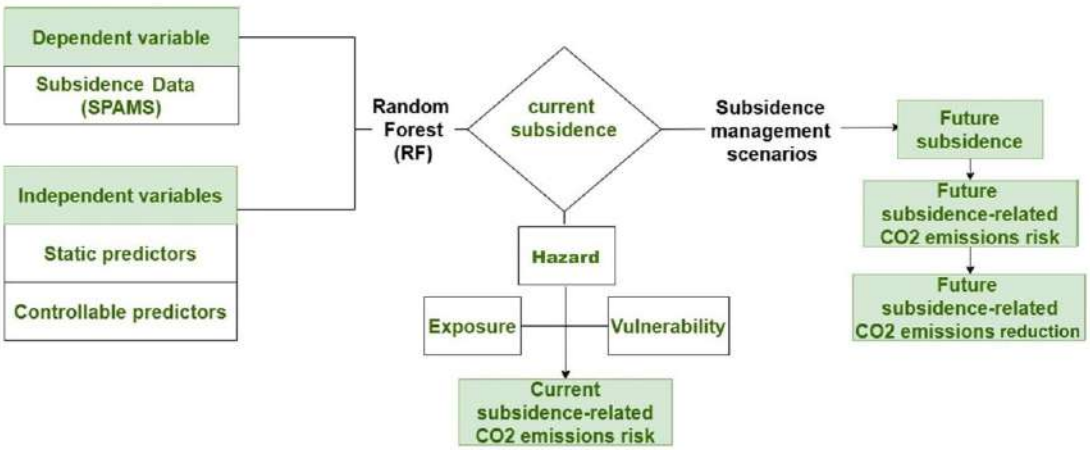
Abstract

Dutch peatland drainage for intensive dairy farming purposes causes land subsidence and releases massive amounts of soil carbon as CO_2, confronting policymakers with the challenge of sustaining dairy farming while fulfilling the reduction commitments of land subsidence and CO_2 emissions under the Dutch Climate Act and the Paris Climate Agreement. This study presents a machine learning-based framework that allows predicting future land subsidence and assessing associated soil carbon loss and CO_2 emission risk in Dutch peatlands, using Krimpenerwaard municipality as a case study. A Random Forest model was trained on irreversible subsidence data derived from the still-under-refinement Simple PArameterization for the Motion of Soils (SPAMS10 - Version1) empirical model for the 2016 - 2022 period, together with six geospatial predictors representing surface and subsurface conditions on a 5 m grid pixel scale. The trained model achieved good testing performance (R^2 = 0.903, RMSE = 0.173 mm/year). Feature importance analysis revealed that the most important controllable predictor is soil moisture index. Land subsidence data was converted to hazard (oxidized volume loss) and integrated with vulnerability (soil carbon stock) and exposure (peat presence) within a normalized hazard-vulnerability-exposure framework to produce the 2016-2022 risk index map within a GIS environment. The resulting risk index map identifies managed grassland parcels near Stolwijk as priority areas for intervention. This framework enables future scenario testing by modifying controllable predictors to evaluate the effectiveness of potential interventions. This study provides a reproducible decision-support tool for identifying high-risk parcels and guiding sustainable mitigation of land subsidence across Dutch peatlands.

Keywords: Hazard, Machine learning, Peatlands, Risk assessment, Subsidence



The overall workflow for hazard and risk assessment of subsidence-related CO_2 emissions in Dutch peatlands.

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Land Subsidence Monitoring Using Distributed Fiber Optic Sensing and Its Implications

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Abstract

It is estimated that approximately 19% of the global population will be affected by land subsidence by 2040. Accurately characterizing the spatiotemporal evolution of land subsidence is fundamental to developing effective mitigation strategies, yet significant challenges persist due to geological heterogeneity and structural complexity, which limit conventional subsurface deformation monitoring techniques. To overcome these limitations, we have pioneered a spatially continuous deformation monitoring methodology leveraging distributed fiber optic sensing (DFOS) technology. This innovation enables the precise identification of primary contributing layers and their deformation processes. By integrating fundamental soil mechanics principles with field measurements, the deformation trends can be predicted. The continuous subsurface deformation data by DFOS also provides rich observational evidence for regional subsidence assessments that integrate both data-driven and knowledge-driven approaches. Validated through 13 years of in-situ implementation across diverse geological settings in China, this technology has not only proven capable of delivering long-term, accurate deformation monitoring but has also evolved into an industry-standard benchmark. It also shows promising potential for broader applications in areas such as seawater intrusion mitigation, underground space development, geo-environmental challenges, etc.

Keywords: Land subsidence, Distributed fiber optic sensing, In-situ monitoring, Subsurface deformation

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Subsidence Induced by Groundwater Over-Exploitation in Tuscany (Italy): A Multidisciplinary Monitoring and Modelling Approach

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Abstract

The continuous overexploitation of groundwater resources in urbanised and industrial areas can lead to significant ground deformation, posing risks to infrastructures, buildings, and hydrogeological stability. This study presents a comprehensive approach to detect and model a subsidence phenomenon in the Montemurlo industrial area (Tuscany, Italy), by integrating satellite InSAR data with field surveys, levelling campaigns, borehole monitoring, and geophysical modelling. Multitemporal Sentinel-1 InSAR data revealed an abrupt vertical ground deformation in mid-2017, with velocity values exceeding 50 mm/year. Field surveys identified structural damages, which were further quantified through levelling and a vertical settlement gauge. Moreover, geotechnical investigations identified compressible layers, clayey silt with gravel, at depth consistent with the deformation source modelled using the Geodetic Bayesian Inversion Software (GBIS). The estimated source depth and volume change closely correspond to an aquifer exploited by a nearby industrial structure, confirming overpumping as the triggering mechanism. The proposed workflow demonstrates the effectiveness of integrating remote sensing and in-situ monitoring for the early identification and characterisation of subsidence phenomena. The methodology is scalable and replicable and offers practical guidelines for territorial planning and hydrogeological risk mitigation. In light of the increasing vulnerability of ground conditions to climate variability and anthropogenic stress, this multidisciplinary approach offers a robust tool for engineering geologists and decision-makers to manage ground deformation events in subsidence-prone areas.

Keywords: Subsidence, Groundwater overexploitation, InSAR, Multiplatform monitoring, Field surveys

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Wetting and Drying Cycles, the Influence of Fluctuations in Water Content on Creep and Undrained Shear Strength

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Abstract

Climate change intensifies and lengthens the alternating periods of heavy rainfall and drought. This increases fluctuations in the water content of clay layers. These wetting and drying cycles influence both creep behaviour and the undrained shear strength of clay. This study uses oedometer tests to measure creep and mini-CPTs to describe the relationship between water content and undrained shear strength for different clay types. The first tests were performed on Vingerling clay, an artificial clay with homogenous properties. The results show that the creep rate is three times higher under moderate wetting and drying cycles compared to a constant water content in the clay. Further testing was done on natural clay. These tests are compared with findings from literature. Similar trends were found, although the natural clay results show more scatter. The water content has a significant influence on the clay strength. The effect of the various wetting and drying cycles on the undrained shear strength appeared limited. However, ongoing creep may lead to irreversible settlement.

Keywords: climate change, clay, settlement, undrained shear strength, wetting drying cycles

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Geotechnical Data for Geological Characterization of Almere Pampus, the Netherlands

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Abstract

3D Geological modelling of Holocene deposits traditionally relies largely on lithological borehole descriptions, in the Netherlands following the 'Standaard Boorbeschrijfmethode' (SBB). However, integrating additional data types can enhance both the density and quality of subsurface information. This study presents the application of geotechnical borehole data within a geological modelling workflow. Almere Pampus, west of Almere City, is planned to host a major housing development of 25,000–35,000 homes and associated infrastructure. To ensure that subsurface conditions and water management are addressed early in the planning process, the municipality of Almere collected more than 2000 archaeological boreholes, geotechnical boreholes and cone penetration tests. Combined with existing subsurface data, the dataset allows for detailed geological modelling of the Holocene. We created a geological voxel model of Almere Pampus with a 50x50 m resolution containing geological unit, most likely lithological class, and the probability distribution of lithological classes as attributes. These attributes are essentially derived from the lithological borehole descriptions, making accurate extraction and harmonization of lithological information essential. The current modeling workflow is tailored to geological, SBB-coded borehole descriptions. However, the geotechnical boreholes follow the NEN-ISO-14688 standard. To incorporate the latter, we developed rules to translate NEN-ISO-14688 descriptions into SBB-compatible lithological information. The resulting lithological information aligns with the geological and archeological data. As geological datapoints dominate the dataset, the translated geotechnical descriptions influence the resulting model modestly. Although translating NEN-ISO-14688 to SBB requires interpretative choices, this case shows that it can provide a valuable addition to the geological dataset.

Keywords: data harmonization, geotechnical borehole description, geological borehole description, high resolution modelling

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A Hybrid Framework Integrating Numerical Model with Machine Learning for Land Subsidence Prediction in the Irrigation Area of Yellow River Flood Plain

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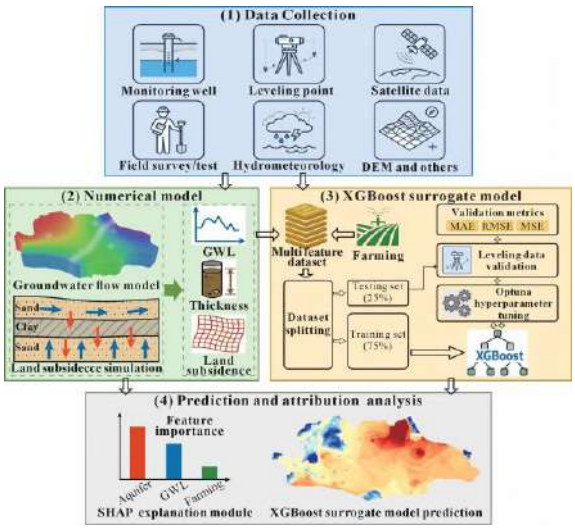
Abstract

Land subsidence (LS) induced by over-extraction of groundwater and complex hydrogeological conditions poses significant risks to regional infrastructure and safety. In this study, a comprehensive framework integrating physical numerical model with data-driven machine learning was developed to predict and analyze LS along a newly constructed high-speed railway section in Lankao County, a representative agricultural region. A three-dimensional coupled groundwater flow and LS model was first developed and calibrated using FEFLOW and the SUB+ plugin. The physically validated model outputs and agricultural activity data were integrated to construct a multi-dimensional feature dataset. Subsequently, an XGBoost surrogate model was trained on the simulated physical fields to characterize the nonlinear relationships between environmental drivers and LS. Validation results demonstrated that the XGBoost model effectively corrected the overestimation in the numerical model, reducing the error to within 10 mm. LS prediction for the 2021-2025 period indicated that LS was primarily concentrated in the northeastern region, with a maximum cumulative subsidence exceeding 145 mm, although the overall LS intensity exhibited a decelerating trend. Finally, the Shapley Additive Explanations (SHAP) method was employed to quantify the factors affecting land subsidence in the study area. The results indicated that the thickness (L3) and groundwater level (GW3) of the third aquifer were the primary determinants of LS. This hybrid approach provides a robust basis for long-term LS prediction and risk assessment in regions characterized by limited data and complex hydrogeological environments.

Keywords: Land subsidence, Groundwater extraction, Hybrid Framework, Physical Numerical Model, Machine learning



Technical framework diagram of land subsidence prediction by Integrating Physical Numerical Model with data-driven fusion

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Land Subsidence in the Eastern Thessaly Plain, Greece. Assessment of Groundwater Overexploitation, Land Use, and Storm Daniel through InSAR Monitoring

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[3] Laboratory of Engineering Geology & Hydrogeology, Aristotle University of Thessaloniki, Thessaloniki, Greece

Abstract

The Thessaly Plain is the second biggest agricultural region in Greece. Since the 1970s, significant groundwater exploitation has occurred to meet increasing irrigation demands. Intensive groundwater abstraction has led to a continuous decline in groundwater levels, resulting in land subsidence in several parts of the basin. In this study, the spatial and temporal evolution of land subsidence in the eastern Thessaly Plain, along with its interaction with extreme flooding events (Storm Daniel - September 2023), is examined. InSAR data derived from the EGMS Copernicus Service is used to quantify ground deformation patterns and identify land subsidence. The observed deformation was analyzed with groundwater level records, hydrogeology, and land-use changes to evaluate the primary driving mechanisms. Primary results indicate that prolonged overexploitation of groundwater has affected the groundwater level, which has, in some areas, decreased to 100 m below surface level. Therefore, the induced subsidence is caused by compressible alluvial deposits and intensive agricultural activity. Following Storm Daniel, a temporary increase in groundwater levels was recorded due to exceptional rainfall and widespread flooding. InSAR observations suggest that this recharge event locally reduced subsidence rates and, in some cases, produced slight ground uplift.

Keywords: Land Subsidence, Groundwater overexploitation, InSAR, EGMS, Land Use

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Can we monitor water infiltration in a dyke using shear waves?

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Abstract

The knowledge of water infiltration in the subsoil and its spatiotemporal changes is important in many site-investigation projects e.g., landslides, slope stability, coastal erosion, flood protection, dyke stability assessments, etc. Although seismic methods using shear (S) waves can offer high-resolution images of the shallow soil layers, the use of S waves for near-surface water monitoring remains underexplored and the quantitative interpretation challenging. In this talk, we will discuss the results of a time-lapse S-wave tomography experiment performed on a field-scale test dyke with controlled water levels, allowing for detailed examination of how S-wave velocity (VS) responds to water infiltration. Our results demonstrate that VS decreases progressively, starting from the high-water-side slope and extending across the dyke, as the water level rises, with the most significant changes occurring in the sand body and not in the clay cover. The maximum decrease in VS is about 40–60 m/s, corresponding to approximately 25%–30% reduction from the initial condition. To understand the interplay between bulk density and shear modulus, we examine the squared velocity ratio. In the initially unsaturated zone, both factors contribute significantly to the observed VS changes as the zone becomes fully saturated. In fully saturated zones, we assess the changes in the effective stress. Although the low-water side of the dyke shows stress changes that are consistent with numerical modelling, the high-water side shows larger stress changes than expected, possibly due to excess pore pressure during the dynamic flow conditions. These findings highlight the potential of S waves for high-resolution, near-surface hydrologic monitoring, and provide insights into the complex interactions between physical properties that influence VS changes under varying water levels in field environments.

Keywords: Water infiltration, shear wave, dyke monitoring, slope stability, tomography

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Engineering Geology for Flood Levee Design to Alleviate Emergency Humanitarian Situations in South Sudan

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Abstract

South Sudan has experienced extensive and severe flooding over the past five years, resulting in the displacement of thousands of people, damage to infrastructure and essential services, and disruptions to livelihoods primarily reliant on agriculture. This paper examines a practical approach to incorporating engineering geology in the design and construction guidance of flood levees intended to protect displaced communities. The discussion focuses on how the recommendations are customised to address the specific constraints and opportunities arising from this difficult situation, which includes limited geological mapping and field testing, the absence of laboratory testing, and low-capacity construction methods. All of this must be accomplished using suboptimal locally available materials, typically fluvisols and vertisols, such as Black Cotton Soil. The paper concludes by summarising how this approach enhances resilience for the affected communities. By utilising local materials and community-driven construction, it results in a low-carbon, nature-positive solution that is easy to maintain.

Keywords: Ground model, Black Cotton Soil, Levee, Floods, South Sudan

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Mechanical Characterization of Tidal Marshlands: Insights From Different Scale in Situ Loading Experiments

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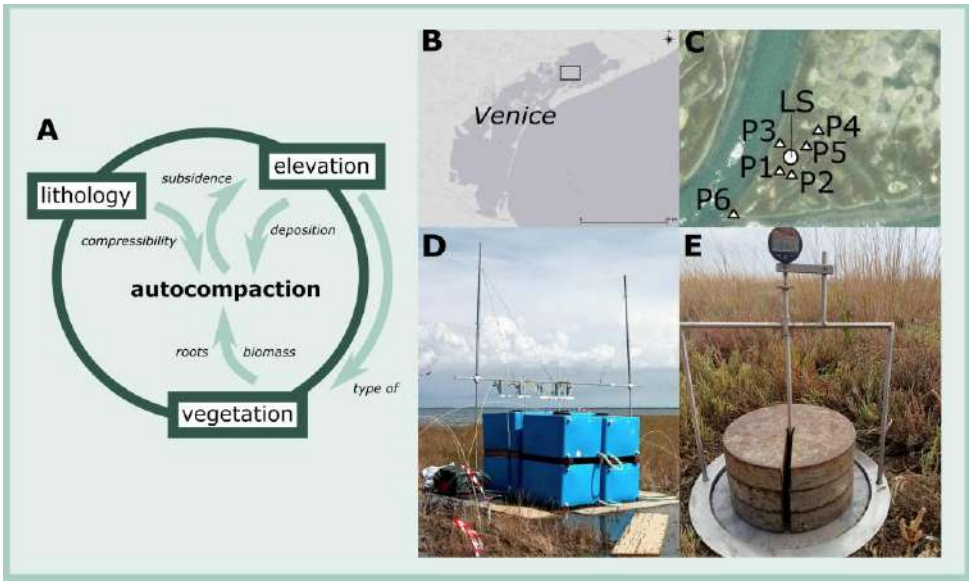
Abstract

Salt marshes are crucial coastal environments, and their preservation is of key relevance for maintaining the ecosystem services they host. One intrinsic characteristic of salt marshes is the highly heterogeneous lithological distribution. This heterogeneity significantly influence sediment autocompaction, which in turn affect marsh surface elevation and morphology. In this study, we investigate the role of autocompaction in shaping tidal marshes elevations by quantifying the influence of subsurface lithology and halophytic vegetation. We employed two-scale in-situ testing approach – consisting of a large scale (loaded area ~4.0 m²) test and a portable (loaded area ~ 0.08 m²) field test - to monitor marsh soils responses under controlled loading/unloading conditions in the Venice Lagoon, Italy (see Figure). These tests emulate standard oedometric procedures through measurements of vertical displacements. Comparing the results of the two-scale tests, we found that vertical displacements recorded during the large-scale test are generally higher than those measured with the portable test at ~10 kPa loading conditions. This might be due to the different loading area, which correlates with depth, and the time allowed for consolidation - 48 hours vs 45 minutes in the large and portable tests, respectively. However, the interpretation of the field records by a Biot-based coupled model provides a consistent geomechanical characterization of the upper 0.1 to 0.2 cm soil depth - in terms of stiffness, pre-consolidation stress, compression-to-recompression ratio. By combining the outcomes of both tests scales, we gained valuable insights into marsh autocompaction and its spatial variability, linking vegetation, roots system, and lithology.

Keywords: marsh deposits, in-situ oedometric test, compressibility,



A. Feedbacks among factors influencing soil autocompaction in salt marshes. B. Location of the field site in the Venice Lagoon, Italy. C. Location of the large-scale (LS) and the portable (P) loading field tests. D. Photo of the large-scale experiment with the eight water-filled tanks exerting the load on the marsh soil. E. Photo of the portable experiment with the same loading conditions (10kPa).

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Soil Loss Estimation in a Coastal Environment: The Case of Southeastern Brazil

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Abstract

In the context of environmental degradation, tropical forests—which play a crucial role in containing or mitigating extreme geo-hydrological events—have been disappearing at an accelerated pace in the Global South over the past two decades. In 2024, this process reached its historical peak, as evidenced by Global Forest Watch.

In Brazil, the Atlantic Forest, the first biome to be intensely exploited by European colonizers since the 16th century, still preserves important remnants that are essential for the stability of environments such as the Serra do Mar, a geomorphological feature that stretches for approximately 1,500 kilometers along the southeastern Atlantic coast.

Based on this context, the objective of this study was to estimate soil loss in a coastal area of the Serra do Mar, in the state of São Paulo. For this purpose, the Universal Soil Loss Equation (USLE) was applied, and the applicability of this model in transitional environments was also analyzed.

As a result, a soil loss estimation map was produced, indicating that areas with moderate to very high soil loss are concentrated in the coastal plain, where the Restinga Forest is located—an ecosystem associated with the Atlantic Forest, characterized as a transitional phytophysiognomy developed over Pleistocene and Holocene marine-origin geological substrates.

Keywords: Erosion, USLE, Coastal Plain, Tropical Forest, Spodosol

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Soft Deltaic Sediment Characterisation for Infrastructure and the Environment: Examples from the Niger Delta, Nigeria

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Abstract

The coastal Niger Delta in southern Nigeria is a large wetland divided into dry plains, swampy areas, and coastal hydrogeomorphological regions, each with distinct subsurface soil profiles consisting of the alternation of peaty clay, clay, silt and sand which can vary laterally and vertically within short distances and intervals rapidly. The delta is the hub of large-scale activities in the petroleum industry which require simple and complex infrastructure in the upstream and downstream sectors, including the production, transportation and storage of oil and gas. Often, massive oil spills accompany the exploration and production process. Factors including pervasive water bodies, highly compressible organic soils and low bearing capacities constitute formidable foundation challenges for infrastructural development and good environmental housekeeping. In the past two decades continuous site subsoil investigations for both foundation design and pollution mitigation have yielded data from studies which provide valuable insights into soil properties and the transport and mobility of contaminants underground. In this presentation, we shall discuss the complex engineering and environmental geology of the delta, citing case studies from the authors' experiences with site investigations using simple and design-for-purpose methods. The paper will improve the availability of sustainable scientific information to build resilient infrastructure and foster innovation in line with Sustainable Development Goal (SDG) 9.

Keywords: Soft Sediment, Chararacterisation, infrastructure, environment, SDG 9

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Static Liquefaction Assessment of a Dutch Flood Defence - A case Study

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Abstract

Waterschap Hollandsche Delta (WSHD) is the regional authority responsible for dike safety in the province of Zuid-Holland. The latest safety assessment identified dike segments that do not meet current safety requirements with respect to static liquefaction. This study investigates a dike section along the Oude Maas near Rotterdam, where site investigations indicate layered sand deposits with potentially contractive (liquefiable) behaviour. Cone penetration test (CPT) data collected along the alignment are processed to screen for susceptibility and to determine the depth and thickness of potentially critical layers. Bathymetric surveys further indicate progressive riverbed erosion at the dike toe, and a representative cross section is selected based on the CPT-derived trends together with local geometry and the observed scour extent. Finite element analyses are then used to quantify the mechanical consequences of toe erosion, modelled as staged soil removal consistent with the measured bathymetric evolution. The results show that scour-induced unloading reduces lateral confinement and lead stress paths toward instability, bringing the stress state close to an instability boundary within the most critical zone.

Keywords: Dike Stability, Liquefaction, Safety Assessment, Finite Element

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Riverbank Protection Designs and Performance Evaluation in the Niger Delta, Nigeria

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Abstract

The Niger Delta region faces significant challenges from erosion and sea-level rise, necessitating innovative approaches to shoreline and river bank protection. The methods of river bank and shoreline protection in current use in the region have been reviewed and reveals critical insights into their ineffectiveness. Assessing riverbank protection design and performance is essential to identify failure factors and develop effective sustainable measures. The paper examines case histories of shoreline protection, from design of the protection structure to the assessment of their performance during the period of their service life. It identifies the strength and weaknesses in the design and explains why some river bank protection structures have not performed as expected. This knowledge helps protect vulnerable communities and ecosystems from environmental hazards, ensuring the longevity and stability of riverbank structures against erosion and collapse. A central factor in the success or performance of the protection measures is the application and integration of geosynthetics in the design of erosion protection structures in the Niger delta. The use of geosynthetics in river bank applications is often found to provide financial benefits through the reduced cost of imported materials, minimal waste production, and an efficient use of resources compared with traditional solutions that use soil, concrete or steel. The usage of geosynthetics for river bank protection in the Niger Delta has emerged as a vital solution for addressing the challenges posed by weak and erodible soil conditions. Geosynthetics, when integrated with other materials and technologies enhance infrastructure resilience.

Keywords: Riverbank, Shoreline, Protection, Niger delta, Geosynthetics

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A Transferable Framework for Integrating Remote Sensing and Field Data to Assess Hydro-saline Soil Risk in arid Coastal Cities

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Abstract

Hydro-saline ground conditions are intensifying in arid coastal cities, accelerating infrastructure deterioration under rapid urban expansion. This study presents a transferable framework that integrates multi-temporal satellite remote sensing with field-based calibration to assess soil salinity, moisture dynamics, and land-use/land-cover (LULC) change in Port Sudan and Suakin (2008–2024). Landsat and Sentinel imagery were processed in Google Earth Engine to derive Short Wave Infrared (SWIR)-based Salinity Index (SI) and Soil Moisture Index (SMI) indices, while LULC dynamics were quantified using Moderate Resolution Imaging Spectroradiometer (MODIS) and ArcGIS Living Atlas datasets. Field validation was conducted using Vertical Electrical Sounding (VES), enabling calibration of satellite-derived salinity against subsurface electrical conductivity.

Results show that built-up areas increased by ~85–100% between 2008 and 2024, primarily expanding into low-lying sabkha and reclaimed zones. This expansion coincides with a 30–50% increase in the spatial extent of high-salinity zones and a marked rise in moisture-retaining surfaces. Elevated salinity values (SI > 110) are concentrated along building–road interfaces, reflecting drainage disruption by impervious surfaces. VES-derived conductivity confirms elevated subsurface salinity (locally exceeding 6–10 dS/m equivalent), consistent with satellite patterns.

Field observations document widespread salt crusts, persistent dampness, concrete spalling, and reinforcement corrosion, with damage concentrated in newly urbanized coastal districts. The strong spatial agreement between LULC change, hydro-saline intensification, and infrastructure deterioration across two cities demonstrates the robustness and transferability of the framework. The approach provides a scalable tool for hydro-saline risk screening and supports salinity-aware urban planning in arid coastal environments.

Keywords: Hydro-salinity, sabkha soils, arid coastal cities, remote sensing, engineering geology

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To Dredge or Not to Dredge: Data-Driven Feature Engineering of Side Channels

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Abstract

Side channels improve river resilience by increasing flow capacity and providing water buffer space. Keeping these side channels flowing properly is crucial for preventing fluvial flooding, especially given the more extreme weather caused by climate change. In this paper, we extract insights directly from measured geographic data in order to predict sedimentation behaviour of side-channels within the Dutch Waal, Lek, and Nederrijn rivers. We investigate how features of a side channel can be identified and extracted to enable predictive maintenance. By reviewing existing literature, key side channel characteristics are identified and captured into machine-readable features using an automatic pipeline. Using these features, a proof-of-concept machine learning model is trained to predict sedimentation, achieving 84% accuracy with a 5cm error margin for a case study channel. The result is an automated node-based data processing pipeline using the FME software, alongside a geospatial database with 19 features for 26 side channels, and a machine learning model showcasing the predictive ability of the derived features.

Keywords: Side-Channel, Feature Engineering, Machine Learning, GIS, Sedimentation

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Automated Processing and Visualisation of Resistivity Data for Flood Defence Embankment Monitoring

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Abstract

Powderham Banks, in Devon, UK, is a critical flood defence embankment protecting agricultural land, residential areas and the Great Western Main Line railway. The earthen embankment has a long history of repairs and recurring issues such as seepage and revetment damage. To better understand the state of the embankment, an Electrical Resistivity Tomography (ERT) monitoring system was installed along ~1.2 km of the structure to provide continuous, real-time monitoring of subsurface deterioration. An automated processing pipeline and interoperable dashboard has been developed to integrate resistivity measurements with environmental datasets, including tide, rainfall and soil property data. Machine-learning methods were applied to identify dominant environmental controls on resistivity behaviour and to classify spatial zones with similar responses. Additional diagnostic metrics, such as short-term resistivity rate-of-change and interpercentile range (IPR) exceedances are used to detect rapid water ingress and longer-term deviations indicative of structural deterioration or emerging seepage pathways. The automated monitoring results highlight both previously identified 'at-risk' locations and newly emerging anomalies not captured by earlier inspections, demonstrating the value of continuous geophysical surveillance. The integration of automated data delivery, advanced analytics and real-time visualisation provides actionable insight into embankment behaviour. Overall, this work shows that automated ERT monitoring can facilitate more targeted maintenance and support proactive flood-risk management for ageing, long-linear geotechnical assets.

Keywords: geophysics, monitoring, embankments, flooding, levees

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Inventory and Characterization of Hard Coastal Defenses in the Municipality of La Costa, Buenos Aires Province, Argentina

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Abstract

Since the 1980s, coastal erosion has become one of the main issues affecting the marine coast of Buenos Aires Province, generating significant impacts on geomorphology, infrastructure, and associated ecosystems. Causes of coastal erosion can be natural or anthropogenic; however, several studies indicate that human activities along the coast of Buenos Aires are a significant contributing factor and can further intensify naturally occurring erosive processes. The main objective of this paper is to inventory and analyze hard coastal defense structures, considering their functionality, effectiveness, and the environmental impacts generated on coastal dynamics and ecosystems. In order to mitigate these processes, numerous localities within the Municipality of La Costa have implemented different coastal defense structures. These interventions mainly correspond to hard structures classified as armoring and moderation strategies. Among the moderation structures, breakwaters and groynes stand out, as they are designed to reduce wave energy and modify littoral dynamics. On the other hand, the armoring structures presently used include seawalls, gabions, tetrapod, geotextile tubes, concrete blocks revetments, and combined defenses. The results obtained have been variable. Some structures succeeded in protecting urbanization for long periods, although many have now reached their limit of effectiveness. Nevertheless, none of the implemented mitigation measures contribute to the preservation of a natural coastal environment.

Keywords: Armoring, Coastal Erosion, Coastal Hazards, Coastalisation, Defenses

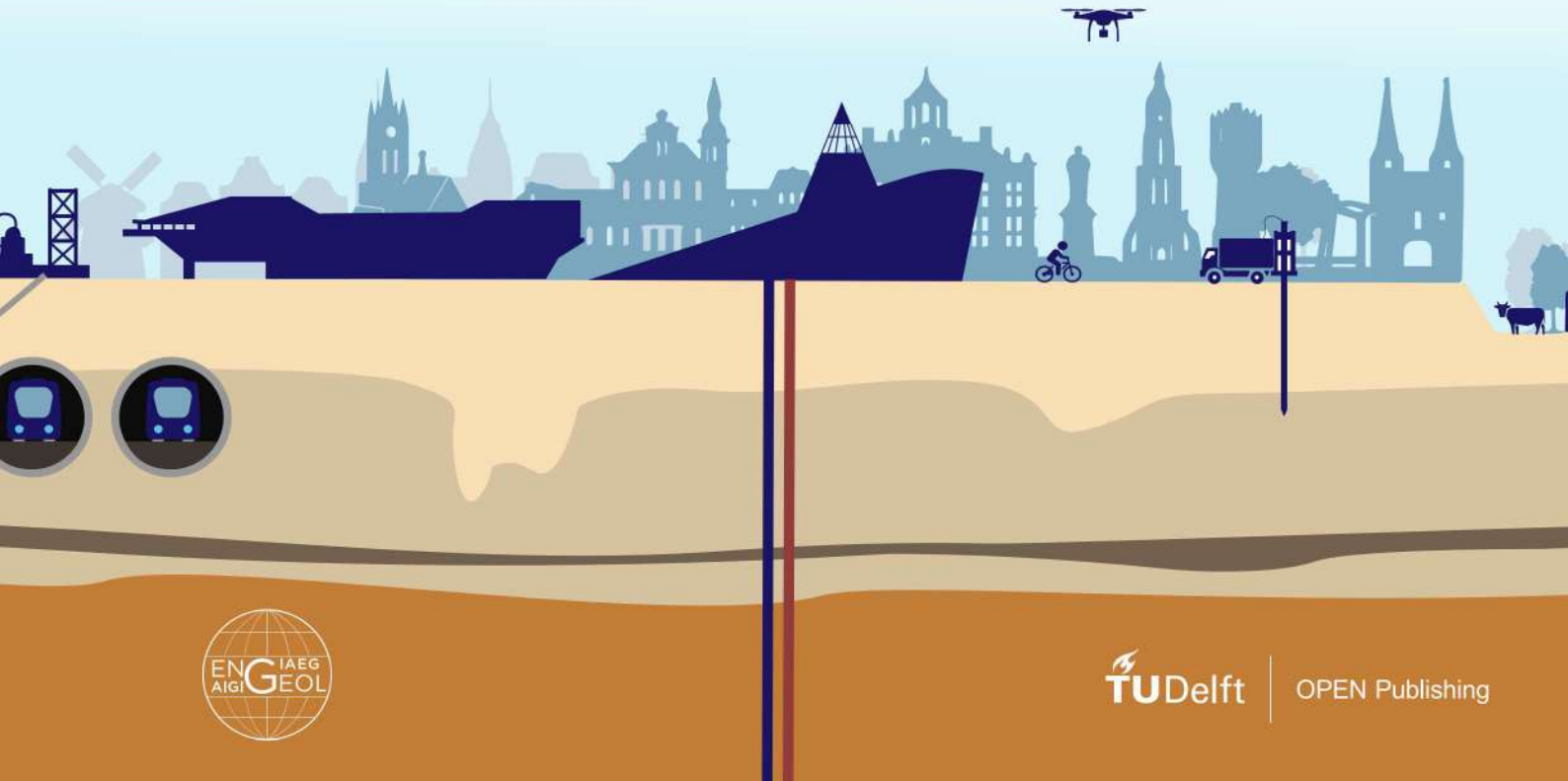


Figure 1: Image of the study area, Argentine Republic, Buenos Aires Province, Municipality of La Costa. a) Breakwater, Las Toninas. b) Revetments, Las Toninas. c) Groyne, Santa Teresita. d) Seawalls, Mar del Tuyú. e) Tetrapods, Mar del Tuyú. f) Gabions, Mar del Tuyú. g) Combined coastal defenses, Mar de Ajó.

3. Geohazards



Engineering Geology and managing natural and man-made geohazards through identification, monitoring, modelling, prevention, mitigation, and adaptation. Focus on landslides, earthquakes, volcanoes, tsunamis, karst subsidence, droughts, erosion, and flooding. Special attention to cascading multi-hazards.



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Hazards Triggered by Geological Phenomena in Georgia

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Abstract

Georgia is characterized by complex engineering-geological and geomorphological conditions, which are further complicated by active neotectonic processes that increase the likelihood of hazardous geological events. The occurrence of such events is associated with disturbances in the natural equilibrium of environmental components caused by natural and anthropogenic factors. As a result, Georgia experiences a complicated geodynamic situation that poses significant risks to the population, infrastructure, and economy. The country is highly susceptible to earthquakes, as demonstrated by several destructive events recorded during the twentieth century, including the Gori (1920), Tabatskuri (1940), Chkhalta (1963), and Racha-Imereti (1991) earthquakes. In addition, complex relief conditions favor the development of landslides, rockfalls, and debris/mudflows, many of which have caused severe damage. The abundance of groundwater and surface water further contributes to geological hazard development.

This study is based on the analysis of geological, geomorphological, seismological, and hydrometeorological data, together with historical records of hazardous events across Georgia. The spatial distribution, triggering factors, and impacts of major geodynamic hazards were assessed to identify areas of elevated risk.

The results indicate that active tectonics, rugged topography, intense precipitation, and human activities are the principal factors controlling the occurrence of earthquakes, landslides, rockfalls, and mudflows. Mountainous regions and densely populated valleys were identified as particularly vulnerable areas. The findings highlight the importance of continuous monitoring, hazard assessment, and the implementation of effective risk-reduction and disaster-mitigation measures.

Keywords: Landslide, Hazard, Georgia, Geology, Engineering-Geology

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Reactive managed retreat from landslide hazards - lessons from the Auckland storms of 2023

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Abstract

Auckland is the largest urban area of New Zealand's North Island with a population of ~1.7M. Auckland has a sub-tropical climate, with warm and humid summers which can be associated with intense rainfall. January 2023 was Auckland's wettest month since records began. The heaviest rainfall produced widespread flooding across Auckland on Friday 27 January described as at least a 1-in-200-year event. Two weeks later Cyclone Gabrielle hit Auckland. West Auckland recorded 248 mm of rain.

Tragically these events resulted in six deaths in Auckland, three of which occurred when landslides hit buildings. Two volunteer firefighters lost their lives while undertaking search and rescue operations, and tens of thousands of landslides were triggered. In the following two years Auckland Council undertook quantitative risk assessment for over 3,500 homes, and purchased over 1,000 homes at intolerable risk including several hundred exposed to landslide risks.

This paper describes the reactive adaptation process and summarises lessons learned from this to inform responses to, and preparation for, future natural hazard disasters.

Keywords: Landslides, Adaptation, Risk, Emergency

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Typology of Landslides in the Himalaya

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Abstract

The Himalayas are among the most landslide-prone regions in the world. The diversity of landslide types in this region reflects the complex interplay of micro-climatic conditions, active tectonics, geological weaknesses, high relief, and steep slopes. The specific typologies of landslides in the Himalayas, in general consider factors like material type, movement style with common landslide types that include debris slides, debris flows triggered by heavy rainfall or glacial melt; rockslides caused by steep slopes, interplay of slope and geological discontinuities surfaces, tectonic activity triggered by rainfall and seismic activities. The Himalayas have almost all types of slides, of all dimensions and proportions from huge tectonic slides to shallow debris slides which are ubiquitous, often occur in deep overburden mass or old landslide debris mass. However, in cryosphere regions and around, the mass movements are influenced by climate change, extreme precipitation, glacial retreat, and permafrost degradation. In trans-Himalayan region where cold desert conditions occur, the landslides are distinctively different types as huge talus, slope wash and rock fall or rock avalanche on steeper slopes. The creep and subsidence's are very slow, continuous, and often imperceptible down-slope movement of soil and weathered rock are rampant. Climate changes, increased snowmelt, and Glacial Lake Outburst Floods (GLOFs) are expected to further intensify landslide activity and potentially alter their types. The paper describes a wide spectrum of distinctive landslide typologies in different regions driven by a combination of active tectonics, fragile geology, steep terrain, and climatically driven rainfall pattern, often aggravated by human activities.

Keywords: Landslides, Himalaya, Typology, Cryosphere, Trans Himalaya

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Himalayan Landslide Science and a need for a New Landslide Classification Framework

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Abstract

Landslide science has long depended on established classification systems, notably the Varnes (1978) framework, which categorizes landslides based on movement type and material. While globally foundational, this system is increasingly inadequate for the Himalayan region, where complex geomorphic, lithologic, and climatic conditions prevail. The region experiences diverse mass wasting processes—including Deep-Seated Gravitational Slope Deformations (DGSDs), shallow landslides, debris flows, rockfalls, and debris slides—driven by active tectonics, steep terrain, and intense monsoonal rainfall. DGSDs, in particular, are large-scale slope movements that can evolve gradually or rapidly, often acting as precursors to multiple secondary landslides. These interconnected processes are not sufficiently represented in traditional classifications, which were developed in temperate and geologically stable settings. Himalayan DGSDs may involve creep, block sliding, and rockfall simultaneously, often exacerbated by rainfall and seismic activity, making hazard assessment and mitigation more complex. There is a pressing need for a region-specific classification system that captures the full spectrum of Himalayan slope deformation. Such a framework should integrate recent advances in remote sensing, AI, geotechnical investigation, and geomorphology, while accounting for the dynamic interactions between deep-seated and shallow landslides. A refined classification system will enhance hazard modeling, susceptibility mapping, early warning, and engineering design, ultimately supporting more effective risk reduction strategies.

Keywords: Himalaya, Landslide, DGSDs, Landslide Classification

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Development of a Landslide Hazard Map with the Participation of Local Residents: A Case Study from Mountainous Regions in Japan

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Abstract

In Japan, Landslides hazard maps are generally created based on legally designated sediment alert areas. However, these zones are delineated using uniform, nationwide methodologies, which often fail to reflect local geographical and environmental characteristics. As a result, it remains challenging for communities to adequately prepare for landslide disasters. To address this issue, the authors have developed a landslide hazard map that considers local geographical characteristics in Tatsuno Town, a mountainous area in Nagano Prefecture, Japan. Since 2015, they have been creating community-based landslide disaster prevention maps through participatory approaches involving local residents.

The disaster prevention map includes potential landslide initiation points identified based on geoscientific knowledge, hazardous locations related to landslide disasters gathered through workshops and interviews with local residents, and designated evacuation routes. In areas assessed to have a high risk of landslide, soil thickness surveys and other field investigations were conducted with the participation of community members, allowing them to gain a tangible understanding of the potential threat posed by sediment-related disasters.

A post-development questionnaire survey of the landslide disaster prevention map revealed that the majority of respondents provided positive evaluations, with many indicating that they believed the map would be useful during disasters. These results suggest that the map has contributed to enhancing community disaster resilience. Furthermore, the survey indicated a strong demand for making the map accessible online, which has prompted ongoing efforts to develop a 3D visualization of the map.

Keywords: Landslide Hazard Map, Community-Based Hazard Map, Disaster prevention awareness survey, 3D map

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Stakeholder Perspectives on Landslide Susceptibility Models in Nepal

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Abstract

Landslides are a recurring and fatal hazard in the Nepal Himalaya, leading to widespread development of landslide susceptibility maps to support planning and disaster risk management. Despite advances in modelling techniques, their practical uptake in governance remains inconsistent. This study explores how decision-makers and technical experts conceptualize and apply landslide susceptibility models in Nepal. Ten semi-structured interviews were conducted with stakeholders involved in landslide risk reduction and analyzed using Reflexive Thematic Analysis. Findings indicate a divergence in interpretation: participants with technical backgrounds tended to frame susceptibility maps as advisory or awareness-raising tools, whereas non-technical decision-makers expected more definitive information to guide regulatory action. Field verification was considered essential for decision legitimacy, particularly where model resolution, outdated data, or terrain complexity limited confidence. Scale mismatches, prediction errors, and ambiguity in terminology and color-coded classifications further influenced trust and practical application. The study reinforces international evidence that challenges in susceptibility mapping stem less from technical sophistication and more from clarity of scope, uncertainty communication, and alignment with governance needs. Strengthening this interface is critical to improving the real-world value of landslide models in Nepal as well as providing direction for the application of susceptibility maps elsewhere.

Keywords: landslide susceptibility, model usability, communication, decision-making, Nepal Himalaya

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Shallow-Seated Landslide Susceptibility and Hazard Assessment in Volcanic Edifices: A Chilean Case Study, the Llaima Volcano.

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Abstract

Landslides are one of the most important geological hazards in South America, especially in mountain environments, such as the Andes in Chile. The Llaima Volcano (38°42'S, 71°44'W), located in the Southern Andes Volcanic Zone (ZVS) of the Araucanía region, is one of the most active volcanoes in South America, with intense eruptive activity and abundant occurrence of landslides and lahars during the last centuries. This work seeks to evaluate landslide hazards based on a methodology that combines the determination of landslide susceptibility, calculated by integrating conditioning factors with a geological-geotechnical approach to identify critical areas through lithological, structural, and geomechanical characterisation, as well as stability analysis. A mapping of geological-structural rock masses, geomorphological units, and soil classification (USCS) was also conducted. The geotechnical tests performed according to the relevant standards included particle size distribution (MOP Vol. 8/8.100), in-situ density by sand cone test (ASTM D1556), CID drained triaxial tests (ASTM D7181), point load on rock (ASTM D5731), and hardness using a Schmidt hammer (ASTM D5873), in addition to the geotechnical characterization of the rock mass according to the GSI criteria. The resulting parameters enabled the generation of stability models under static and pseudo-static conditions, which were evaluated using software (DIPS, RocPlane, Slide, and Swedge of Rocscience Inc.). The results indicate high susceptibility on the north, southeast, and southwest flanks, associated with slopes exceeding 30°, GSI values of 55–75, and a fractured rock mass with low cohesion. Saturation and seismicity significantly reduce the safety factor (<1.2), increasing the probability of failure. The methodology proved effective for hazard zoning in volcanic edifices, providing key inputs for risk management and land-use planning in active volcanic environments.

Keywords: landslides, susceptibility, volcanic debris flows, Llaima volcano, Chile

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Coupled InSAR and Stability Index for Early Detection of Rainfall-Induced Landslides

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Abstract

Rainfall-induced landslides triggered by short-duration intense precipitation frequently lack detectable precursory surface deformation in InSAR time series, owing to geometric distortions (layover and shadow) and limited satellite revisit intervals. To overcome these constraints, this study proposes an integrated early identification framework that couples SBAS-InSAR deformation monitoring with a rainfall-driven time-series SINMAP stability index. Using long-term Sentinel-1 data from the Xishancun and Huangnibazi landslides in Li County, Sichuan Province, InSAR applicability was first quantified through R-index visibility and measurement sensitivity analyses. In zones of poor InSAR performance, a spatio-temporal cross-validation approach was applied to fuse deformation trends with dynamic stability index evolution for enhanced hazard delineation. Results indicate that the Xishancun landslide remains largely stable, with instability confined to the toe under heavy rainfall, whereas the Huangnibazi landslide exhibits greater rainfall sensitivity but severe monitoring challenges due to geometric distortions. Retrospective application to the catastrophic 23 July 2019 Jichang Town landslide (Shuicheng, Guizhou) successfully captured progressive destabilisation signals—via sharp stability index declines preceding failure—that were undetectable by InSAR alone. This coupled deformation–stability index method substantially improves early detection of concealed, rainfall-triggered landslides and provides a practical, transferable tool for risk assessment and early warning in complex mountainous terrains.

Keywords: Rainfall-induced landslide, InSAR, stability index, applicability, Early Detection

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Distribution Features and Formation Mechanisms of Large Landslides Along the Yalong River of China

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Abstract

The Yalong river is featured with high relief, narrow river gorges and steep slopes, causing serious landslides, which is situated on the eastern margin of the Tibetan plateau in China, covering an area of 1.28×105 Km. In this study, a comprehensive landslide database was firstly established through a combination of field observations and high resolution satellite imagery analysis. Based on this database, typical landslide types, failure and distribution patterns were then analyzed. The result revealed that majority of the large landslides are concentrated in the middle segment of the Yalong Jiang river with the high mountainous canyon, which are mainly distributed along the active faults/the river banks, showing strong spatial clustering. Most large landslides are concentrated at the elevation of 2000-3500m with the slope of 20º-40º, the dominant dipping direction of southwest, south and southeast, and with the topographic relies of 400-600m/km2. In addition, the large landslide tend to be concentrated in the areas with relative hard rock mass, including shale, dolomite and carbonate rocks. The distance to fault is also a significant influencing factor, with landslides being mainly distributed in the area within 1000m of active faults. At the same time, according to field investigation, the failure patterns of landslides in this area can be classified into three types: the tensile cracking sliding, the sliding bending and the toppling, which are influenced by various factors, including bedding orientation, main structural planes and slope characteristics. The results provide valuable insights into the spatial distribution and formation mechanisms of large landslides in the Yalong river, which is helpful for landslide hazard prevention and mitigation in this region.

Keywords: large landslides, distribution features, failure patterns, Yalong river

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Physics-Informed Neural Network for Modelling Slow-Moving Landslides

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Abstract

Accurate modelling of slow-moving landslides remains a significant challenge due to the complex interplay of mechanical, hydrological, and geological processes, often under conditions of limited observational data. This presentation focuses on the application of Physics-Informed Neural Networks (PINNS) as a novel framework for data-constrained, physics-consistent modelling of slow-moving landslide dynamics. PINNs integrate partial differential equations (PDEs) governing landslide behavior—such as momentum conservation, groundwater flow, and viscoplastic rheologies—directly into the loss function of neural networks. This allows the model to learn from sparse observational data (e.g., InSAR or GNSS deformation time series, rainfall records) while strictly adhering to physical laws. By embedding domain knowledge within the neural architecture, PINNs reduce the dependence on large training datasets and improve the interpretability and generalizability of predictions. In this study, we construct PINN-based models to simulate surface displacement fields and infer subsurface slip distributions for selected slow-moving landslides. We demonstrate how PINNS can reconstruct spatio-temporal deformation patterns from incomplete observations and provide physically plausible forecasts under varying hydrological and mechanical boundary conditions, leading to reliable early warning systems. The presentation will detail the neural network architecture, physics integration strategy, and training methodology, along with challenges related to model convergence, parameter tuning, and real-world data assimilation. PINNs represent a promising approach for advancing landslide modeling, bridging the gap between theoretical geomechanics and practical, data-driven forecasting systems.

Keywords: Deep Learning, Physics, Landslides, Artificial Intelligence, Model

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A Method for Estimating the Potential Damage Zone of Debris Flow using a Random Walk Model

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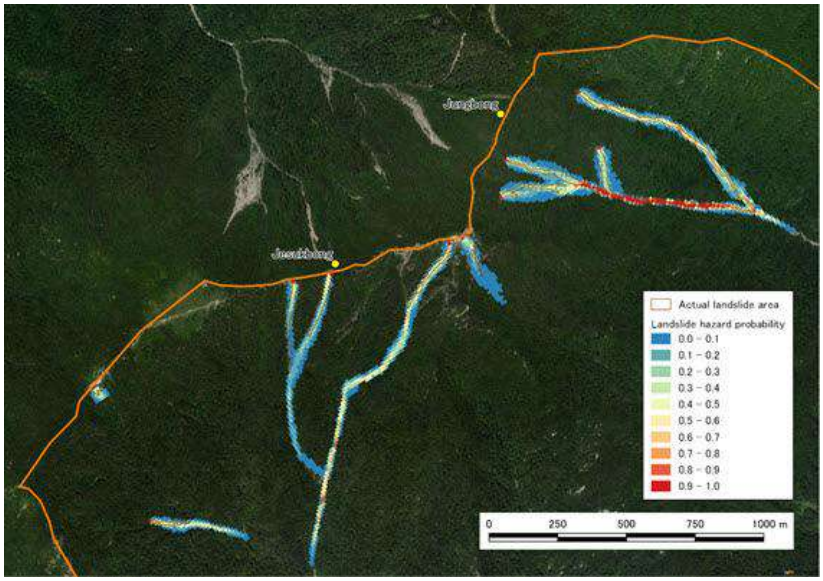
Abstract

A random walk model was applied to predict debris flow potential damage zones induced by landslide occurrences. The volume of failed material was estimated using the empirical relationship proposed by Guzzetti et al. (2009), and the runout distance corresponding to the failed material volume was predicted using the empirical relationship suggested by Corominas (1996). Debris flow runout trajectories were simulated using a random walk model, in which flow and deposition characteristics were simplified as a function of slope angle. The applicability of the proposed method was evaluated using landslide inventory data from the Cheonwangbong area of Mt. Jiri. The results indicate that the proposed approach can estimate debris flow potential damage zones with reasonable accuracy, and that a 10 m × 10 m cell resolution allows realistic reproduction of the observed damage zones.

Keywords: debris flow, failed material volume, runout distance, Potential damage zone, random walk model



Potential Damage zones estimated using the proposed random walk model

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Enhancing Landslide Susceptibility Modelling by Incorporating a Probabilistic Physical Model for Non-Landslide Sample Selection

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Abstract

Machine learning (ML) techniques have become prominent in landslide susceptibility analysis over recent decades. However, the performance of ML is critically dependent on the quality of its training data, particularly the precise selection of non-landslide samples. Conventional methods frequently employ random sampling of landslide-free areas in landslide inventory. However, this approach can inadvertently misclassify undiscovered landslides as stable, thereby compromising the accuracy of landslide susceptibility maps.

In order to address this limitation, a physically based approach was proposed that utilizes the evaluation of the factor of safety (FS) using a physical slope model, and subsequently, pixels exhibiting FS values greater than 1.0 were designated as non-landslide areas. The designated non-landslide samples were then employed in an ML-based landslide susceptibility analysis. However, given the inherent uncertainty in the input parameters (e.g., cohesion and friction angle) of the physical slope model due to limited availability of data, a probabilistic framework is adopted in this study, treating these parameters as random variables. Monte Carlo simulation is then employed to assess the probability of failure, thereby refining the identification of non-landslide locations based on probabilistic outcomes.

Subsequently, the refined samples are incorporated into a multi-layer perceptron (MLP) model for landslide susceptibility analysis, and the resultant maps are compared with those generated using conventional MLP approaches. The results of this study indicate that incorporating a physically based approach, employing a probabilistic analysis, into the sample selection process significantly enhances the reliability of ML- based landslide susceptibility mapping.

Keywords: landslide, physically based approach, probability of failure, susceptibility map, non-landslide sample

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Stability Analysis of the Dubičná Landslide: The Role of Temperature-Dependent Friction in a Warming Ground

Jan Jerman[1], Tomáš Kadlíček[1], Om Prasad Dhakal[1], Ondřej Racek[2], Jan Blahůt[2], Jan Klimeš[2], Gianvito Scaringi[1]

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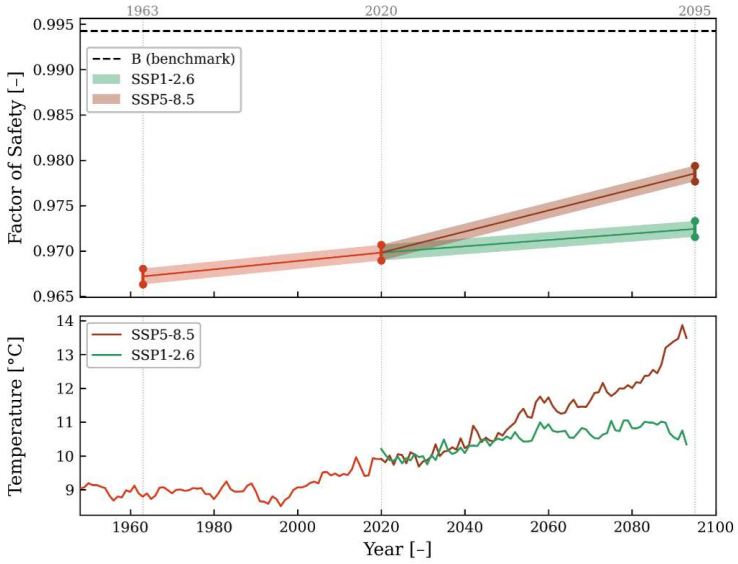
Abstract

The role of ground temperature in slope stability remains under-researched outside of permafrost contexts, despite experimental evidence that residual shear strength varies measurably with temperature in clay-rich soils. Here, we present a preliminary thermo-mechanical stability analysis of the 5.5 m-thick Dubičná landslide in the Czech Republic, occurring in high-plasticity marlstones of the Březno Formation. Using a modified ring-shear apparatus, we quantified the thermal sensitivity of the residual shear strength of the shear-zone material, revealing measurable thermal strengthening during slow shearing. To evaluate potential slope-scale impacts, we developed a transient heat-flow model and calibrated it against historical data and in situ monitoring. This thermal history, combined with future projections to 2100, was used in combination with temperature-dependent Mohr-Coulomb failure criterion for slope stability determination. The model captured the phase lag and depth-dependent amplitude attenuation of temperature, allowing the factor of safety's sensitivity to surface temperature changes to be quantified. Transient stability analyses yield seasonal FS oscillations of ΔFS = 0.003 and a net thermally induced strengthening of ΔFS = 0.011 under the IPCC SSP5-8.5 projection (2015–2100) from pre-warming period to 2100.

Keywords: slope stability, temperature, thermo-mechanical coupling, residual strength, climate change



Long-term evolution of slope stability and shear-zone temperature for the upper landslide. Upper panel: factor-of-safety envelopes (monthly minimum to maximum) interpolated between the period midpoints (1963, 2020, 2095) for SSP1-2.6 and SSP5-8.5, with the benchmark (B) as a horizontal dashed line. Lower panel: mean annual temperature at 5.5 m depth from the transient thermal model; the two scenarios share a common history and diverge after 2020. Vertical dotted lines mark the period midpoints.

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A Novel PLS-FR-Entropy Framework for High-Accuracy Landslide Susceptibility Modeling

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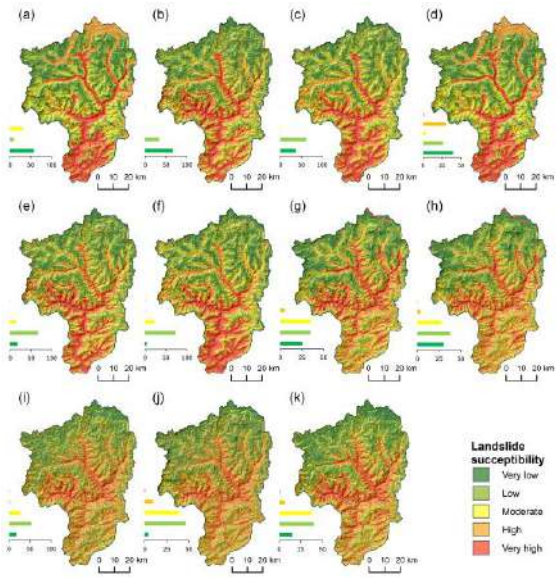
Abstract

The prevalence of machine learning (ML) in landslide susceptibility modelling is hindered by inherent "black box" limitations, compromising explainability and transparency. This study addresses this critical gap by developing a statistically enhanced, fully transparent, and explainable modelling framework. Utilising 17 geological, geomorphological, and climatic parameters from the Eastern Himalayas, a rigorous multi-stage approach was implemented. Initial parameter analysis employed Entropy and Principal Component Analysis (PCA) for reduction. Frequency Ratio (FR) and Entropy models were then developed and subsequently ensembled. Crucially, a novel Partial Least Squares Regression (PLSR) model was applied to this ensemble to explicitly characterise variable interactions influencing landslide susceptibility. Variable Importance in Projection (VIP) values derived from PLSR guided the remodelling of all parameters using FR, generating the final susceptibility map. Validation results demonstrated significant performance differences: Entropy-based models achieved 68-75% accuracy, FR models 70-89%, while the final PLS-FR model attained a superior accuracy of over 90%. This research presents a significant methodological advancement, delivering high predictive performance (> 90% accuracy) alongside crucial explainability, transparency, and replicability. The PLS-FR framework effectively characterises parameter contributions, offering a powerful and interpretable alternative to conventional black-box ML for landslide risk assessment and management.

Keywords: Landslide susceptibility, Frequency Ratio, Entropy, PLSR, Himalaya



Landslide susceptibility mapping using (a) Entropy, (b) Entropy-R, (c) Entropy-PCA, (d) Entropy optimized, (e) Entropy optimized-R, (f) Entropy optimized-PCA, (g) FR, (h) FR-PCA, (i) FR-Entropy, (j) FR-Entropy-PCA, and (k) PLS models.

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Network Disruption Under Cascading Geohazards: A Transport Modelling Framework for combined Landslide and Flood Risk

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Abstract

Transport systems cover vast areas across different terrains and climates. As an example of critical infrastructure, they are essential for economic and social connectivity worldwide. However, this vast spread does make them vulnerable to a range of geohazards. Among these landslides and flooding events triggered by extreme precipitation or earthquakes pose serious risks to road and rail networks, particularly when occurring as cascading or compound events. For example, earthquake-induced landslides may form dams that fail during rainfall events, or prolonged precipitation may simultaneously trigger floods and slope failures. These interactions demand an integrated hazard assessment approach to better understand the full range of risks posed to transport systems.

Considering this, we present a modular, multi-hazard risk assessment framework using hazard simulation and a transport modelling framework to assess the risks associated with multi hazard events and transport infrastructure under a changing climate. To conduct this a slope stability analysis based on the infinite slope model and factor of safety under precipitation and seismic conditions is used to map landslide susceptibility. Additionally, the Synxflow modelling package is applied to simulate both shallow landslide runout and flood inundation across the sites.

Finally, we bring together hazard maps with transport network modelling to understand not just where landslides and floods are likely to happen, but how they affect movements through the network. By simulating blocked roads and railways, we can see how travel is disrupted through delays, longer routes, or reduced access providing an essential insight into system resilience under a changing climate.

Keywords: Transportation , Climate Change , Flooding , Landslide , Multi - Hazard

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Exploring the Applicability of Three-Dimensional Limit Equilibrium Models for Landslide Susceptibility Analysis at the reservoir basin scale

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Abstract

Landslides affecting slopes delimiting reservoir impoundments and the surrounding areas are a common hazard that can occur at different stages of a reservoir operational life, due to factors like: heavy rainfalls, earthquakes and impoundment levels changes. Their occurrence significantly undermines safe operations of reservoirs, hence developing efficient techniques to assess landslide susceptibility is vital. This study is aimed at extending the application of 3D limit equilibrium (LE) slope stability analysis technique to the entire reservoir scale to generate landslide susceptibility maps under different groundwater conditions at San Pietro Dam, Southern Italy. The 3D LE assessment of landslide susceptibility, which is commonly performed at single slope scale, was implemented for the examined reservoir basin by using Slide3 software. All calculations were carried out on a geotechnical model with representative strength parameters built on a 3D geometry generated from a 10-m DEM. Results show that the approach can detect landslide-prone areas around the reservoir, being characterized by low safety factor values. Results accuracy increases from the assumption of dry slopes to scenarios of shallow groundwater levels. A general overestimation or an underestimation of the landslide susceptibility is observed when residual strength or peak strength parameters are respectively used. This implies that landslides in the area probably occurred under post-peak strength parameters, i.e. intermediate between peak and residual. Basically, the results shed green light on the possibility to extend 3D LE analysis for slope stability analysis at the reservoir scale, even for deep landslides and complex geological contexts.

Keywords: Slope stability, 3-D limit equilibrium analysis, Basin scale,

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Applying Weight of Evidence Analysis in Geohazards Assessment: An Example for Prediction of Long Runout Landslides

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Abstract

Weight of Evidence (WoE) analysis has long been used in epidemiology to diagnose health issues and to conduct forensic studies of illnesses. Because the stakes are literally life-and-death, the method carefully integrates lines of evidence, reliability, judgement, and quantitative approaches to arrive at the most plausible conclusion. It has not been applied to geohazards assessment in a formalized structure, yet it offers many benefits in consistency and objectivity of analysis, and it can be used in both predictive and forensic capacities. We present the use of WoE analysis for prediction of long runout landslides, defined as events where slope failures have runout length in excess of five times their height. These events are difficult to predict, with many examples of landslides that travel unexpectedly long distances and cause damage and fatalities in unexpected areas. Using datasets of long and short runout landslides, we show how WoE guides the collection and organization of lines of evidence, weighs their relevance and reliability, and then integrates the information into increasingly rigorous methods from best professional judgment, to causal criteria and logic approaches, and finally to indexing based on empirical models and fully quantitative systems using formal decision analysis and statistical methods. While geohazards professionals may already be implementing some of these methods, an awareness of and adherence to WoE principles can improve the accuracy and reliability of hazard analysis such as long-runout-landslide prediction, thus improving mitigation of complex and dangerous geotechnical hazards.

Keywords: landslide, long runout, prediction



West Salt Creek Landslide in Mesa County Colorado, USA. On 25 May 2014 this 80M m3 event traveled over 5km and killed three people. Both the size and the travel distance were surprising, underscoring the critical need to be able to better predict long-runout landslides.

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Monitoring of Subsoil Deformations for a More Correct and Complete Interpretation of Slow or Extremely Slow Kinematic Phenomena

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Abstract

Technological improvements have led to a significant increase in the use of remote sensing and proximal remote sensing techniques in the field of landslide monitoring in the last decade. These systems enable the characterization of unstable area evolution at various scales and sample rates. Particular interest is in phenomena characterized by slow or very slow kinematics, which, over time, can induce medium- and long-term stress and critical issues, especially on large infrastructures (railway and road lines, dams, etc.). In this context, it is crucial to observe deformation dynamics both on the surface and underground. Surface observation alone can sometimes hide (or mask) the true and complex deformation dynamics occurring underground. Deformation measurements must therefore also be performed on the subsoil with a correct temporal frequency, adequate vertical discretization, but also with sustainable long-term costs. We present results from extremely deep inclinometer monitoring activities (up to approximately 250 m), conducted using robotic inclinometer systems with almost daily measurement frequencies. The system used, equipped with a single biaxial probe operated by a robotic system, allowed for the acquisition of high-quality measurements useful for a more complete and correct interpretation of process kinematics (both above and below ground). The results obtained with a 50 cm discretization and double reading (0/180°) confirm that it is possible to obtain high-quality measurements in even complex contexts, but also that the data must be analyzed appropriately

Keywords: Inclinometer, Underground deformations, Landslides, Monitoring, Slow kinematic



250 meters capability robotized inclinometer system

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Recent Experiences with the Slope Stability Probability Classification (SSPC)

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Abstract

The Slope Stability Probability Classification (SSPC) is a classification system designed for estimating stability of slopes. The classification system is based on probabilities for individual failure mechanisms acting in slopes. Failure mechanisms considered are sliding, plane and wedge sliding, toppling and groundmass failure. The SSPC works with weighting factors for method of excavation and weathering to compensate for past and future damage and changes due to method of excavation and weathering. The SSPC system may forecast major slides or failure of masses, but also includes smaller but still devastating effects on the stability of a slope, such as loss of structure, raveling and erosion of a slope. The SSPC system was developed on mainly rock slopes, but also works for groundmasses with a more soil-type character. The system was developed in the early 1990's and has been used throughout the world since thereafter. Some of the slopes that were classified in the 1990's have been revisited in recent years to see whether the SSPC system still holds. In addition, a couple of other slopes have been assessed. The slopes are located in the Falset region in Catalunya, Spain, and in Germany. The results show the SSPC system is still very much useful and forecasts stability to a high degree of reliability.

Keywords: Slope, Stability, SSPC, Mechanics, Weathering

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Comparative Model Tests on Deposition Characteristics of Debris Flows under Straight versus Bending Channel Configurations

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Abstract

Debris-flow deposition zones often exhibit evolutionary characteristics such as dispersed sediment particles and deflected morphology due to changes in flow-path configuration. Current research in this field remains insufficient, constraining hazard prevention and comprehensive utilization of deposition zones. In this study, three types of debris-flow deposits with varying densities were employed as prototype materials. Indoor physical model tests were conducted using a self-developed variable-flow-path simulation system under three channel configurations: straight (Type I), single-bend (Type C), and continuous-bend (Type S). By integrating high-speed photography, distributed sensing, and image processing techniques, parameters including flow velocity, discharge, deposition morphology, thickness distribution, and particle size distribution were simultaneously monitored. Deflection angle and offset distance were introduced to quantitatively analyze flow-path deviation behavior. Results show that flow-path morphology dominates deposition patterns: straight channels form strip-like deposits, while curved channels produce fan-shaped distributions. Deposited particles display longitudinal sorting, with finer grains near the flow path and coarser grains farther away; bends significantly hinder the transport of fine particles. Path deviation is primarily controlled by channel morphology, while flow velocity and material density play regulatory roles at specific stages. This study reveals the movement–deposition response mechanism of debris flows under complex flow paths, providing a scientific basis for risk assessment and mitigation engineering design of debris-flow hazards in mountainous regions.

Keywords: debris flow, variable flow path, modeling tests, accumulation characteristics, offset

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Numerical Analysis of the Ngouache Iv Landslide (Bafoussam, Cameroon) Using ABAQUS: Influence of Geotechnical Parameters

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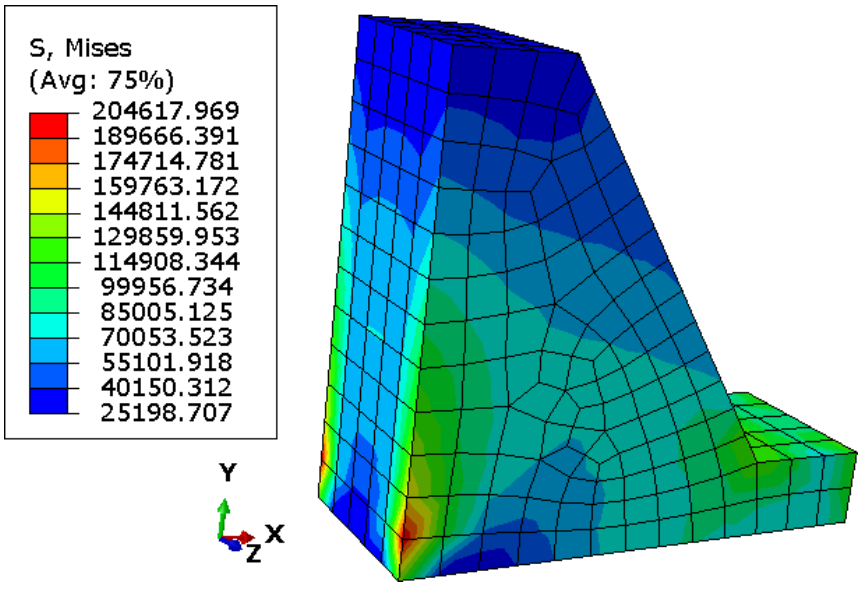
Abstract

Over the past 25 years, landslides have caused substantial loss of life and damage to infrastructure in Cameroon. Among the most devastating events are the Ngouache IV landslide, which claimed more than 40 lives in October 2019, and the Mawoh landslide in Limbe, which resulted in 21 fatalities in 2001. More recently, the Dschang Cliff landslide caused multiple fatalities and severely disrupted national road traffic, underscoring the growing landslide hazard in the country. This study focuses on the Ngouache IV landslide and aims to model its failure mechanism to improve the understanding and mitigation of landslide hazards in similar geological and geomorphological settings across the country. Slope stability was evaluated through a numerical analysis that assessed the influence of key geotechnical parameters on slope behavior. The analysis was conducted using the finite element software ABAQUS. The investigated parameters include Young's modulus, Poisson's ratio, cohesion, angle of internal friction, pore-water pressure, and void ratio. Results from this parametric study indicate that besides the pore-water pressure, the Young's modulus exerts the greatest influence on slope deformation, leading to the largest predicted ground displacement and volume of mobilized material. These findings highlight the critical role of geotechnical parameters in slope stability modeling and provide valuable insights for landslide risk assessment and mitigation strategies in landslide-prone regions of Cameroon.

Keywords: Ngouache IV landslide, Stresses, Deformations, Cameroon, ABAQUS



Stress distribution in the presence of water pore pressure

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Fabric-Replicated Modeling and Macro-Mesoscopic Identification of Irreversible Critical State for Rainfall-Induced Redbeds Landslides

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Abstract

Physical models for redbeds landslides cannot accurately replicate the fabric and diagenetic processes of natural rocks. Moreover, the lack of effective macro-mesoscopic linkage methods to identify the irreversible critical state of landslide deformation greatly limits the accuracy of hazard mechanism research and early warning. To solve this problem, this study innovatively constructs an integrated technical system of "fabricated model synthesis - macro-mesoscopic test characterization - critical state identification". A specialized synthesis system was developed to prepare scaled layered slope models (600×400×300 mm) that match the fabric and physical-mechanical properties of natural redbeds, with a similarity error of 0.1%~10.6%. Combined with Digital Image Correlation (DIC) technology, a macro-mesoscopic dual-scale test scheme was designed to systematically monitor slope displacement, stress, pore water pressure and mesoscopic damage evolution under heavy rain conditions (1.5 mm/min). Based on the critical slowing down theory, three types of damage zones were defined, and macro-mesoscopic identification criteria for the irreversible critical state were proposed. Results show the model reproduces the traction-type progressive failure process, with the first landslide occurring at 10 h (sliding surface at the top-middle interface). Strain of the globally damaged zone identifies the weak interlayer's irreversible state; top layer strain (R^2=0.92) accurately identifies the critical state, and middle layer strain (R^2=0.88) responds optimally to deformation. This study verifies the model's reliability and provides core technical support for the prediction and prevention of rainfall-induced redbeds landslides.

Keywords: redbeds landslide, fabricated model synthesis, irreversible critical state, macro-mesoscopic test, weak interlayer

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Control of Catchment Hypsometric Integral on the Spatial Distribution of Coseismic Landslides

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Abstract

Coseismic landslides are an important factor influencing landscape evolution, due to their large number and wide distribution. However, the effects of catchment-scale landscape evolution on landslide area and spatial distribution remain unclear. This study uses the Hypsometric Integral (HI) to quantify catchment evolutionary stage and investigates its influence on the spatial distribution of coseismic landslides triggered by the 2008 Mw 7.9 Wenchuan earthquake in the Longmenshan region. The results show that HI significantly influences landslide frequency, area, and spatial position. Most landslides are concentrated in catchments with HI ≤ 0.6, particularly in the maturity stage (0.4 < HI ≤ 0.6). From the perspective of the slope position, landslides exhibit a general tendency to cluster near ridges. Small landslides (area < 5000 m2) are more strongly concentrated near ridges, whereas larger landslides tend to extend downslope toward valleys. At the regional scale, large landslides (> 50,000 m2) in western catchments of Longmenshan Mountain exhibit overall sliding across the slope, while those in eastern catchments are distributed at different positions on the slope and are relatively more scattered. With increasing seismic intensity, landslide positions become more dispersed, indicating that seismic forcing mainly increases spatial variability rather than shifting mean positions or concentrating failures in specific locations. Overall, catchment evolutionary stage controls the spatial pattern of landslide occurrence, while the seismic intensity mainly exerts its influence by enhancing the spatial dispersion of the landslide distribution. These findings highlight the combined effects of landscape evolution and seismic forcing on landslide distribution.

Keywords: coseismic landslides, catchment, Hypsometric Integral, landslide position, the Wenchuan earthquake

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Seismic Landslide Controls and Transferable Probabilistic Assessment Modeling in Taiwan: Insights From the Chi–Chi and Hualien Earthquakes

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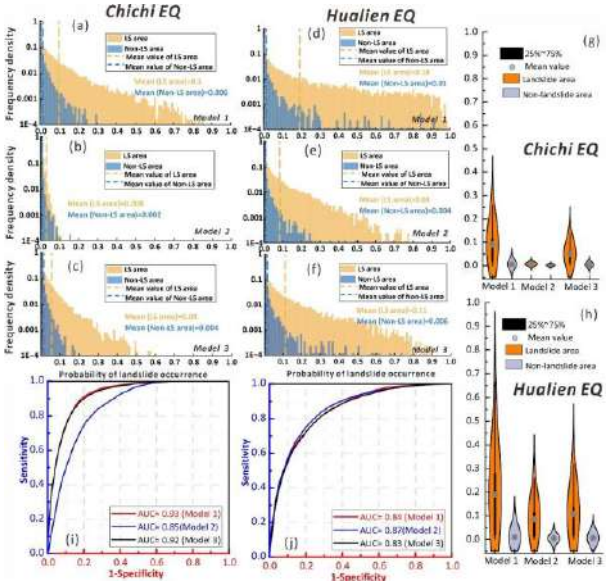
Abstract

Frequent strong earthquakes in Taiwan's steep mountains trigger massive landslides, but the relative roles of tectonic setting and topography in their spatial distribution remain unclear. This study investigates the dominant controls and spatial variability of landslides triggered by the 1999 Mw 7.6 Chi–Chi and 2024 Mw 7.4 Hualien earthquakes and develops a transferable approach for rapid hazard assessment in Taiwan. A unified dataset integrating two event-based landslide inventories and ten conditioning factors was used to construct three logistic regression (LR) models: Chi–Chi-specific, Hualien-specific, and hybrid cross-event. The SHapley Additive exPlanations (SHAP) method quantified feature importance and nonlinear interactions among seismic, topographic, and hydrological variables. Results show that landslide occurrence is mainly governed by the interaction of strong ground motion and rugged topography, with relative influences varying by tectonic setting. The Chi–Chi event featured near-fault failures within 10–30 km of the Chelungpu fault, while the Hualien event depended more on slope aspect, relief, and moisture. In probability mapping, single-event models achieved high accuracy locally but showed bias when transferred, whereas the hybrid model produced more consistent and robust predictions. This study provides an interpretable method for assessing seismic landslide hazards and supports near-real-time hazard mapping in Taiwan.

Keywords: Chi–Chi Earthquake, Hualien Earthquake, Coseismic Landslides, Logistic Regression (LR) Model, SHAP Interpretation



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From Cloudburst to Disaster: Modeling Debris Flow Dynamics in Bayshonai Kalay, Buner District, Khyber Pakhtunkhwa, Pakistan

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Abstract

On August 15, 2025, a cloudburst over Buner District, Khyber Pakhtunkhwa, Pakistan (>150 mm of rain in one hour) triggered debris flows and a flash flood that left 228 dead, 120 injured, and 134 missing. We reconstruct the event at Bayshonai Kalay, one of the worst-hit villages, by combining field observations, change detection on 3 m PlanetScope images (6 and 20 August 2025), and runout modelling. Unsupervised NDVI change detection maps a 2.80 km² flash-flood footprint extending 12.3 km along the valley floor and intersecting 424 buildings, plus three tributary debris-flow tracks (7.41 ha) originating from failures of steep colluvial slopes. The debris flows were back-analysed with a verified two-dimensional depth-averaged model using Voellmy–Salm friction, the rheology of RAMMS::DEBRIS FLOW. A 120-run calibration gives $\mu = 0.15$ and $\xi = 400$ m/s² (hit rate 0.94); μ is well constrained, ξ much less. For a release volume of about 2.9×10^4 m³, modelled velocities reach 11.5–13.5 m/s, maximum depths 1.5–2.9 m depending on grid resolution, and impact pressures 265–367 kPa in steep channels, far above building-damage thresholds. Ten scenarios show that release volume and μ control runout and exposure. Bayshonai Kalay lies inside the flood footprint, about 500 m from the nearest modelled debris flow. This points to a cascade: debris flows supplied sediment and boulders to the channels, and the debris-laden flood destroyed the village. Hazard assessments should treat hillslope debris flows and valley flooding as one coupled process chain, with implications for hazard mapping, early warning and land-use planning.

Keywords: Debris flow–Flash flood, cloudburst, Voellmy–Salm rheology, PlanetScope change detection; multi-hazard cascade, multi-hazard cascade



Debris Image

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Neural emulation of gravity-driven geohazard runout across diverse real-world landscapes

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Abstract

Gravity-driven mass flows, including landslides, debris flows, and avalanches, are among the most destructive geohazards, often travelling kilometres from their source and threatening downstream communities, infrastructure, and ecosystems. Forecasting their runout remains challenging because outcomes depend strongly on uncertain initial conditions, material behaviour, and complex terrain controls. For operational warning and scenario-based risk assessment, models must therefore be both physically realistic and computationally fast. Current numerical approaches can capture important flow processes but are often too computationally expensive for large-scale forecasting, ensemble simulation, or rapid uncertainty propagation. This creates a persistent trade-off between physical realism and operational speed. Here, we present a neural-network emulator for predicting the final outcomes of gravity-driven mass-flow runout across diverse real-world landscapes. The model is trained on approximately 90,000 numerical simulations spanning more than 5,000 topographies. It predicts both inundation extent and deposit thickness with high spatial accuracy while achieving computation speeds orders of magnitude faster than conventional numerical solvers. The emulator reproduces key emergent behaviours, including flow avulsion and heterogeneous deposition, and generalizes across a broad range of rheologies, release volumes, and topographies. Our results show that neural emulation can make runout modelling fast enough for regional-scale scenario analysis and uncertainty quantification. This approach complements physics-based models and supports more practical forecasting of landslide impacts across space and time.

Keywords: Mass flows, Runout, Neural networks, Landslides, Emulators

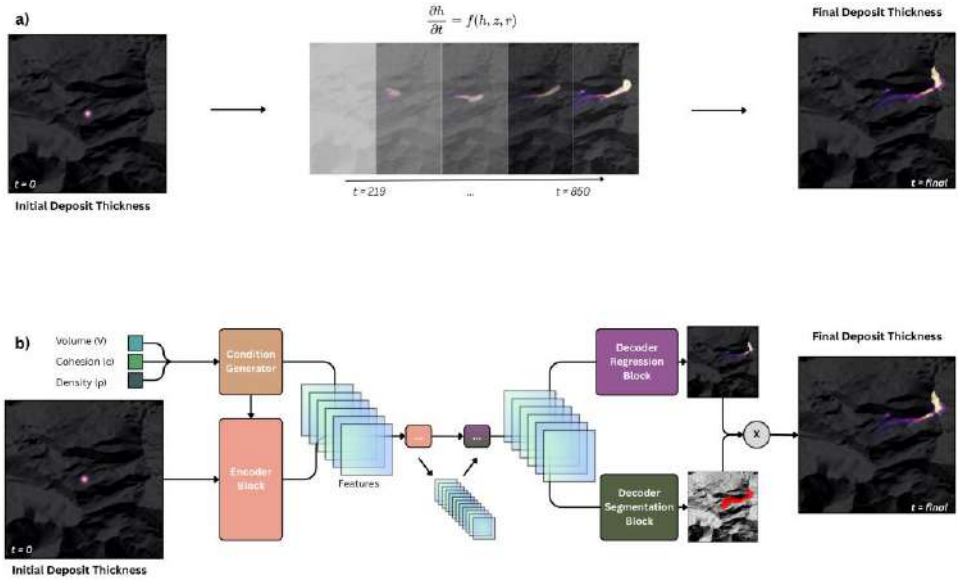

Image source: Nava et al 2025

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Numerical Simulation Analysis of Resurrection and Surge of Paleolandslide Based on FDE-SPH Method

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Abstract

Reservoir-triggered landslides present critical challenges to the sustainable development of hydropower infrastructure in mountainous regions. This study focuses on a representative paleolandslide in the Gushui Hydropower Station reservoir, Upper Lancang River. An advanced fluid-solid coupling model integrating the finite discrete element (FDE) and smoothed particle hydrodynamics (SPH) methods was developed: the FDE method was designed to insert zero-thickness cohesive interface elements between finite elements, enabling simulation of the landslide mass's deformation, progressive fragmentation, and movement. The SPH method, by contrast, was capable of flexibly handling the evolution of the free surface of water and wave propagation, and accurately simulating the dynamic coupling interaction between the landslide mass and water after it enters the water. Simulation results reveal that the landslide fragmentation process consists of three stages: initial disintegration, movement fragmentation, and post-fragmentation. The destabilized landslide mass reaches a peak velocity of 80 m/s, generating impulse waves with a maximum surge velocity of 34 m/s and a maximum run-up of 50 m on the opposing shoreline. Comparative simulations using computational fluid dynamics methods demonstrate that the FDE-SPH framework more accurately captures real-world landslide motion by resolving discrete particle interactions and energy dissipation through fragmentation and collisions.

Keywords: Reservoir-Triggered Landslide, Fluid-Solid Coupling Method, Numerical Simulation, Movement Process, Landslide Surge

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Understanding the Geohazard Characteristics of the Bobonaro Mélange Lithology and Its Implications for Sustainable Infrastructure in Timor-Leste

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Abstract

Geological hazards like landslides and slope failures have a major impact on the infrastructural development in Timor-Leste due to the geological complexity and the widespread occurrences of synorogenic deposits of Bobonaro Mélange lithology across Timor Island and the Banda Arc, with approximately 40% of Timor-Leste's surface geology. This study presents an understanding of the geohazard characteristics of this lithology from a mineralogical and geotechnical framework across three study locations: Suai Expressway, Bee-Mean Road, and Balibo-Leolima Road. This study demonstrates the variability in concentrations of smectite clay (0.8-20%), with a clay content range up to 96.5%, a high plasticity index of up to 53.1%, and a low coefficient of permeability (in the 10^{-4} cm/sec range); these factors contribute directly and significantly to geological hazards. These values also determine the swelling-shrinking behavior with progressive and retrogressive landslide evolution, which revealed a high susceptibility to deformation under natural factors such as rainfall as well as anthropogenic influences, including deforestation and man-made slope cuts. Based on these characteristics, this study designates the Bobonaro mélange lithology as "Bobonaro problematic clay." These findings provide an understanding for sustainable development in complex geological conditions through fostering a more resilient and sustainable infrastructure in Timor-Leste as well as contributing to safety and economic productivity. It also proposes transferable insights for geological hazard assessment that are applicable to the Bobonaro problematic clay found within the Banda Arc collision zone, as well as similar tectonic settings globally.

Keywords: Bobonaro mélange, Geohazard, Geotechnical Characterization, Clay Mineralogy, Sustainable Infrastructure, Timor-Leste

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Geodetic Observation and Inversion of Slow-Moving Landslides.

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Abstract

Slow-moving landslides present persistent hazards to infrastructure and communities, particularly in mountainous and tectonically active regions. Their gradual evolution enables continuous monitoring using space geodetic techniques, which offer critical insights into their kinematics and underlying mechanics. This presentation outlines an observation and inversion approach to slow-moving landslides through the integration of numerical modelling, geotechnical modelling and Interferometric Synthetic Aperture Radar (Insar).

Through selected case studies at multiple locations, we illustrate the application of these techniques in monitoring landslide activity and detecting temporal trends in movement at a vast regional scale. We also discuss the inversion of landslide velocity using inversion of Hoek-Brown methods to estimate hillslope strength reduction. These inversions are further analysed in the context of external forcings, such as precipitation and seismicity.

The talk emphasises the benefits and limitations of current satellite geodesy for landslide research, as well as emerging solutions in data processing and sensor fusion. By integrating multiple observation techniques, we enhance our ability to characterise slow-moving landslides and improve the reliability of hazard assessment and early warning systems.

Keywords: Remote Sensing, Landsldies, Inversion, InSAR,

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Improvement of landslide investigation in deeply weathered ultramafites by parallelizing ERT with direct field observations

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Abstract

The threat of landslides to lifes of inhabitants in mountainous areas, especially in the global south, is rising due to global warming and increasing population. In Medellín, the second largest city of Colombia, the heavily weathered dunite unit in the east of the city is the most landslide-susceptible unit, where most of the landslides of the last 100 years have taken place. Detailed on-site investigation of these landslide-prone slopes is essential for the planning of mitigation measures. To accomplish this for our study area, we developed a multi-step approach, combining electrical resistivity tomography with mapping, core drilling, and structural analysis of discontinuities. Electrical resistivity tomography was performed to determine the drilling locations and re-evaluated once the drill cores were available. The investigation showed a bedrock of heavily weathered ultramafites (dunites & serpentinites) with pseudokarst structures and overlying colluvium material deposited by former landslides. It became apparent that the first geological model was not sufficient to describe the site as the supposed layering of weathered dunite and saprolite on top of non-fractured dunite was not existing. Rather, the fractured dunite reaches down to more than 50 m in some parts, and there is only little saprolite cover above the fractured bedrock or the landslide deposits. Based on these results, a hazard map and subsequently the mitigative measures can be planned, demonstrating how accurately calibrated electrical resistivity tomography measures combined with direct field and subsurface observations can achieve considerable knowledge increase for landslide hazard assessment in deeply weathered ultramafites.

Keywords: electrical resistivity tomography, landslides , ultramafites, Medellín, serpentinization

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Advancing remote sensing for semantic landslide hazard mapping and monitoring

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Abstract

Landslide hazard assessment and monitoring have traditionally relied on visual interpretation and heuristic classification methods, often limiting the spatial and temporal resolution of actionable insights. Recent advances in remote sensing technologies and machine learning offer new opportunities to automate and enhance the semantic understanding of landslide processes across diverse terrains. This study proposes a novel framework that integrates very high-resolution remote sensing data with semantic segmentation and classification algorithms to improve the accuracy, consistency, and interpretability of landslide hazard. Using a multi-sensor fusion approach, the framework applies deep learning-based semantic classification to differentiate landslide-prone areas from stable terrain while identifying geomorphic features such as scarp zones, depositional zones, and tension cracks. Time-series analysis enables continuous monitoring and detection of precursory signals, supporting dynamic hazard assessment and monitoring. The method is validated in complex coastal and mountainous environments with diverse lithologies and land cover, demonstrating robust performance in both detecting active landslides and mapping specific zones. This research highlights the potential of semantic remote sensing approaches for scalable, data-driven landslide hazard mapping and monitoring. The results support more informed decision-making for early warning systems, infrastructure planning, and disaster risk reduction in landslide-prone regions.

Keywords: landslide hazard, remote sensing, object-based image analysis, geohazard monitoring, contextual classification

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A Source-Term Refinement Framework for Rockfall Hazard Assessment in Near-Vertical Coastal Cliffs: The Navagio Beach Case Study, Greece

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Abstract

Rockfall hazard assessment is commonly organised around a source–propagation–runout sequence, in which release areas are defined, detached blocks are propagated downslope, and affected zones are delineated. At Navagio Beach, Zakynthos, Greece, this conventional sequence cannot be applied as a simple linear workflow because of geometry and exposure. The cliff is near-vertical to locally overhanging, and the elements at risk lie almost directly below it. During the tourist season, visitors occupy the narrow beach, while boats use the adjacent sea corridor to approach the shipwreck. For this reason, the main uncertainty is not only the runout distance of detached blocks, but the identification of compartments capable of detaching and the conditions under which failure may occur.

This study develops a three-dimensional engineering-geological and geotechnical framework for refining the rockfall source term before propagation, runout, energy, and exposure analyses. The work builds on previous efforts to identify rockfall source areas from topography, discontinuity patterns, geomorphometric criteria, UAV-derived point clouds, and source-area zonation methods (Jaboyedoff et al., 1999; Loye et al., 2009; Albarelli et al., 2021;).

High-resolution UAV-SfM models are treated as quantitative data for source characterization rather than only as visual representations. Fresh detachment scars are mapped on slope-facing orthoprojected panels and projected back onto the 3D point cloud to define an activity-informed layer. Slope-relief modelling is then used to detect protruding, overhanging, or unsupported compartments close to recent detachments. The resulting compartments are compared with mapped discontinuity sets to assess compatibility with planar sliding, wedge failure, or toppling. Persistence, aperture, and rock-bridge conditions are incorporated so that residual stability is linked to mechanically interpretable intact-rock contribution. Factor of Safety values are calculated under water-infilled joint and seismic scenarios, leading to a 3D Rockfall Source Hazard Index that ranks release compartments at source level before future trajectory modelling.

Keywords: UAV-SfM, rockfall source hazard, fresh detachment scars, slope relief modelling, rock bridges

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Accelerating Coastal Landslides in a Changing Climate: InSAR Analysis of The Undercliff Complex, Isle of Wight, UK

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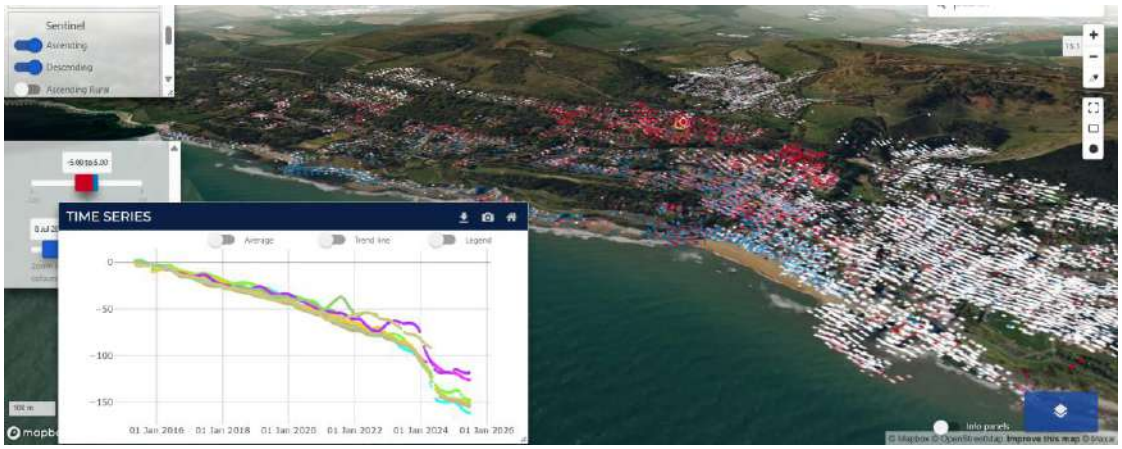
Abstract

The Undercliff, Isle of Wight, is the largest urban landslide complex in north-western Europe, extending 12 km wide and 1 km inland. The area has c.6,000 residents across Ventnor, Bonchurch, St Lawrence and lower Niton. The Ventnor landslide behaviour unit (~1 km²) has exhibited progressive seaward movement since the 1800s, making it a critical location for slope stability monitoring and climate change impact studies. Historical ground-based monitoring (1992-2002) using automated crack meters, settlement cells, and piezometers documented steady deformation rates of 5-10 mm/yr, with acceleration during elevated groundwater periods (Moore et al 2010; Carey et al., 2015). Since 2015, Interferometric Synthetic Aperture Radar (InSAR) from Sentinel-1 satellites has provided high-frequency displacement monitoring (every 6-12 days) through SatSense's UK-wide mapping program, confirming historical rates and faster winter movements. Between October 2023 and April 2024, a distinct period of acceleration was detected, with up to 40 mm of displacement occurring during a 6-month period. Winter 2023/24 was the wettest winter on record since 1839, with the Isle of Wight recording extreme rainfall (c.170mm) in February 2024; almost triple its average rainfall for the month. This acceleration demonstrates the landslide's response and sensitivity to prolonged precipitation and groundwater fluctuations. Climate projections indicate increased sea levels and more frequent heavy winter rainfall will accelerate ground movement and landslide frequency across The Undercliff (Moore et al., 2010). Management involves further developing ground behaviour models and continued monitoring. InSAR monitoring provides essential data to support planning and early warning systems in this vulnerable coastal environment.

Keywords: landslides, InSAR, remote sensing, geohazard, climate



Sentinel-1 InSAR data at Ventnor

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Multi-Temporal Assessment of Slope Reactivation and Dormancy in a Himalayan Catchment Using Rainfall Patterns

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Abstract

The Mandakini catchment in the central Himalayas experienced widespread landslides during the 2013 North Indian Floods, particularly due to the Chorabari glacial lake outburst. The landslide activity within this catchment is monitored for over a period of 10 years from 2014-2023, during which many landslides show reactivation and new ones are initiated. This study analyses decadal rainfall patterns (2013–2023) using satellite precipitation data to investigate the hydro-meteorological conditions associated with landslide recurrence and slope behaviour over time. We analyze seasonal rainfall distribution, interannual variability, and trends, including those of extreme rainfall events, to explore potential links between monsoonal dynamics and the reactivation of mapped landslides. The temporal correlation between rainfall anomalies and landslide activity provides insights into how slopes transition between active, dormant, and reactivated states. This analysis identifies hydro-meteorological thresholds that contribute to the initiation of slope failures in such settings. This work highlights the need to consider long-term rainfall trends and seasonal thresholds in landslide-prone regions, especially with more frequent extreme rainfall events. The findings improve and support hazard assessment and the development of adaptive early warning strategies for Himalayan environments increasingly exposed to extreme hydroclimatic events.

Keywords: Multi temporal, Central Himalayas, Landslides , Hydro-meterological, Hazard assessment

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Geo-engineering Characterization of a Large-Scale Low-Angle Translational Landslide Triggered by the February 6th, 2023 Kahramanmaraş Earthquakes

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Abstract

Southeastern Türkiye experienced two devastating earthquakes on February 6, 2023, the Mw 7.7 Pazarcık and Mw 7.6 Elbistan events. Among the various ground failures triggered, co-seismic landslides were widespread, particularly low-angle planar slides in southern Hatay. A striking example is the Tepehan landslide (Altınözü, Hatay), which occurred within the Neogene (Middle-Upper Miocene) Tepehan Formation, consisting of clayey limestone, claystone, and marl. This large-scale landslide spans approximately 530 m in length, with an average width of 150 m (reaching 230 m at its widest point) and a failure depth of 10–25 m, extending to 35 m in some areas. The landslide displaced approximately 1.1 million m³ of material and is classified as a planar slide triggered along an average 10° inclined bedding plane. This study examines the engineering geological characteristics of the Tepehan landslide, focusing on seismic triggering and the properties of the slip surface material. XRD analyses revealed a high smectite content, which significantly reduces shear strength upon contact with water. Direct shear tests were performed on clayey limestone and weathered claystone-marl interface materials with different infill thickness and water content. Sensitivity analyses using the limit equilibrium method were carried out to identify the critical factors responsible for the failure. With weathered infill materials of 50% water content, the safety factor dropped below 1.0 at horizontal acceleration levels between 0.45 g and 0.5 g. These findings align with the peak ground acceleration (PGA) of 0.54 g recorded at the nearest station during the Pazarcık earthquake.

Keywords: Tepehan, low-angle translational landslide, shear strength of discontinuities, slope stability analysis

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Risk Assessment of Bridges Affected by Landslides

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Abstract

Following the failure of Morandi Bridge, the Italian Ministry of Infrastructure has prepared the Guidelines for the control and supervision of road bridges. These guidelines emphasize the assessment of various types of risks that may affect bridge infrastructure. While structural risk is the main one, an interdisciplinary approach has been adopted to also consider seismic, hydraulic and landslide risks. In Italy, activities have started to evaluate the risk level for bridges, involving experts in Structural Engineering, Hydraulic Engineering, Geotechnical Engineering and Engineering Geology. In relation to landslide risk, the guidelines propose a multi-level approach, starting from a preliminary assessment and progressing to a more accurate evaluation. A group of universities and research institutes, associated under the Consorzio Fabre (https://www.consorziofabre.it/) is conducting research to improve knowledge about the interaction between landslides and bridges. A research project has been launched: MARIE (Methodological Approaches for RIsk assessment in the framework of landslide-bridge IntEraction). The project unfolds in several key phases. The first phase involves a detailed analysis of case studies to understand the diverse interactions between landslides and bridges. Special attention is given to rainfall-induced landslides, debris flows, and their effects on structural elements. Slow moving landslides interacting with bridges and viaducts foundations are also carefully considered. Advanced numerical models will then be used to evaluate the risk of landslides. Utilizing geological, topographical, and hydrological data, the models will assess both the probability and the consequences of landslide events. In collaboration with governmental bodies and infrastructure managers, the project aims to support the implementation of innovative risk management procedures and effective monitoring strategies. This multidisciplinary effort seeks to address critical gaps in current practices by adopting an integrated and detailed approach. The project aspires to improve the safety, resilience, and longevity of critical infrastructure in the face of evolving environmental challenges.

Keywords: Geotechnical hazards, Landslide–infrastructure interaction, Risk assessment, Landslide susceptibility, Numerical modelling

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Geohazard-Induced Landslide: Stability Analysis and Engineering Perspectives, Case Study Applications and Insights.

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Abstract

This study addresses the investigation and stabilization method of a landslide that occurred downstream of the Zemkan Dam, located in western Iran, impacting an irrigation canal approximately 550 meters downstream. The landslide developed along the interface of colluvial overburden and the Taleh Zang Formation's bedrock, comprising alternating limestone, calcareous marl and intercalation of thin shale layers dipping towards the hill. The findings revealed that the instability was primarily controlled by seismic activity (Sarpol-e Zahab earthquake, 2018), surface water infiltration following heavy rainfall and the additional load deposited on top of the hill from spillway excavation. Detailed field surveys and geotechnical investigations confirmed extensive cracking, ground displacement, and structural canal damage. Numerical modeling for Stability analyses achieved by using Phase2 V08 under static and pseudo-static loading conditions and Based on the results, a comprehensive stabilization strategy was developed, involving reinforced in-situ concrete piles, an anchoring system and slope modification measures. Numerical analysis confirmed that the proposed design achieves adequate safety factors and under both static and dynamic conditions. Key design parameters, pile spacing, anchor capacity, and seismic coefficients, were determined following FHWA and ASTM standards. Numerical modeling validated the effectiveness of the stabilization plan, ensuring controlled instability within allowable limits under static and dynamic loading. This study highlights the critical influence of combined geotechnical, hydrological, and seismic factors on slope stability and presents effect of the anchorage system on ground displacement control and reduction of induced forces along the piles.

Keywords: Geohazard, Landslide Stabilization, Anchored Spaced Pile, Phase 2, Ground Displacement

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Research on the residual strength characteristics of landslide slip zone soil in reservoir areas based on ring shear testing

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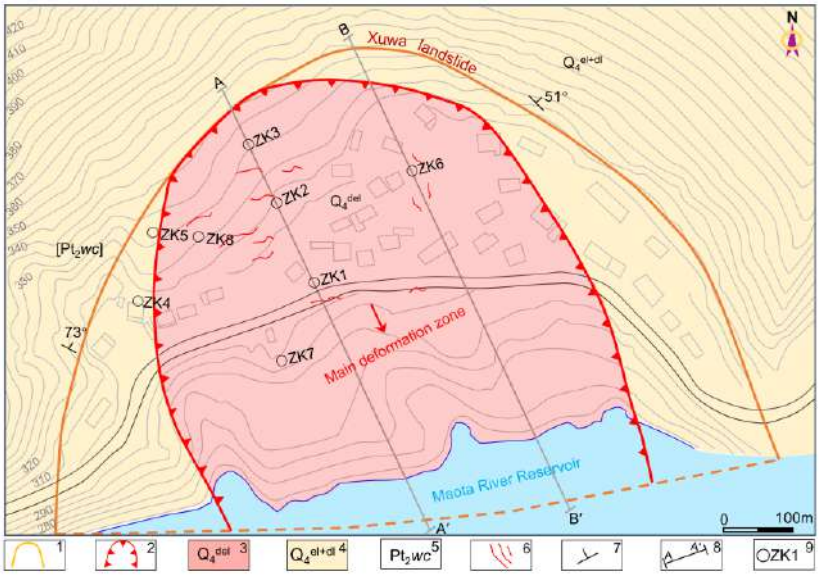
Abstract

Slip zone soil plays a critical role in controlling landslide stability and is of significant importance for investigating landslide initiation mechanisms and assessing landslide stability in reservoir areas. However, research on the residual strength of slip zone soil in such settings remains relatively limited. To address this gap, this study focuses on slip-zone soil from the Xuwa landslide and employs ring shear tests to examine its residual strength characteristics at varying moisture contents and shear rates. The test results reveal that specimen failure is characterized by concentric circular scratches centered within the ring-shaped samples. At low moisture content, the scratches are deeper, and the failure surface is rough, featuring numerous steps and fine fragments; in contrast, at high moisture content, the scratches are shallower, and the surface becomes smoother, with fewer steps and thicker fragments. The effect of shear rate is similarly evident: under lower shear rates, the scratches are more scattered and the surface rougher, whereas at higher shear rates, the failure plane becomes notably smoother and flatter. Moreover, as the moisture content increases, the deformation behavior of the slip zone soil transitions from strain softening to strain hardening. These findings provide a valuable reference for understanding the residual strength behavior of slip zone soils in reservoir landslides.

Keywords: Reservoir landslide, Ring shear test, Residual strength, Water content, Shear rate



Topographic map of the Xuwa landslide.

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Evolution of Shear Zone Materials in a Slowly Deforming Rock Slope: Mechanical Implications for Gámanjunni-3, Northern Norway

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Abstract

Rockslides with basal shear zones often creep with periodic accelerations controlled by shear-zone material properties. These properties influence hydraulic conductivity, residual friction angle, and rate dependence. We present mineralogical, grain-size distribution, and ring-shear data from a shear-band soil at the Gámanjunni-3 rockslide Northern Norway. X-ray diffraction indicates phyllosilicate-rich assemblages (>70 wt.% clay minerals) dominated by illite/mica and illite–vermiculite, with minor illite–smectite. Grain-size distributions at outcrop scale are sandy–gravelly. Ring-shear tests on a representative sample give apparent residual friction angle of ≈19–24° and predominantly rate-strengthening behavior from 0.01 to 2 mm/min, with a tentative drop in apparent friction at 10 mm/min. These results are consistent with a model in which deformation localizes along inherited foliation-parallel ductile shear zones, with comminution-driven clay enrichment reducing frictional strength and leading to steady deformation without rapid acceleration periods (the precursor to failure). Gámanjunni-3 is sensitive to external forcing, with implications for seasonal acceleration and climate-driven changes in slope stability in an area where increased rainfall intensity and duration is expected.

Keywords: Shear zone soil, ring-shear tests, rockslides, inherited weakness, rockslide evolution

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Multi-Source Data Analysis of Active Slow-Moving Landslides with Limited Geomorphic Evidence: The Santa Cecilia Case Study (Northern Apennines, Italy)

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Abstract

The detection and kinematic assessment of slow-moving landslides in geologically complex settings can be challenging, especially when the landslides exhibit limited geomorphic evidences despite being active. The Santa Cecilia landslide, located in the Piacenza Apennines (Northern Italy) is one of these cases. This study aims to a preliminary characterization of the landslide through the integrated analysis of geomorphological observations, subsurface investigations, and multi-temporal monitoring data. High-resolution UAV-LiDAR data were used to support geomorphological mapping and the identification of surface features. Subsurface conditions were investigated through geophysical investigations, boreholes, and inclinometer monitoring, providing constraints on lithological heterogeneity and deformation depth. Multi-Temporal SAR Interferometry (MT-InSAR) analysis, based on Sentinel-1 data acquired between 2019 and 2024, was applied to detect and quantify surface displacements, from both ascending and descending orbits, allowing assessment of the influence of satellite line-of-sight geometry on displacement detection. The integration of MT-InSAR results with inclinometric measurements highlights spatial variability in deformation rates within the landslide body, with more active sectors showing coherent kinematic signals across independent datasets. Results suggest a transition from brittle deformation affecting competent lithologies in the upper slope to more distributed movement within fine-grained materials downslope. Although the proposed kinematic model is preliminary, it provides a coherent framework for interpreting landslide dynamics and for guiding future monitoring and investigation campaigns, aimed at defining the most appropriate rick mitigation strategies.

Keywords: Slow-moving landslide, Northern Apennines, Landslide kinematics, Integrated monitoring, Hazard assessment

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Monitoring Earthflow Displacements Using UAV Surveys and Offset Tracking Techniques: Case Studies from the Northern Apennines, Italy

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Abstract

Landslides represent one of the most widespread and impactful natural hazards, and their monitoring remains a key issue for risk assessment and mitigation. In recent years, multitemporal UAV surveys have become an important data source for landslide monitoring, enabling detection of surface changes through repeated acquisitions. This study proposes a fully UAV-based workflow to quantify planar displacements of active, moderately rapid earthflows using multitemporal LiDAR and optical data. The approach is tested on two landslides in the northern Apennines (Italy): the Sassi Neri and Antognano landslides, with different activity trends and geomorphological maturity. Three UAV campaigns were conducted for each landslide. Surface displacements were estimated using an automated offset tracking approach implemented through the SenseTrack algorithm, based on Digital Image Correlation applied to UAV-derived hillshade. The reliability of offset tracking results was validated through Homologous Point Tracking, based on manual tracking of surface objects and features on orthomosaics and hillshades. Displacement maps reveal a well-defined deformation pattern at Sassi Neri, whereas the Antognano landslide shows a more heterogeneous and discontinuous displacement distribution. Quantitative comparison between automated and manual measurements shows strong agreement for both case studies, with R^2 values of 0.92 for Sassi Neri and 0.93 for Antognano. These results demonstrate that multitemporal UAV surveys combined with offset tracking provide accurate estimates of planar displacements from decimetric to multi-metric magnitudes. The proposed workflow is a rapid, flexible, and cost-effective solution for short- to medium-term landslide monitoring, particularly for emergency scenarios and areas where ground-based instrumentation is unviable.

Keywords: Earthflow, Multi-temporal UAV surveys, LiDAR, Offset Tracking, Monitoring

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LNCC-LES Experimental Site in Petrópolis, Rio de Janeiro, Brasil

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Abstract

Disastrous landslides occur almost every year in Petrópolis. Although studied for a long time and well understood by Brazilian geotechnical specialists, research programs will always be necessary, since heavy rainfall is becoming increasingly severe and the occupation of landslide hazard areas continues to increase landslide risk. One of the most difficult tasks in developing such studies is gaining access for research teams and monitoring devices to high slopes, particularly to the point of landslide initiation. For this reason, a group of researchers has chosen the LNCC area as the optimal location to conduct preliminary investigations before approaching the most important landslide sites. In the experimental site at LNCC methodological procedures conducted involving geological mapping, MASW, VES and DPL demonstrate that anisotropy is the norm of the slope model. The landslide causes or potential is a response of this heterogeneity

Keywords: landslide, geotechnical investigation, geological model

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Spatio-Temporal Distribution Pattern and Susceptibility of Reservoir-Induced Landslides in Xiluodu Hydropower Station

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Abstract

Jinsha River basin is located in the alpine gorge region at the eastern margin of the Tibetan Plateau, with fragile geological environment and abundant hydro energy resources, with 25 levels of cascade hydropower stations planned. However, the spatio-temporal effect of reservoir storage on reservoir bank reconstruction is still unclear. We took Xiluodu hydropower station as an example to study the distribution pattern of reservoir-induced landslides, and used multi-period remote sensing images from 2013 to 2020 to interpret the reservoir-induced landslides within the Xiluodu reservoir area. On this basis, the trend of the number and area of reservoir-induced landslides with impounding time was analyzed. Subsequently, the distribution of reservoir-induced landslides in relation to six factors was statistically analyzed using the frequency ratio method.The study concluded that: (1) Reservoir-induced landslides mainly occur during the initial 3-4 years of impounding, after which the number and area of landslides gradually decrease and the bank slope exogenetic reconstruction gradually stabilizes.(2) The range of slope and aspect that are liable to induce landslides are 30-60° and SE, W, NW direction respectively. Landslide development is more favorable in the range of 400-3200m from the fracture and 100-200m from the reservoir area. (3) The AUC is 0.912, which proved that the evaluation result is highly reliable. (4) The main control factors of reservoir-induced landslide are the elevation and distance from the dead water level. The extremely high susceptibility area and high susceptibility area are mainly located within 400m from the reservoir area and below 1km in elevation. In this paper, a database of reservoir-induced landslides is established for the first time using multi-period remote sensing images, and the research results can provide support for the planning and construction of hydropower plants and disaster prevention and mitigation.

Keywords: Reservoir landslide, Jinsha River, Qinghai-Tibet Plateau, Geohazard, Landscape evolution

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Slope Geohazard Susceptibility Zonation Along a Mountainous Highway: A Case Study of the Sichuan-Tibet Highway, China

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Abstract

The Sichuan-Tibet Highway is considered as the link between Tibet and eastern China, which is of strategic importance to China. The frequent occurrence of collapses/rockfalls and landslides in this region has attracted wide attention from geoengineering scholars. Various kinds of evaluation methods were employed for the susceptibility of geological hazards. Based on the analysis of the geological environment, seven main factors correlated with the development of slope geohazard were obtained, including lithology, tectonics, aspect, slope gradient, elevation, river system, and landuse type. The susceptibility of slope geohazard in the region was predicted using the certainty factor method. The evaluation results were validated using the area under curve method. The study area was divided into 5 levels based on the combination of the assessment results and field investigation. Very high susceptibility zones were distributed in Kawabaiqing Town, Lagen Town and Yupu Town. High susceptibility zones were distributed in Tongmai-Guxiang Town, Songzong-Yupu Town, the area between Ranwu and Jida Town, and Baima Town. Moderate susceptibility zone was distributed in the west of Zhamu Town. Low susceptibility zones were distributed in the east of Gu Town and Ranwu Town. Very low susceptibility zones were distributed in Jida Town, and the east of Zhamu Town.

Keywords: Sichuan-Tibet Highway, Collapse, Landslide, Certainty factor, Susceptibility zonation

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Study on the Formation Mechanism and Characteristics of Landslides in Different Watersheds on the Southeastern Tibet Plateau With GPS Data Constraints

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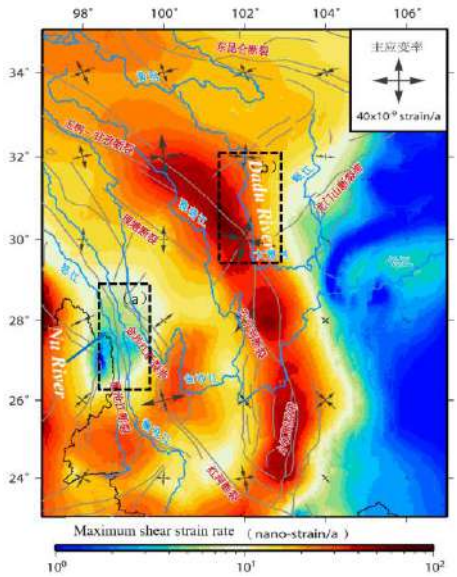
Abstract

As a significant factor influencing landslide formation, it is challenging to incorporate internal factors such as rock mass fracturing, its fracture conditions, and potential sliding surfaces into predictive models during regional landslide hazard assessments. The emergence and widespread application of GNSS and InSAR technologies in geoscience not only provide robust technical support for quantitatively understanding the kinematic and dynamic processes of tectonic evolution but also enable such research. The latest GPS velocity field data reveal significant variations in the strain rate field across spatial locations on the southeastern Tibetan Plateau, highlighting differences in the tectonic stress environments of the Dadu River (b) and Nujiang River basins (a). The Dadu River Basin is located on the east side of the southern section of the Xianshui River Fault which is in a high strain rate zone, it is characterized by near east-west compression and near north-south tension. In contrast, the Nujiang River, which is a part of “Three Parallel Rivers Belt” is located near the eastern Himalayan tectonic node, with a much lower strain rate and a predominantly east-west tensile stress state. Different stress combinations and their intensity variations can exert varying impacts on rock mass fracturing behavior. Based on understanding regional differences in tectonic stress fields and integrating local geological and geomorphological characteristics, identifying and combining the "material sources" and "force sources" of landslides across different regions to predict potential sliding surfaces formed by rock mass fracturing and constructing predictive models tailored to research objectives serve as effective supplements to existing evaluation methods.

Keywords: Southeastern of the Tibetan Plateau, GPS data, Tectonic stress field, Landslides , Rock mass fracture mechanism



Maximum shear strain rate shown in the southeastern Tibetan Plateau

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Landslides in Motion: Smart Technology and Immersive Visualisations for Monitoring and Awareness

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Abstract

Smart sensors are increasingly used for landslide monitoring, but their application and validation remain at an early stage. In this study, a concrete cobble of around 10 cm in diameter was equipped with a smart sensor, which included a 9-axis inertial measurement unit, with accelerometers, gyroscopes and magnetometers, a low-power 3-axis accelerometer for set-in-motion detection, and LoRaWAN wireless transmission for data transfer. The sensor, powered by a lithium battery, is triggered when acceleration exceeds a set threshold and is calibrated to capture the dynamics of cobble movement. Laboratory tests involved releasing the instrumented cobble down an inclined table at various slopes to simulate rolling and sliding, with movements tracked by a GoPro camera. Sensor data were integrated with video tracking profiles to reconstruct position, velocity, and kinetic energy. The experiments showed that sensor data separate rolling from sliding and allowed for testing of the LoRaWAN in different conditions. Beyond the technical validation, this study explored the creation of immersive visualizations to bridge science and community engagement. Three-dimensional photogrammetric models of both the cobble and a landslide site in Lyme Regis (UK), were generated using structure-from-motion techniques, then imported into Unreal Engine (software for game designing). These visualizations show aerial perspectives of the landslide, zooming in on the sensor-equipped cobble, and are designed for projection in immersive vision theatres. The aim is to increase awareness in communities exposed to landslide hazards by making the science accessible and to enhance understanding and acceptance of this type of digital technology in hazard studies.

Keywords: smart sensor, landslide, EWS, flooding, immersive visualisation



snapshot of the immersive visualisation movie created for communication and engagement, this image shows the sensor coming out of a block placed on a slope

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Geological Investigation and Process Interpretation of a Landslide-Prone Area in Medellín, Colombia

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Abstract

The project Inform@Risk has been developing a landslide early warning system in the informal settlement Bello Oriente on the north-eastern slope of the city of Medellín, Colombia, the subsurface of which is made up entirely of the ultramafic 'Medellín Dunite'. The geotechnical investigations carried out in the project to determine the requirements of that system included multiple mappings, drillings, and laboratory tests. All these investigations discovered highly heterogeneous subsurface conditions, created by a combination of fracturing, weathering, serpentinization, and pseudokarst. This highly landslide-prone block-in-matrix structure, already influenced by past landslides, reaches a depth of at least 50 m, and shows no correlation between degree of weathering and depth. The shear parameters vary to a high degree, making the determination of a critical slope angle very difficult. All these factors make it impossible to predict the exact size, depth, velocity, and location of a possible landslide and are a great challenge for the layout of the early warning system. This study emphasizes the importance of detailed geological investigation and the collection of field data for a hazard analysis as basis for the development of landslide early warning systems.

Keywords: Medellín Dunite, Pseudokarst, Serpentinization, Block-in-Matrix Structure, Critical Shear Parameters

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Geotechnical and Rheological Characteristics of Fine-Grained Sediments and Influencing Factors for Debris Flow Mobility

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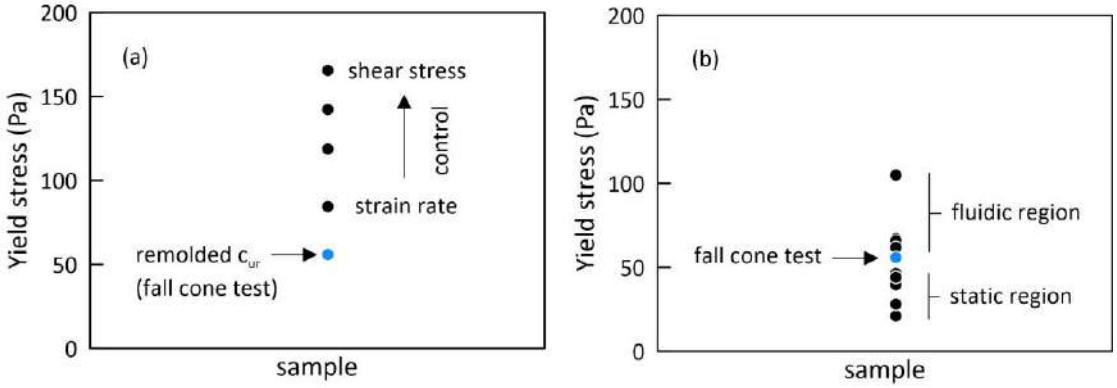
Abstract

Fine-grained sediments that are remolded after slope failure may transform into debris flows; therefore, their post-failure mobility is better described by rheological parameters than by conventional intact-soil strength alone. This study evaluates the geotechnical and rheological behavior of natural fine-grained sediments collected in the Republic of Korea, using fall cone tests, steady-state shear tests, and oscillatory shear tests. The fall cone test was used to determine the remolded undrained shear strength, whereas the rheometer tests were used to estimate Bingham yield stress, Bingham viscosity, and dynamic yield points derived from storage and loss moduli. The results show shear-thinning behavior over the tested shear-rate range and indicate that rheological yield stresses are generally higher than the remolded undrained shear strength. In oscillatory shear, the fall cone strength lies between the first yield point, associated with the elastic or static regime, and the second yield point, associated with the onset of flow. These results suggest that undrained shear strength can be used as a simplified input when yield stress cannot be measured directly, but it should be interpreted as the maximum resistance of fully remolded soil rather than as a direct substitute for rheological yield stress.

Keywords: Debris flows, Rheology, Yield stress, Shear strength, Mobility



A conceptual comparison between fall-cone undrained shear strength and rheological yield stress obtained from steady and oscillatory shear tests

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Modeling Suffusion via CFD-DEM Simulation

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Abstract

Internal erosion, particularly suffusion—the migration of fine particles through the voids of a coarse particle skeleton—is a primary cause of instability in earth structures such as levees and earth-fill dams. Since the microscopic triggering conditions and evolution processes of suffusion remain poorly understood, it is important to establish quantitative evaluation for suffusion. In this study, a three-dimensional coupled Computational Fluid Dynamics with Discrete Element Method (CFD-DEM) simulation was employed to reproduce suffusion numerically. In a rectangular container modeling a levee cross-section, the mixture of coarse particles (10 mm) and fine particles (1 mm) were deposited horizontally, and the initiation of suffusion and fine particle discharge induced by stepwise upward seepage from the bottom was analyzed. By assuming the surface of coarse particles as "fixed walls," it is possible to reproduce realistic local flow within void space among the coarse particles. The proposed method captured the local concentration of water flow velocity accompanying the increase in water inflow velocity and the associated movement of fine particles successfully, thereby reproducing the occurrence of suffusion numerically. Specifically, the water flow line obtained from the simulation revealed that the distribution of high-water flow velocity zones closely coincided with the areas where suffusion occurred, demonstrating that the increase in water flow velocity is a direct factor in triggering suffusion. This study aims to establish quantitative evaluation for suffusion and improve the predictive accuracy of numerical models, thereby contributing to the advancement of structural integrity assessment and disaster risk prediction technologies for levee structures.

Keywords: Internal erosion, CFD-DEM, Suffusion, Fluid–particle interaction, Seepage flow

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Numerical Integration and Step-Size Sensitivity for a Coupled Hydro-Mechanical Constitutive Model of Root-Reinforced Unsaturated Soil

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Abstract

Increasing rainfall variability driven by climate change poses growing challenges to the stability of unsaturated slopes, where hydraulic and mechanical processes are highly coupled. Vegetation provides an effective nature-based solution, but its integration into quantitative geomechanical models remains limited. This study builds on a coupled hydro-mechanical constitutive model that incorporates root reinforcement effects within unsaturated soils. The formulation extends the Barcelona Basic Model by introducing root volume fraction as an internal variable, which modifies the critical state parameter, preconsolidation stress, and shear strength evolution. Both suction and biological reinforcement are treated as independent state variables that govern the yield surface geometry, hardening behavior, and deformation response under environmental loading. The model is implemented using an implicit elastic predictor–plastic corrector stress update under strain control, and the numerical integration accuracy is evaluated through a step-size sensitivity study. Numerical results demonstrate convergence of the deviatoric and volumetric responses to a fine-increment benchmark and quantify relative errors as a function of strain increment. These findings provide practical guidance for selecting strain increments in subsequent parametric and finite-element simulations, where suction evolution and root-volume effects are activated and numerical artefacts must be distinguished from physical trends.

Keywords: Unsaturated soils, Root reinforcement, Constitutive modeling, Numerical integration, Step-size sensitivity

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Erosion Mechanisms of Landslides: Granular Column Collapse Experiment on Erodible Beds and DEM Insights

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Abstract

Dynamic erosion and entrainment of loose path materials can fundamentally reshape the mobility, kinematic stages, and deposition morphology of rapid granular landslides. However, it remains challenging to isolate controlling factors because erosion results from coupled momentum transfer, bed deformation, and local mass exchange at the particle scale. This paper investigates erosion development during granular column collapse over erodible beds through laboratory experiments and three-dimensional discrete element method (DEM) simulations. A transparent flume (120 cm long, 80 cm high, 20 cm wide) was used to release granular columns onto a 5 cm-thick erodible layer, enabling systematic comparisons across material combinations and initial aspect ratios while minimizing wall effects by ensuring a sufficiently large flume-width-to-particle-size ratio. Experiments were repeated three times for each condition to ensure reproducibility. Three distinct regimes were identified from synchronized observations of free-surface evolution, erosion-interface migration, and front kinematics: (i) non-erosion, (ii) overriding (covering) erosion, and (iii) plunging (penetrating) erosion. Front-position evolution exhibits a characteristic S-shaped trajectory with acceleration, quasi-steady propagation, and deceleration stages. Erosion significantly prolongs the initial acceleration and final deceleration stages while shortening the quasi-steady stage, yet the total flow duration remains proportional to the free-fall timescale. DEM results reproduce these trends and reveal that the particle density ratio between the column and bed governs regime transitions, whereas particle size ratio and initial aspect ratio play secondary roles.

Keywords: Landslide erosion, Granular column collapse, Discrete element method(DEM), ,

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The Infinite Slope Length: Investigating the Length-to-Depth Ratio Threshold

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Abstract

The Infinite Slope Method (ISM) is a standard tool in geotechnical engineering for rapid slope stability assessment, yet its validity depends on the geometric assumption that landslide length (L) greatly exceeds thickness (H). This research investigates the precise limits of this assumption by defining the minimum dimensions required for a slope to be characterized as "infinite." We present an innovative extension of the ISM that incorporates internal stress evaluation to quantify the stabilizing influence of the landslide toe on the Factor of Safety (FS). Following validation against empirical field data, a sensitivity analysis was conducted to determine the critical Length-to-Depth (L/H) threshold. Results indicate a clear quantitative boundary: for landslides with an L/H ratio below 30, the stabilizing effects of finite length are significant, and the conventional infinite slope assumption may no longer be considered negligible.

Keywords: Landslide toe, Passive failure, Infinite slope

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Influence of Giant-Particle Content on Reservoir-Induced Deformation of Soil–Rock Mixed Bank Slopes: A Physical Simulation Study

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Abstract

Periodic reservoir water level fluctuations significantly affect the stability of soil–rock mixed bank slopes. To investigate the influence of giant-particle content on bank slope deformation during impoundment, physical model tests were conducted using the Zhugangshan Tunnel accumulation body in Tianquan County, Ya'an, as a prototype. Three slope models with different giant-particle contents (10%, 30%, and 50%) were tested under cyclic reservoir water level fluctuations. The results demonstrate that slope deformation mainly occurs during the first impoundment cycle. The deformation process includes soil softening, consolidation settlement, internal erosion, particle loss, and shallow surface sliding. As giant-particle content increases, the heterogeneity of the soil–rock mixture initially weakens slope stability. However, when a stable giant-particle skeleton forms, deformation resistance and overall stability improve significantly. The findings provide a reference for stability assessment and treatment of giant-particle soil–rock bank slopes in reservoir areas.

Keywords: giant particle soil, mixed soil-rock bank slope, physical model test, failure mode

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Temperature Evolution in Sandy Soil under Large-Displacement Shear

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Abstract

Granular material within the sliding zone of a landslide can undergo large-displacement shearing during its motion. The mechanical behaviour of the material under such shear process significantly affects the basal friction of a landslide and therefore governs its mobility. Both field observations and laboratory experiments have provided evidence that this shear process is companied by significant temperature generation. The generated heat can dynamically modify the shear strength of the material by degrading organic matter or influencing pore pressure. Although the effects of shear-induced temperature rise have been discussed in previous studies, it remains difficult to directly record the temperature evolution during large-displacement shearing. In this study, a direct temperature measurement unit integrated with a ring-shear apparatus is developed to record the complete temperature evolution process, from heating to cooling. Ring-shear tests were conducted on silica sand samples with two different grain sizes. The results indicate that the temperature evolution curve exhibits an initial increase followed by a steady rising phase once the specimen reaches the critical state. With continued shearing, the temperature generation rate gradually decreases, which is attributed to grain crushing occurring within the shear zone. The measurements further reveal a pronounced spatial heterogeneity in temperature distribution along the shear zone, with the temperature at the centre being approximately four times higher than that near the boundary. These obtained data are expected to be valuable for calibrating parameters in thermal-mechanically coupled numerical analyses of landslide dynamics.

Keywords: large-displacement shear, ring-shear test, temperature generation, grain crushing, shear zone

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Mineralogy-Controlled Thermal Sensitivity of Residual Shear Strength: Evidence from Illitic Landslide Clay and Reconstituted Kaolin

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Abstract

Residual shear strength governs the long-term stability of slow-moving landslides and reactivated clayey shear zones. Temperature variations associated with seasonal changes, geothermal gradients, or climate-driven warming may alter interparticle interactions and, consequently, residual shear resistance. While the thermal response of soils has been studied on various soil properties, comparatively little attention has been given to residual shear strength, which governs long-term slope stability. In particular, the coupled effects of temperature, water content, stress history, shear rate, and soil structure in influencing the mobilized strength remain poorly understood. This study investigates the thermal sensitivity of residual shear strength in two fine-grained soils: (i) a natural illitic clay obtained from the Dubičná landslide (Czechia) and (ii) a commercially available Malaysian kaolin. Multi-rate ring shear tests were performed at normal stresses of 50, 100, and 150 kPa under controlled temperatures of 20 °C and 70 °C. Specimens were prepared at three initial water contents (55–100%) representing apparent over-consolidated, transitional, and normally consolidated states. Shearing rates ranged from 0.018 to 1.8 mm/min to evaluate potential rate-dependence under residual conditions. Statistical analyses, including Welch's t-test with defined significance thresholds, were used to distinguish systematic thermal effects from experimental scatter. Results reveal stress-dependent and mineralogy-controlled thermal response. Dubičná clay exhibits thermal strengthening at high normal stress (150 kPa), whereas Malaysian kaolin shows systematic thermal weakening under the same normal stress. At low normal stress (50 kPa), temperature effects remain within experimental variability for both soils. The findings highlight the dominant role of normal stress and clay mineralogy in governing thermal sensitivity at residual conditions, with implications for stability assessment of thermally affected slopes and reactivated clay shear zones.

Keywords: Residual shear strength, Thermal sensitivity, Slow moving landslides, Clay mineralogy

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A Case Study on Risk Analysis of Tailing Dam Failure Based on the MPM-DEM

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Abstract

Numerical simulation of tailings dam failure impact zones enables the preemptive assessment of flood propagation ranges under various operational conditions, playing a crucial role in safeguarding human lives and property. The MPM-DEM coupled algorithm combines the MPM capability for handling large deformations with the DEM advantage in simulating particle motion. It demonstrates good applicability in tailings dam failure simulations. However, existing research often simplifies the treatment of actual three-dimensional topography, failing to adequately reflect the impact of valley floor roughness variations on sand flow energy dissipation and retention behaviour. In response to the aforementioned circumstances, this study employs an MPM-DEM coupled algorithm to simulate the large-deformation motion of tailings particles. By adjusting the mesh density to characterise surface roughness, it more accurately reflects flow-contact responses under complex topographical conditions. Using a tailings dam in Lingbao City as a prototype, a numerical simulation of the dam failure process was conducted to analyse the influence of topography on tailings slurry flow, with validation through laboratory model testing. The results indicate that the movement process of dam-burst sand flows can be divided into three typical phases: acceleration, constant velocity, and deceleration. Furthermore, the movement characteristics are significantly influenced by topography, with varying degrees of roughness leading to pronounced energy dissipation and retention effects. During the acceleration phase, the tailings flow in the uniform grid simulation reached a maximum velocity of 18.74 m/s at 27 s, decreasing to 14.5 m/s by 30 s, with some tailings entering the branch channel. In the localised encrypted grid simulation, the tailings flow reached its maximum velocity of 14.94 m/s at 105.6 m downstream. By 30 s, this had decreased to 9 m/s, and due to topographical obstruction, it did not enter the branch channel. During the uniform flow stage, the terrain becomes increasingly gentle. The flow velocity simulated by the uniform grid predominantly ranges between 8 and 10 m/s, while that simulated by the locally refined grid falls within the range of 3 to 7 m/s. By the deceleration phase, due to the influence of the rough valley floor, the flow velocity in the uniform grid model decreased to 6 m/s, while in the locally refined model it further dropped to 2 m/s or even stagnated. The numerical simulation results agree well with physical experiments, and the locally refined mesh method can more accurately reflect the flow characteristics of sand under actual terrain conditions. This study provides a scientific basis for assessing the risk impact zone of this tailings dam failure and may also serve as a reference for dam failure simulations and disaster prevention design in similar projects.

Keywords: Tailings pond, Risk analysis, MPM-DEM Coupled Simulation, Terrain roughness, Physics model test

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Slowing a Large Landslide to Maintain a Highway

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Abstract

In August 2023, cracking across both lanes of State Highway 1 ('SH1') was observed near Utiku, New Zealand. The locations of the mapped cracks coincided with the headscarp of the existing Utiku Landslide, a large, deep-seated, slow-moving landslide that has intermittently impacted SH1 and the North Island Main Trunk railway, since at least the 1960s. The surface cracking and deformation resulted from renewed movement of the landslide along the basal failure plane some 55-75 m below SH1, caused by elevated groundwater levels resulting from many months of above-average rainfall. A remedial design involving four components was developed: (i) minor road realignment, as well as undercut and subgrade improvement; (ii) installation of fanned inclined drains to relieve groundwater pressure and improve landslide stability; (iii) surface water and pavement drainage improvements; (iv) ongoing instrumentation and monitoring. The fanned inclined drains almost immediately had significant impacts on groundwater levels, in places lowering them by close to 9 m. This paper addresses the geology and history of the Utiku Landslide, and how this informed the remedial design. The assessment of the 2023 landslide movement, the design of the fanned inclined drains, including the performance-based approach to optimising design and construction, as well as the monitoring results which show the beneficial impacts of the drains on groundwater levels and landslide stability are discussed in detail. We conclude by providing recommendations for the application of this approach to similar projects.

Keywords: Landslide, Groundwater, Highway, Inclined drains, New Zealand

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The Australian Geomechanics Society Guidelines for Landslides Risk Management 2026

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Abstract

The Australian Geomechanics Society Guidelines for landslide risk management 2007 (AGS 2007) provide guidance on best practice in landslide risk management within Australia and have developed international recognition and standing since their introduction. They present a framework for landslide risk management, guidance on landslide zoning for land use planning and guidance on assessing risk from landslide.

In 2023, the Australian Geomechanics Society jointly with the New Zealand Geotechnical Society commenced a process to update the guidelines. This process involved contribution from a broad range of experts from both within Australia and internationally seeking to bring together state of the art practice in landslide risk management.

This paper is intended to communicate key updates made to the guidelines which will be of interest to the international landslide community, including:

* The development of a guide which communicates principles of landslide management in simple terms for non-technical stakeholders.
* Methods for assessing and communicating uncertainty in landslide risk assessment.
* Methods of quantitative landslide risk assessment including the estimation of probability for different scenarios.
* Practical guidance for estimating inputs to landslide risk assessment.
* Guidance for the development of landslide inventories.
* Guidance for the development of landslide hazard, susceptibility and risk maps.
* The development of a collation of international contributions setting out best practice in landslide risk management across the globe.

A summary of the revised guidelines will be presented with focus on new developments and inclusions by the chairs of the committee responsible for updating the guidelines.

Keywords: AGS2007, Landslide risk assessment, Landslide Mapping, Uncertainty

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Potential Considerations for Resilient Slope Design in a Changing World

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Abstract

With the ever seemingly worsening detrimental effects of climate change on the built environment, is it time to move away from the traditional engineering design approach to one that deals effectively with resilience to these extreme conditions? This paper seeks to set out the reasons why a resilient approach should be looked at in the context of slope design, along with the related aspects of who and what is at risk, how do we measure resilience, how historically has this been looked at in the past, and what are the areas of potential consideration that should be focused upon moving forward. The defined approach covers also a possible Slope Risk Management framework including the critical stakeholder engagement factors. In doing so the paper seeks to define the areas of uncertainty related to triggering mechanisms for slope instability associated with climate change covering not just rainfall/groundwater, but also the other end of the spectrum in covering the effects of drought conditions.

Keywords: Slopes, Resilience, Climate Change



Sarina, Central Queensland, Australia - Failure of an Anchored Slope due to Cyclone Debbie (2017)

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European Influence on the Design and Construction of Slope Drainage Measures

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Abstract

Slope drainage can play a vital role in the short- and long-term performance of cut slopes and must be carefully considered in design and construction particularly in light of climate change predictions. Any additional features within a design including drainage measures introduces further maintenance requirements during an asset lifespan. In the UK it is common practice to install counterfort, herringbone, crest and toe drainage to intercept and manage groundwater which would otherwise compromise the resilience of the cut slopes. However, these localised largely trenched measures are infrequently used on the continent where engineers instead opt for drainage and weight masks (placed rock fill) solutions. The paper will compare experiences from UK and French practice considering design, buildability, sustainability and maintenance aspects and document a number of case studies for slope drainages measures.

Keywords: Geohazards , Climate , slope drianage, ,

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A Predictive Debris Flow Warning System Using Saturation Modelling: Development at Scotland's A83 Rest and Be Thankful

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Abstract

The A83 at Rest and Be Thankful (RaBT), Scotland, is a strategic transport corridor affected by frequent rainfall-triggered debris flows. Following two large landslide events in 2020 and the recognition of evolving slope behaviour, a need emerged for an operational tool to support proportionate exposure risk management of hazards, while longer-term resilience options are progressed. A Saturation Hazard Matrix (SHM) was developed to provide daily hazard levels derived from a simplified soil saturation index and forecast rainfall totals, calibrated against a landslide inventory supported by rainfall records and time-lapse monitoring. The SHM expresses hazard in five levels linked to predefined operational actions, including enhanced inspection and diversion via the Old Military Road. Performance assessment against events reaching the A83 or protection measures indicates that higher hazard levels correspond to increased event likelihood, while maintaining a practicable balance between false alarms and missed events. The approach demonstrates how simplified saturation modelling can translate complex processes into a transparent decision framework for managing debris-flow hazard on transport infrastructure under conditions of uncertainty.

Keywords: Rest and Be Thankful, Debris Flow, Landslide Prediction, Asset Management,



A83 Rest and Be Thankful & OMR with Glen Croe

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Catastrophic Rainfall-Induced Landslide Thresholds to Disaster Prevention in the Chilean Andes.

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Abstract

Chile is one of the most vulnerable countries to climate change. Landslides represent one of the most frequent geological hazards in mountainous environments due to the geological, geomorphological and geotechnical characteristics of steep upland landscapes. Unfortunately, fatalities and material losses caused by landslides usually concentrate in areas with high degrees of marginalisation. The total landslide death toll in Chile was 1010 between 1928 and 2017, 54% of them in Central Chile. This work aims to identify and compare the main characteristics of rainfall-induced landslides in Central Chile during two continuous periods, 1980-2010 and 2010-2024, the second one characterised by persistent drought. Additionally, we seek to determine rainfall-induced landslide thresholds, with special focus on catastrophic debris flows triggered by atmospheric rivers, and to improve our understanding of their mechanics, temporal-spatial distribution, and geological controlling factors applicable to urban/territorial planning and disaster prevention strategies. First, we prepared a rainfall-induced landslides inventory from 1980 until the present. Then, a multivariate statistical study based on the logistic regression method is presented. The model provides equations that allow the computation of combined meteorological triggering factors associated with a probability of rain-induced flow occurrence. Finally, we compare with an analysis of the spatial and temporal distribution of landslides from these inventories and prepared representative characteristics of rainfall-triggered landslide hazards (main types, spatial distribution, size and volume), their potential consequences and suggestions for possible mitigation actions or engineering interventions.

Keywords: Rainfall-induced landslides, atmospheric rivers, Chilean Andes, thresholds, Disaster prevention

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Landslide Risk Management in Mountainous Terrain, an Example From Georgia.

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Abstract

The paper deals with the management of landslide risk in mountainous regions in Georgia. In the study area, volcanic formations are significantly affected by weathering and as a result the rock structure is decomposed and weathered residual soils are formed. Weathering of volcanic rocks is a significant predisposing factor to slope movements. The main triggering factor is rainfall, which in combination with the steep terrain and presence of soil materials with low strength, result in moderate to high landslide susceptibility in the study. Specific hazard maps for landslides, mudflows and rockfalls have been produced for the entire country, which identify the prone areas in national scale. Specifically for the study area, the main types of instabilities were identified and were grouped into six categories considering the various types of geological materials from hard rock to soil formations. An extensive landslide risk assessment was performed in areas where high risk was evident and where construction activities for wastewater treatment were planned. The risk rating was based on a hazard scoring system and assessment of probability of slope failure. The system was applied in various sites and was used as a decision tool to decide on mitigation actions to reduce the risk level to as low as reasonably possible.

Keywords: landslide, management, mountainous, volcanic, risk

Landslides in volcanic formations in the study area

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How to Better Link Landslide Inventory Mapping with Damage and Loss Reporting

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Abstract

Landslides (mass movements) are one of the more complex hazardous events to consider in multi-hazard Early Warning systems. Landslides are inherent multi-hazard events, with different types of triggering mechanisms (among which earthquakes, extreme rainfall, human activities, temperature changes in permafrost regions, volcanic eruptions), and due to their widely varying typologies (fall, slide, flow, lateral spread, complex movements), movement mechanisms, and speed of movement. Landslides are underrepresented in global disaster databases, such as EM-DAT, due to their high frequency and low impacts. Individual events often fail to meet the threshold for inclusion in the database, whereas their cumulative effect is underestimated. Landslides triggered by earthquake or extreme rainfall events are often not considered separately in disaster databases, and their impact is grouped under the main trigger. Landslides are notoriously difficult to predict, as subsurface variations control their occurrence, and causal factors are difficult to map. Earth science organisations or scientists often generate landslide inventory maps, and there is no common database that contains information on their types, movement components, date of occurrence, and impact. As part of the process to strengthen national capabilities in tracking disaster losses and damages, UNDRR and its partners encourage the development of data standards and methodological frameworks. These frameworks will enable national actors to coherently record hazardous events and their impacts. This, in turn, will enhance the understanding of disaster impacts and support multiple data applications, including early warning, early action, and risk reduction efforts.

Keywords: Damage, Loss, Landslide, Database, Inventory



Cover image for the questionnaire to landslide experts.

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Prevention is More Beneficial than Remedy: Landslide

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Abstract

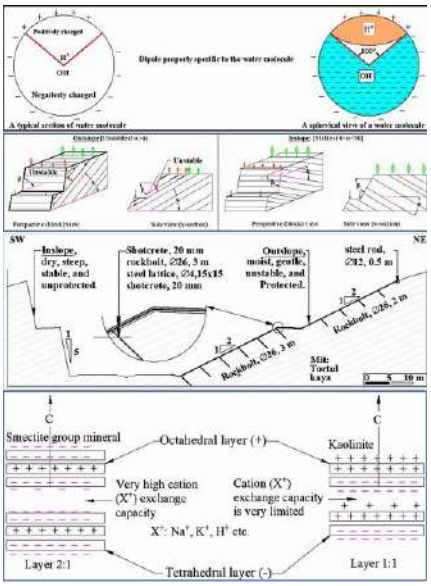
The water-discontinuity-clay mineral (WDC) triad is the major causative of all geotechnical problems including landslides. Joints, unconformity planes, igneous contacts, and fault planes are very locally effective discontinuity types. Almost all landslides originate as a plain failure and evolve into rotational slides with time. They could easily be detected on a topographic map by "()" appearance (two sets of concave contours).

Where the major discontinuity system is inslope or the unit is massive the WC wouldn't cause failure. Similarly, where a rock unit is dry, the DC wouldn't either. When the water ingress into a slide mass is stopped, it sustains stability in a few months. The driving time and construction/operation costs at the Dranaz mountain crossing with two major landslides (Turkey) were reduced to one-third in 1998. The highway still works efficiently.

The field inspection of the trinity WDC is significant particularly in alignment selection studies. The authors' team has developed and used these principles in international projects since 1980s. The highway alignment selection between 3-settlements which are at the seaside (Oman) was tendered in 2005. The construction was stopped due to high geotechnical problems and sky-high costs. It was re-tendered in 2022.

The authors' team executed the selection study orderly; corridor, route, alignment, and construction line based on surface inspection of the trinity WDC and execution of elevation correction data in hydrology-hydrogeology. Ultimately, a stable alignment with a corrected length (Lcor)=64 km (not 295 as that of formers) and maximum topographic elevation (Temax)=200 m (not ~1600) was conducted.

Keywords: Landslide, Water, Discontinuity, Clay mineral, Motorway/Highway



The trinity Water-Discontinuity-Clay mineral (WDC) is the main agent causing landslide.

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Influence of a Deep-Drainage System on the Dynamics of the Succiso Landslide (Northern Apennines, Italy)

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Abstract

Deep-seated landslides in the clay-rich formations of the Northern Apennines are strongly influenced by groundwater dynamics and climatic variability. The Succiso landslide provides a valuable case study due to long-term monitoring and the installation of a deep drainage system between 2014 and 2016. By combining multi-decadal rainfall data with displacement time series, we assess the evolution of hydrological forcing and drainage effectiveness across different activity phases. Displacement rates, computed from cumulative displacement increments, show a marked and sustained reduction following drainage installation, particularly during 2015–2023, confirming the effectiveness of groundwater lowering in reducing deformation. From late 2023 onwards, a renewed increase in displacement is observed across both monitored sectors. The relationship between hydrological forcing and landslide kinematics varies over time. During the pre-drainage phase, velocity generally increases with precipitation, though variability indicates additional control by internal hydromechanical processes. In the post-drainage phase, velocities remain low and largely insensitive to rainfall. In the most recent phase, increased activity occurs under wetter conditions; however, the relationship with antecedent precipitation remains weak and highly variable, suggesting that landslide response cannot be explained by hydrological forcing alone. These results highlight a non-stationary landslide behaviour and emphasise the role of evolving hydro-mechanical conditions in modulating system response. Continuous monitoring and adaptive management are therefore essential to ensure the long-term effectiveness of mitigation measures.

Keywords: Deep-seated landslide, Antecedent Precipitation Index (API), Groundwater dynamics, Mitigation works

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Landslide Mitigation in Volumetric Sensitive Soils: Integrated Stabilization Design for the Kalibeng Formation

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Abstract

Landslides and ground movements significantly threaten Semarang City, Indonesia, particularly in the Deliksari area. This region's vulnerability is driven by its location within the Kalibeng Formation, characterized by brownish-gray marly clay identified as montmorillonite. This expansive clay, combined with complex geological structures like joints and faults, creates high soil porosity and erosivity, leading to discontinuous layers prone to failure. This study conducts a geotechnical assessment and stability analysis. Field investigations via cone penetration tests (qc) yielded a cone resistance of 82 kg/cm² (8.04 MPa) at 20 m depth. Laboratory results showed a Liquid Limit (LL) of 148.12% and free swell of 425%. Using the Stark and Eid (1994) correlation, the average friction angle (ϕ Average) was determined at 12.65°. Back-calculation via GeoStudio on the existing slope revealed a critical Safety Factor (SF) of 0.343. To mitigate instability, two reinforcement simulations were modeled. The first, utilizing a counterweight, gabions, bamboo piles, and one 600 mm diameter bore pile, yielded an SF of 0.684. The second simulation, adding a second bore pile, significantly increased the stability to an SF of 1.611. Consequently, the recommended design features a 1V:5H slope counterweight supported by two bore piles, gabions, and 4 m deep bamboo piles. To manage pore water pressure, a 60 cm sand drain wrapped in non-woven geotextile is integrated between the embankment and original soil.

Keywords: Landslide Mitigation, Kalibeng Formation, Montmorillonite Clay, Slope Stability, Bore Pile Reinforcement



A residential structure in the affected area exhibiting a diagonal wall fracture and detachment from its foundation slab, indicative of differential ground displacement associated with the active landslide

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Remote sensing capability for rock mass characterization in active rock fall areas

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Abstract

Accurate rock mass characterization in active rock fall areas is critical for understanding failure mechanisms and improving slope stability assessments. This study evaluates the potential of integrated remote sensing techniques for detailed rock mass characterization in dynamic slope environments. Using different remote sensing methods, including LiDAR, photogrammetry, and thermal scanning, high-resolution 3D datasets were collected across selected active rock fall sites in the Stawamus Chief granitic massif, British Columbia, Canada. Each method was assessed based on its spatial resolution, accessibility, coverage, and ability to capture key geological features such as discontinuities, joint set orientations, and block geometries. This integrated approach enables comprehensive rock mass and stability assessments and improves hazard zoning in challenging terrain. The findings highlight the importance of method selection and sensor integration for effective remote sensing-based rock fall hazard management. This research contributes to the advancement of geotechnical investigations in unstable rock slopes and supports the development of cost-effective, safe, and scalable monitoring strategies.

Keywords: Rock Mass Characterization, Rock Fall, Remote Sensing Techniques, Geohazards

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Understanding rock fall and rock avalanche processes for comprehensive hazard assessment

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Abstract

Rock falls and rock avalanches are significant geological hazards characterized by complex failure processes and potentially far-reaching, often destructive consequences. This study examines the geological causes, as well as the pre-failure and post-failure mechanisms that drive these events. The primary aim is to deepen our fundamental understanding of these processes while improving our ability to detect early-stage indicators of failure and reliable runout distance assessment methods.Using selected case studies from the Austrian Alps, we analysed initial failure mechanisms, including rupture surface formation driven by subcritical crack growth, failure of intact rock bridges, and the coalescence of pre-existing discontinuities. Our methodology integrated detailed geological field surveys, UAV- and TLS-based discontinuity mapping, laboratory testing of rocks, and geomechanical numerical modelling. Post-failure rock slope processes, including the long-term deformation behaviour after collapse, were examined using high-resolution GB-InSAR and TLS measurements to evaluate ongoing stress release induced stability problems. This research also includes new data concerning the runout dynamics, which are essential for assessing the spatial extent and impact of these events.Results of a regional study will be presented, identifying nearly 2,000 failure events, with volumes of up to 200,000 m³, that occurred between 2006 and 2017 across a mountainous area spanning 2,950 km². This extensive database was analysed to explore the influence of climate change-related triggers such as permafrost degradation, glacier retreat, and heavy precipitation.Our findings have significant implications for improving early detection methods and warning systems, runout predictions, developing effective risk mitigation strategies, and informing land-use planning in vulnerable regions.

Keywords: Rock fall and rock avalanche, Climate change, Monitoring, Modelling, Event inventory



Multiphase rock fall event from 2019 in Salzburg, Austria

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Engineering-Geological Features of Tectonogenic Rock

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Abstract

In the general classification of rocks compiled by us in 2023, the geological formations under consideration are represented by a new group of tectonogenic rocks which have an independent place next to igneous, sedimentary, metamorphic and technogenic rocks. Tectonogenic rocks are divided into disjunctive and plicative subgroups, which can be represented by different genetic types and varieties of rocks, depending on their material composition and physical condition. Based on this classification, we have demonstrated the necessity of adding two new groups—tectonogenic and technogenic—into the engineering-geological system developed by T. Savarensky and V. Lomtadze. The long history of underground construction highlights the significant challenges and dangers of building tunnels, shafts, mines, and other subsurface facilities in geological environments composed of tectonogenic rocks. It is significant that the areas structured with tectonogenic rocks are associated with complications, accidents, hazardous geological phenomena, overconsumption of resources and, unfortunately, human injuries and deaths.

Many studies conducted by us for the design and construction of tunnels in the Caucasus have established that the total length of tectonogenic rocks encountered in the tunnel routes accounts for 7-10% of their total length. The time and costs of tunnel construction in such rocks often exceed the costs of the remaining 90-93% of route sections. The presentation will analyze and evaluate the current knowledge of the engineering- geological features of tectonogenic rocks. The ways of researching theoretical problems and solving practical problems related to their genesis, occurrence mode, composition, physical condition and properties will be substantiated as well.

Keywords: Tectonogenic rocks, Tunnel engineering, Rock classification, Underground hazards, Engineering geology

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Volume-Class Correlation of Rockfall Frequency With Overhang Geometry

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Abstract

The magnitude-frequency relationship of rockfalls is crucial for hazard assessment but remains challenging to establish it in areas lacking historical data. This study expands on a previous study by the authors, who identified a linear correlation between rockfall frequency and total rock overhang area for seven slopes along a coastal road in Gipuzkoa, Basque Country, Spain. Using 15 years of recorded data this research investigates the correlation by categorizing rockfalls into four volume classes (m^3): A (≤ 0.5), B (0.5–5), C (5–50), and D (50–500).

High-resolution 3D digital slope models, generated using Terrestrial Laser Scanning and UAV/Terrestrial Photogrammetry during a May 2022 field campaign, are used to extract overhang geometries and bedding layer thicknesses. A probabilistic Monte Carlo-based approach estimates the likelihood of overhangs generating rockfall volumes in each volume class. This methodology includes: (a) extracting overhang areas and bedding thickness distributions per slope; (b) simulating the rock volume above the overhangs for various bedding layer combinations; (c) identifying the overhang and layer parameters associated with each volume class; and (d) calculating correlations between filtered overhang areas and event frequency per volume class.

Normalized results by road length and slope area are also presented. These refined correlations enhance predictive modeling and risk assessment for infrastructure exposed to rockfall hazards.

Acknowledgements

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Keywords: rockfalls, frequency, overhangs, 3d slope models,

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Dynamic rockfall susceptibility modelling in Czechia: integrating climatic drivers and temperature-dependent thresholds

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Abstract

Rockfalls represent a high-mobility and high-energy geohazard affecting steep slopes, often triggered by climatic drivers such as intense rainfall, freeze-thaw cycles, and extreme temperature fluctuations. In this study, we present an integrated approach combining data-driven and physically-based models to assess rockfall spatial distribution and runout trajectories, with a focus on the landscape-protected area of Kokořín in Czechia.

A dynamic rockfall susceptibility model is thus developed using a multi-temporal inventory of documented events. We employ Generalized Additive Models (GAMs) via the mgcv R package to identify and interpret climatic predictors derived from MODIS in the Google Earth Engine (GEE) platform. Special attention is given to thermally driven thresholds, such as freeze-thaw cycles and extreme temperature fluctuations, which are hypothesised to influence rock deformation and consequent potential detachment.

To extend the spatial assessment beyond source zones, we couple the susceptibility model with the physically-based STONE model to simulate rockfall trajectories and spatial runout patterns. This hybrid modelling framework allows us to define both the likelihood of rockfall occurrence under climatic conditions and the areas at risk of impact, offering practical insights for hazard evaluation and land-use planning.

Our work aims to integrate dynamic climatic variables into spatial models, together with a simulation of rockfall trajectories. This approach might better support a dynamic risk assessment in a changing climate and provide insights into cascading effects in rock slope environments.

Keywords: Rockfall, Climate variable, Temperature-dependent threshold, Generalized additive model, Physically-based model

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Development of a Rockfall Hazard Map: A Case Study from Rumkale, Türkiye

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Abstract

This paper presents the development of a rockfall hazard map for the steep slopes located within the Rumkale Archaeological Site, situated in Gaziantep, Türkiye. The site is an ancient fortress constructed on high rock cliffs, surrounded by a dam reservoir on three sides, and contains a variety of historical remains, including above-ground structures dating back to the 12th–14th centuries. The primary objective of this study is to assess the rockfall potential of these inclined bedrock slopes and to provide a spatial hazard representation for risk management and conservation planning.

The study area has an average slope of 57.5%, with locally very steep zones including near-vertical sections. These slopes are underlain by the Gaziantep Formation, predominantly composed of fossil-rich limestones. This geological setting has a direct influence on slope stability and rockfall behavior.

As part of the assessment, 508 individual rock blocks were identified and evaluated. Among these, rockfall simulations were carried out for 42 selected blocks along seven critical cross-sections. The analyzed blocks ranged in mass approximately from 50 kg to 27.500 kg. The simulations produced key results related to parameters such as rock end points, bounce heights, and kinetic energy distributions. The rockfall analyses were conducted on the steep slope located across from the fortress, containing the observation deck, with a vertical height of nearly 90 meters as seen in Figure 1

The resulting hazard map provides essential input for both structural preservation and visitor safety, contributing to the sustainable management of this culturally and geotechnically sensitive site.

Keywords: Rumkale, rockfall, hazard map, preservation of heritage



General view of the study area: the analyzed slopes and hazard map area are shown on the left, the Rumkale Fortress is visible on the right.

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Remote rockfall assessment using publicly available imagery: the 2014 South Tyrol incident

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Abstract

The back-analysis of rockfall incidents typically involves field observations and physical inspections, which can be costly, potentially hazardous, and prone to delays that risk the loss of critical perishable evidence. This study presents a fully remote, data-driven methodology that utilizes publicly available imagery, such as UAV videos and news footage, to analyze rockfall events without requiring physical site access. Building on previous work, this approach is applied to the well-documented 2014 rockfall event in Tramin (South Tyrol, Italy), where large boulders impacted a 300-year-old building, attracting significant media attention. The methodology involves sourcing relevant imagery, generating a high-resolution 3D model using Structure-from-Motion photogrammetry, and conducting trajectory back-analyses of the detached blocks. The Tramin event offers an ideal validation case due to the availability of high-quality footage and well-documented conditions. The results accurately reconstruct the detachment zones, block volumes, trajectories, and final positions. This case study highlights the potential of publicly available imagery to remotely reconstruct complex rockfall events in a timely, cost-effective, and non-invasive manner. This is particularly valuable for developing global rockfall inventories and improving the calibration of rockfall modeling tools

Keywords: Rockfall remote assessment, Publicly available imagery, Structure-from-Motion, 3d trajectory analysis

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Insights on Mechanisms of Rock Slope Failures in Seismic Conditions From 3D Numerical Analysis: A Case Study From 2016 Central Italy Seismic Sequence

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Abstract

This study presents the results of numerical investigations conducted on the Valle Orteccia landslide, a major rock slope failure triggered by the 2016 Central Italy seismic sequence. Utilizing high-resolution geological, structural, and geomechanical data obtained through UAV surveys and detailed field investigations, numerical modelling was performed to reconstruct slope behaviour under both static conditions and seismic loading. Modelling results indicate that the slope was near failure during the Visso earthquake on 26 October 2016 and subsequently collapsed at the onset of the Norcia earthquake on 30 October 2016. The analysis also highlights the significant role of major rock discontinuities in controlling the failure mechanism, as well as the influence of local morphological features in modifying ground motion. In a broader view, this research demonstrates the critical importance of local structural controls and seismic amplification effects in triggering large rock slope failures during moderate to strong seismic events. Finally, given that a similar geological and structural setting is widespread throughout the central-northern Apennines, this study provides important insights for assessing earthquake-induced landslide hazard across the entire region.

Keywords: rock slope, earthquake, slope stability, numerical modelling, Central Italy

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Mechanical and Microstructural Characterization of Deformed Volcaniclastic Rocks from the Lower Comondú Group, Baja California Sur, México.

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Abstract

Volcaniclastic rocks are widespread in tectonically deformed regions and play a key role in slope stability and hazard mitigation. However, their mechanical behavior remains poorly understood, particularly in weakly lithified, porous rock masses. This study examines the deformation mechanisms of pyroclastic and volcanoclastic rocks of the Lower Comondú Group in southern Baja California, Mexico. Field mapping reveals Miocene compressional deformation, characterized by folding, faulting, and injection features related to crustal shortening. Uniaxial and triaxial compressive tests were conducted on rock specimens. Unconfined and confined tests (30 MPa) were performed using a servo-hydraulic MTS 815 system with cyclic loading protocols. In addition, micro-CT scans were performed before and after these mechanical tests to monitor microstructural changes. Ignimbrites samples exhibit unconfined compressive strength (UCS) values of 16.5–17.5 MPa and elastic moduli of 0.8– 1 GPa, while sandstones range from 13.2 to 18.8 MPa and 0.78–1.6 GPa, respectively. Poisson's ratios range from 0.1 to 0.3. The results indicate that porosity, mineralogy, and pumice-rich textures strongly control the brittle–ductile transition. Cyclic loading experiments also reveal progressive fracture development, stiffness degradation, and dilatancy. Micro-CT image analysis confirms that the internal damage zones are aligned with fractures existing in the non-deformed specimen. These results improve the geomechanical characterization of volcanosedimentary successions in compressive tectonic settings relevant for slope stability analysis, engineering design, and the assessment of geohazards in volcanic terrains such as those in some places in Baja California, México.

Keywords: Rock mechanics, Deformation, Fracturing, Compression, México

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A Low-Cost Camera–YOLO Framework for Fully Automated Rock Instability Hight Precision Displacement Measurement

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Abstract

Reliable quantification of rock displacement is a key requirement for investigating rock-slope instability and identifying early-stage failure processes. Nevertheless, many established monitoring approaches rely either on labor-intensive field measurements or on costly sensor systems, thereby limiting their feasibility for continuous, large-scale applications. In this study, we introduce a cost-effective, image-based monitoring framework that enables fully automated estimation of rock movement based on a YOLOv8 pose estimation model. The system was deployed at the Miroir d'Argentine rock wall, a limestone rock flake located in the Swiss Alps, Switzerland, where images were collected using a low-cost digital camera observing a Futuro BRW mechanical comparator. The deep learning model was trained to automatically recognize the dial indicator and localize the pointer positions, from which rock displacement could be derived directly from images without manual interpretation. To evaluate the robustness and transferability of the approach, additional image datasets acquired during different monitoring periods were used for independent validation. The results indicate that the proposed method accurately estimates rock displacement under real field conditions and exhibits strong generalization performance.

Keywords: Rock displacement monitoring, Image-based monitoring, Deep learning, YOLOv8, Alpine rock slopes

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A Comparative Slope Stability Analysis Using Empirical Methods in Kumaun Himalaya, Uttarakhand, India

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Abstract

The Himalayas are prone to natural hazards such as cloudbursts, landslides, flash floods, and earthquakes. The engineered/natural slopes along the national highway (NH)-109, from Jaurasi to Chausali in the Lesser Kumaun Himalayas, are significantly influenced by tectonic activity, lithologic diversity and external factors such as precipitation and seismic triggers. Construction and road expansion along highways pose major protection concerns in mountainous regions. Slope stability assessment requires a thorough understanding of the mechanical behaviour of rock masses, including structural deformation and intact rock geo-mechanical parameters. This study assessed two vulnerable road-cut slopes in Nainital and Almora districts, Uttarakhand, India, using empirical classification systems. Field data on slope geometry and discontinuity sets, along with laboratory data on intact rock characteristics, were collected. These datasets were used for kinematic analysis and empirical rock mass classification methods, such as the basic rock mass rating (RMRb), continuous slope mass rating (CSMR), and slope mass rating (SMR). On the basis of comparative assessment of the aforementioned classification systems, both slopes showed instability, and remedial measures such as rock bolting with wire mesh and a toe wall/ditch, and shotcrete with surface drainage are required to mitigate landslide incidents. This multifaceted study will help mitigate landslide vulnerability along this corridor and improve safety for commuters.

Keywords: Rock mass classifications, kinematic analysis, Kumaun Himalayas, slope instability

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Realistic Geometric Modeling and Dynamic Fragmentation Simulation of Potential Unstable Blocks in High and Steep Rock Slopes

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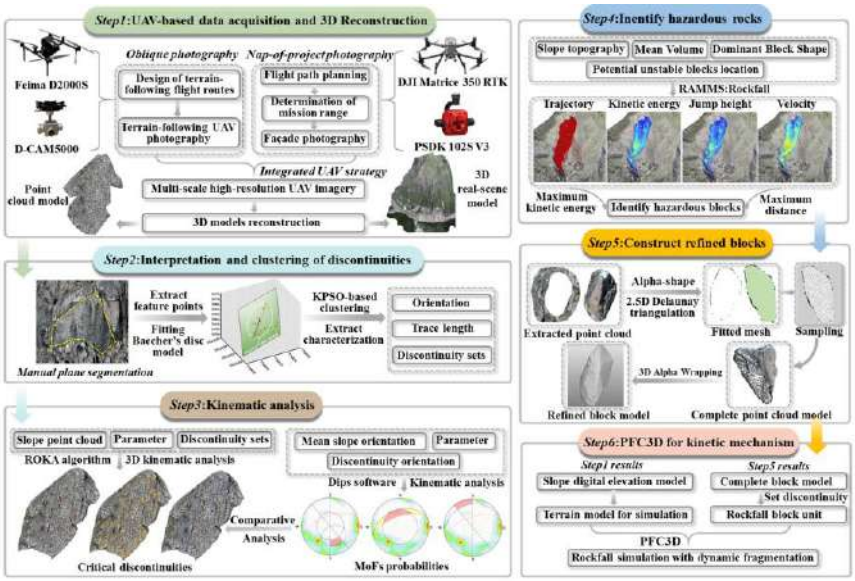
Abstract

Accurate rockfall hazard assessment is hindered by oversimplified block representations, unreliable source identification, and the neglect of fragmentation, limiting the reliability of conventional simulations. This study presents a novel framework that integrates realistic geometric modeling and dynamic fragmentation simulation to capture the full evolution of potential unstable blocks in high and steep rock slopes. Applied to a critical zone at the Shuangjiangkou Hydropower Station, the approach combines multi-scale UAV photogrammetry, 3D rock slope kinematic analysis (ROKA) incorporating topographic and discontinuity constraints, and PFC3D-based discrete element modeling to bridge structural characterization with physics-driven dynamics. Unlike traditional methods that rely on averaged slope geometry and infinite discontinuities, ROKA identifies 186 potential unstable blocks with flexural toppling as the dominant mode, which is overlooked in standard stereographic analysis. Realistic block geometries are reconstructed using boundary-preserving surface algorithms, capturing sharp edges and mass heterogeneity. Dynamic simulations provide new insights into how fragmentation does not simply reduce hazard, but also transforms it. While structural fragmentation dissipates up to 63% of kinetic energy, it triggers rotational breakup and lateral deviation. Local fragmentation generates high velocity secondary fragments that bypass predicted runout zones. The result is a dual effect: energy dissipation coexists with expansion of the hazard affected area. This study demonstrates that only by integrating measured structure, realistic geometry and dynamic failure processes can rockfall behavior be realistically predicted. The proposed workflow advances hazard modeling toward physics-resolved representations, providing a robust basis for optimized protection design in alpine engineering projects.

Keywords: Rockfall hazard, Unstable block identification, 3D kinematic analysis, Realistic block modeling, Dynamic fragmentation



This figure presents the detailed workflow of the framework proposed in this research, which enhances the readability and comprehensibility of the abstract.

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Rockfall monitoring design and initial results from an alpine rock-slope laboratory (Tyrol, Austria).

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Abstract

Rockfalls represent a major hazard to people and infrastructure in high-alpine areas. Due to glacier retreat and permafrost degradation, factors controlling rock-slope behavior are changing, reducing the transferability of past knowledge to current conditions. Therefore, identifying precursors and acceleration phases requires continuous, multi-scale and multi-sensor observations.

The in-situ rock-slope laboratory at the Schaufelspitze, Stubai Glacier (2880–3332 m a.s.l.) aims to monitor active instabilities at multiple scales, combining in-situ measures with remote sensing. UAV-based thermal and optical surveys, terrestrial laser scanning (TLS), ground-based InSAR (GB-InSAR), and time-lapse webcams are used to investigate, detect, and monitor displacements. These can be correlated with temperature and precipitation data from nearby meteorological stations to identify precursors. Preliminary analyses indicate that this configuration resolves deformations across different spatial and temporal scales: i) GB-InSAR is particularly effective for short-term accelerations and heterogeneous displacement patterns at millimeter accuracy, especially for monitoring continuous displacement precursory; ii) periodical TLS and optical UAV surveys identify larger displacements and quantify rockfall activity, while thermal imaging highlights surface temperature anomalies potentially linked to rock fracturing and water pathways; iii) temperature sensors capture the variability that can delineate potential activation zones while iv) webcam imagery constrains event timings.

This study aims to structure a long-term record of displacement and acceleration phases to identify predisposing and triggering mechanisms under changing hydro-meteorological conditions. By combining multiple techniques, practical thresholds to support early warning purposes in high-alpine environments can be derived. Expected outputs include validated workflows for sensor configurations, change detection, photomonitoring, and multi-sensor data fusion.

Keywords: rockfalls, remote sensing, multi-sensor monitoring, GB-InSAR, thermal imaging

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Structural Controls on High-Alpine Rock Slope Failures in Heavily Fractured Metamorphic Rocks (Tyrol, Austria)

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[1] BOKU University, Institute of Applied Geology, Department of Landscape, Water and Infrastructure, Vienna, Austria

Abstract

Rockfalls and rock avalanches with large runout distances are a major hazard in high-mountain regions. We evaluate a dataset of events with individual cumulative volumes up to 1’000’000 m3 that occurred over the last three decades, endangering people and infrastructure. The events occur in metamorphic, strongly schistose, fractured, and anisotropic rock suits, including para- and orthogneiss, mica shists, and amphibolites. Pre-existing discontinuities are crucial for the initiation, as these structures may be reactivated during rock slope failure. However, the influence of highly fractured rock masses on rock slope failure processes remains insufficiently understood. A primary research question is to understand which lithological and structural factors lead to the formation of small-scale rock falls and which to large-scale rock avalanches, and how to detect such events early on. Our integrated approach combines field-based and remote sensing methods. Lithologies, structural and geomorphological features including location, orientation, spacing, and persistence of pre-existing discontinuities were mapped during extensive fieldwork and in 3D models. Terrestrial laser scanning (TLS) and unmanned aerial vehicle photogrammetry (UAV-P) compliment these data, providing information on internal deformation processes and high-resolution digital terrain models (DTMs) of post-failure rock surfaces. Intact rock bridges and pre-existing discontinuities along the exposed rupture surfaces were identified to support the reconstruction of a geological and kinematic model. Further work will focus on numerical modelling to reconstruct failure mechanisms and kinematics of these processes consistently with site observations and remote sensing results. This approach will contribute to a better understanding of the evolution of rock slope instabilities.

Keywords: rockfall and rock avalanches, high-alpine rock slope failure, structural control and propagation, post-failure invesitgation

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Quantitative assessment of rockfall-induced risks to infrastructure: a framework for fragmentation, mitigation measures and socioeconomic consequences

Maddalena Marchelli[1], Bernardino Chiaia[1], Valerio De Biagi[1], Daniele Peila[1]

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Abstract

Accurately predicting the consequences of geohazards remains a major challenge in quantitative risk assessment. Public and private stakeholders often face difficulties in defining risk management strategies, prioritising interventions, and allocating resources for mitigation, particularly in the case of rockfall hazards, where ensuring resilient infrastructure and safe communities is increasingly urgent. Building on a quantitative risk assessment framework previously developed by the authors, this study presents an enhanced methodology that integrates a new fragmentation model for propagation analysis. Understanding the size and energy of blocks potentially impacting elements at risk is crucial for the accurate design of protective systems and the estimation of their probability of failure, enabling a more realistic assessment of residual risk. Consequences are analysed across both social and economic dimensions. By capturing the interplay between hazard dynamics, infrastructure vulnerability, and the effectiveness of protective measures, the proposed framework supports the development of safer and more resilient transport networks in rockfall-prone areas, and it serves as a robust decision-support tool for policymakers and public authorities.

The method is applied to viable infrastructure exposed to rockfall, such as high-traffic or mountainous roads that often serve as the sole access routes to remote areas.

Keywords: Quantitative risk assessment, Fragmentation, Residual risk, Protective measures,



Rockfall prone area insisting on a road infrastructure in the Authonomous Region of Aosta Valley (Italy)

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Assessing rockfall risk over time: evolving scenario analysis and management of protective structures

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Abstract

Quantitative Risk Assessment (QRA) for rockfall hazards is a dynamic and evolving process that must consider not only the current state of the rock slope face and the elements at risk, but also how these conditions may change over time. Traditional single-scenario risk assessments often fail to capture the increasing or shifting nature of risk, potentially leading to under preparedness or inefficient allocation of mitigation resources.

This study presents a time-integrated QRA framework that incorporates a comprehensive range of possible rockfall scenarios. It also proposes strategies to address their evolution, driven by natural processes such as weathering, erosion, and climate change, as well as human-induced factors such as land-use modifications and infrastructure development.

To demonstrate the practical application of this methodology, two case studies at different scales, each requiring varying levels of input data accuracy, are presented. The first case study, at regional scale, applies the framework to the provincial road network of Bolzano, integrating long-term trends in recorded rockfall arrivals, variations in traffic exposure and the time-dependent reliability of mitigation measures into a corridor-scale risk model. The second case study, at slope scale, examines a road section in the Eastern Alps where a windthrow event and subsequent geomorphological disturbances progressively altered block-detachment conditions, reach probabilities and event frequencies, requiring repeated updates to the risk assessment. These examples highlight how integrating the temporal evolution of risk into QRA enhances the accuracy of hazard assessments and supports more strategic, sustainable, and cost-effective risk management.

Keywords: Time-integrated risk assessment, risk management, rockfall scenarios, frequency evolution



Rockfall prone area and interventions for mitigate the risk in the Eastern Alps (BZ, Italy).

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Is a landslide responsible for >2000 m rockfall runouts in Bolonia Bay, southern Spain? FEM back-analysis of a possibly earthquake-triggered landslide

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Abstract

The Bolonia Bay area near the Strait of Gibraltar in southern Spain has been the target of paleoseismic studies that revealed the occurrence of moderate earthquakes in the region. In the frame of these studies, rockfall deposits in the village El Chaparral caught the scientists' attention because the blocks with volumes of more than 400 m3 were deposited at distances of up to 2000 m from the source cliff. Even with seismic acceleration, these runout distances could not be replicated in rockfall simulation experiments. New high-resolution digital elevation data confirmed the suspected presence of a possible landslide body on top of which the rockfall boulders are deposited, suggesting the hypothesis of a "piggyback" transport of the rockfall boulders through the landslide.

Here, we implemented the finite element method (FEM) to back-analyze said landslide and determine the triggering conditions and degree of slope deformation with the deposited rockfall blocks as undrained loading. We analyzed different triggering scenarios with water saturation and earthquake acceleration, and whether the deformation was sufficient to displace the rockfall deposits on top of the landslide.

The results help to explain the extraordinary rockfall runout distances and shed more light on the role of medium seismic events shaping the geomorphology of the study area and their implications for possible hazard cascades induced by future earthquakes.

Keywords: landslide, finite element method, earthquake, rockfall, back-analysis

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A Reliability-Based Approach for Assessing the Safety of Rockfall Protected Slopes

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Abstract

Rockfall is a high-energy natural hazard that poses significant threats to inhabited areas and infrastructure in mountainous regions. Rockfall net fences, or barriers, are widely used passive structural systems designed to mitigate this hazard. These devices intercept and arrest falling rocks by dissipating energy through permanent deformation. Despite their widespread use, the design of these systems is not fully codified. European guidelines recommend ensuring that the factorized capacity exceeds the increased action for both energy and height capacities. However, this approach overlooks the failure probability of the system, which is crucial for assessing risk in engineered slopes. The Authors have developed a mathematical framework to compute the failure probability of rockfall mitigation systems based on reliability considerations. Unlike other approaches, their method accounts for all potential block volumes that may reach the mitigation measure, recognizing that smaller blocks are more frequent than larger ones. The time-integrated formulation offers two main advantages: it provides the design characteristics of the protection system for a specified failure probability, and it quantifies the failure probability for an existing net fence. The present paper incorporates the variability in the capacity of the barrier into the mathematical framework. Different probability distributions associated with the system's capacity to arrest blocks or intercept rockfall trajectories were assigned, critically discussing the sensitivity of the failure probability concerning the parameters of the distributions. Examples of applications demonstrate that the method can lead to more informed management of rockfall risk in hazardous areas.

Keywords: rockfall barrier, failure probability, reliability, sensitivity analysis

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Coupling Numerical Modelling and Laboratory Mechanics to Investigate Coastal Cliff Instability in Tuffaceous Rocks

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Abstract

Rocky coastal cliffs are highly vulnerable to progressive failure mechanisms, increasingly driven by environmental forcing. This contribution presents a multidisciplinary investigation conducted on the sea cliffs of Ventotene Island (Italy), aimed at deciphering the complex interplay between structural, thermal, and marine factors in coastal slope instability. A multi-scale modelling approach was adopted with 2D finite-discrete element simulations (FDEM) to explore both static and dynamic stress conditions. Since 2024, the "Ventotene Field Laboratory" has been active on the island, equipped with meteorological and geotechnical sensors, as well as an offshore Acoustic Wave and Current Profiler (AWAC). The environmental data acquired from this system were used to constrain numerical analyses, enabling realistic simulations of wave forcing and temperature fluctuations acting on the cliff face. An experimental campaign was carried out to characterise the mechanical behaviour of the tuffaceous rocks composing the cliff. Laboratory tests assessed variations in mechanical properties due to thermal cycling and sea breeze exposure, both significant drivers of progressive weakening and fracture propagation. Semicircular bending tests were also performed to determine fracture toughness parameters. Numerical results show that notch undercutting, thermal fluctuations, and wave impact act synergistically to promote progressive failure. The study demonstrates a double polarity in crack propagation: downward from thermal-induced expansion, and upward from mechanical overhang stress. Fatigue modelling further suggests that even minor cyclic loads, repeated over time, critically reduce rock strength and trigger collapse. These insights contribute to improving hazard scenarios and predictive assessments for soft-rock coastal environments.

Keywords: stress-strain modelling, coastal cliffs, progressive rock failure, sea waves

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Strengths and limitations of the Distinct Element Method (DEM) for rockslide modelling

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Abstract

Mechanical numerical modelling is a valuable tool for studying slope instabilities. It allows researchers to test hypotheses regarding failure processes and gain a deeper understanding of the kinematic behaviour. In this study, we applied the DEM code 3DEC to simulate the complex kinematic behaviour associated with the partial failure of the Brienz/Brinzauls rockslide in eastern Switzerland, which occurred in June 2023. During this event, approximately 1.9 million cubic metres of rock were mobilised, narrowly missing the village. This case study was used to explore the influence of mechanical and geometrical properties on the model results. We evaluated both the potential of the distinct element method to capture complex rockslide kinematics and the challenges posed by increasing model complexity, particularly when geological structures are represented in three dimensions with higher spatial detail and resolution.

The simulation results highlight the importance of accurately representing geological structures, such as bedding orientations, mesh geometries, and spatial resolution, as well as appropriate mechanical parameters used for the different lithologies. Results show both the strengths and limitations of using DEM to model rock slope instabilities, particularly in relation to process simplification during the failure. Our findings also shed light on key challenges for future modelling efforts aimed at improving the understanding of rock mechanical processes in complex slope systems.

Keywords: Rockslide, DEM modelling, Brienz/Brinzauls

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A combined laboratory method for studying the failure mechanism of structurally complex rocks from Greece

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[2] School of Mining and Metallurgical Engineering (NTUA), Athens, Greece

Abstract

The formation mechanism, tectonic regime and later weathering acting on each rock throughout their geological history, severely govern their physical and mechanical characteristics. These properties in turn are intrinsically linked to their failure and microcrack propagation mechanisms. In this study, a combined methodology utilizing simultaneous deformation and AE monitoring was implemented in both simple UCT-AE and cyclic CUCT-AE laboratory tests. Rock specimens were collected from various locations around Greece, each characterized by a distinct geological setting. These include a brittle Limestone both in intact and karstic condition, a Mudshale and a porous Trachyandesite. Particularly, this study focuses on identifying the principal stages of microcrack evolution , namely the crack initiation (σci) and crack damage (σcd), alongside important AE indicators, including the B-value and Felicity ratio. These results were utilized for determining the failure behavior of every rock type in high stress conditions. Particularly, calcareous rocks exhibit intense AE activity and brittle behavior, making the distinction between different microcracking stages a difficult process. In contrast, more ductile or plastic rocks exhibit lower and more progressive fractural response, accompanied by increasing lateral and irreversible deformations after each loading cycle. This behavior is attributed to factors such as high porosity, the presence of weakness planes and the distinctive mineralogical composition of the investigated rocks.

Keywords: rock mechanics, laboratory, Acoustic Emissions (AE), brittle failure, tunneling



Experimental setup for the UCT-AE laboratory tests (Engineering Geology & Rock mechanics laboratory, NTUA).

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Evaluating the Earthquake-Induced Rockfall Triggering through Rocking Response Dynamics

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Abstract

Understanding the conditions that trigger rockfalls under seismic loading is critical for accurate trajectory estimation, hazard and risk assessment. This study focuses on the initial kinematic conditions that lead to the onset of rockfalls due to earthquake-induced ground motions, with an emphasis on the dynamic response of free-standing rock blocks. Based on the dynamics of the planar rocking response of free-standing rigid blocks, representative boulders are simulated to capture their seismic behavior prior to overturning and detachment. Time-history analyses are conducted using ground-motion records compatible with a target seismic hazard level to quantify translational and rotational velocities at the time of detachment. In addition, the influence of both ground motion characteristics and the geometry of the rock block on the initiation of the rockfall is examined. The resulting initial conditions are then compared against simplified empirical and pseudo-static assumptions. This work emphasizes the importance of incorporating dynamic response modelling to enhance the accuracy of rockfall trajectory modelling, hazard and risk assessment, and mitigation planning in seismically active regions.

Keywords: Rockfall, Earthquake-induced triggering, Rocking response, Rockfall Trajectory modelling

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Comparison of Numerical Rockfall Modeling Methods: Case Studies in Central America and Mexico

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Abstract

Rockfall represents a geological process with significant implications for infrastructure and safety in mountainous regions. This study aims to compare the accuracy, applicability, and effectiveness of various numerical rockfall modeling methods, applying them to seven real-life cases in Costa Rica, Guatemala, Panama, and Mexico. The sites analyzed present critical geomechanical conditions, characterized by different lithologies, degrees of weathering, and proximity to key infrastructure. The methodology is based on the use of RocFall2 software, which allows for two-dimensional probabilistic and deterministic simulations. Technical data provided by Geobrugg AG will be used, including topographic surveys and geotechnical parameters of the slopes. Based on these inputs, simulations will be performed to analyze block trajectories, kinetic energy, rebound height, and stopping distance, as well as the effectiveness of dynamic barriers designed to mitigate the risk. The approach seeks to evaluate whether methods developed in temperate regions are directly applicable in tropical contexts, were factors such as accelerated weathering and vegetation influence landslide dynamics. The results are expected to establish selection criteria for methodologies better suited to tropical environments and provide practical tools for the design of mitigation works. This work offers a significant contribution to applied geotechnics, supporting the development of safer and more resilient infrastructure in the face of natural hazards.

Keywords: Rockfall, numerical modeling, slope stability, Rocfall2, risk mitigation

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Numerical Modelling of the Stability of Rocky Cliff

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Abstract

Rocky coastal cliffs are highly non-linear systems in which geomechanical, hydraulic, and dynamic processes interact across very different spatial and temporal scales. Numerical modelling—nowadays mainly performed with FEM and DEM codes—is indispensable for estimating safety thresholds and forecasting collapse scenarios, yet its reliability is hindered by several critical issues. First, the uncertainty about strength parameters (cohesion, friction, tensile strength) which are often derived from a few laboratory tests that are not representative of the real heterogeneity of the cluster. There is also uncertainties about piezometric levels conditioned by groundwater flow through fractures. Consequently, it is essential to embed the model within a systematic sensitivity analysis: controlled variation of input parameters makes it possible to identify those to which the factor of safety is most sensitive, isolate the "key parameter" governing stability, and guide targeted experimental campaigns to narrow its confidence range. Given the intrinsic complexity of the phenomenon, it is imperative to adopt an advanced constitutive model that can accurately reproduce the tensile-deformation response of the rock mass in situ, incorporating the effects of anisotropy and the effect of weakness rocky levels and the progressive erosion at the toe also in the light of the evolution of discontinuities. Such an advanced approach has been applied to the rocky cliffs in weak rock sandstone yielding innovative failure-prediction results that markedly improve the reliability of modelled failure mechanism obtained by numerical modelling, that are relevant in the light of reliable early-warning assessments for this high-risk coastline stretches.

Keywords: Rock Cliff, Sandstone, Numerical modelling, anisotropy, weak rock

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Engineering-Geological Controls on Coastal Rockfall Revealed by Calibrated Explainable Probabilistic Modeling

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Abstract

Effective mitigation of coastal rockfall requires engineering-relevant tools that provide both probabilistic assessment and geological interpretability. This study proposes a calibrated and explainable machine learning framework based on a field inventory from 552 coastal cliff sites along the Pohang coast, South Korea. Ten engineering-geological parameters were evaluated, including lithology, slope aspect, discontinuity characteristics, undercutting, and vegetation cover. Among six classifiers, XGBoost showed the best discrimination (AUC = 0.851). Out-of-fold calibration yielded an Expected Calibration Error of 0.049 and a Brier score of 0.146, supporting interpretation of outputs as reliable probabilities. Explainable analysis (SHAP) revealed lithology and aspect as dominant conditioning factors. Pyroclastic breccia exhibited higher predicted probabilities, consistent with its weak matrix-supported structure and susceptibility to basal erosion. Undercutting was observed at 67% of breccia sites, indicating notch development as a critical preparatory process for block detachment. Southwest-facing slopes also showed elevated probabilities, likely reflecting enhanced weathering under high insolation and prevailing winds. By linking model attributions to measurable engineering-geological characteristics, the proposed framework provides a transparent, first-stage screening tool for coastal cliff management and site prioritization. This study was conducted as part of the project "Development of long-term environmental change prediction technology for high-level radioactive waste disposal sites (RS-2024-00419276)" funded by the Korean Ministry of Trade, Industry and Energy and supported by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) under the subproject titled ‘Development of monitoring and operational technique for site characterization factors in national/site scale (RS-2024-00419806)’

Keywords: Coastal rockfall, Probabilistic assessment, Lithological control, Engineering geology, Explainable machine learning

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Prediction Models for Post-Fire Debris Flow Susceptibility and Debris Flow Volume in Yajiang County, Sichuan, China

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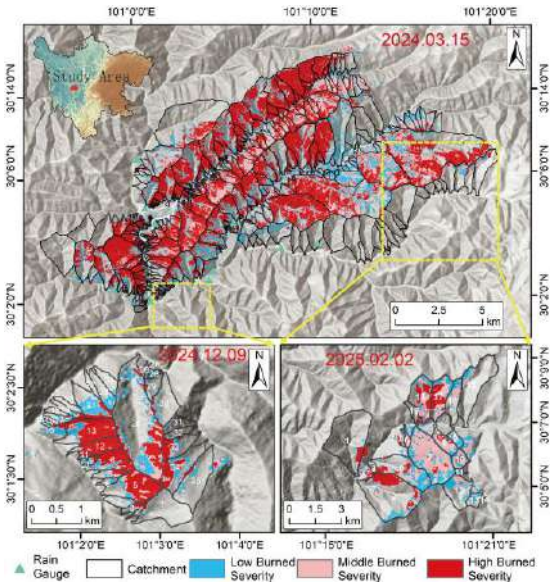
Abstract

Post-fire debris flow (PFDF) susceptibility and runout volume prediction are vital for disaster mitigation in mountainous regions of southwest China. This study developed PFDF susceptibility and volume models using field surveys, unmanned aerial vehicle (UAV) imagery, satellite remote sensing, and rainfall data. Models were trained on the March 15, 2024, Yajiang County PFDF database and applied to two burned areas: Chengxiang (Dec 9, 2024) and Muzexi (Feb 2, 2025). Results show: (1) The optimal Random Forest susceptibility model achieved an area under the receiver operating characteristic curve (AUC) of 0.905 and accuracy of 0.950. In Chengxiang and Muzexi, 10 and 22 catchments were classified as high or extremely high susceptibility, accounting for 18.52% and 40.74% of total catchments, respectively. Specifically, 48.57% of Chengxiang and 73.68% of Muzexi catchments fell into high-risk categories. (2) The optimal volume model included hourly rainfall intensity, steep-slope area, clay content, gully density, normalized difference vegetation index (NDVI), and burned severity. The generalized additive model achieved an R^2 of 0.65. Under low (Q25%, 25th percentile), moderate (Q75%, 75th percentile), and high (P20%, 5-year return period) rainfall scenarios based on the Yajiang PFDF database, debris-flow volumes exceeded 200 m³ in 2.86%, 25.72%, and 34.29% of Chengxiang area respectively, and exceeded 1000 m³ in 0%, 15.79%, and 63.16% of Muzexi area. Chengxiang shows smaller volumes but higher vulnerability, especially in catchments CX05, CX08, CX13, and CX25. Muzexi has larger flows, with MZX02 and MZX04 identified as high-risk zones.

Keywords: Post fire debris flow, Susceptibility, Debris flow volume, Prediction model, Yajiang County



Regional location and classification of burn severity of the study area

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Landslide hazard mapping in Tbilisi (Georgia)

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Abstract

Geological hazards such as landslides, debris flows, rock avalanches, rockfalls has always been and still represents a major threat for communities all over the world, causing extensive damage and often times the destruction of infrastructures and facilities. Geological-related, adverse phenomena are more frequent in mountainous countries with complicated geological, tectonic, climate and morphological settings. Tbilisi has a very convenient location and is not only the capital of the country, but also a hub of the transit corridor. However, in the conditions of complex morphological and geological environment, as well as high pressure of technogenic activities, geoecological complications have reached a critical level. Within the framework of a program led by Department of Geology of Georgia, landslide hazard assessment was done. Based on the analysis and generalization of produced (historical) materials, laboratory and field studies, the research evaluates the combination of factors that determine the tendencies of landslide hazards. Landslide processes are widespread, causing economic loss and damage to the city's infrastructure and, most tragically, often resulting in human casualties. Surveys in the study area revealed different type of landslides, based on that inventory map and GIS database was created/updated. Geological maps published in the last century were revised and updated, as well as various thematic (elevation, slope and aspect) maps were processed. Based on all this information, a hazard zoning map was compiled. Research classifies the protective adaptation measures, which are necessary to mitigate or completely eliminate the hazards, according to their type and genesis.

Keywords: Landslide, Hazard zoning, Georgia, Urban Geology, GIS

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Assessing the feasibility of crowdsourced pavement roughness as a proxy for landslide impacts on roads in Italy

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Abstract

Monitoring landslide impacts on transport infrastructure remains challenging at national scale, where systematic damage surveys and high-resolution monitoring are rarely feasible. This study explores the potential of using crowdsourced road pavement roughness data as a proxy indicator of landslide-related road degradation across Italy, with particular emphasis on the contrast between national- and regional-scale analyses under heterogeneous data conditions. Vehicle-based pavement roughness observations from the SmartRoadSense platform were spatially intersected with the Italian Landslide Inventory (IFFI) and analyzed at both national and regional scales. Pavement roughness distributions inside and outside mapped landslide polygons were compared using descriptive statistics and non-parametric approaches. Results show that at national scale, median pavement roughness values inside and outside landslide areas are comparable, with substantial overlap between distributions, limiting the interpretability of roughness as a uniform proxy. In contrast, regional-scale analyses reveal highly variable behaviour: several regions exhibit higher roughness within landslides, others show weak contrasts, and in some cases higher roughness occurs outside mapped landslides. These differences reflect regional variability in landslide inventory completeness, roughness data coverage, and spatial correspondence between mapped landslides and deformation zones. These findings highlight both the potential and the limitations of crowdsourced pavement roughness for large-scale screening of landslide–road interactions. While national-scale aggregation tends to obscure landslide-related signals, regional analyses provide more informative results where data conditions are favourable. This emphasises the need for scale-aware interpretation when integrating crowdsourced infrastructure proxies into landslide risk frameworks, particularly for early-warning applications.

Keywords: Landslides, Road infrastructure, Pavement roughness, Degradation, Crowdsourced data

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An Overview of Landslides in Volcanic Rocks of West Java, Indonesia: Causes, Triggers, and Impacts

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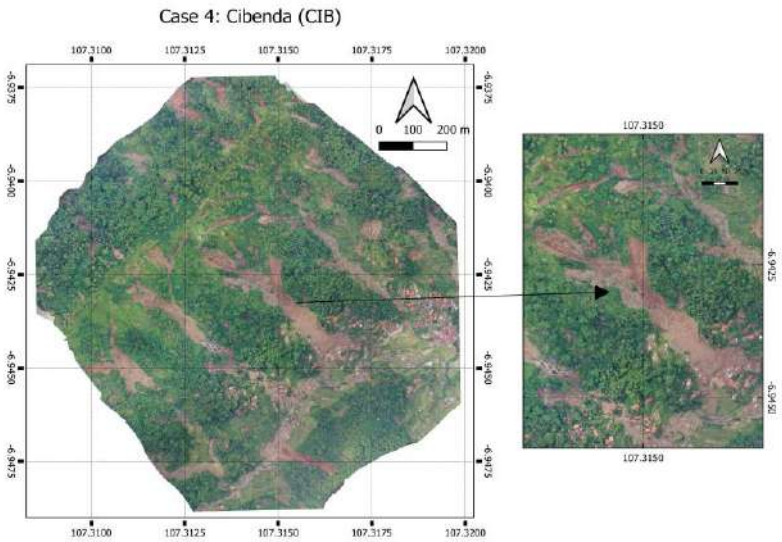
Abstract

Landslides in volcanic rocks in West Java, Indonesia, are influenced by a combination of natural and human-induced factors. This study investigates the causes and triggering mechanisms of landslides at four locations through field investigations, geotechnical analyses, and impact assessments, focusing on their effects on infrastructure and communities. In Sarinagen (Case 1), a slide impacted several houses and a retaining wall, with poorly designed construction destabilizing the slope by altering its geometry. In Rongga (Case 2), a slide displaced approximately 126,000 m³ of material, damaging numerous buildings and obstructing a nearby river. The Binong slope movement (Case 3) disrupted electricity towers and posed a threat to a national highway, while the complex Cibenda slide-flow (Case 4) caused eight fatalities and led to displacement of 527 individuals. Our investigations identified thick volcanic deposits (5-8 m on average) with low shear strength properties (mean cohesion of 6-20 kPa and mean internal friction angle of 9-16°), combined with land use activities, as primary causes of these landslides. In addition, results show that heavy rainfall was acting as the critical trigger to promote failure by changing groundwater levels and increasing pore pressures, finally leading to slope instability. The resulting impact include extensive damage to buildings, infrastructure and agricultural land, causing significant economic losses. In order to mitigate these risks, our study recommends improved process understanding, sustainable land use practices, advanced slope stabilization techniques and hazard assessment methods, adjusted to the particular geological-climatological situation of the region.

Keywords: landslides, rainfall, infrastructure and settlements, volcanic rocks



Rainfall induced landslides in West Java, Indonesia. Large number of complex earth slides and flows resting on volcanic rocks and impacted dense settlement.

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Geological Risk Assessment on Villages at North Lisbon Area

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Abstract

This study assesses the geological-induced risks at building block level in A-dos-Melros, a small village, located at the foot of the SW slope of the CIMPOR concrete plant quarry, at North Lisbon Area. In order to identify the causes of the damage to the buildings, an observation system was implemented based on three components: a) monitoring of ground displacements using remote sensing techniques, including their historical evolution over a minimum period of one year; b) identification of building types and their pathologies; c) monitoring of blast-induced vibrations in quarries, through the surveying of measuring points installed at selected blasting sites. The displacement history of the study area was analyzed using InSAR data provided by the European Ground Motion Service. In addition, digital photogrammetric surveys were also carried out to identify the zones with greater displacement. Vibration monitoring was conducted at selected experimental blasting sites to quantify its evolution according to the quarry's progression towards the village. Buildings were inspected using a specific methodology that emphasized monitoring of existing cracks. By integrating geospatial and vulnerability data, this study offers a more comprehensive understanding of geological-induced risks at building block level aiming to improve management and mitigation strategies in small urban areas.

Keywords: Geohazards, InSAR, EGMS, Digital photogrametry, Building vulnerability

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--Risk Assessment in Road Corridors; the Case of National Route 32, Costa Rica

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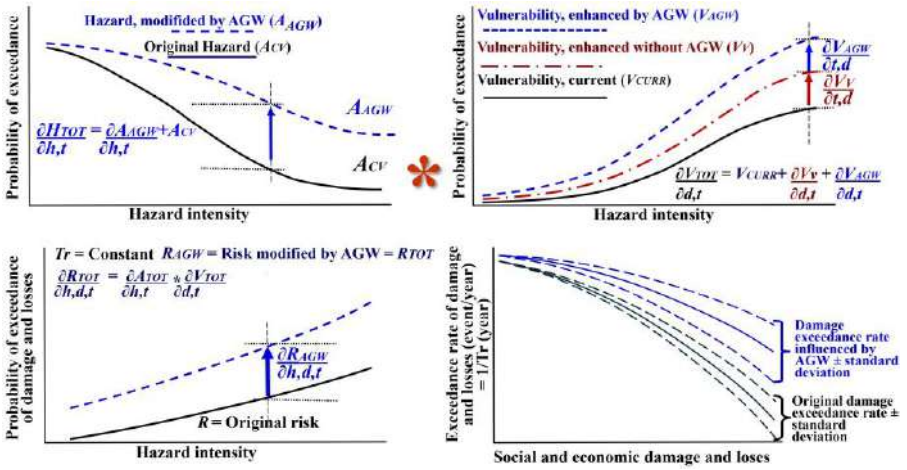
Abstract

A methodological guide was developed in Costa Rica to integrate risk assessment and management in road corridors exposed to earthquakes, slope instability, lahars, and floods, which was applied to a pilot study case on National Road 32. A multicriteria approach identifies hazards, quantify vulnerability, and supports the formulation of mitigation and adaptation measures. Seismicity, landslides and short-term climate variability, potentially altered by anthropogenic global warming, are the most significant hazards; combined with increasing vulnerability, they are the primary drivers of current and future structural and economic damage and losses. The accuracy of risk estimates depends on the availability and reliability of data on exposed elements, as well as access to software capable of detailed hazard and vulnerability assessments. Results with reduced epistemic uncertainties rely upon robust datasets and information, including digital elevation models, geological and geotechnical, rainfall, and river flow records, as well as seismic acceleration and spectral data. This foundation supports rational recommendations for strengthening road infrastructure exposed to intense events in mountainous, piedmont, and lowland areas. The guidelines provide a framework for informed decision-making design, planning, and operation of resilient investments and offer a replicable methodology for other lifelines to enhance the capacity to manage risk and adapt infrastructure to current and future climate, hydrometeorological, and geodynamic challenges.

Keywords: Risk management, Risk assessment, Resilient infrastructure, Natural hazards assessment, Costa Rica



Evolution of risk under the influence of anthropogenic global warming (AGW). *: probabilistic convolution; CV: climate variability; H, h: hazard; HCURR: Current level of hazard; HTOT: total hazard; HAGW: hazard modified by AGW; V: vulnerabil-ity; VCURR: current vulnerability; Vv: vulnerability without AGW; VAGW: vulnerability increased by AGW; VTOT: total vulnerability; d: damage; t: time; Tr: return period; R: original risk; RAGW: risk, modified by AGW; RTOT: total risk (after Mora et al., 2022a).

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Time-Series InSAR Analysis of Pre- and Post-Fire Erosion and Its Link to Changes in Soil Geotechnical Properties

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Abstract

This study investigates the annual evolution of geotechnical soil properties (shear strength, saturated hydraulic conductivity, and water repellency) over three years following a wildfire in a 4.88 km² Mediterranean microbasin underlain by Upper Permian limestone and covered with shallow regosols. The study evaluates the relationship between these properties and erosion patterns derived from InSAR-based vertical surface displacements, providing spatial and temporal insight into post-fire erosion rates. To ensure meaningful comparison with InSAR-derived erosion and minimize external influences, a geologically homogeneous area was selected. Slope gradient, slope length, rainfall erosivity, land cover, and erosion control practices remained relatively uniform across the study area. No shallow landslides occurred during the monitoring period. Thus, InSAR-detected negative (subsidence) and positive (accumulation) displacements were attributed primarily to erosion and sediment transport. Soil sampling and mini-disk infiltrometer testing were conducted annually under consistent seasonal conditions, covering varying burn severities, slope aspects, and slope parts. Burn severity was quantified using the dNBR index. Findings indicate a marked increase in erosion rates immediately after the fire, closely associated with decreased shear strength and hydraulic conductivity. Recovery of geotechnical properties was faster on south-facing slopes. The shear strength of upper slopes was consistently greater than that of lower slopes, regardless of aspect, suggesting downslope transport of weakened material. Over time, declining erosion rates were strongly correlated with the gradual recovery of soil geotechnical parameters. This integrated analysis demonstrated the value of coupling geotechnical monitoring with InSAR-derived erosion metrics to assess post-fire soil recovery trajectories.

Keywords: Erosion, Wildfire, InSAR, Geotechnics, Soil recovery

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Mapping Coastal Susceptibility to Landslide-Triggered Tsunamis: An Expert-Based Approach

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Abstract

Tsunamis generated by landslides entering oceans, lakes, and rivers pose an increasing global threat, particularly since around 10 % of the world's population lives in coastal areas. Managing the hazard of such landslide-triggered tsunamis is especially challenging, as the resulting waves are highly localized phenomena, and the time between their generation and coastal impact is often too short for effective early warning. One possible mitigation strategy is the development of susceptibility maps to raise public awareness and support land-use planning. However, data-driven approaches are limited due to the scarcity of documented events—only about 350 well-recorded cases of landslide-triggered tsunamis are known globally. Consequently, this study applied a heuristic approach using expert knowledge. Through an online survey, 26 experts in landslides and tsunamis were asked to rank 37 parameters influencing the susceptibility of both subaerial and submarine landslides capable of generating tsunamis. The findings indicate that factors such as the volume of past landslides, slope angle, presence of oversteepened slopes, and the depth and magnitude of historical earthquakes are among the most significant contributors to susceptibility. The results of this study offer a novel approach to addressing the hazard posed by landslide-induced tsunamis. The proposed methodology is intended for future application to map tsunamigenic landslide susceptibility along coastal areas using publicly available data.

Keywords: landslide, tsunami, susceptibility, heuristic

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Municipality-Level Landslide Hazard Mapping in Greece: A Methodology for National Implementation

Natalia Spanou[1], Katerina Kavoura[1], Andreas Antonakos[2], Natalia - Christina Patsioti[2], Eleftheria Poyiadji[1], Panagiota Kokkali[1], Alecos Demetriades[1]

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Abstract

In the framework of a national initiative led by the Hellenic Survey of Geology and Mineral Exploration (H.S.G.M.E.) and the General Secretariat for Civil Protection (G.S.C.P.), a National Landslide Hazard Map at the Municipal Community level has been produced. This project aims to support national efforts towards landslide hazard prevention and preparedness while contributing to spatial planning and emergency response mechanisms.

The methodology integrates susceptibility analysis and hazard evaluation, utilising geological, geomorphological, hydrological, and anthropogenic parameters, considering landslide occurrence. Hazard assessment is assigned based on (a) the national–scale landslide susceptibility mapping, (b) the frequency of recorded landslide events from H.S.G.M.E.'s national database, and (c) areas officially declared in a state of emergency for landslides.

Each Municipal Community is classified into five hazard levels, ranging from Very Low to Very High. The classification is conducted through geospatial processing and modelling, enabling consistent nationwide mapping while maintaining local-scale applicability.

The resulting National Landslide Hazard Map, along with the relevant tabular classification of all 6,132 Municipal Communities, provides a scientific tool for prioritising civil protection measures, supporting infrastructure planning, and local and regional emergency preparedness strategies.

This work represents the first phase of an evolving geospatial framework for landslide hazard management in Greece, designed to be periodically updated in response to new scientific data, observed events, and climate-driven changes.

Keywords: Landslide susceptibility, Hazard assessment, Frequency analysis, Municipal scale, Civil protection

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Integrating Geoethics into Disaster Risk Management: A Framework for Resilience in Peru

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Abstract

Disaster risk management (DRM) in Peru remains constrained by fragmented governance, rapid informal urban expansion, and limited integration of geoscientific evidence into territorial planning. Recurrent impacts from earthquakes, landslides, floods, and debris flows demonstrate that predominantly technocratic and response-oriented approaches are insufficient to reduce risk in complex geodynamic settings. This paper proposes a geoethics-based framework for disaster risk management that strengthens engineering practices by embedding ethical principles, responsibility, transparency, equity, and prevention into decision-making processes. Building on the IAEG–IAPG Peru White Paper and the Sendai Framework Midterm Review, the study analyses structural, institutional, and technical gaps that hinder the effective use of hazard and risk information in Peru. The analysis shows that risk is not solely driven by natural hazards, but by cumulative interactions between geological processes, land-use decisions, and governance failures. Inconsistent methodologies, limited data interoperability, and weak enforcement of planning regulations contribute to the siting of settlements and infrastructure in high-hazard areas. From an engineering perspective, geoethics functions as a quality-control mechanism, reinforcing the obligation to apply scientifically robust methods, communicate uncertainty, and uphold duty of care in public safety–critical decisions. The proposed framework integrates geoethical principles with strategic actions in governance, territorial planning, geoscience education, and stakeholder engagement. Its implementation supports a shift toward prevention-oriented, socially accountable, and resilience-focused DRM. While grounded in the Peruvian context, the framework can be applied to other high-risk regions in Latin America and beyond, facing similar governance and geodynamic challenges.

Keywords: Disaster Risk Management, Risk Prevention, Territorial Planning, Informal Urbanization, Geoethics

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A Multi-Scale, Index-Based Approach to Coastal Vulnerability Assessment in Greece: Integrating National Screening with Regional-Scale Analysis

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Abstract

Coastal zones represent dynamic interfaces between terrestrial and marine environments, shaped by natural processes and human activities. One of the most pressing challenges in these areas is coastal erosion, driven by both anthropogenic pressures and the impacts of global climate change. This study presents a two-tiered, index-based methodology for assessing coastal vulnerability at a national and regional scale in Greece. At the national scale, a Coastal Vulnerability Index (CVI) was applied to the entire Greek coastline to identify areas of heightened risk. This broad-scale assessment identified multiple regions of high and very high vulnerability, encompassing approximately 11% of the total coastline, and providing a foundation for targeted, regional-scale investigations. At the subsequent regional scale, highly vulnerable coastal segments were selected for in-depth analysis, integrating high-resolution spatial data, instrumental monitoring, remote sensing imagery, and geotechnical as well as marine parameters. The integration of these multidisciplinary datasets enhanced the spatial precision and contextual relevance of the CVI, enabling a more nuanced understanding of localized vulnerability patterns. The proposed approach demonstrates the value of multi-scale, data-integrated assessments for informing adaptive planning and risk reduction strategies in coastal environments under climate change.

Keywords: Coastal Erosion, Vulnerability Assessment, Coastal Vulnerability Index (CVI), GIS,

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Risk Reduction Municipal Plan in Brazil – the Case Study of João Monlevade, Minas Gerais

Eduardo Marques[1], Roque Leandro[1], Julio Oliveira[1], Emmanuel Teixeira[1], Cibele Clauver[1], Flávio Ferreira[1], Felipe Tura[1], Denis Massardi[1], Rainara Viana[1]

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Abstract

This paper presents some of the results of a risk reduction plan developed for a city located in Southeast Brazil, in which both mass movements and hydrological frequently occur and have already resulted in some life, houses and infrastructure losses. The methodology was based on the one developed by Ministry of Cities in 2006, updated and modified to encompass both the processes observed in urban areas and the socioeconomic vulnerability of the population. Risk areas were identified based on historical data and field mapping, during which the following activities were performed: evidence identification, geological-geotechnical and hydrological conditioning and occupational conditions. Based on this, the following processes were identified: landslides (translational and rotational), rock fall, creep, erosion (including margin undermining) and flooding. The study has identified 18 sectors with Moderate risk (R2), with 67 buildings; 21 sectors classified as High risk (R3), encompassing 599 buildings; and 17 sectors classified as Very High risk (R4), with 216 buildings. In total, 3204 people live in these risk areas, the majority living in areas subjected to flooding.

Keywords: Geological risk, Hydrological risk, Urban Planning

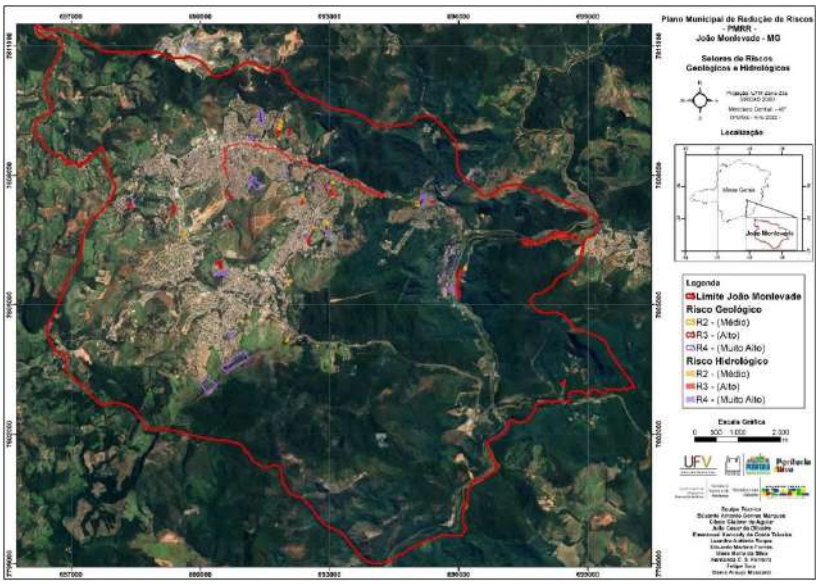

Figure 1 – Location of all risk sectors mapped for João Monlevade urban area.

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Geological Hazard Team in Central Chile: Contributions to Cascading Geological Risk Management with a local scale and an Interdisciplinary Perspective

Alejandra Serey[1], Ricardo Fuentealba[1], Francisca Vergara-Pinto[2], Jorge Romero[1], Tania Villaseñor[3], Laura Becerril[1], Paulina Vergara-Saavedra[4]

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[2] University of Manchester, Manchester, United Kingdom
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[4] Universidad de Chile, Santiago, Chile

Abstract

Cascading geological disasters are increasing in frequency worldwide due to climate change. Since 2013, Central Chile has been affected by extreme hydrometeorological events associated with atmospheric rivers (ARs are relatively long, narrow regions in the atmosphere, like rivers in the sky, that transport most of the water vapour outside the tropics), causing catastrophic floods and landslides. This poses a significant challenge for scientists, policymakers, and communities in disaster risk reduction. This work recounts the development of an interdisciplinary perspective at a local scale that combines social and geoscience knowledge, working with public institutions and communities over time (short, medium and long term). Based on a paradigmatic shift (from a top-down and emergency-based approach to collaboration and coordination throughout the disaster management cycle), dialogue, a common language, local practice-based research, and anticipatory actions are required. A Geological Hazards Team was established in 2021 between researchers (Geosciences and Social Sciences) and State representatives from the National Disaster Prevention and Response Service, the Ministry of Housing and Urbanism, the Regional Government, and the Ministry of Public Works, among others. The activities have different fronts of action: quick geological assistance at the local scale, development of a robust dataset of landslide inventories at a local scale, construction of educational and interactive material for landslide risk visualisation at the local scale, development of landslide susceptibility maps, Evacuation Routes (ER) and Meeting Points (MP) based on the susceptibility zones, capacitations of public workers, participatory workshops in affected communities to validate or propose new ER/MP and outreach amog others.

Keywords: Mass removal, cascading geological risk, disaster prevention, interdisciplinary approach,

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Embedding Communication into Engineering Project Cycles: Insights from Risk-Sensitive Contexts in Peru

Sandra Villacorta[1, 2], Yamile Claudia Alessandra Quispe Villacorta[3], Katia Vila[4], Juan Carlos Piscoya[5, 6]

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Abstract

Engineering and geoscientific projects implemented in socially sensitive and risk-prone territories frequently experience operational disruption despite technically robust designs. This study examines how the timing, structure, and professionalisation of communication influence engineering and research performance in such contexts. Using a comparative qualitative design, six Peruvian cases spanning mining, infrastructure, geoscientific research, and disaster risk management were analysed under comparable conditions of geological uncertainty and social vulnerability.

Communication was operationalised through five theory-informed variables, timing, dialogic depth, structural embedding, translation of uncertainty, and continuity—assessed using an ordinal scoring rubric to enable systematic cross-case comparison. The results show that cases characterised by late-stage, fragmented, or compliance-oriented communication consistently experienced negative performance outcomes, including project cancellation, suspension of field activities, implementation delays, security exposure for technical teams, and limited institutional uptake, despite sound technical assessments. In contrast, cases where communication was embedded early, institutionalised, and supported by specialised communication and social-science professionals maintained operational continuity and demonstrated improved alignment between technical risk assessments and stakeholder understanding.

By explicitly contrasting unsuccessful and successful trajectories, the study demonstrates that communication functions as a performance-modulating governance variable rather than a peripheral dissemination activity. Based on the findings, a five-phase operational framework is proposed to embed communication across engineering and geoscientific project cycles. The framework identifies when and why multidisciplinary communication expertise is required to reduce socio-territorial risk and protect engineering and research performance in complex environments.

Keywords: Communication Management, Engineering Geology Projects, Risk Governance, Social Legitimacy, Peru

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Multi-hazard risk Assessment from theory to practice

Cees Van Westen[1], Manzul Hazarika[2], Ashok Dahal[1], Arun Mandal[3], Salsabilla Ramadhani Prasetya[2]

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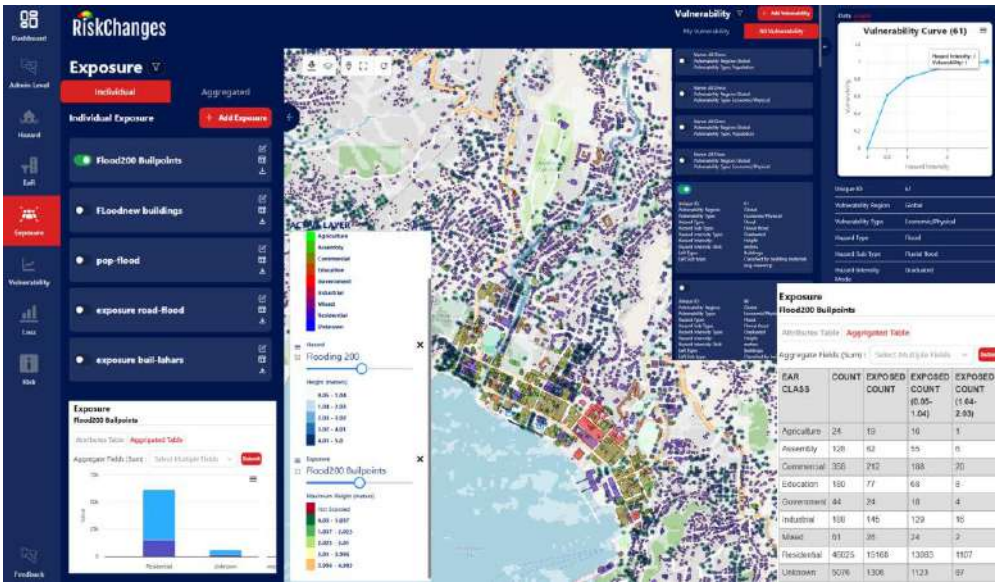
Abstract

RiskChanges is an open-source, web-based platform developed to support decision-making in disaster risk reduction (DRR) by analysing the impact of alternative planning strategies on present and future risk. Initially created under the European InCREO and CHANGES projects, the platform underwent a full redevelopment in 2021 within the EU PARATUS project (Horizon 2021, Grant No. 101073954). RiskChanges facilitates spatial risk analysis through a structured workflow that integrates administrative boundaries, hazard and asset data, vulnerability modelling, and the estimation of losses and risk scenarios. It enables users to evaluate and compare risk reduction measures through analytical tools such as cost-benefit analysis and multi-criteria evaluation. The platform is designed for flexibility, operating across diverse geographic, legal, and institutional contexts, and is managed by an international consortium: UT-ITC (Netherlands), GIC-AIT (Thailand), and Youth Innovation Lab (Nepal). Emphasizing stakeholder engagement, RiskChanges provides an intuitive interface that bridges the gap between technical analysis and policy decision-making. This presentation will highlight the platform's functionality, recent enhancements, and its role in supporting risk-informed planning at local to regional levels.

Keywords: Multi-hazard, Risk, Software , Vulnerability, Exposure



Screenshot of the RiskChanges tool (http://Riskchanges.org)

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An Overview of The Natural Hazard Risk Atlas of the Tibetan Plateau and Adjacent Mountains

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Abstract

The Tibetan Plateau exhibits intense tectonic uplift, complex terrain, and a highly variable climate, making it prone to frequent natural disasters. Since 2019, the Second Tibetan Plateau Scientific Expedition has included a dedicated task to systematically study the distribution, patterns, mechanisms, and risks of these natural hazards, resulting in the Natural Hazard Risk Atlas of the Tibetan Plateau and Adjacent Mountains. The atlas provides the first comprehensive overview of hazard distribution and risk patterns across the region. It analyzes the correlations among the environment, disasters, and human activity, supported by first-hand expedition data. The atlas also explores disaster mechanisms through case studies and assesses hazard risks to the population, direct economic losses, and transportation infrastructure. The atlas is organized into seven sections, including environment, hazard distribution, regional analysis, case studies, and risk assessment, containing 140 maps with 518 illustrations. It is intended to serve as a valuable and systematic reference for understanding natural disaster risks on the Tibetan Plateau.

Keywords: Tibetan Plateau, Natural Hazards, Risk Assessment, Scientific Expedition, Atlas

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From Risk Area Mapping to Engineering Design: A Methodological Path

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Abstract

Municipal Risk Reduction Plans (Planos Municipais de Redução de Riscos – PMRR) have evolved from essentially cartographic diagnoses into strategic instruments for urban management and planning. This paper analyzes the current methodology adopted by the Institute for Technological Research (IPT), with emphasis on engineering innovations for the indication of structural measures and cost estimation. The study details the methodological workflow that replaces conventional tables with graphical representations over drone-based aerial photogrammetry and implements parametric cost estimates based on standardized model structures. The results demonstrate that this approach bridges the gap between diagnosis and execution, underpinning municipal decision-making and enabling access to federal funding, such as the New Growth Acceleration Program (Novo PAC), by prioritizing integrated urban upgrading and mitigating involuntary resettlement.

Keywords: Cost estimation, Municipal Risk Reduction Plans, Parametric spreadsheet, Risk mapping, Geotechnical engineering



Intervention works sheet in Jundiaí – SP. Source: IPT, 2025b;

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Spatiotemporal Monitoring of Post-Fire Slope Erosion Using SBAS-InSAR in Zirang Gully, Sichuan, China

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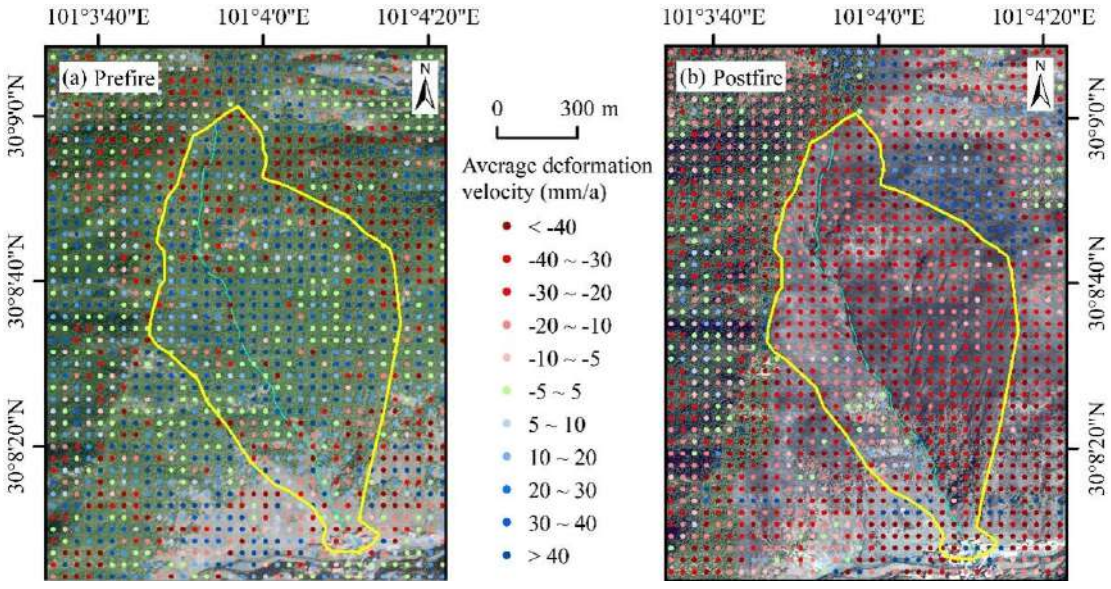
Abstract

On March 15, 2024, a large forest fire burned approximately 278.8 km² in Gala Town, Yajiang County, Sichuan Province, southwestern China. To quantify the wildfire's impact on slope erosion, this study investigated the Zirang Gully watershed using SBAS-InSAR to analyze spatiotemporal deformation patterns before (September 2022–March 2024) and after (March 2024–May 2025) the fire. Results reveal a substantial intensification of slope erosion following the wildfire. The proportion of eroded area increased sharply from 29% to 93%, and erosion points evolved from sparse, localized distributions near watershed divides and anthropogenically influenced zones to widespread, spatially clustered patterns across the entire watershed, particularly along channels and ridge boundaries. The median annual slope erosion rate shifted from 13.8 mm yr^{-1} (weak accumulation) to –26.8 mm yr^{-1} (intense erosion), with the absolute magnitude increasing by a factor of 1.94. Mean daily erosion rates rose from 0.18 ± 0.26 mm d^{-1} to 0.67 ± 0.16 mm d^{-1}, representing a 3.39-fold increase. Erosion exhibited strong seasonal variability consistent with the monsoon regime, with peak deformation during the rainy season (May–October). Notably, despite lower total and peak daily rainfall during the first post-fire rainy season compared to pre-fire conditions, erosion intensity was significantly greater, indicating enhanced rainfall sensitivity. These findings demonstrate that wildfire disturbance markedly amplifies slope erosion and increases post-fire debris flow susceptibility, providing a scientific basis for hazard assessment and risk mitigation in fire-affected mountainous regions.

Keywords: Burned area, Post-wildfire debrisflow, First rainy season, SBAS-InSAR, Erosion



Average Deformation Velocity in the Zirang Gully Burned Area

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Optimizing a Prediction Model for Engineering Disturbance Hazard susceptibility in the Qinghai-Tibet plateau

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Abstract

The China-Nepal transportation corridor, a vital link, includes the western route of the China-Nepal Highway from Lhasa to the Jilong Border. This route has faced persistent engineering disturbance hazards since its construction in 1965, significantly compromising its safety. The planned China-Nepal Railway is set to be built largely in parallel to the existing highway. Therefore, a systematic study of the existing types, characteristics, triggering factors, and susceptibility zones of engineering disturbance hazards along the China-Nepal Highway can provide valuable insights for mitigating such hazards in future railway construction. Field investigation along the highway have cataloged over 160 hazard sites, classified into six main types: earth slides, debris-bedrock binary slides, earth-rock mixture slides, earth-rock mixture falls, rock falls, and rock topples. The susceptibility prediction model has been refined by applying the First Law of Geography to the hazards identified in field investigations. A comparison with ANN and Simple CNN models demonstrates that the proposed sample optimization strategy effectively enhances model performance. This strategy addresses the limitation in susceptibility prediction where point-format hazards fail to adequately represent the environmental characteristics of the entire hazard body. Results indicate two areas of extremely high susceptibility to engineering disturbance hazards along the China-Nepal Highway. The first area features rocky slopes with unloading fractures in broad river valleys, particularly where slate is exposed. The second area includes slopes of Quaternary loose deposits that have been disturbed by slope excavation in alpine valleys with heavy rainfall.

Keywords: Tibetan plateau, Highway engineering disturbance hazards, Susceptibility, Convolutional neural network, Geohazards

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An SPH Framework for Simulating the Landslide–Damming–Breaching–Flood Cascading Hazard With Heterogenous Materials

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Abstract

Landslide–damming–breaching–flood (LDBF) processes constitute a typical hazard chain in mountainous regions, posing significant threats to downstream communities and infrastructure. This cascading process generally involves rapid landslide motion, impact with the valley floor and river channel, river blockage and dam formation, followed by dam breaching and catastrophic flooding. Grain size plays a critical role throughout the entire evolution of this hazard chain. The magnitude and spatial distribution of grain sizes strongly influence landslide mobility, landslide–water interaction dynamics, internal segregation during deposition, and erosion mechanisms during dam breaching. In this study, a Smoothed Particle Hydrodynamics (SPH) framework is developed to simulate the full LDBF process considering heterogenous geomaterials. The proposed method incorporates a grain-size segregation model to capture grain-size segregation during landslide motion and deposition, as well as a size-selective erosion model to represent differential entrainment during overtopping and breaching. By coupling multiphase flow dynamics with grain-size-dependent constitutive behavior, the model enables integrated simulation of landslide propagation, impact-induced river blocking, formation of a spatially heterogeneous landslide dam, and progressive breaching of the heterogenous landslide dam. The proposed SPH approach provides a physically consistent and computationally robust tool for analyzing the dynamic evolution of LDBF hazard chains involving heterogeneous materials. The results highlight the importance of grain-size distribution in controlling dam morphology, breach development, and downstream flood characteristics, offering improved insight for hazard assessment and risk mitigation in mountainous river systems.

Keywords: Cascading Hazard, Landsldie dam, SPH, Grain size

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Seismic Response and Failure Analysis of the Layered Rock Slope by a Shaking Table Test

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Abstract

Layered rock slope failures frequently occur in mountainous regions and cause catastrophic disasters worldwide, yet their recognition and prediction remain challenging, particularly under complex seismic excitations. A generalized physical model of a dip-bedded rock slope, incorporating joints and other discontinuities, was established on a shaking table and subjected to a seismic sequence to investigate the spatiotemporal characteristics of dynamic response and failure processes. Based on the experimental results, temporal variations of seismic amplification along slope height and relative positions to slope surface were presented in time domain, together with the final failure patterns under sinusoidal excitations. The results indicate that aftershocks with lower seismic amplitudes can contribute to damage progression, even if they produce less deformation than main shocks. Moreover, the slope surface-free effect exhibits a clear but nonlinear height-dependent profile. Gently dipping layered slopes display complex failure mechanisms governed by multiple discontinuities rather than solely by dip bedding planes. Notably, variations in time domain preceded visible slope deformation, suggesting their potential use for early-warning stage of impending rock slope failures and mitigation of geological hazards.

Keywords: Layered rock slope, Seismic response, Failure process, Experimental modelling, Shaking table test

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Probabilistic Landslide Assessment in a Changing Climate: Insight from Multi-Hazard Interactions

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Abstract

Landslides are expected to become more frequent and severe under climate change. At climate-change time scales, slopes are subjected to repeated exposure to multiple hazards (e.g., rainfall and earthquakes) in many regions. However, long-term landslide assessment under multiple hazards remains a major challenge, owing to the distinct characteristics of hazard occurrence, the nonstationarity introduced by climate change, as well as the complex interactions between these different hazards affecting slope stability. This study proposes a probabilistic multi-hazard framework for assessing landslide under rainfall and seismic hazards in a changing climate, based on stochastic renewal process theory. An illustrative example is provided for a representative slope to demonstrate the applicability of the proposed framework. The results indicate that neglecting the interactions between rainfall and seismic hazards lead to a substantial underestimation of long-term landslide probability. Moreover, the impact of climate change on landslide probability is highly dependent on the relative dominance of climate-sensitive hazards (i.e., rainfall) within the multi-hazard system in the analyzed region.

Keywords: Landslides, Climate change, Multi-hazard interaction, Stochastic renewal process, Probabilistic assessment

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Comparative Controls of Coseismic Landslides in Two Strike-Slip Earthquakes: Insights From the 2017 Jiuzhaigou and 2022 Luding Events

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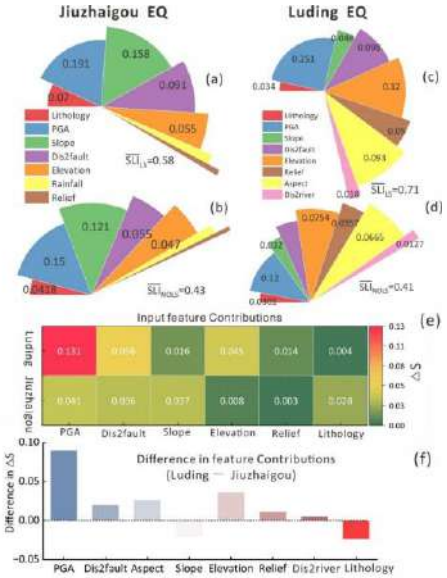
Abstract

Understanding why coseismic landslides respond differently under similar strike-slip tectonic settings remains a key challenge in regional hazard assessment. This study compares the first-order controlling factors of coseismic landslides triggered by the 2017 Ms 7.0 Jiuzhaigou earthquake and the 2022 Ms 6.8 Luding earthquake using an interpretable Superposable Neural Network (SNN) framework. We focus on Level-1 feature contributions derived from major seismic, topographic, and environmental variables. The results show that both earthquakes exhibit a shared "ground shaking–topography" control pattern, but their dominant first-order factors differ markedly. In the Jiuzhaigou case, landslide occurrence is mainly controlled by PGA, slope, and lithology, indicating a stronger constraint from slope condition and geological background. In contrast, the Luding event is more strongly governed by PGA, elevation, aspect, and fault proximity, suggesting a greater sensitivity to near-fault shaking and terrain configuration. Inter-event differences in feature contributions further demonstrate that Luding landslides are more directly linked to the combined effects of seismic intensity and topographic setting, whereas Jiuzhaigou landslides are relatively more conditioned by lithological properties. These findings highlight that even among strike-slip earthquakes, coseismic landslides can be controlled by distinct first-order factor combinations, and that interpretable models provide an effective way to reveal such event-dependent differences.

Keywords: coseismic landslides, strike-slip earthquake, Jiuzhaigou, Luding, interpretable neural network



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Identifying Landslide Triggers in Data-Scarce Mountainous Regions: Toward a Multiscale and Proactive Framework from the Cameroon Volcanic Line

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Abstract

Landslide hazard is increasing in mountainous regions worldwide due to climate change, rapid urbanization, and land-use change. However, identifying the main triggering mechanisms remains difficult, especially in data-scarce regions where monitoring systems and geotechnical data are limited. In tropical environments, intense rainfall and deeply weathered soils create conditions highly prone to slope failure, yet these regions remain underrepresented in global landslide research. This study focuses on the Mount Oku region in the Cameroon Volcanic Line, a data-scarce mountainous area characterized by high rainfall, steep slopes, and growing human exposure. A landslide inventory of 179 events is combined with factor of safety (FS) analysis, Newmark displacement (ND) modelling, and spatial clustering to investigate landslide triggering mechanisms. Results indicate that rainfall is the dominant trigger, particularly under saturated conditions. However, elevated Newmark displacement values in otherwise stable slopes suggest that seismic activity may contribute to slope preconditioning and reactivation. Spatial clustering highlights distinct patterns associated with valley-controlled (rainfall-driven) and ridge-controlled (potentially seismic) landslides. Beyond this case study, the work contributes to a multiscale and multifactorial framework for landslide hazard assessment in data-scarce regions. The approach integrates geo-environmental factors, soil geomechanical properties, and multiple triggering mechanisms, while enabling the progressive expansion from detailed local investigations to regional and national-scale susceptibility mapping. Ultimately, it supports a shift from reactive response to proactive risk reduction through improved hazard assessment, land-use planning, early warning systems, and long-term monitoring.

Keywords: Landslide triggers, Newmark displacement, multi-trigger analysis, data-scarce regions, Cameroon Volcanic Line

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Post-Fire Ground Deformation and Debris-Flow Activity across Lithologies in Southwestern China

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Abstract

The Hengduan Mountains of China are characterized by strong tectonism and complex geomorphic environments, resulting in pronounced variability in post-fire debris-flow processes across different lithologies. Despite this heterogeneity, few studies have systematically examined lithology-controlled variability, particularly regarding the long-term spatiotemporal evolution of post-fire debris flows. This study investigates three fire-affected sites—Muli, Xichang, and Zhongba—that share similar geographic settings and synchronous fire timing but differ markedly in lithology. Field surveys, UAV photogrammetry, and SBAS-InSAR were jointly employed to quantitatively assess pre- and post-fire ground deformation and hillslope erosion across these contrasting lithological settings. Results demonstrate distinct contrasts in debris-flow activity and hillslope deformation among the three sites, revealing the mechanisms that govern long-term debris-flow evolution. The Muli site, underlain by metamorphic rock, exhibited the most frequent and intense post-fire debris flows, far exceeding those in Xichang and Zhongba. Post-fire hillslope erosion in Muli increased to 4-18 times pre-fire levels, and accelerated deformation zones (DADZs) developed along both channel banks with evident erosional features. In contrast, Xichang and Zhongba showed no significant increases in erosion or deformation. These findings indicate that slope structural configurations shaped by lithological and geomorphic factors exert a dominant control on sediment transport efficiency and debris availability, and in turn govern post-fire erosional and deformational processes. In Muli, enhanced post-fire erosion and DADZ development sustain long-term debris-flow activity, with the deformational response of the metamorphic terrain providing a continuous sediment supply. This study advances understanding of lithology-controlled variability in post-fire debris-flow dynamics and offers valuable insights for hazard mitigation in the Hengduan Mountains and similar high-relief regions.

Keywords: Post-fire debris flow, Lithological control, Hillslope deformation, SBAS-InSAR monitoring

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Early Holocene global sea-level rise: what does it tell us?

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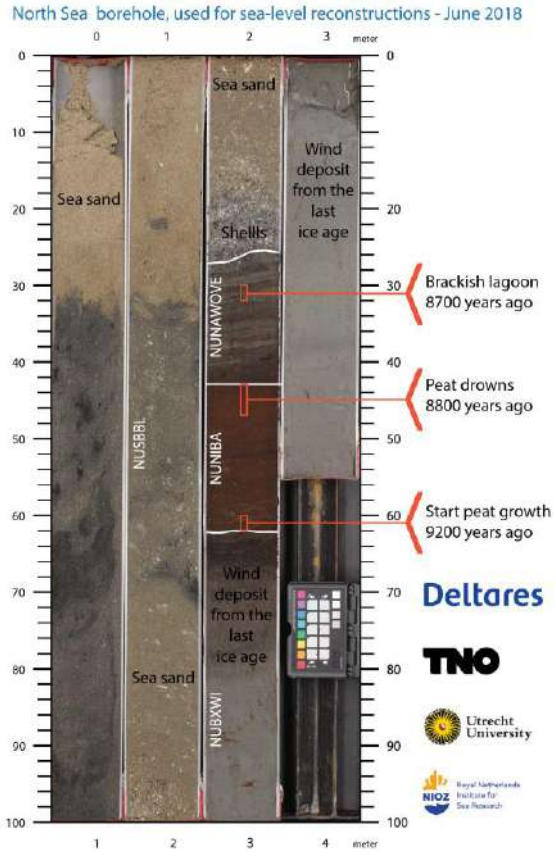
Abstract

We all know that the Earth is heating up and sea level is on the rise. But forecasts of expected sea-level rise have large uncertainty bands and this makes it hard for policy makers to decide how to prepare for the future. The uncertainty stems for a large part from not knowing enough about the complex relations between ice sheets, climate and sea level. These relations are put into models, but it is essential to have good datasets to train or validate these models.

A logical thing is to look at the past for such datasets, to periods where temperatures were also rising and ice sheets were melting. The most recent period is the Early Holocene, the warm period after the last ice age. Sediment sequences to study sea-level rise in the Early Holocene are preserved at many places in the North Sea and are of global importance, since such widespread and intact sequences are rare. The sequences have been sampled and studied in recent years, resulting in important new insights.

In this presentation I will show how paleo sea-level can be reconstructed, what its significance is and probably will make a link to North Sea archaeology as well. Most likely new fieldwork on the North Sea will take place in 2026, because we want to extend our dataset all the way to the last ice age. It now ends 700 years short of it.

Keywords: sea-level rise, Doggerland, geo-archeology, ice sheets,



Example of the drowning sequence in the North Sea

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A Semi-Quantitative Methodology for Hydrological Risk Evaluation

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Abstract

Flood-related disasters are among the most common events in the world. Factors like climate change, urbanization process and rise of population exposure influence the risk of flooding. Consequently, it is crucial to develop accurate flood urban risk mapping methods. The city of São Paulo presents a complex scenario: it encompasses eight main river basins with 264 secondary river basins, with hundreds of low-income settlements located in flood-prone areas. Hence, the city context demands tailored risk mapping methods. In this work, we present a two-steps semi quantitative methodology for hydrological risk mapping developed by technicians from the Prevention Division of the Municipal Coordination of Civil Defense of São Paulo City. In the first step, 1020 target areas were delineated by crossing the information of the flood susceptibility map with the low-income settlements map.The susceptibility map was obtained with Height Above the Nearest Drainage model. The second step of the methodology evaluates hazard and vulnerability parameters that are collected in field: 1) kinetic energy and carrying capacity, rising level, channel interferences, recurrence, associated processes and susceptibility, for hazard analysis, and 2) housing density, building standards, sewage system and garbage, surface drainage system and house accessibility, for vulnerability analysis. Each parameter is assigned a weight and the final risk classification is the product of vulnerability and hazard analysis, as presented in Figure 1. This is the first time that hydrological risk is mapped in the city of São Paulo. The methodology presented in this paper is novel and resulted in 360 risk mapped areas.

Keywords: Risk assessment, Urban flood, Flood susceptibility, HAND Model, Risk management

Risk matrix					
Risk (R = H x V)		Vulnerability weight			
		1	2	3	4
Hazard weight	1	1	2	3	4
	2	2	4	6	8
	3	3	6	9	12
	4	4	8	12	16

Risk classification		
Risk (R)	Class	Final Value
	R1 – Low risk	1 ≤ R < 4
	R2 – Medium risk	4 ≤ R < 8
	R3 – High risk	8 ≤ R < 12
	R4 – Very high risk	12 ≤ R ≤ 16

Risk matrix and risk classification

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Wetting-Drying Cycles and Cone Penetration Tests in Clay - How Does Seasonal Drought and Vegetation-Induced Suction Affect Clay Strength?

Suzanne van Eekelen[1], Adam Bezuijen[2], Maria Konstantinou[1], Remco van den Berg[1]

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[2] Bezuijen Consult, Berkel en Rodenrijs, Netherlands

Abstract

The increasing frequency and duration of droughts over the last decade raise concerns about the behaviour of clay soils that support shallow foundations. This study investigates the response of clay strength to repeated wetting–drying cycles using mini-cone penetration tests (mini-CPTs). A laboratory procedure was developed to subject clay samples to controlled and reproducible realistic wetting-drying cycles. Tests were conducted on two clay types: a homogeneous, artificially prepared Vingerling clay, and a natural clay obtained from the eastern Netherlands. The resulting mini-CPT results show a clear relationship between water content and cone penetration force. For the Vingerling clay, this relationship follows an almost perfect logarithmic trend. The natural clay, which is considerably stronger, shows the same logarithmic trend, although with greater scatter, likely due to the clay's heterogeneity. No systematic trend was observed between the number of wetting–drying cycles and the cone penetration force.

Keywords: clay, drought, wetting-drying cycles, mini-cone penetrations, climate change

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Effect of Cyclic Drying-Wetting on the Hydromechanical Behaviour of a Dutch Expansive Clay

Maria Konstantinou[1], Adam Bezuijen[2], Henk Kooi[1], Harry Van Essen[1], Alba Rodríguez Piedrabuena[1], Suzanne Van Eekelen[1], Remco Van den Berg[1]

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Abstract

Soils in nature undergo periodic drying-wetting (DW) cycles. The amplitude of these DW cycles is increasing due to climate change. The DW cycles can strongly influence the soil's hydro-mechanical properties. This study investigates the effects of repeated DW cycles on the swelling pressure, volumetric response, and pore structure evolution of a clay from Zevenaar, the Netherlands. Soil-water retention behaviour was characterized using the HYPROP device. Laboratory DW cycles were applied under controlled conditions to reproduce suction levels representative of shallow field conditions. Swelling behaviour was examined using constant volume and constant stress swelling tests at different vertical stress levels. An approximately linear relationship was observed between swelling pressure and suction pressure, independent of DW history, test type, and applied stress, with the one-dimensional swelling pressure equal to approximately 24% of the suction pressure. Volumetric measurements obtained by 3D scanning revealed significant, largely reversible shrinkage and swelling, with no accumulation of permanent deformation. µCT imaging showed an increase in micropore number and mesopore volume with successive DW cycles, indicating progressive pore rearrangement and increased susceptibility to crack formation.

Keywords: Clay, drying-wetting cycles, swelling pressure, volumetric strain, pore evolution

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Rainfall Induced Landslide Behaviour and the Implications of Climate Change on the Undercliff, Isle of Wight, UK

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Abstract

The Undercliff, on the south coast of the Isle of Wight UK, is a complex deep-seated mass movement, the origins of which date back to the Late Quaternary, when sea level and climate conditions were different than today. Development of urban infrastructure upon the Undercliff expanded rapidly from the 1850s which has since been subject to repeated damage from ground movement and landslides. The sustainability of development within the Undercliff is at risk from the impacts of future landslide-driven climate change and sea level rise. Forecasting the effects of climate and sea level change on land stability requires long-term empirical data and landslide ground model to show the relationships between weather (rainfall), groundwater, ground movement rates and landslide frequency. The likelihood and severity of the landslide behaviour scenarios range from the present day i.e. progressive slope creep to those that require pre-cursor initiating events i.e. failure of coastal defences, and others that cause a step change i.e. new landslide mechanism. Linking the landslide behaviour response to climate change, threshold events and mitigation using quantitative methods provides an objective basis to inform strategies to manage the risk, including planning and development control, engineering measures, in situ monitoring and engagement of the local community to share information and homeowner guidance.

Keywords: Landslide, Coastal, Geohazard, Climate

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Laboratory Study of the Influence of Freeze-Thaw Cycles on Limestone - PermaPyrenees Project

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Abstract

In the context of climate change, the degradation of permafrost, observed in the deepening of its active layer (which freezes and thaws seasonally), leads to changes in the intensity and frequency of freeze-thaw cycles in it. As part of European PermaPyrenees project (EFA 063/01), laboratory experiments were conducted to study the link between freeze-thaw cycles and the cracking of rocks. 12 hours freeze-thaw cycles between -10 and 20°C were performed in a climatic chamber on saturated and unsaturated limestone from St-Maximin (France). Each week, mass, size and elastic waves velocities (P-waves and S-waves) through the samples were measured to estimate the evolution of voids volume and thus sample cracking. Two samples, 1 saturated and 1 unsaturated have also been studied through micro computed tomography (micro-CT) to witness the microcracking of rock due to freeze-thaw cycles.

Keywords: limestone, freeze-thaw cycles, elastic waves, microtomography, laboratory experiments

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UK shrink–swell hazards under climate-change-driven weather extremes

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Abstract

Subsidence related to shrink-swell in clay soils costs the UK more than £400M–£1,000M every year and is forecast to double by 2050 due to climate change-driven weather extremes. Between January and June 2022, the UK experienced unprecedented hot, dry conditions which resulted in levels of subsidence related to clay shrinkage never previously experienced in the UK.

We aim to understand how soils with varying shrink–swell susceptibility, respond to, and recover from, extreme hot and dry conditions. This will inform updates to BGS data products, which underpin hazard susceptibility assessment for the UK construction and finance sectors.

We have established three field observatories with high, medium and low shrink–swell potential in London Clay, Lias Group and the Mercia Mudstone. At each location we make repeated measurements of ground deformation and soil moisture at regular depth intervals in the upper 2m of soil. Along with laboratory based analysis of samples taken from each location and automated weather station information, the automated in-situ measurements allow an understanding of how soil moisture varies within the subsurface in response to weather events. Results from the field and laboratory measurements are enhanced through remote sensing measurements of soil moisture change, temperature, and ground deformation.

The outputs include a calibrated model of shrink–swell hazard, incorporating future climate change scenarios, to inform engineering standards and guidance for the depth and quality of building foundations (e.g. NHBC, BS, CIRIA and BRE), with the potential for expansion to other major UK clay-rich geological units.

Keywords: Shrink-swell, Climate change, Soil moisture, Extreme Weather, Drought

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Mapping Hydrological Risk in Brazilian Cities: The Cases of São Paulo and Itaquaquecetuba

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Abstract

Hydrological risk mapping plays a central role in disaster risk reduction in Brazilian cities, particularly within the framework of Municipal Risk Reduction Plans (MRRPs). Although national guidelines for risk mapping were first standardized in 2007, methodological heterogeneity persists in the assessment of flood-related processes. This study presents a comparative analysis of hydrological risk mapping methodologies and intervention prioritization criteria used in MRRP plans for two municipalities in São Paulo State: São Paulo and Itaquaquecetuba. Both cases illustrate typical challenges faced in the Global South, where rapid urbanization, informal settlements, and limited drainage infrastructure intensify exposure to hydrological hazards. Results show that the two methodologies share several vulnerability and hazard parameters, including housing characteristics, surface drainage conditions, construction materials, maximum flood height, water energy, and frequency of flood events. However, substantial differences were observed. Itaquaquecetuba incorporates broader social vulnerability indicators—such as population profile, proximity to public facilities, and access to formal electricity—while São Paulo applies a semi-quantitative weighted system focused on reducing analytical subjectivity. Community participation also distinguishes the methodologies: Itaquaquecetuba employs participatory mapping and risk perception activities, whereas São Paulo restricts community input to interviews for hazard characterization. Differences were also found in the use of susceptibility mapping, risk level classification and criteria for prioritizing structural interventions. The analysis highlights methodological advancements since the 2007 national guideline but also reveals significant gaps, particularly regarding standardized criteria for prioritizing interventions. The findings contribute to ongoing national efforts to define minimum technical parameters and strengthen hydrological risk management practices across Brazilian municipalities.

Keywords: Risk assessment, Urban flood, Risk management, Flood susceptibility

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Impact of Climate Change on Sediment Transfer and Associated Debris Flow Management: A Case Study in the Swiss Alps.

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Abstract

In recent decades, the Swiss Alps have been affected by climate change at a much higher rate than world average. Several signs, including hydrological modifications and changes in the frequency or magnitude of slope instabilities are altering the landscape. Rock glaciers show very high melting rate that can lead to severe debris flow events and thus a change in both the associated risk and vulnerability of the population in affected areas. This leads public authorities to constantly increase the share of their budget allocated to natural hazards. Since 1950, 200 alluvium dumps have been built in canton Valais (South Western Swiss Alps) to mitigate debris flow risk, which represent an average annual cost of roughly 80 million €. In this paper we present the case study of Péterey torrent, a stream flowing from the Bonnard rock glacier above the village of Zinal. Episodes of debris flow and slope erosion put the village under pressure. Geomorphological analysis and recorded environmental data show an increase in glacier movements and sediments transfer through debris flow. Here in Zinal, public authorities invested 4 million francs to increase the resilience of infrastructures and mitigate the risk for the local residents. Among other measures, the dumps capacity was increased by 700% to reach 40'000 to 60'000 m3.

Keywords: Climate change, Natural hazards, debris flow , management, adaptation



Bonnard rock glacier front above Zinal - Copyrights: Eric Bardou

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Data Fusion for Modelling the Bed Topography of a Rock Glacier

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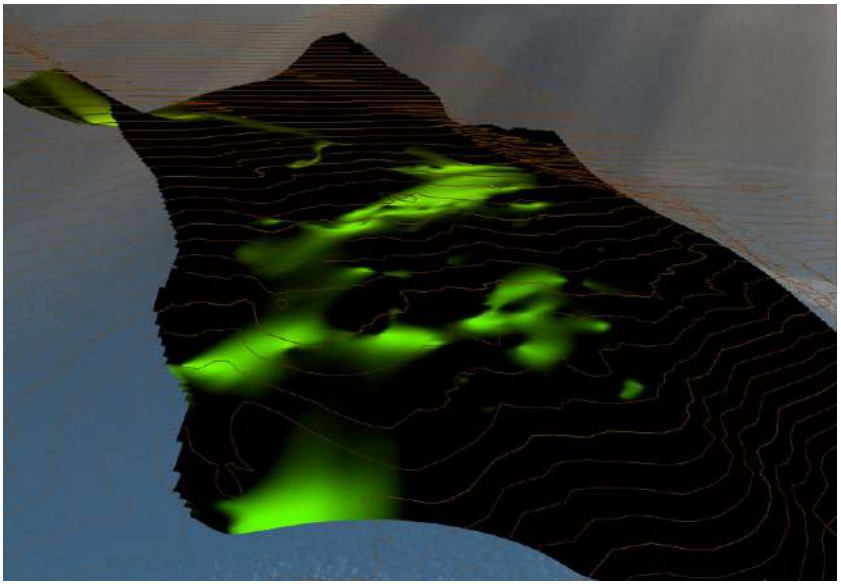
Abstract

The methodology that will be presented has been applied on a pilot site: the Bonnard glacier. This glacier is located in the south-west of Switzerland, between 3000-3200 masl, which corresponds to the regional lower limit of permafrost. The terminal part of the glacier is the source of particularly dangerous debris flows, which justifies this choice. To be able to do this fusion, the following data were used: existing surface topography (LIDAR), geophysics (refraction seismic), drilling (destructive), geomorphological surveys and displacement measurements (GNSS). We used a software that allows to fuse several types of data into a single reference frame, allowing to generate a consistent set of point. Based on these points an interpolation was generated. It gives the stable bed position. The position of the stable bed permits us to calculate the volumes in displacement, the thicknesses of the different layers, which allows to estimate the impact of the rock glacier on the triggering of debris flows.

Keywords: glacier, climate change, geohazard, risk analysis, monitoring



3D view of the modelled stable surface (green to black) under the contour lines of the natural ground

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Dynamic glacial sediments contribute to debris flow activity in the eastern Himalayas, Tibet Plateau

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Abstract

Extensive exposures of unconsolidated glacial sediments (tills) in alpine regions, resulting from ongoing glacier retreat under climate change, constitute primary source materials for cryosphere-related hazards, particularly debris flows. Therefore, understanding the dynamic characteristics of glacier sediments and their supply process is of great significance for disaster prevention and mitigation. This study aims to investigate the provenance heterogeneity and complex sediment supply mechanisms governing debris flow initiation. Specifically, it examines how variations in lithological, geomorphological, and climatic drivers modulate sediment properties and mobility, thereby influencing debris flow magnitude-frequency relationships. To address these objectives, we integrated field-based methodologies (geomorphological mapping, in-situ sediment sampling) with laboratory geotechnical analyses and multi-temporal remote sensing data. Through comparative analysis of sediment cores across topographically diverse catchments combined with digital terrain modeling, we quantitatively characterize sediment sources, textural evolution, and transport pathways in debris flow systems. This work advances the mechanistic understanding of paraglacial debris flow processes while providing empirically constrained parameters for enhancing hazard assessment models in the Eastern Himalayas.

Keywords: Debris flow, Source classification, Supply process, glacier retreat, Tibet Plateau

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Prevention is More Beneficial than Remedy: Flood

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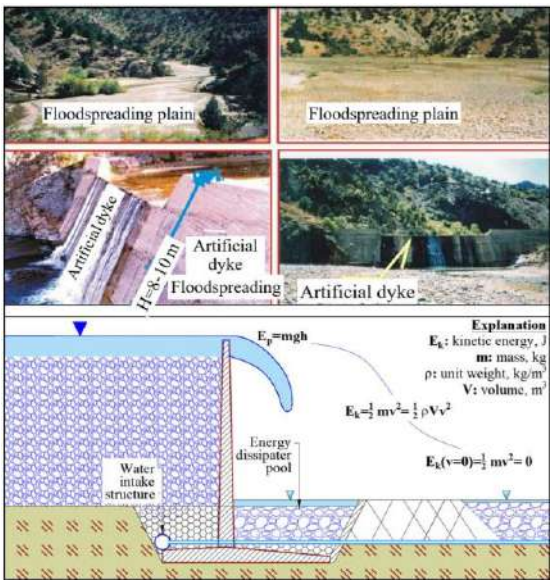
Abstract

The flood disaster constitutes ~44% of all disasters caused by natural events. The flood comes after the earthquake in term of loss of life. The destructive effect of the flood is directly proportional to the percentage of inorganic substances it carries and height of the flow. The flood spreading system with qanat, water intake structures, terrace plantation, afforestation, energy breakers, subsurface reservoirs, SCADA system, and other auxiliary systems can alleviate/prevent the flood problem. In addition, the proposed system can provide domestic and/or irrigation water at a desired quality and quantity for downstream settlements, afforesting-plantation land, and farm fields under the influence of gravity. The recommended system is proper particularly for the upper to middle reach of a catchment. An artificial dyke system in suitable gorges creates a wide alluvial (Qa) plain behind it in a few seasons. The flood spreading platform reduces the height and speed of water and allowing (a) the deposition of Qa, (b) recharging the groundwater, and (c) resetting energy in the downstream energy dissipater pool. Moreover, the fines and fine-grained sand components of Qa contain numerous inorganics and organics to enrich farm lands and provide better soil conditioning too. The coarser constituents are favorable as aggregate source.

Keywords: Flood spreading, Qanat, Energy dissipator, Groundwater recharge, Plantation



Outline of a flood spreading system

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Is Climate Change Altering the Stability Image of Slovakia?

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Abstract

The geological stability of the Western Carpathians is increasingly challenged by the accelerating effects of global climate change. In Slovakia, this phenomenon manifests primarily through extreme precipitation events and prolonged drought periods. These fluctuations in groundwater levels directly influence the geodynamic stability of various engineering geological zones. This paper evaluates current stability patterns and geological hazards in three distinct regions: the Danubian Hillside (Dolné Semerovce), the Upper Nitra Basin (Dolné Vestenice), and the volcanic structures of the Štiavnica Mountains (Podhorie). Based on an analysis of technical reports and geological surveys conducted in these areas, we observe a significant correlation between local lithological conditions and susceptibility to climate-driven instability. By synthesizing data from these site-specific surveys, this article aims to redefine the "stability image" of Slovakia. It argues that the traditional classification of engineering geological zones must be updated to reflect the increased frequency of geodynamic hazards induced by climatic extremes.

Keywords: Climate change, Landslide, Slope stability, Remediation, Western Carpathians

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Multiscale Damage Evolution and Topological Connectivity Degradation of Luohe Sandstone Subjected to Freeze-Thaw Cycles

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Abstract

Freeze-thaw (F-T) cycling significantly compromises the integrity of sedimentary rocks in cold regions, yet the multiscale linkage between microstructural evolution and macroscopic mechanical degradation remains inadequately quantified. This study investigates the damage mechanisms of Luohe Formation red sandstone subjected to up to 30 F-T cycles through an integrated experimental framework combining mechanical property testing and integrated microstructural characterization techniques. A novel topological damage index, derived from 3D pore skeleton networks, is introduced to characterize the connectivity evolution of the pore network system. Results reveal a two-stage mechanical deterioration: a rapid reduction in strength occurs within the first five F-T cycles, with uniaxial compressive strength decreasing from 12.49 to 8.58 MPa (-31.3%), followed by a subsequent saturation stage. Concurrently, pore coarsening is observed, with micropores converting into mesopores and the porosity showing a relative increase of approximately 4%. Crucially, the Euler characteristic decreases monotonically, while the topological damage index increases rapidly and then gradually approaches a plateau, indicating a progressive transition from isolated pores to a highly interconnected network. This work demonstrates that F-T damage is governed not merely by geometric expansion but by fundamental topological reorganization of the pore network, offering a new paradigm for multiscale damage assessment in geomaterials.

Keywords: Freeze-thaw cycling, Red sandstone, Multiscale damage, Pore structure , Topological connectivity

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Quantitative Assessment of Weathered Slope Soil Strength during Rainfall-runoff Processes

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Abstract

In high-intensity rainstorms, weathered soil performance deteriorates with changes in soil mechanical properties caused by soil erosion, which will result in landslides. However, evaluation of weathered slope soil strength during rainfall-runoff processes is difficult. We proposed a temporal and spatial evaluation method of soil erosion and strength based on surface wave tests and three-dimensional (3-D) laser scanning. A rainfall experiment and a surface wave test were set up in a completely decomposed migmatitic granite slope of a highway. Shear wave velocity and rill distribution of slope during rainfall were obtained. With the increasing influence of infiltration and erosion, the shear wave velocity decreased from 105.8 m/s to 102.4 m/s, while the erosion rate increased slowly from 0% to 3.5%. The shear wave velocity decreased from 102.4 m/s to 97.3 m/s with an increase in erosion degree in the later stage, while the erosion rate increased rapidly from 3.5% to 7.1%. A correlation model between the erosion rate and shear wave velocity was obtained. With an increase in the erosion rate, the shear wave velocity decreased, which is related to the shear strength. A nonlinear decrease in soil shear strength at a certain depth increases the risk of sudden local collapse. Based on that, we can evaluate slope erosion degree by surface wave method and analyze the slope stability under rainfall erosion.

Keywords: Weathered slope, Rainfall, Soil erosion, Model test, Soil strength

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Postfire net primary productivity recovery informs debris flow susceptibility assessment in a burned area, southwestern China

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Abstract

Postfire debris flows are a major cascading hazard in steep burned landscapes, yet rapid susceptibility assessments commonly emphasize burn severity and static terrain conditions while giving less attention to the evolving recovery of vegetation productivity. Here we develop a remote sensing based and process interpretable framework for basin scale postfire debris flow susceptibility assessment in the Yajiang wildfire area of southwestern China. Sentinel imagery was used to map burn severity, and monthly net primary productivity (NPP) from 2019 to 2025 was reconstructed using a CASA model driven by MODIS vegetation indices and ERA5 Land climate variables. The 2019–2023 mean growing season NPP was used as the prefire baseline to quantify productivity loss and recovery in 2024 and 2025. Fire disturbance, vegetation recovery, and terrain metric were summarized for 407 basin units using three final predictors: moderate-high burn ratio, assessment year specific mean NPP change rate, and Melton ruggedness number. A generalized additive model was trained using 2024 debris flow occurrence records and then extrapolated to 2025 by updating the NPP recovery predictor. The burned area showed a strong productivity decline in 2024, followed by partial recovery in 2025. The GAM achieved a ten fold cross validated AUC of 0.728 ± 0.082. Independent 2025 validation yielded an AUC of 0.773. These results demonstrate that integrating burn severity, NPP based recovery information, and Melton ruggedness provides an interpretable and temporally updateable basis for postfire debris flow susceptibility assessment in steep mountain regions.

Keywords: Postfire debris flow, Net primary productivity, Burn severity, CASA model, Generalized additive model

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The Preliminary Study of Liquefaction-Induced Ground Deformation: The Banda Aceh-Sigli Toll Road Section I (Padang Tiji-Seulimeum), Sumatra Case

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[2] Universitas Semarang, Semarang, Indonesia

Abstract

The simulation of potential geohazards over strategic infrastructure must be conducted, particularly in areas that are prone to ground deformation due to earthquake-induced liquefaction. Based on an existing liquefaction susceptibility map, a segment of the toll road of the Padang Tiji Interchange & Access is moderately prone to liquefaction. Moreover, part of the toll road is located near the North-Seulimeum Fault. Also, near this toll road section, historical earthquakes occurred and came from various sources (subduction and faults). This study simulated those earthquake sources and by using standard penetration test results, it generated lateral displacement and settlement maps. In several scenarios, it is clear that Padang Tiji Interchange and access potentially have lateral displacement greater than 1 m and settlement > 0.7 m. For the other potential liquefied zone near North-Seulimeum (part of Sumatera Fault) in the western part of this section, it is predicted that the impact of lateral displacement is up to 1 m and settlement is up to 0.3 m. This result is in line with the liquefaction susceptibility map.

Keywords: Lateral Displacement, Settlement, PGA, Liquefaction, Earthquake Sources

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A Trilogy of Liquefaction Research; From Regional to Site-Specific Scale

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[2] University of Ferrara, Ferrara, Italy

Abstract

Soil liquefaction is a seismically induced phenomenon that occurs in saturated, non-cohesive soils under undrained conditions. The evaluation of the liquefaction hazard at a site/region involves several steps, starting from the assessment of the liquefaction susceptibility to the calculation of the liquefaction potential. The present study focuses on the evaluation of liquefaction potential in an area where numerous liquefaction phenomena were triggered by the 2021 Damasi, Greece, earthquake. It is important to point out that a holistic assessment of the liquefaction hazard/potential should consist of three steps; i) a detailed post-earthquake survey aimed to mapping the liquefaction occurrences, ii) an assessment of the evolution of a complex river system with emphasis on the meandering process, aimed at delineating the location and identifying the type of morphological features, and finally iii) the conduction of in-situ tests to evaluate the liquefaction potential at a site specific scale. Following this workflow, this study presents the implementation of new tools, based on remote sensing, that facilitate the post-earthquake survey and the compilation of detailed surficial geological maps. Finally, a recently developed methodology, highlighting the role of stratigraphy to the generation of ejecta, is applied to forecast the liquefaction manifestation and the relevant severity by considering data derived by CPTu.

Keywords: ejecta, liquefaction, potential, CPT, geomorphology

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Assessing the Relationship Between Liquefaction and Geomorphological Formations Based on Data Derived by Worldwide Case Studies

Maria Taftsoglou[1], George Papathanassiou[2], Sotiris Valkaniotis[2], Aliki Kokkala[2], Elena Arkoulaki[2], Markos Zampoglou[3]

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[2] Aristotle University of Thessaloniki, Thessaloniki, Greece
[3] University of the Aegean, Chios, Greece

Abstract

This study investigates the relationship between surficial geological units and the spatial distribution of liquefaction phenomena triggered by recent seismic events. Specifically, the earthquakes occurred in Damasi (Greece, 2021), Kahramanmaraş (Türkiye, 2023), and Christchurch (New Zealand, 2010–2011) triggered extensive liquefaction in the river valleys of the Pinios, Orontes, and Avon Rivers, respectively. Recognizing the critical role of geomorphological mapping in enhancing the accuracy of liquefaction susceptibility assessment, this study aims to statistically quantify the correlation between liquefaction manifestations and geomorphological formations. Utilizing a combination of historical, geological, and topographic maps, along with aerial photographs and satellite imagery, the evolution of each meandering fluvial system was reconstructed. Four primary geomorphological units were identified and delineated: (1) point bars, (2) abandoned meanders, (3) floodplains (<300 years) and (4) floodplains (>300 years). The density of liquefaction features (ejecta and lateral spreading) was calculated for each unit and for the overall study area. A novel methodology is proposed, where the Liquefaction Weight Factor (LWF) is determined using the formula of:

LWF = ln (DenseUnit / DenseMap) in which DenseUnit and DenseMap represent the liquefaction density within each formation and the entire study area, respectively. The outcome of this study indicates that the highest LWF values correspond to point bars and abandoned meanders, verifying the strong correlation between these geomorphological formations and liquefaction occurrence. In contrast, the floodplain units exhibited lower weight factors, and consequently a lower reduced susceptibility. These findings highlight the value of detailed geomorphological analysis in improving regional liquefaction susceptibility assessments.

Keywords: Liquefaction, Geomorphology, Remote Sensing , Liquefaction Weight Factor

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Causative Factors of Coseismic Landslide Inventories in Eastern and Western Taiwan: An Analysis of Major Seismic Events

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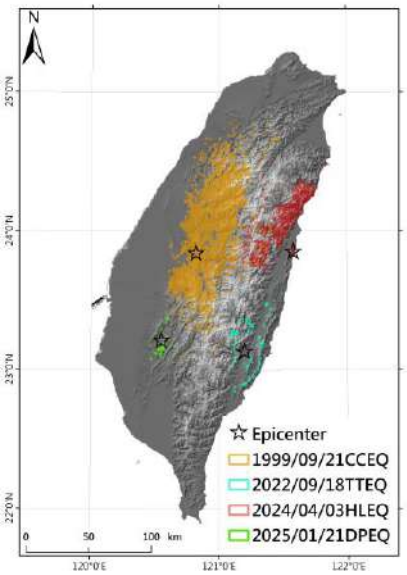
Abstract

Coseismic landslides represent significant hazards associated with earthquakes, resulting in considerable loss of life and alterations to the landscape. A thorough analysis of comprehensive inventories is essential for elucidating their spatial distribution and the factors that govern them. The eastern and western regions of Taiwan, characterized by differing topographical, lithological, and seismic conditions, display distinct patterns of coseismic landslides. Recent seismic events in eastern Taiwan, such as the 2024 Hualien earthquake (ML 7.1) and the 2022 Taitung earthquake (ML 6.8), have resulted in considerable landslide activity, primarily manifesting as rockfalls in steep metamorphic terrains, frequently occurring on southeast-facing, closer to ridge and hollow foot slopes. In contrast, the 1999 Chi-Chi earthquake (ML 7.3) in western Taiwan triggered widespread landsliding, including numerous large-scale landslides, which can be attributed to more intense and extensive ground shaking affecting a broader range of sedimentary formations. This region exhibited greater variability in slope aspect and was characterized by landslides occurring on convex slopes, in contrast to the patterns observed in the east. Additionally, the 2025 Dapu earthquake (ML 6.8) in southwestern Taiwan triggered coseismic landslides within dip slope landforms. These divergent patterns highlight that while seismic intensity is a critical factor in triggering landslides, lithology, slope morphology, and the characteristics of ground shaking also play significant and regionally specific roles in influencing the type, size, and distribution of landslides. A deeper understanding of these factors is vital for enhancing landslide susceptibility assessments and developing effective disaster risk reduction strategies.

Keywords: Coseismic landslide inventory, Statistical analysis, Topographic factors, Topographic Position Index, Seismic factors



The inventories of coseismic landslides in Taiwan are associated with the 1999 Chi-Chi earthquake (CCEQ), the 2022 Taitung earthquake (TTEQ), the 2024 Hualien earthquake (HLEQ), and the 2025 Dapu earthquake (DPEQ).

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Preliminary Consideration of the Relationship Between High-Boron Groundwater and Swarm Earthquakes in the Abu Volcanic Field, Japan

Takehiro Ohta[1], Chihiro Kawakami[2], Souta Inoue[3, 1], Nayu Takayoshi[4, 1], Tomohiro Tsuji[1], Masaaki Owada[1], Eishi Yoshino[1]

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Abstract

Groundwater with high boron (B) concentrations is distributed across the plain area of Abu Town, Yamaguchi Prefecture, Japan. Our investigation reveals that the source of this groundwater is high-salinity spring water with elevated B content, which discharges from a spring located in the upstream region of the Gou-kawa River. Notably, travertine deposition occurs at the spring outlet, indicating active mineral precipitation.

In the surrounding region, particularly within a 5–7 km radius southeast to east of the spring, a series of seismic swarm has been observed. These seismic events, typically around magnitude 1, exhibit both short-period and long-period waveforms. The short-period events are likely caused by brittle failure of bedrock; however, the origin of the long-period events remains unclear.

This region lies within the Abu monogenetic volcanic field, raising concerns about potential natural hazards associated with magmatic or deep fluid activity. In this context, we aim to investigate the relationship between the occurrence of seismic swarms and the water level, flow rate and chemical composition of the high-salinity groundwater. Understanding this relationship may offer insights into the underlying mechanisms driving seismicity in the area.

The results showed that while the water quality of the high-salinity groundwater remained largely constant, the groundwater level was observed to rise in sharp response to significant seismic activity and rainfall in the surrounding area. Seismic swarms were observed occurring during the slow decline in groundwater level following this rise. This suggests that subtle stress changes within the crust, associated with fluctuations in the high-salinity groundwater level, may be triggering seismic swarms.

Keywords: High-Boron Groundwater, Swarm Earthquakes, Abu Monogenetic Volcano, Magmatic Activity, Deep Fluid Activity

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Towards Coseismic Landslide Early Warning Using Initial P-Wave Displacement

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Abstract

Rapid assessment of coseismic landslide distribution and associated impacts following an earthquake is essential for effective emergency responses. Traditionally, strong-motion shacking proxies such as peak ground acceleration (PGA), peak ground velocity (PGV) and Arias intensity have been used to rapidly evaluate the potential locations of coseismic landslides. However, complex seismic responses due to subsurface geological conditions and topographic effects, and variability in failure mechanisms yielded significant discrepancies in the threshold values of these proxies for coseismic landslide triggering. Moreover, such information is typically available only after the landslides have occurred. Recently, the vertical peak ground displacement amplitude of the initial P-wave motion (Pd) has been proposed as a potential on-site, threshold-based metric for coseismic landslide early warning (CoLEW). In this study, we conducted a series of Pd threshold tests and found that a threshold of Pd=0.3 cm effectively captured the majority of earthquake-induced landslides across different earthquake events. Our results suggest that Pd value provides a simple and universally applicable on-site threshold for different earthquake events, enabling timely warnings—within a few seconds—for potential landslide sites. However, the proposed threshold of 0.3 cm still requires validation through more additional earthquakes.

Keywords: coseismic landslide early warning (CoLEW), initial P-wave motion, peak ground displacement

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Lake Biwa, Japan: A Valuable Case Study for Investigating Geological Conditions Vulnerable to Ground Failure

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Abstract

Nearly a hundred submerged archaeological sites have been identified in Lake Biwa, Japan, yet the causes of their submergence remain largely unknown. This study investigates whether these underwater ruins are evidence of catastrophic ground deformation caused by past large earthquakes. Through high-resolution underwater acoustic surveys, we identified multiple undulating microtopographic features on a gently sloping underwater surface with an inclination of approximately 1.2°, with maximum elevation differences reaching up to 1 meter. These features reflect subtle geomorphic variations that may be related to earthquake-induced ground deformation. Multichannel analysis of surface waves (MASW) further revealed laterally continuous low-velocity layers with s-wave velocities below 150 m/s. These may represent soft, water-saturated sediment layers that could be prone to failure under seismic loading. In the second phase, we compare these findings with well-documented international examples—such as the 1692 liquefaction-induced submergence of Port Royal (Jamaica), earthquake-triggered land collapse at Degirmendere during the 1999 Izmit Earthquake (Turkey), and slope failure caused by the 2018 Sulawesi earthquake (Indonesia). These comparisons may reveal common geological conditions that are prone to triggering geohazards under seismic influence. This research bridges geology, archaeology, and disaster science, and proposes a new perspective: that submerged ruins can serve as geological archives of past extreme events. By integrating field forensics with historical disaster records and geophysical modeling, this work highlights the value of constructing a global database of earthquake-induced submergence to support hazard assessment, interdisciplinary research, and cultural heritage protection.

Keywords: Submerged Ruins, Seismic Geohazards, Underwater Landslides

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Geological and Hydrogeological Controls on Liquefaction in Delta Environments: Evidence From the Po Delta, Northern Italy

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Abstract

Liquefaction during earthquakes is strongly influenced by the depositional history, including sediment type, age, layering, and groundwater depth. Holocene, unconsolidated sediments —particularly in palaeo-channels and coastal point bars— are more susceptible than other deposits. Youd and Perkins (1978) categorized liquefaction susceptibility into four levels: low, moderate, high, and very high. The accuracy of susceptibility maps depends on the scale of investigation and the quality and density of geological, geomorphological, and hydrogeological data. This research focuses on a 560 km² area in the eastern sector of the Po River Plain (northern Italy), encompassing part of the modern Po Delta, to assess the liquefaction susceptibility of local geological units. A comprehensive dataset was used, including lithological, chronological (14C), geomorphological, hydrological, and hydrogeological information, as well as satellite imagery, historical and modern maps, archaeological evidence, and subsurface data from core drilling and penetrometer tests.

This multidisciplinary approach enabled the creation of a detailed liquefaction susceptibility map, identifying four classes: a) Very high (4% of the area), in the floodplain of the main Po River channel; b) High (26%), associated with floodplains, active and abandoned channels, crevasse splays, and coastal dunes; c) Moderate (20%), mostly in beach barrier formations; and d) Non-susceptible (50%), in clay-filled marshes and lagoons of the delta plain.

The results provide valuable tools for public authorities to support sustainable land management in this ecologically, culturally, and economically important area, much of which falls within the Natura 2000 network.

Keywords: Delta environments, Liquefaction, Susceptibility

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Engineering Geology Framework for City-Scale Seismic Liquefaction Assessment: Case Study of Lisbon Portugal

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Abstract

Soil liquefaction is one of the most critical geotechnical hazards in seismic regions, capable of causing severe structural, economic, and environmental damage. This study evaluates the liquefaction susceptibility and potential of the alluvial areas of Lisbon (Portugal), with a particular focus on Zone 1 of the riverside sector. The assessment is based on the simplified deterministic methodologies proposed by Seed & Idriss (1971, 1982) and Boulanger & Idriss (2004, 2014) and the Liquefaction Potential Index (LPI) introduced by Iwasaki et al. (1984). A comprehensive database comprising 756 geological and geotechnical reports, including approximately 4,865 boreholes (433 analysed in Zone 1), supported the study. Additional field investigations were conducted to address data gaps. Standard Penetration Test (SPT) results were used to calculate the cyclic resistance ratio (CRR), while the cyclic stress ratio (CSR) was determined by considering an earthquake of magnitude 7.5 with a return period of 475 years (Type 1 seismic action) and a conservative groundwater level. Zone 1 is characterised by several types of alluvial and landfill deposits overlying limestone, volcanic, and Miocene bedrock. Results indicate that approximately 60% of the area is susceptible to liquefaction, particularly near the Tagus River, where thick sandy deposits of natural and anthropogenic origin occur. Liquefaction Potential Index (LPI) values reveal highly variable liquefaction severity, ranging from low to very high, with no discernible spatial trends. The resulting susceptibility map provides a preliminary tool for urban planning and seismic risk management, although site-specific investigations remain essential for engineering design and mitigation measures.

Keywords: Liquefaction, engineering geological modeling, 3D mapping, alluvial sands, Lisbon

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Twenty-Five Years of Liquefaction Studies in Greece; From Susceptibility Assessment to Hazard Analysis

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Abstract

Soil liquefaction is a coseismic phenomenon that is generated on Holocene deposits under specific conditions. These conditions include strong earthquakes and saturated, cohesionless subsoil layers. Liquefaction-induced failures are typically reported in coastal areas and alluvial plains, resulting in structural damage to port facilities in the former case and to bridges, airports, and buildings in the latter. Greece is well known that is the most seismically active country in Europe and one of the most seismically active countries worldwide. It has experienced numerous cases of liquefaction since 373 BC, as documented in the Database of Liquefaction Occurrences (DALO) versions 1.0 and 2.0. This study offers a comprehensive overview of the past twenty-five years of liquefaction research conducted in Greece by the EngeoHazard group of the Department of Engineering Geology and Hydrogeology at Aristotle University of Thessaloniki. It encompasses a wide range of studies, including susceptibility assessment and hazard analysis, offering a multifaceted understanding of the subject. As an outcome of this research, the liquefaction susceptibility map of Greece at a scale of 1:500,000 was released. Furthermore, a compilation of liquefaction potential maps was conducted, encompassing several urban areas, based on data derived from in-situ tests. Recently, our group proposed a comprehensive flowchart delineating the steps that should be followed during post-earthquake surveys for detecting and reporting liquefaction surface evidence.

Keywords: liquefaction, Greece, earthquake engineering geology, susceptibility, hazard

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Are Earthquake Early Warning and Prediction Systems Effective, Useful and Applicable for Risk Management in Costa Rica?

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Abstract

Increased attention to earthquake prediction and early warning systems intend to reduce disasters. However, several issues affect their transparency and reliability; many efforts have yielded inconclusive and unreliable results. We recommend more adaptive multi-modal cohesive information sharing systems that require integrated observation, surveillance, warning, alarm and response instruments. Communications should be expedient, clear and trustworthy to enable society to enhance preparedness, act effectively in emergencies, reduce vulnerability and promote resilient recovery. The approach requires integrated protocols, community involvement, technological efficiency, and precise scientific and communication skills to avoid confusion and ensure effective risk management. Anticipation, prediction, prognosis and forecast need to be clearly defined. Since frequent and intense seismicity has occurred for tens of millions of years and will not stop in the future, Costa Rica should prioritize proactive risk management, considering the unresolved limitations of precise and available data in its complex tectonic settings. Past and recent failed prediction efforts have caused false alarms, public fear, and economic harm. Advanced technologies like AI show promise but are still nascent and should support, not replace, preparedness. Early warning systems offer limited reaction time, are costly, often fail in rural or near-source areas, become overdependent on high-tech solutions, and create false senses of security. Worse, they undermine essential measures like building codes, public education, and hazard-based land use planning. Priority should be on communication, long-term resilience and reducing vulnerability. The key to saving lives and economic loss lies in risk management, not on unreliable earthquake predictions and warnings.

Keywords: Early warnings, Risk management, Risk communication, Risk management, Earthquake prediction

Factors: Observation, surveillance, warning, alarm, response, continuity, recovery		Alert, permanently.						
Stage	Natural hazards	Observation: Evolution analysis (alert)	Surveillance: Probability of causing damages	Warning: Imminence of a damaging event	Alarm: Materialization of a damaging event	Reaction: Response, action	Continuity: Operative, functional	Recovery: Return to normality
Rapid to medium gestation, sometimes predictable and visible	Sudden, flash/progressive flooding	Prospective stage: Identification and prognosis of hazards, vulnerability and risk; models, scenarios, simulations, drills…	Hydrometeorological variability and seasonality	Hydrometeorological hazards; situation at the watersheds	Hydrology, hydraulics, floods, overflows	Mobilization of required human, financial, material and technical resources Activation of action and response protocols Assessment of materialized risk, identification and mobilization of financial and technical resources Quantification of contingent liabilities and residual risk	Activation of protocols, procedures and actions to guide and carry out the resumption and restoration of the quality of life, and sustainable development processes	Alert conditions maintained; observation and surveillance processes continued and improved, based on documentation and lessons learned Identify and become aware and acquainted with the lessons not learned, or not understood Avoid reproducing previous vulnerability factors
	Slope instability: landslides, slow-sudden, violent; variable size		Evolution of shear strength, deformation, groundwater behavior, safety factor…	Acceleration, terrain deformation; influence of seismicity, intense rainfall, anthropogenic activity	Landslides, torrential debris flows, rock falls, intense erosion…			
Frequent, visible/invisible gestation; slow to sudden materialization	Seismicity: Vibrations, liquefaction, landslides, surface rupture, tsunami, continental uplift	With the support of territorial planning, comprehensive risk management, environmental management, institutionality, legislation, regulations and codes	Evolution of crustal deformation, seismic gaps; seismogeographic and accelerations records	Reliable only through probabilistic determination of seismic hazard; models with AI. Predictive models are still underdeveloped	Earthquakes and associated effects: intense vibrations, liquefaction, tsunami, landslides, etc.			
	Meteorology: Cold fronts; tropical systems (waves, depressions, storms, hurricanes), gales		Weather; atmosphere and oceanic synoptics	Gestation, synoptic evolution, trajectory, observed and foreseeable intensities (pressure, winds, temperatures, rainfall, surge)	Direct and indirect influence: pressure, winds, rains, swells, gales, surges			
Observable short and medium-term gestation	Drought		Climate variability: El Niño/La Niña-ENSO, ITCZ…	Extended dry seasons; severe water stress and deficit for more than three months; hydro/agrological effects/impacts	Drought types: meteorological, agronomic, hydrological, structural			
	Volcanism: Eruptions, lahars, gas, acid rain, tephra, lava, etc.		Micro-seismicity, thermal changes, degassing; crustal deformation…	Precursor evidence and indicators (GPS, geochemical, seismic, satellite…)	Explosive eruptions, lava and pyroclastic flows, domes, acid rain, lahars.			
	Asteroid impact		Astronomic observations, trajectory, approach, time…	Trajectory: interference to avoid and/or reduce impact	Local to global impacts			
Slow gestation (medium to long term)	Effects of anthropogenic global warming on climate variability		Evolution of greenhouse gases, vapors and particles (RCP/SST); ocean and atmosphere temperatures	Glaciers retreat; rising sea levels and temperatures; variations of wind, rainfall regimes; changes in microclimates	Very long-term local to global impact of climate extremes			
Very long-term	Climate change			Glacial-interglacial (cold-warm) periods; geological time scales				

Observation, surveillance, warning, alarm, response, operational continuity and recovery factors to consider when facing the materialization of natural hazards. The color code represents the classic traffic light scale palette of alarm systems (After Mora, et al., 2024).

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Sustainable Geological Risk Management: Insights for Post-Disaster Resilience and Mitigation from the February 6, 2023 Türkiye Earthquakes

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Abstract

The 6th February 2023 earthquakes in Turkey, with magnitudes of 7.8 and 7.5, caused widespread devastation, claiming thousands of lives and displacing millions. The aftermath exposed critical shortcomings in Turkey's approach to geological risk management. Despite considerable progress in disaster preparedness, recovery efforts revealed significant gaps in sustainable risk mitigation and underscored the urgent need for an integrated, multi-hazard framework.

This study assesses the lessons learned from the 2023 earthquakes, focusing on strategies to enhance post-disaster resilience and integrate sustainable risk management into future earthquake recovery plans. The primary objective is to distinguish key opportunities to improve building codes, land-use planning, risk monitoring, and preparedness, all of which are crucial for reducing vulnerability to both seismic and secondary geological hazards.

In the instant outcome, detailed site-specific studies were carried out to evaluate ground instability, liquefaction potential, and secondary risks like landslides and flooding. These studies played a critical role in identifying high-risk zones for future interventions and informing recovery strategies.

Furthermore, the study intends a holistic, integrated risk management framework that combines seismic and multi-hazard mitigation strategies, along with climate change resilience, to guide the rebuilding process. This framework underlines the importance of innovative technologies, institutional coordination, and community-based preparedness in fostering long-term sustainable development in post-disaster scenarios. By implementing this approach, the nations can better prepare for future geological hazards while enhancing resilience, recovery, and sustainability in disaster-prone regions.

Keywords: sustainable, geological risks, risk management, resilience, land use planning



10February2023-12.40 - one of the scenes right after the post disaster and its management

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Constraining Paleoseismicity Activity via Paleo-Landslide and Structural Analysis: Implications for Seismic Hazard in the Outer Western Carpathians

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Abstract

The Outer Western Carpathians (OWC) have traditionally been considered seismically stable, but emerging geological evidence challenges this assumption with significant implications for regional hazard assessment. This study investigates paleoseismic activity along the Czech-Slovak border by analyzing paleo-landslides and structural deformation patterns. We employed an integrated approach combining LiDAR mapping, electrical resistivity tomography, and paleoseismological trenching across the Holocene-active Lidečko Fault system. Timing was constrained using radiometric dating (radiocarbon, OSL, ^{10}Be), while slope stability was assessed through pseudo-static analysis and Newmark Displacement Analysis. Distinct-element numerical modeling validated earthquake-triggered slope failure interpretations. Structural analysis reveals active polyphase deformation, including strike-slip and oblique-reverse faulting with clear surface ruptures. We identified three generations of paleo-landslides characterized by half-ellipsoidal source zones and debris runouts exceeding 1 km; radiometric dating constrains the corresponding major paleoseismic events to ~91 ka, ~45 ka, and ~2 ka, indicating long recurrence intervals. Critical evidence comes from under-dip toppling features, where overturned sandstone beds indicate structural configurations requiring strong ground accelerations consistent with significant seismic events. These findings demonstrate previously unrecorded, significant paleoseismic activity within the OWC, challenging conventional assessments of regional seismic stability. Our integrated structural-geomorphological methodology provides a robust framework for identifying ancient seismicity in regions lacking historical earthquake records, offering essential insights for reassessing long-term seismic hazards and risk mitigation strategies.

The research was funded by the Grant Agency of the Czech Republic (GC22-24206J) and Taiwanese National Technological and Science Council (MOST/NTSC 111-2923-M-008-006-MY3) and development project RVO 67985891, Institute of Rock Structure & Mechanics, Czech Republic.

Keywords: Paleoseismic landslides, Seismic hazard, Stable continental interior Seismicity, Newmark displacement analysis, Outer Western Carpathians

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The Role of Excess Topography and Peak Ground Acceleration on Earthquake Preconditioning of Landslides

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Abstract

Landslides are a pervasive geophysical hazard occurring in all countries and causing almost 20% of all fatalities resulting from natural hazards globally. Therefore, the ability to manage and mitigate landslide risk is an imperative, especially in high relief and earthquake-prone mountainous regions worldwide. Despite decades of progress, landslide research including susceptibility models and landslide forecasts still suffer from significant problems and fundamental limitations. A key limitation is the commonly held assumption that the rate of landsliding through time is constant for a given region and trigger mechanism (i.e., time-independence). Yet research has demonstrated that this is untrue for many regions and that earthquakes can perturb rates of landsliding above a background rate over periods of years to decades – a process that has been termed pre-conditioning. Here, we address the role of earthquake preconditioning of landscapes through: a) the analysis of new and published multi-temporal landslide datasets (i.e., Papua New Guinea 2016-2022) to explore trends in causative factors across different tectonic and climatic regions; and b) the development of an innovative new landscape evolution module for shallow seismically-triggered landslides validated against the inventory data. Ultimately, this project will transform our ability to forecast rates and patterns of landslides before and after major earthquakes and mitigate against cascading and subsequent hazards in earthquake prone areas.

Keywords: Landslide, Earthquake, Preconditioning, Inventory, Modelling

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Paleoseismic Insights from the 2022 ML 6.9 Chihshang Earthquake in Eastern Taiwan and Their Implications for Seismic Hazard

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Abstract

The ML 6.9 Chihshang earthquake that struck eastern Taiwan on September 18, 2022, unveiled a previously underappreciated seismic source within the actively deforming Longitudinal Valley collision zone. Surface ruptures extended approximately 65 km, with cumulative rupture traces exceeding 100 km in length. Field investigations revealed predominantly thrust faulting with a substantial left-lateral component, producing maximum vertical and horizontal displacements of ~1.2 m and ~2.0 m, respectively.

We conducted integrated field mapping, trench excavation, and paleoseismic analysis, and the results document five major surface-rupturing events in the Songpu area over the past 600 years, including the 2022 Chihshang earthquake sequence and the 1951 Longitudinal Valley earthquakes.Based on the cumulative vertical offsets, we estimate a long-term uplift rate of 6.7–7.3 mm/yr for the Songpu site.

Our findings revise the current understanding of fault architecture in eastern Taiwan and highlight the potential for multi-fault ruptures, with important implications for regional seismic hazard assessments.

Keywords: 2022 ML 6.9 Chihshang Earthquake, Paleoseismology

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Numerical Assessment of Landslide–railway Interactions in the Earthquake-Induced Hazard Chains

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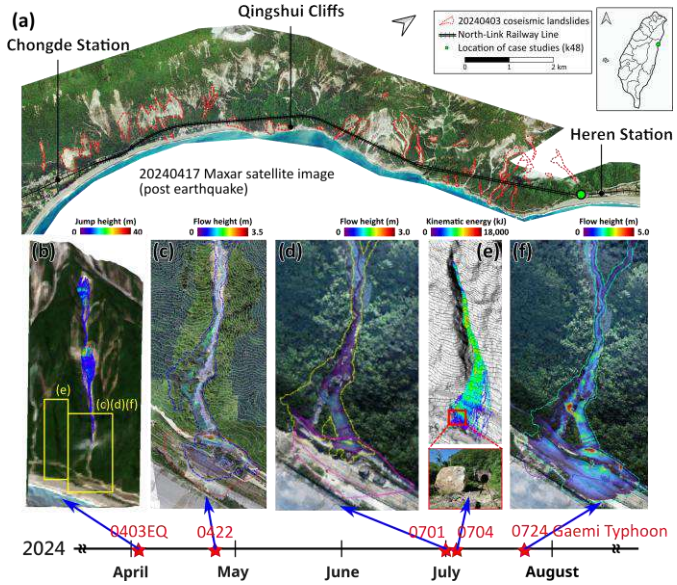
Abstract

On April 3, 2024, a Mw 7.1 earthquake struck Hualien, Taiwan, marking the third major earthquake in eastern Taiwan since the 2018 and 2022 earthquakes. Compared to the previous two earthquakes, the 20240403 Hualien Earthquake was unique because it triggered widespread coseismic landslides, resulting in significant casualties and property damage. Due to the steep terrain of the eastern region, transportation routes often run along foothills. Coseismic landslides heavily damaged the eastern railway and highway network, and the post-earthquake hazard chain posed significant challenges to subsequent reconstruction efforts. This study aims to assess the impact of the earthquake-induced hazard chain, including rockfall and debris flow, on railway facilities after the 20240403 Hualien Earthquake. Based on three-dimensional numerical simulation, we quantified the source magnitudes, movement paths, landslide mechanics change, and deposit impact for each event in a sequence of disasters. A case study at Mileage K48 of the North Link Railway Line shows that the coseismic rockfall deposit remained in the mid-gully with the block size approximately 10 m3. The deposit becomes the source of the following debris flow, and the first chain occurred on April 22 with 2586 m3 deposits at the railway facility. On July 1, the next disaster created a new path for the debris flow, increasing the hazard damage of the subsequent disaster (8490 m3 deposit) during 20240724 Typhoon Gaemi. The hazard damage maps under different risk scenarios will be proposed with the validated numerical approach to contribute to short-term and medium-term mitigation strategies.

Keywords: 20240403 Hualien Earthquake, Earthquake-induced hazard chains, Rockfall, Debris flow, Numerical assessment



(a) Coseismic landslides triggered by the 20240403 Hualien Earthquake and the railway route. Simulations of the (b) coseismic rockfall and the following disasters of the earthquake hazard chains ((c), (d), (f) were debris flow and (e) was rockfall) within 4 months.

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Integrated Evaluation of Urban Soils Liquefaction Hazards Potential Susceptibility Risk Mapping in Selected Districts of Lagos, South-Western, Nigeria

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Abstract

Extensive damage can occur to buildings and other engineering structures during static or dynamic loading owing to liquefaction of the soils beneath the structures. Recent seismic events recorded in Nigeria indicate that the country aseismic as always thought. This study was carried out to evaluate the liquefaction potential of soils from parts of Lagos Nigeria to generate baseline data to prepare for future liquefaction-induced problems. Standard Penetration Test (SPT) results including SPT N-value, percentage fines, bulk density and depth to water table data from 35 boreholes was accessed and used to calculate Cyclic Resistance Ratio (CRR), Cyclic Stress Ratio (CSR), Factor of safety against liquefaction and their corresponding Liquefaction Potential Index (LPI) while assuming an earthquake of magnitude 7.2 and peak ground acceleration of 0.55. The LPI obtained was used to produce a Liquefaction potential map. Correlation analysis of the LPI values with the N-values, groundwater table, percentage fines and density were conducted. The liquefiable areas mostly showed low N-values ($N \leq 10$), high water table and are closer to water bodies while the non-liquefiable areas showed higher N-values ($N \geq 10$), lower water table and are farther away from water tables. The CSR-corrected N-value plots for the liquefiable areas were mostly in the liquefaction zone and the LPI values ranged from 3-23. In addition, they also showed very low LPI values. The evaluation has helped delineate areas into severe, moderate, minor or no liquefaction potential prone areas in addition to understanding how each of the measured parameters affect the liquefaction resistance.

Keywords: Liquefaction, Standard Penetration Test, Earthquakes, Cyclic Stress Ratio, Cyclic Resistance Ratio.

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Preliminary Study on Enhancing Korea's Seismic Hazard Map and Design Standards through Quaternary Fault Information

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Abstract

Following the 2016 Gyeongju earthquake, a series of investigations on Quaternary faults were conducted in Korea, and their findings were made available to the public. However, significant technical challenges remain in applying these natural science-based information to engineering practices, particularly in the development of the National Seismic Hazard Map and the Unified Seismic Design Standards. The lack of established methodologies and technologies for selecting usable fault information, integrating them into engineering frameworks, and formulating seismic hazard and design criteria highlights the urgent need for specific research.

To address this gap, the present study was initiated to establish detailed guidelines for integrating Quaternary fault information into earthquake disaster risk reduction policies and institutional frameworks, such as the National Seismic Hazard Map and Unified Seismic Design Standards. During the first year of the project, a comprehensive investigation was carried out, focusing on three main areas:

(1) a review of development criteria and case studies involving the use of fault data in Korea's officially published seismic hazard maps (1997 and 2013);

(2) an examination of seismic source identification and classification, magnitude-frequency distribution models, and ground motion prediction equations; and

(3) an evaluation of the input parameters, predictive models, and their suitability in previously applied fault case studies.

This paper presents the outcomes of the initial phase of research, which serve as a foundational step toward developing engineering-based methodologies for the effective application of Quaternary fault data in seismic hazard assessment and structural design standards(Project Number: RS-2025-02653118).

Keywords: Quaternary Fault, Seismic Hazard Map, Design Standards, Earthquake

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Assessment of Earthquake Effects on Slope Stability: A Case Study

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Abstract

Slope failures are a widespread geological hazard that frequently cause significant property damage and loss of life. Even slopes generally deemed stable can become susceptible to failure when subjected to sudden external forces, such as earthquakes. This study evaluates the effects of the September 12, 2016 Gyeongju earthquake on slope stability in the Gyeongju region of South Korea. Using field survey data to characterize slope properties, numerical simulations were performed to assess slope stability under both static and dynamic loading conditions. A comparative analysis of pre- and post-earthquake scenarios highlights the impact of seismic events on slope integrity, offering valuable insights into the mechanisms driving earthquake-induced slope failures. Furthermore, to elucidate the relationship between slope safety factors and peak ground acceleration (PGA), analyses were conducted across a range of PGA values. Understanding this correlation is essential for accurate on-site slope stability evaluations and will inform future seismic design practices and related stability assessments(Project Number: RS-2025-02653118]).

Keywords: Earthquake, Slope Stability, Slope failures, seismic design,

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A Comparison Between the Susceptibility Factors Controlling Earthquake-Induced Landslides in a Dryland and Wetland Mountain Landscape

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Abstract

In 2015 an Mw7.8 earthquake occurred in the Nepal Himalayas, affecting a wetland area including subtropical forests, to temperate and alpine mountains. The initial USGS landslide Ground Failure model for this event estimated that the area exposed to earthquake-induced landsliding would be extensive (>1,000km2) and expose a population of 10,000 - 100,000 people. This estimate was broadly corroborated by post-event landslide mapping, which identified a similar order of magnitude of landslides (> 20,000) as anticipated over an area coincident with that shown by the model. In comparison, in 2023, a large (Mw6.8) and exceptionally rare intraplate earthquake struck Morocco, affecting the dryland High Atlas Mountains. The initial USGS landslide Ground Failure model for this event also estimated that the area exposed to co-seismic landslides would be significant (10 - 100km2), but with a more limited population exposure (100 to 1000 people). However, a post-event assessment by the Earthquake Engineering Field Investigation Team (EEFTI) identified only 2000 landslides over a much smaller and more constrained area than that estimated by the USGS model. In order to investigate the differences between the initial USGS ground failure estimates for these two events, this paper explores the main susceptibility factors of the mapped earthquake induced landslides. The results for the two evens are then compared to assess the co-seismic landslide controls in dryland and wetland landscape, with the aim of informing and improve future rapid assessments of co-seismic ground failure.

Keywords: Earthquake, landslides, geohazard, resilience

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Topographic controls on seismic wave amplification and landslide triggering: A case study in Totsukawa Village, Nara, Japan

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Abstract

Seismic wave propagation in complex terrain often leads to significant amplification effects that critically influence landslide initiation, yet the scarcity of instruments in mountainous areas has hindered systematic, field-based quantification. To address this gap, we established a temporary four-station network across contrasting mountain sectors, ridge crest, valley bottom, north–south slope, and east–west slope, in Totsukawa Village, Nara Prefecture, Japan, operating from November 15, 2017 to December 10, 2019. We selected 24 earthquakes recorded during this period and applied a Fast Fourier Transform (FFT) with 81.92 s windows and Parzen smoothing (0.2 Hz) to compute spectral amplitudes on the east–west (EW), north–south (NS), and vertical (UD) components. Our analysis reveals pronounced topographic dependence of amplification: crest sites and specific slope aspects exhibit elevated spectral peaks at distinct frequency bands, whereas valley bottoms show comparatively muted responses. These spatial patterns of energy concentration align with zones of historically documented landslide initiation, underscoring the importance of terrain-driven amplification in seismic landslide hazard. The outcomes provide a robust framework for refining hazard models and tailoring mitigation strategies in similar orogenetic settings.

Keywords: seismic wave, amplification, earthquake, landslide, topography

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Evaluating the Impact of the Laurensberg Fault on Seismic Ground Motion in Aachen (Germany) through Numerical Modeling and HVSR Validation

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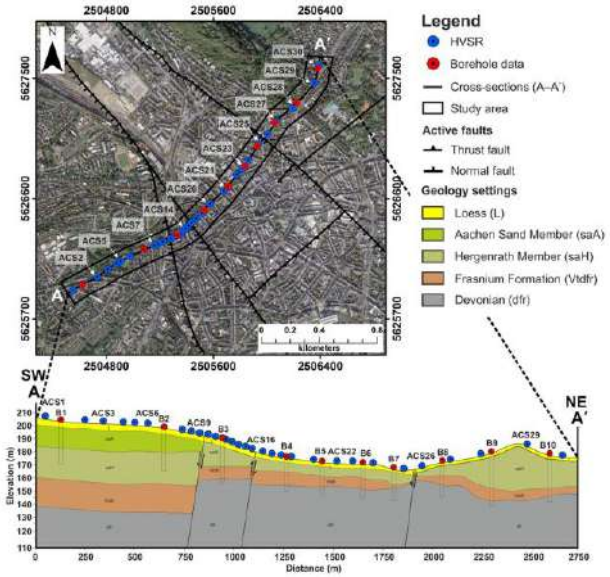
Abstract

Precise seismic hazard assessment in urban areas requires detailed characterization of local geological and tectonic conditions. This study investigates the seismic influence of the Laurensberg Fault in Aachen, Germany, through a combination of horizontal-to-vertical spectral ratio (HVSR) measurements, ellipticity curve inversion, and numerical modeling. A total of 30 HVSR measurements were conducted along a southwest–northeast profile crossing the Laurensberg Fault. The HVSR analysis identified two prominent resonance peaks: a primary peak (f0) in the low-frequency range (1.5–4.5 Hz), indicative of sediment thickness and depth to bedrock, and a secondary peak (f1) at higher frequencies (30–70 Hz), associated with fault-induced subsurface heterogeneities. Spatial variability in fundamental frequency and peak amplitudes strongly correlated with fault proximity and subsurface conditions. Rayleigh wave ellipticity inversion, constrained by geological and borehole data, produced detailed shear-wave velocity (Vs) profiles. These profiles formed the basis for constructing a comprehensive 2D Vs model, delineating four principal seismic layers with Vs values ranging from <250 m/s in shallow sediments to >1000 m/s in Devonian bedrock. Two numerical models were developed to quantify the fault's impact: Profile 1 incorporated the Laurensberg Fault geometry calibrated with HVSR and geological data, while Profile 2 excluded fault structures to isolate their influence on amplification. Dynamic numerical simulations using the Universal Distinct Element Code (UDEC) validated the Vs model and demonstrated substantial variations in seismic amplification and peak ground acceleration attributable to fault-controlled energy redistribution.

Keywords: HVSR, Dynamic numerical modeling, Seismic amplification, Rayleigh wave ellipticity inversion, Laurensberg Fault



Map and geological cross-section (A–A′) of the central Aachen study area. The map shows HVSR points and boreholes on a satellite background. The cross-section illustrates stratigraphy based on Ranft (2011), borehole, and HVSR data, including Loess (L), Aachen Sand (saA, saH), Frasnium (Vtdfr), and Devonian bedrock (dfr). Borehole (B1–B10) and HVSR (ACS1–ACS30) locations are indicated.

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The Role of Halloysite in the Initiation and Movement of Coseismic Landslides on Tephra Slopes

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Abstract

Landslides on tephra-covered slopes triggered by earthquakes often exhibit high mobility and long runout, posing significant threats to lives and infrastructure. Notable examples include those caused by the 2016 Kumamoto and 2018 Hokkaido Eastern Iburi earthquakes. Field investigations revealed that these landslides are typically shallow but destructive, with sliding surfaces formed within weathered tephra layers that are rich in water and halloysite (a clay mineral derived from volcanic glass). Given similar findings in other countries, halloysite is considered a contributing factor to both slope failure initiation and enhanced post-failure mobility. However, its precise role remains unclear. This study aims to clarify the influence of halloysite through field investigations and laboratory tests. In the first phase, XRD, SEM, and TEM analyses confirmed the presence and morphological differences of halloysite in samples from Minami Aso (tubular shape) and Atsuma (platy or crumpled lamellar). The second phase used pF tests to evaluate halloysite's impact on water retention. Results showed that halloysite-rich tephra maintains higher water content, likely due to its microstructure. In the third phase, direct shear and ring shear tests were conducted to examine shear behavior. Findings indicated that adding halloysite reduces peak shear strength, increases brittleness, and lowers the energy needed for shear failure and rapid movement, thereby increasing landslide susceptibility and mobility. In conclusion, halloysite enhances water retention and post-failure mobility while lowering resistance to shear, making tephra slopes more prone to landslides during seismic events.

Keywords: Fluidized landslide, Tephra slope, Halloysite , Shear behavior , Water retention

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Site-Specific Probabilistic Seismic Hazard Analysis for the Akosombo Saddle Dam, Ghana

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Abstract

This study presents a site-specific probabilistic seismic hazard analysis (PSHA) for the Akosombo Saddle Dam located in Akosombo, Ghana. The primary objective is to determine design-basis ground-motion spectral parameters to support the seismic performance assessment of the dam, following the provisions of ICOLD B148. The analysis includes three main components: (1) Seismic Source Characterization (SSC), (2) Ground Motion Characterization (GMC), and (3) PSHA calculations. The SSC phase involves developing a comprehensive earthquake catalogue within a 500 km radius, identifying regional seismotectonic structures, and defining seismic source zones with associated maximum magnitudes (Mmax) and earthquake recurrence parameters. Epistemic uncertainties in SSC are captured through a logic-tree framework representing alternative zonation schemes and seismic source parameters. Under the GMC framework, ground-motion models (GMMs) are developed using a backbone scaling approach and logic-tree structure to account for both epistemic and aleatory uncertainties. The models are selected based on regional seismotectonic compatibility and recent literature on ergodic sigma models. The PSHA is conducted using the OpenQuake platform, generating hazard curves and uniform hazard response spectra (UHRS) for 5% damping at return periods of 145, 475, 2,475, and 10,000 years. Results are provided for two reference site conditions (VS30 = 760 m/s and 1000 m/s). Disaggregation of spectral accelerations at PGA, 0.2 s, and 1.0 s are also performed to identify plausible dominant seismic contributors. The outputs support the development of Maximum Considered Earthquake (MCE) and Design Basis Earthquake (DBE) spectra from international practices (e.g. ASCE/SEI 7), as well as ICOLD B148: Safety Evaluation Earthquake (SEE) and Operating Basis Earthquake (OBE), providing critical input for seismic safety and structural performance evaluation of the dam.

Keywords: seismic hazard, earthquake engineering, dam, ICOLD

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Prevention Is More Beneficial Than Remedy: Earthquake

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Abstract

The inland earthquakes cause disasters only in soil plains, not on/in rocky grounds. The calculated values of local magnitude and intensity through the equations used worldwide do not match the data observed at the seismometer stations. The proposed equations are the dependent functions of only moment magnitude at the origin (Mw) and radius (R, km) to the origin. After each earthquake, the relevant equations are updated using coefficients and factors through regression analysis. However, it doesn't work in the next earthquake particularly for soil basins. Consequently, the seismic risk zoning map is too far from what the observed data indicate. The main reason for this is that; data used in regression analysis are taken from seismometer stations that do not show systematic distribution and thickness of the soil mantle (t>10 m) and soil basin width (w>200 m), depth to the groundwater table (DGWT<10 m), the relationship between seismic wavelength (l, μm) and structure height (H, m), geotechnical properties, and seismic wave velocities in soil and rock in question are ignored. To eliminate the earthquake risk, it is sufficient to first delineate the soil basin-rock boundary and use the soil basins only for agriculture. Even the rocky ground adjacent to the epicenter is safe. Structures, in any case, have to be designed in accordance with international codes. Based on half a century of experience/observations, it has been concluded that the soil basins are only for agriculture whereas rocky grounds with higher safety and sanitary conditions are for residential and engineering structures.

Keywords: Earthquake, Bedrock, Soil, Attenuation, Agriculture



Intracontinental earthquakes destroy only structures in soil basins; they do not destroy structures on/in bedrock.

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A Basic Study on the Acquisition and Analysis of Active Faults at Beokgae area in the Southeastern Korean Peninsula

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Abstract

Active faults in the southeastern part of the Korean Peninsula were first identified about five years ago and have been reconfirmed through recent ground excavation, fault identification, and fault motion analyses. The objective of the fault trench survey is to clarify the relationship between earthquakes and faults, support seismic design, and provide fundamental data for safe ground management in areas affected by active faults. A trench approximately 12 m long was excavated in an east–west direction for fault zone investigation. The excavation revealed clear internal structural characteristics of the fault zone, which can be divided into three parts: a fault zone, a fault nucleus–damage mixing zone, and a damage zone. The fault zone is relatively narrow, about 4 m wide, but represents the core structure where strong shear deformation is concentrated. Within the fault nucleus, dark foliated fault rocks, gray fault gouge, and lens-shaped rock fragments are mixed, showing typical features of a principal slip zone (PSZ). A very narrow PSZ, only several millimeters wide, was observed inside the fault nucleus. This zone consists of extremely fine-grained and densely compacted materials, indicating repeated concentration of seismic slip during fault activity. For detailed analysis, samples were collected from three locations with clearly different lithological characteristics. Microstructural and mineralogical analyses show that the western damaged bedrock consists of siliceous veins with abundant microcracks and shear fractures, providing clear evidence of brittle deformation related to faulting. In contrast, the eastern damaged bedrock is composed of Cretaceous sedimentary rocks containing a dense network of calcite veins. These veins are interpreted to reflect fluid flow and crack-healing processes associated with fault activity.

Keywords: active fault, trench , motion analysis of fault, principal slip zone, damage zone



Trench Site Photo of Active Fault Survey

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Classification of Severity of Liquefaction Phenomena With the Values of Liquefaction Potential Indices

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Abstract

Liquefaction is an earthquake secondary effect that can induce failures on both free-field and structural environments. The severity of the phenomena varies from small-scale sand boils to large-scale damages on structures, mainly located on waterfront areas and buildings constructed on areas of high liquefaction potential. In order to estimate this potential, the indices of Liquefaction Potential Index and Liquefaction Severity Number have been proposed and applied to relevant studies. Recently, thousands of new data points derived by in-situ tests conducted on liquefied and non-liquefied sites are available to research. The main goal of this work is to calibrate the severity of liquefaction phenomena as they have been reported after an earthquake with estimated values of LPI and LSN. Our analysis concludes that LPI values seem to better discriminate between liquefaction and non-liquefaction cases, albeit with some overlap. Moreover, the LPI threshold value derived from our data as a predictor of liquefaction or not is calculated to be higher than the value proposed in the original published paper introducing the LPI index.

Keywords: earthquake, CPT, liquefaction, statistical

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Damage Evolution Characteristics and Instability Mechanism of High-Elevation Shattered Rock Masses in the Wenchuan Meizoseismal Zone

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[2] Changan University, Xian, Shannxi, China

Abstract

High-elevation seismically fractured rock mass refers to rock masses on steep slopes that are cracked but not yet slid, loosened but not yet moved, as a result of strong earthquake-induced damage. Focusing on the key scientific issue of the strength degradation mechanism and instability mechanism of high-elevation seismically fractured rock masses in strong earthquake zones, this study takes the seismically fractured rock masses in the Wenchuan strong earthquake zone on the eastern margin of the Qinghai–Tibet Plateau as the research object. Using multi-source remote sensing interpretation and detailed field investigations, we identify the post-earthquake spatiotemporal evolution characteristics of seismically fractured rock masses on slopes of different geomorphic types and establish geological prototypes for the degradation and instability of fractured rock masses. Based on mechanical property tests of seismically fractured rock masses under adverse conditions such as rainfall, earthquakes, and freeze–thaw cycles, we reveal the strength degradation mechanism of fractured rock masses under multi-factor time-sequential coupling and construct a strength degradation model. By employing a coupled discrete element and discrete fracture network method, we reveal the coupling mechanism of internal stress fields, deformation fields, and fracture propagation evolution in fractured rock masses under different dynamic actions, propose instability criteria and methods for predicting instability scales, and uncover the instability mechanism of seismically fractured rock masses under the influence of multiple environmental factors.

Keywords: High-position shattered rock mass, Characteristics of rock mass fractures, Multi-factors coupling, Deterioration of rock strength, Instability mechanism

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Seepage Assessment and Grouting Strategy in Karstified Limestone at Zemakān Dam Using Integrated Field Investigations and 3D Numerical Modeling

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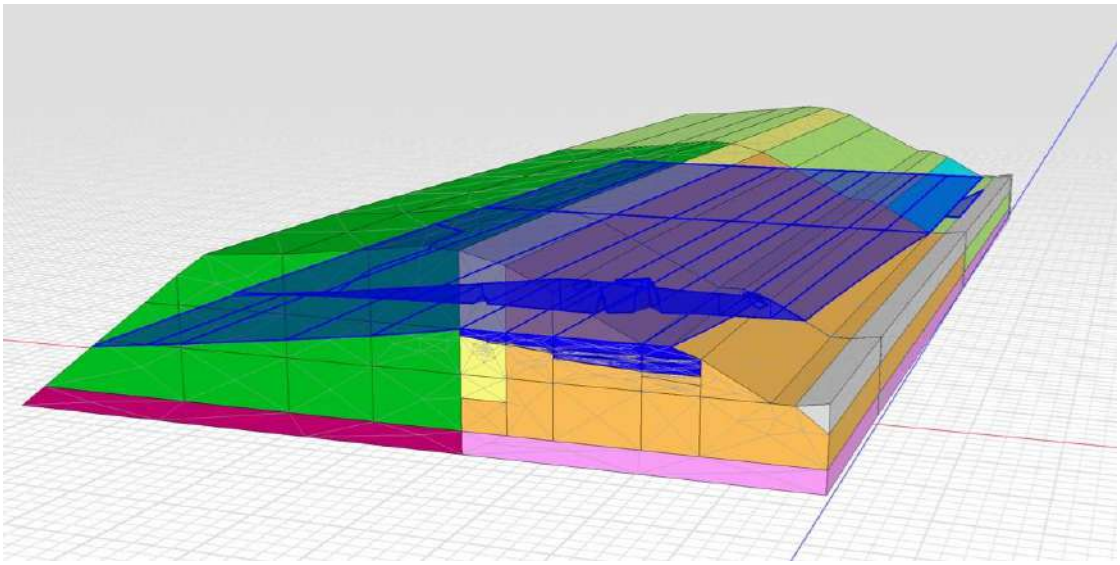
Abstract

Following the impoundment of the Zemakān Dam reservoir in 2017 and seismic activity of Sarpole Zahab earthquakes in November 2017 and December 2018, significant seepage was observed through the karstic limestone of the Taleh Zang Formation on the dam's left abutment. Comprehensive field investigations, including geological mapping, hydrogeological surveys, borehole drilling, geophysical methods (IP/RS, SP), and dye tracing identified water movement through a complex system of joints and fractures, predominantly aligned with the Balul anticline axis. Major discharge points were detected along the left riverbank 700 meters downstream and at Nazari and nearby springs approximately 1200 meters downstream, with seepage volumes reaching up to 1 m^3/s. To assess and predict seepage behavior, a three-dimensional seepage model (SEEP3D) was developed. It was calibrated using observed discharge data at two reservoir levels and permeability data derived from Lugeon tests in 15 boreholes along the existing grout curtain. The model enabled reliable prediction of seepage under normal reservoir conditions (elevation 1542 m). To mitigate leakage, a grout curtain extension is proposed: a 200-meter horizontal extension of the grouting gallery at elevation 1535 m, coupled with a 230-meter surface extension, enhancing the dam's hydraulic integrity and long-term performance.

Keywords: Karst hydrogeology, 3D modeling, Geohazard



3D Model

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Analysis of Hydrodynamic-Induced Stress in the Bossea Mountain Karst Aquifer Through Passive Seismic Monitoring

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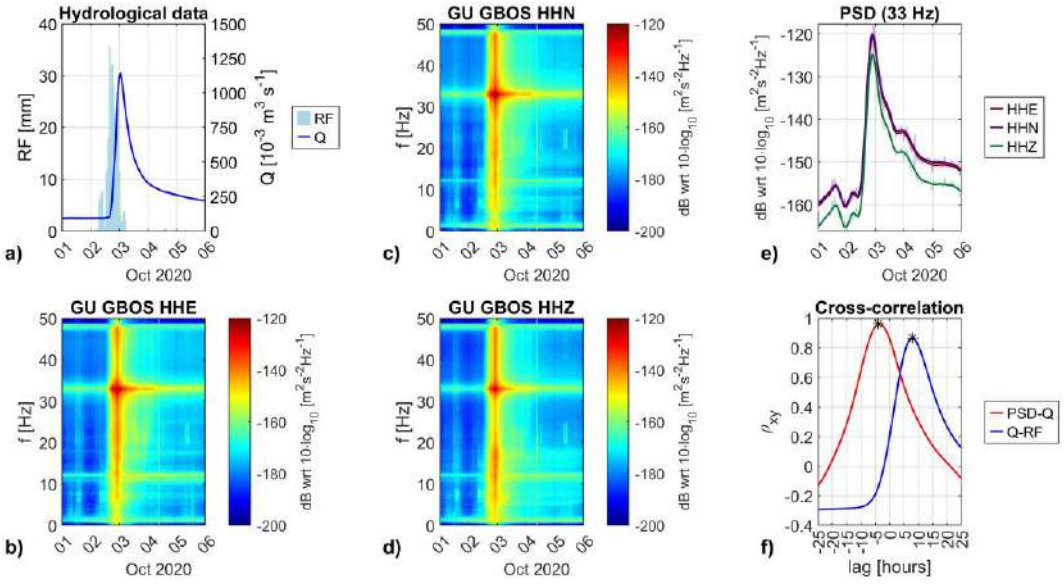
Abstract

Continuous passive seismic monitoring has provided insights into detecting and tracking the evolution of the rock mass responses under hydro-mechanical processes at multi-daily timescales. The Bossea Cave is a mountain karst aquifer located in the Ligurian Alps (Piedmont, NW Italy). It developed at the contact between a Permian impermeable meta-volcanic basement and an overlying Triassic meta-carbonate sequence. This upper unit controls the drainage of infiltrating water, mainly driven by rainfall and snowmelt processes occurring in the aquifer's recharge area. The seismic signature of these water inflows was investigated using a three-component seismometer installed in the hypogeal environment. Ambient-noise Power Spectral Density (PSD) was computed on each component to identify high-energy frequency bands and examine their temporal evolution, comparing it with the discharge trends of the main drain (Mora Creek). A strong correlation was detected at approximately 33 Hz on the North, East, and vertical components, with a zero-lag response under ordinary recharge conditions. In contrast, during extreme inflow events (e.g., October 2020), increases in seismic-noise amplitude preceded the discharge peak by approximately 4 hours. These observations complement the results of a temporary external seismometer survey deployed on the slope above the cave in 2022, where precipitation-driven modulation was identified in the 50–90 Hz band and a 30-Hz amplification occurred about 4 hours before the peak discharge. This combined evidence provides a basis for investigating the triggering mechanisms of coupled thermo- and hydro-induced rock-mass deformation and for characterizing the spectral signatures of impulsive microseismic signals potentially associated with incipient fracturing.

Keywords: karst aquifer, hydrodynamics, passive seismic monitoring, spectral analysis,



Power spectral densities (PSD) of seismic recordings from 1 to 6 October 2020, including an extreme rainfall–flood event. a) Discharge (Q) and rainfall (RF) time series. b) PSD of the East channel. c) PSD of the North channel. d) PSD of the Vertical channel. e) Temporal evolution of the 33-Hz band amplification. f) Cross-correlation results between the discharge and the rainfall (Q-RF), and between the selected 33-Hz band and the discharge (PSD-Q).

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Investigating Land Subsidence in Qatar Due to Underground Cavity Collapse: Insights from Geological and PSI InSAR Data

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Abstract

Sinkholes and cavities caused by evaporite dissolution pose significant geotechnical risks to infrastructure throughout Qatar. These hazards are primarily associated with the dissolution of evaporite layers within the Rus and Dammam formations. This process—driven by percolating water and fluctuating groundwater levels—can result in collapse, ground deformation, or even large-scale subsidence.

To assess these risks, an extensive ground-truth survey was carried out, supplemented by the analysis of borehole logs. Additionally, Persistent Scatterer Interferometry (PSI) was applied to Sentinel-1 SAR imagery from 2017 to 2024 to monitor and quantify surface deformation. Integrating PSI-derived deformation data with geological and geotechnical information enabled the identification of three categories of affected areas across Qatar: (A) zones showing surface deformation without a confirmed link to subsurface cavities or sinkholes, (B) zones where deformation coincides with mapped subsurface cavities, and (C) zones where deformation patterns correspond with known sinkholes.

These findings highlight the critical role of geological knowledge in understanding land subsidence and demonstrate the effectiveness of PSI in detecting and mapping deformation patterns on a regional scale in areas dominated by evaporite formations.

The authors acknowledge the Qatar Geological Mapping Project Phase II.

Keywords: Land subsidence, Sinkholes, evaporites` dissolution, Cavities, InSAR



The Dahl Duhail (A) and Dahl Al Hamam (B) Sinkholes. (C) & (D) present damages in contractions identified at the surmounting areas of the two sinkholes, respectively.

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Discontinuity Characterization and Block Size Evaluation in Calcareous Karstic Units at the Sierra d'Ordal, NE Spain

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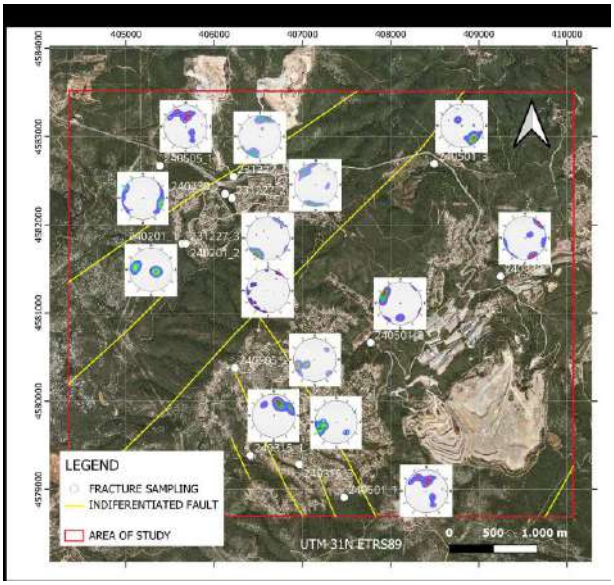
Abstract

The percolation of water, and therefore the potential for dissolution, in karstic terrains is controlled by the number of existing discontinuity sets and their characteristics. Factors such as spacing, persistence, aperture, infilling and surface roughness determine the size and degree of interlocking of rock blocks influencing the susceptibility to collapse and the formation or enlargement of dolines. At the Sierra d'Ordal, Barcelona Province, scanline surveys were conducted on outcrops near pre-existing collapse dolines, some of which are located within or adjacent to residential areas. Our study, first of its kind in the area, indicates that the block size is Large with predominant Fairly Opened and Opened apertures, between 0.25 and 1.0 cm, according to ISRM classifications. JRC is highly variable. This suggests that longer periods may be required for dissolution of the calcareous rock blocks. However, in areas close to regional faults, the number of discontinuity families is larger, diminishing the size of rock blocks. These aspects can be applied in subsequent evaluations of water-rock interaction such as assessing water transmissivity through discontinuities and evaluating rock block stability at walls and roofs of cavities for doline formation or enlargement.

Keywords: caprock, block size, doline, Ordal Sierra



Joint sampling sites for block size evaluation and associated stereograms that represent the number of joint families at Ordal Sierra, Barcelona Province.

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Deformation and Water Loss in Volcanic Valleys of Central Mexico: Geomechanical Analysis and Soil Conservation of Lacustrine Soils

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Abstract

Quaternary lacustrine deposits in the volcanic valleys of the Trans-Mexican Volcanic Belt (TMVB) in central Mexico exhibit distinctive lamination patterns controlled by both environmental processes and active geodynamic conditions during their formation. The fine-grained sediments record the interaction among variations in water content, sediment composition, biological activity, and deformation processes associated with groundwater exploitation, providing valuable insights into the geological evolution and engineering behavior of former lake basins. We present the geomechanical analysis of an interdisciplinary project that integrates geological, hydrogeological, geotechnical, and biological approaches to characterize the physical and mechanical properties of these deposits and to evaluate the socio-environmental consequences of land- and water-use changes in rapidly urbanizing former lacustrine environments. The study focuses on lacustrine sediments that share three defining characteristics: (1) clay-rich sequences composed of altered volcanic minerals, in some cases with high organic matter content; (2) documented land subsidence during the past four decades; and (3) progressive desiccation resulting from climate change and regional aquifer overexploitation. This work aims to investigate the relationships between sediment architecture and the mechanical response of clayey deposits in contrasting lake conditions: Two maar basins located in the state of Guanajuato, Rincón de Parangueo and La Alberca; and two volcanic lakes in the state of Michoacán, the El Marijo Site, Cuitzeo, and Santa Fe de la Laguna Site, Patzcuaro. Emphasis is placed on water retention capacity and soil deformability, which strongly influence land subsidence and ground fracturing. In the context of increasing urban pressure, the final purpose is to integrate the assessment of the geological properties of these clay-rich soils to guide land use decisions in former lacustrine zones, considering that priority should be given to preserving the ecological function of soils, but also to evaluating their potential for sustainable agriculture or urban development.

Keywords: Subsidence, Land use change, Volcanic valleys, TMVB Mexico, Urbanization

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Erosion and Structural Weakening in Sandstone Arches: Geohazard Implications from Pravčická brána

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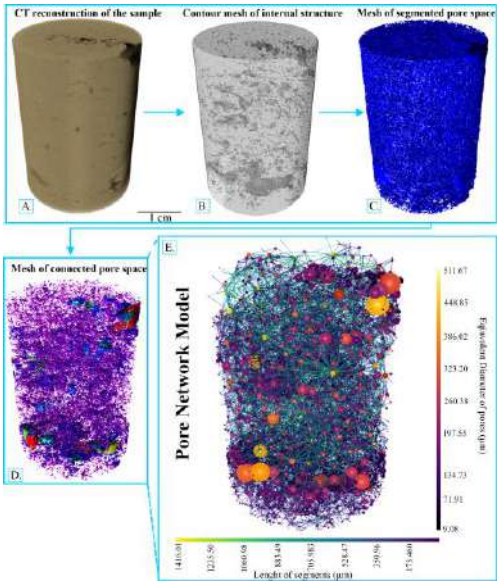
Abstract

This contribution presents a multi-method investigation of the microstructure and weathering susceptibility of sandstone from Pravčická brána, the largest natural rock arch in Europe. The study combines conventional porosity measurements with advanced, non-destructive techniques to assess the rock's internal structure and durability. Mercury intrusion porosimetry (MIP), pore network modelling (PNM) from post-processed µCT data, and saturation flow experiments using non-Newtonian fluids (ANA method) were used to characterize pore size distribution (PSD) and permeability. All approaches revealed a dominant macroporous network with consistent PSD peaks at 18 µm (ANA), 22 µm (PNM), and 48 µm (MIP). The sandstone displays high total (34–45%) and effective (30–42%) porosity, with laboratory-measured permeability (3.1×10^{-5} m·s^{-1}) closely matching the simulated value (2.21×10^{-5} m·s^{-1}). Scanning electron microscopy revealed quartz grain fractures indicative of historical frost action. Although the PSD suggests relative resistance to freeze-thaw and salt weathering, the broader mechanical context—low material strength, tectonic predisposition, and high macroporosity—points to structural vulnerability. These characteristics may amplify fracture development under environmental loading. The findings emphasize the importance of integrating traditional petrophysical methods with advanced imaging and modelling tools to understand the long-term stability of geologically significant formations like Pravčická brána.

Keywords: Microstructural analysis, ravčická brána rock arch, Weathering, Pore Space, µComputed Tomography



The five steps of postprocessing of µCT images and resulting PNM. The first step (A) involves CT reconstruction on object filtering. The second step (B) entails visualization of the internal structure by means of contour mesh. The third step (C) is P-space binarization, which is achieved through a thresholding technique based on visual feedback. The fourth step (D) is connected pore space separation, which is accomplished through a watershed segmentation algorithm. Finally, the fifth and final step (E) is the resulting PNM.

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A Novel Data-Graphics Integrated Method for Quantifying Macro-laws Analysis of Karst Morphology Based on Borehole Data

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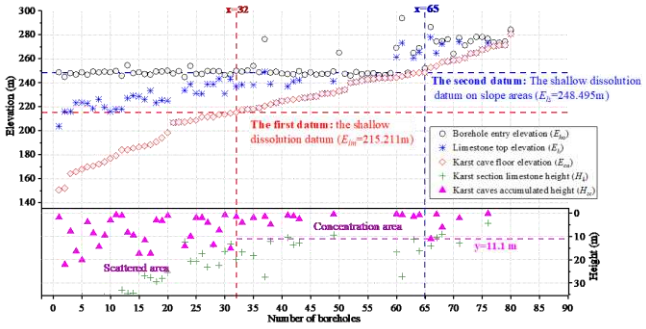
Abstract

This study addresses the longstanding challenge of quantitatively characterizing macro-laws analysis in karst morphology across both engineering geological cross-sections and planar zones. The core innovation lies in the construction of one specialized diagrams and the definition of two critical elevation datums: the shallow dissolution datum (Elm) and the slope-specific shallow dissolution datum (Els). Regions situated below Elm are classified as Class DD, predominantly featuring horizontal caves, whereas those above Elm are designated as Class SD. The presence of the slope-area datum Els further subdivides Class SD into subclasses SD1 and SD2, which are dominated by vertical dissolution fissures and grooves. Crucially, this approach enables quantitative macro-laws analysis of karst morphology at both microscopic cross-sectional and planar scales. Field validation demonstrates that the method effectively guides bridge foundation selection, pile length optimization, construction troubleshooting, shallow tunnel burial depth determination, and overall project cost control. Compared to conventional methods, the implementation of this framework resulted in an average reduction of 20%–40% in pile length modifications across multiple projects, significantly mitigating project expenditures.

Keywords: Karst morphology, Shallow dissolution datum, planar karst zones, karst classification, macro-laws analysis



The determination method of two elevation datum

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Occurrence of Karst Features in Northeast Belgium and the Southeast Netherlands

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Abstract

For the construction of large underground infrastructures such as the Einstein Telescope (ET), it is essential to understand the geology of the subsurface as accurately as possible. This contribution focuses on the occurrence of karst in the Euregion Meuse-Rhine (EMR), which is considered as a possible location for the ET. The occurrence of karst can have a significant impact on engineering works through both rock quality and hydrogeology. Although the exact location of karst cavities often cannot be predicted with sufficient accuracy for the construction of underground structures, it is useful to identify and map karst-sensitive lithologies at an early stage of the project planning process. Karst phenomena in the study area that may be relevant to underground construction activities are expected only within the carbonates of the Lower Carboniferous ('Dinantian'). When these carbonates are covered by Upper Carboniferous ('Namurian') shales, there is a reasonable chance of encountering paleokarst. In cored boreholes drilled for the ET-EMR project, hardly any open cavities were found in the massive limestones, but porous 'ghost' karst horizons were identified, which can easily be reactivated and transported by changing the hydraulic conditions. In addition, the possible occurrence of hydrothermal karst must also be considered. This type of karst is closely related to Zn-Pb mineralizations found in the southeastern part of the study area, and may affect both water quality and the processing of excavated material.

Keywords: Karst, Belgium, The Netherlands, underground infrastructure

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Sandification-Induced Physical and Mechanical Property Damage of Dolomite in Yunnan, China

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[2] Chengdu University of Technology, Chengdu, Sichuan, China

Abstract

Dolomite undergoes karst-related sandification due to multi-stage tectonic movements and the coupled effect of dissolution and weathering. This process is characterized by the gradual disintegration of microcrystalline to fine-grained dolomite into a heterogeneous structure interbedded with sandy, clastic, and weakly weathered rock masses. When such a special geological body is encountered during underground engineering, it easily triggers disasters such as collapse, mud inrush, and water gushing, which seriously threaten engineering safety. In this paper, Cambrian dolomite in Yunnan Province, China, is used as the research object. Based on field investigation, on-site sampling, laboratory tests, thin-section identification, mineral and chemical composition analysis, physical and mechanical experiments, and theories including rock mechanical damage variables and damage mechanisms, the damage characteristics of mechanical properties caused by dolomite sandification are systematically described and studied. Mechanical property evaluations demonstrate a pronounced nonlinear correlation between the degree of dolomite sandification and mechanical deterioration. The fundamental mechanism driving this degradation during karst-induced sandification is attributed to the synergistic coupling of mineral dissolution, topological reconfiguration of the pore-fracture network, and water-rock interactions. Based on the analysis of the dynamic evolution mechanism of “dissolution–cementation–connection”, it is proposed that the mechanical damage evolution process of sandified dolomite exhibits a three-stage progressive development characteristic.

Keywords: Dolomite, Karst sandification, Physical property, Damage law, Mechanical property

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Green and Low-Carbon Tilt Correction of a High-Rise Building on Karst Ground Using Controlled Grouting-Induced Uplift

Xuedong Cui[1], Tengyue Cui[1], Tenghao Cui[1]

[1] Beijing Hengxiang Hongye Foundation Reinforcement Technology Co., Ltd, Beijing, Beijing, China

Abstract

Karst cavities and weak foundation soils can induce differential settlement and tilt in pile-supported high-rise buildings, creating significant serviceability and safety concerns. This study investigates an 18-storey building in Weining County, Guizhou, China, and develops a controlled grouting-induced uplift method for green and low-carbon tilt correction. Field monitoring and drilling investigations recorded a maximum settlement of approximately 107.7 mm. Several piles were not embedded in stable bedrock, while localized subsurface voids and soft-plastic red clay further weakened pile support. An analytical pile-soil-void model and numerical simulations were then used to quantify the effects of cavity geometry and soil stiffness and to guide treatment design. The adopted scheme first reinforced the weak soil layers above the pile tips and subsequently generated controlled uplift through pressure grouting with an environmentally friendly composite grout. Construction was performed in stages under continuous deformation monitoring to control the magnitude and uniformity of uplift. Post-treatment measurements showed that the final building deviation was controlled to within 2 cm, meeting the relevant code requirements. By using in-situ reinforcement, reducing redundant drilling and limiting material waste, the method provides a green and low-carbon approach for treating differential settlement and tilt in urban karst ground conditions.

Keywords: differential settlement, karst ground, controlled grouting uplift, numerical modelling, green and low-carbon rehabilitation

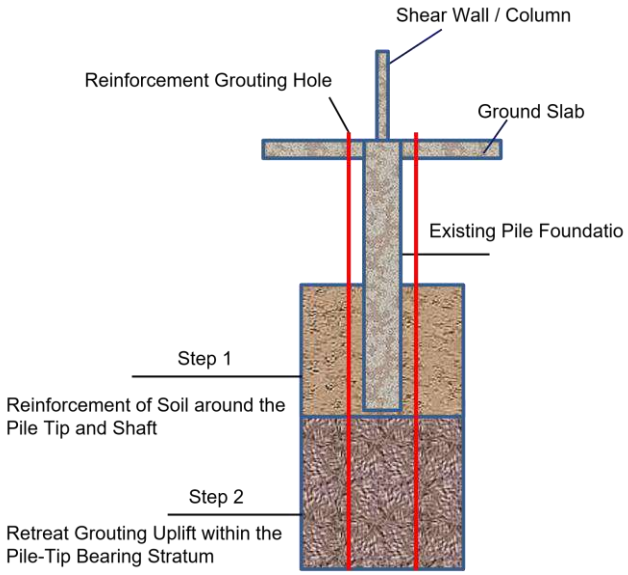

Fig. 1. Schematic Diagram of Two-Stage Pile Foundation Reinforcement and Controlled Grouting Uplift

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Monitoring-Guided Controlled Uplift by Compaction Grouting for Green and Low-Carbon Tilt Correction of a High-Rise Building on Soft Ground

Xuedong Cui[1], Tengyue Cui[1], Tenghao Cui[1]

[1] Beijing Hengxiang Hongye Foundation Reinforcement Technology Co., Ltd, Beijing, Beijing, China

Abstract

Differential settlement of pile foundations in complex soft ground can induce tilt and structural distress in high-rise buildings. Large-scale jacking and other highly intrusive correction measures may also disturb the existing structure and surrounding environment. This study investigates a high-rise building in Zhangzhou, Fujian, China, and develops a green and low-carbon-oriented, monitoring-guided controlled compaction grouting uplift method for tilt correction. Engineering investigation and three-dimensional numerical analysis indicated that inadequate pile embedment and excessive thickness of weak soil were the principal causes of differential settlement. A volumetric-strain-based simulation method was used to reproduce soil expansion and building uplift induced by compaction grouting, allowing the responses of candidate treatment schemes to be predicted and compared. The selected scheme combined shallow staged reinforcement with deep regressive compaction grouting uplift, with construction parameters adjusted according to field deformation monitoring. After treatment, the measured maximum cumulative uplift reached 84.91 mm and the building inclination rate decreased from 3‰ to 0.07‰. The maximum difference between simulated and measured post-grouting settlement was only 3.1 mm, confirming the predictive capability of the numerical method. With limited disturbance to the existing structure and surrounding environment and reduced need for large-scale reconstruction, the approach provides a green, low-disturbance and low-carbon solution for tilt correction of high-rise buildings on soft ground.

Keywords: differential settlement, soft ground, controlled compaction grouting uplift, numerical modelling, green and low-carbon rehabilitation

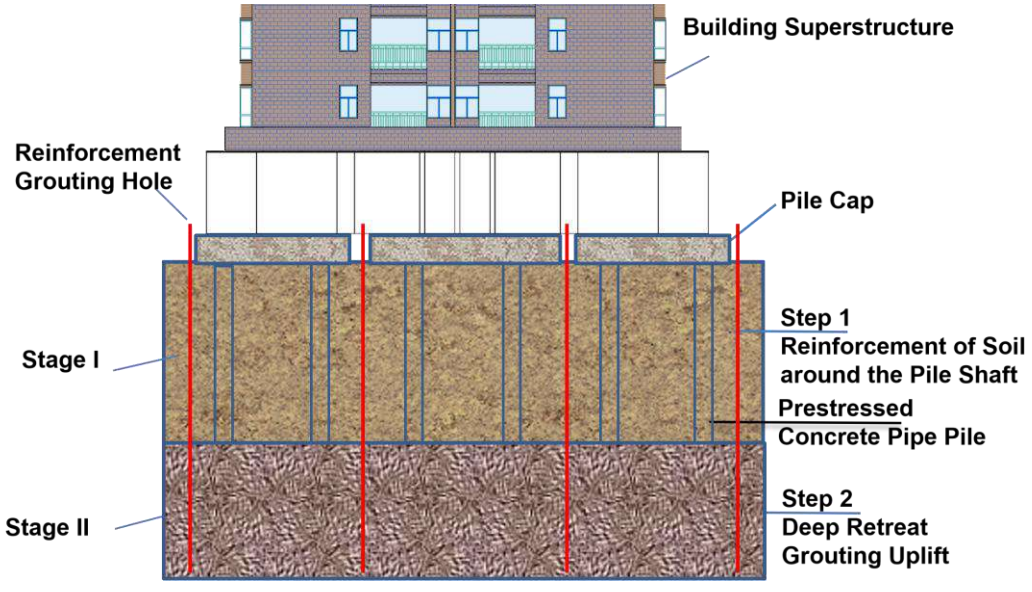

Fig. 1. Schematic diagram of staged pile-foundation reinforcement and controlled deep retreat grouting uplift.

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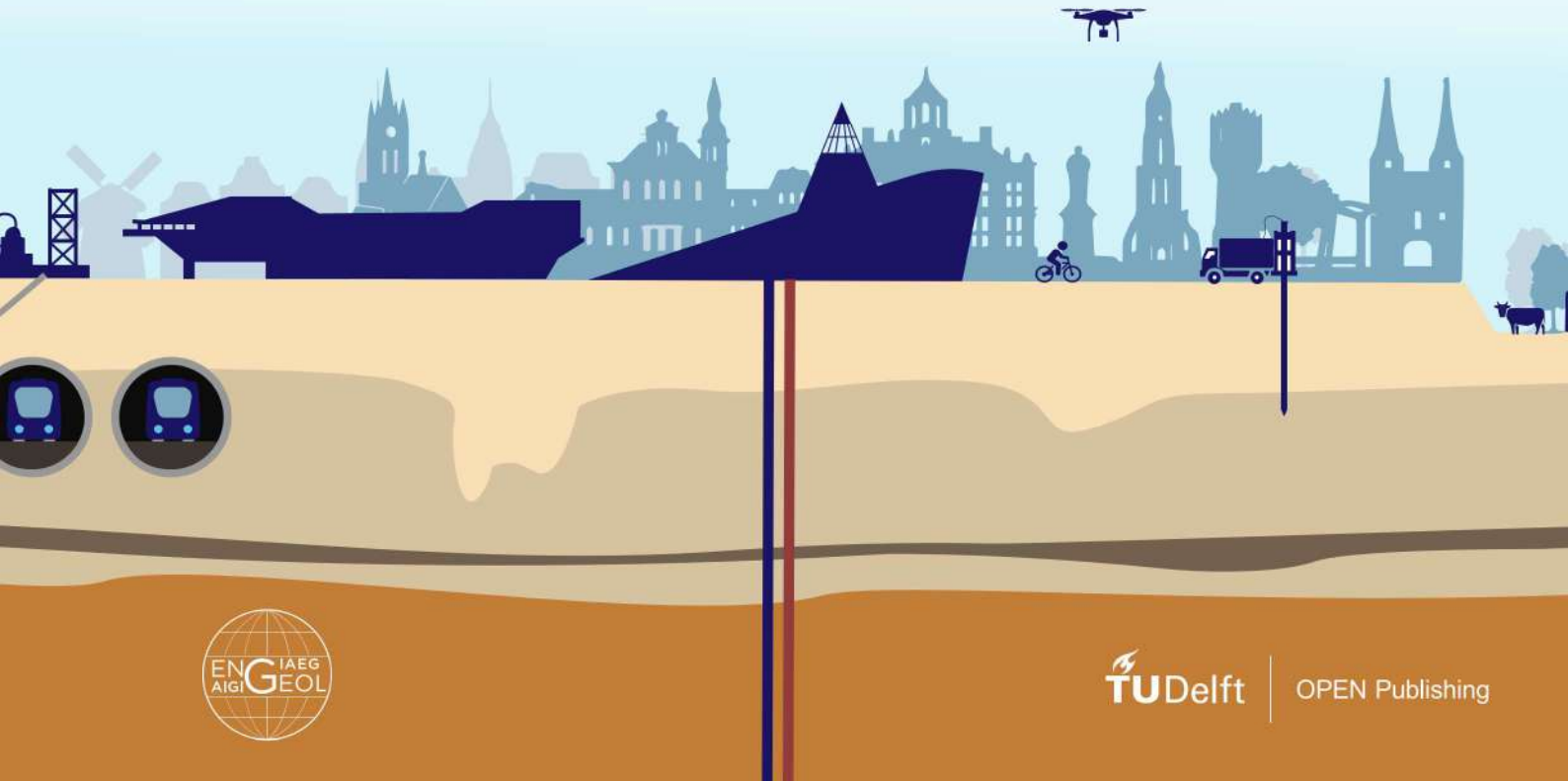
4. Engineering Geology in the Energy Transition



Role of Engineering Geology in CO sequestration, energy storage, geothermal energy, wind energy, hydropower, and nuclear energy.



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Cross-scale fracture development around deep geothermal wellbores in the North Alpine Foreland Basin, SE Germany

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Abstract

This study investigates the fracture behavior of limestone and dolostone using the finite-discrete element method (FDEM), specifically analyzing the influence of mesh refinement on fracture patterns and joint roughness coefficient (JRC). Simulations employed semi-circular bend (SCB) and double-notched Brazilian disk (DNBD) test configurations, supplemented by 2D borehole models. Key findings demonstrate that increased mesh refinement systematically alters fracture mechanisms: the proportion of tensile fractures decreases while shear fractures increase. Concurrently, JRC values, quantifying fracture surface roughness, decrease with both greater refinement and increased measurement base length. A comparative analysis revealed that dolostone exhibits more shear-dominated fracture patterns and higher JRC values than limestone. Borehole simulations further localized high JRC values to zones of elevated stress and damage, confirming the inverse relationship between JRC and base length. The results underscore the significant impact of numerical discretization on simulated fracture characteristics. This work provides critical insights for enhancing the accuracy of rock fracture simulations and contributes to a better understanding of the mechanical behavior of carbonate rocks in engineering contexts.

Keywords: deep geothermal energy, numerical FDEM modelling, fracturing characteristics, scale transfer, mechanical characterization

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Geology of the North Sea in relation to wind-farm construction: just an aspect to take care of or should it determine where to build?

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Abstract

To achieve its ambitious climate goals, the Dutch government has introduced a comprehensive roadmap for offshore wind farm development, aiming to generate approximately 21 GW of offshore wind energy by 2032. Currently, the Netherlands' offshore wind farms have a combined capacity of nearly 5 GW. This means that very large wind farms will be built in the coming years. The government has selected several potential wind-farm areas. For these areas geological desk studies are executed, followed by detailed research including geophysical surveying and subsurface sampling. This results in a good 3D-overview of the subsurface and potential engineering challenges being identified. But how are all these researches used in the final decision to place the monopiles at specific locations? In this presentation I will start with giving an overview of the relevant geology of the North Sea. I will show examples of the research that is generally executed, both from desk studies and more detailed investigations. I will link this to the decisions that were made to build wind farms at a certain location. For this I will have talks with people in charge of these decisions. Based on these upcoming talks I will answer the question in the title.

Keywords: windfarms, geology, North Se, geophysical data

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Hydro-mechanical laboratory testing of deep Paleogene clays

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[1] Delft University of Technology, Delft, Netherlands

Abstract

In the Netherlands, deep Paleogene clays are being considered as potential host formations for geological disposal of radioactive waste. These clays are known to possess favourable properties for containment in their natural state; however, their hydro-mechanical behaviour remains poorly characterised, partly due to limited availability of high-quality samples. This study aims to propose appropriate testing procedures and obtain key parameters describing the rate-dependent volumetric behaviour under one-dimensional vertical loading for these stiff clays.

Constant Rate of Strain (CRS) and incremental oedometer tests are conducted on Boom Clay samples obtained at the level of the HADES Underground Research Laboratory beneath Mol (~225 m b.g.l.) and Landen Clay Formation samples extracted from the DAPGEO-02 borehole beneath Delft (~400 m b.g.l.). The two clays are both considered as potential host formations, and differ in stress history, mineralogical composition and pore water chemistry. Sample preparation and testing protocols are specifically designed for these clays, with particular attention to the preservation of their natural structure and minimisation of disturbance. Sample preparation and testing procedures have first been verified using Boom Clay samples obtained at shallow depth, and the interpretation of the laboratory results is supported by coupled hydro-mechanical finite element modelling.

Test results are compared across clay types and testing methods. The findings highlight the importance of tailored protocols for mechanical testing on deep clays and provide the first hydro-mechanical test results for deep Landen Clay, thereby contributing to the reduction of uncertainty in the design of a disposal facility in the Netherlands.

Keywords: deep clays, hydro-mechanical behaviour, testing protocol, CRS

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The Delft Subsurface Urban Energy Laboratory: Overview and progress

Philip J. Vardon[1], Hemmo A. Abels[1], Taylan Akin[1], Auke Barnhoorn[1], Stijn T.W. Beernink[1, 2], Martin Bloemendal[1, 3], Diederik Boersma[1], David Bruhn[1], Alexandros Daniilidis[1], Guy Drijkoningen[1], Amirhossein Hashemi[1], Alexis Koulidis[1], Ergin Kükrer[1], Susanne Laumann[1], Paula Rulff[1], Martin van de Schans[2], Thorben Schöfisch[1], Evert Slob[1], Liliana Vargas Meleza[1, 4], Denis Voskov[1]

[1] Delft University of Technology, Delft, Netherlands
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Abstract

Geothermal energy from sedimentary systems, especially for heating purposes, is projected to play a critical role in the (thermal) energy transition. This brings subsurface energy extraction close to urban environments, due to low energy densities and energy losses during transit. The demand in urban areas can be high, and therefore sub-surface space will be limited, and adjacent projects may interact. Geothermal energy can be produced year round, and is not dependent on the weather, however thermal energy has a large annual variation in demand, and therefore energy storage can play an important role in both making geothermal projects more financially efficient and supplying peak demands, which are often supplied by fossil fuels. Adverse effects, e.g., cooling induced seismicity, are of increased importance in urban areas. To address these and other challenges, the Delft Surbsurface Urban Energy Laboratory (DSUEL) is being implemented. This centres around a deep (~2.2 km) geothermal doublet, a High Temperature Aquifer Thermal Energy Storage (HT-ATES) system, and an ultra-deep >4km monitoring and exploration borehole. The energy system supplies the campus of Delft University of Technology and will supply around 15 000 equivalent households in the city of Delft, and is an important source of critical knowledge and testing technology. A sophisticated measurement system and measurements and sampling during installation will be outlined, as will the current status of the laboratory.

Keywords: Geothermal, Living laboratory, Field testing



Illustration of the Delft Subsurface Urban Energy Laboratory

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Fracture mechanical characterization of an analogue sandstone for a medium-depth geothermal reservoir in SE-Germany

Lilith Fröhlich[1], Daniel Sebastian Albrecht[1], Catharina Drexl[1], Laura Mackh[1], Kurosch Thuro[1]

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Abstract

Deep geothermal energy offers significant potential to address the challenges of climate change. In Germany, the Federal state of Bavaria has a pioneering role, with geothermal plants operating successfully in the Jurassic carbonates of the North Alpine Foreland Basin. However, to achieve climate targets, the Geothermal-Alliance Bavaria is exploring new reservoirs, with a promising option in the medium-deep Triassic sandstones of northern Bavaria. To successfully realize geothermal projects, understanding the geomechanical properties of the reservoir rocks and associated fracture processes is crucial, as these significantly influence wellbore stability, with the fracture toughness as a key parameter controlling fracture propagation. Hence, for an analogue sandstone representing the Triassic reservoir, the Mode II fracture toughness was determined using the Punch-Through Shear test. By combining the laboratory setup with acoustic emission monitoring and a 2D FDEM model of the test, microscopic fracture patterns and failure modes could be evaluated. Across four stages, comprising crack closure, elastic and plastic deformation, and the post-peak stage, several fracture processes and types were observed, including tensile wing and tensile radial fractures, and shear failure. Despite the development of tensile fractures, failure was predominantly shear-driven. FDEM realistically depicted laboratory-scale fracturing. The workflow enhances the understanding of microscale processes in the studied analogue rock. It provides a methodological basis for future investigations of the medium-deep reservoir rocks, supporting improved assessments of wellbore stability in clastic geothermal systems.

Keywords: Punch-Through Shear test, Finite-discrete element modelling, Acoustic emission, Keuper sandstone, Medium-deep geothermal energy

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Determination of the Hydraulic Conductivity of Sandstone using Triaxial Permeability Tests – Applicability and Challenges

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Abstract

Sandstone is a common reservoir rock widely encountered in subsurface engineering applications, such as carbon capture and storage (CCS), geothermal systems, and hydrocarbon reservoirs. Accurate evaluation of rock permeability and porosity under varying effective stress conditions is crucial for these applications. Porosity determines the storage capacity of a reservoir, while permeability, or hydraulic conductivity, significantly influences fluid transport feasibility. Insufficient permeability can lead to excessively high injection pressures, potentially compromising the structural integrity of reservoir barriers. However, collecting deep in-situ cores is prohibitively expensive and logistically challenging, creating a practical barrier to routine reservoir characterization. To address this challenge, this study investigates the relationship between porosity and permeability of existing sandstone cores under varying effective stresses (0.4, 0.8, 1.6, 3.2, and 6.4 MPa) using triaxial permeability tests. Sandstone samples were systematically subjected to increasing effective stresses to assess their impact on pore structure and fluid transport characteristics. Computed tomography (CT) was employed to evaluate total and effective connected porosity, verifying that connected pore spaces were fully saturated with water. Gas presence could disrupt water saturation and fluid flow pathways, affecting measurement accuracy. These comprehensive results provide valuable guidance for optimizing injection strategies, reservoir management, and evaluating potential storage sites.

Keywords: CO2 sequestration, triaxial permeability tests, porosity, sandstone, injection pressure

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Multi-method analysis of the fracture toughness of rocks from geothermal reservoirs and analog samples in SE Germany

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Abstract

Deep geothermal energy could be a climate-friendly heat source in south-eastern Germany, where the geological subsurface offers favorable conditions for using deep geothermal energy. However, technical challenges can still limit the economic feasibility of geothermal plants, such as borehole instability, which can be caused by fractures that form in the borehole due to thermal, mechanical, or hydraulic stresses.

The rock mechanical properties of the surrounding reservoir rock play a decisive role in predicting such risks, particularly the so-called fracture toughness. This describes the resistance of a material to the propagation of fractures. As knowledge of the fracture toughness of the rocks is of enormous importance, these parameters are determined on selected reservoir rocks and corresponding analog rocks from quarries.

Various fracture toughness tests are available for this purpose, such as the semi-circular bend test, the punch-through shear test, or the double-edge notched Brazilian disk test. For a more detailed analysis of fracture initiation, the fracture propagation in the laboratory is recorded with a high-speed camera. In addition, acoustic emission sensors are used to record micromechanical fracture events in real time, thus enabling the localization of fracture processes that are not visible to the high-speed camera.

Combining both measurement methods on a laboratory scale enables a detailed characterization of the fracture behavior with a high temporal and spatial resolution. These insights into the fracture mechanics of geothermal-relevant rocks are essential for improving geomechanical models, optimizing borehole designs, and ultimately increasing the economic efficiency of future geothermal projects.

Keywords: Fracture Toughness, Acoustic Emission, Granite, Deep Geothermal Reservoir, Fracture Mechanics

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Assessment of Shallow Geothermal Capacity for Urban Heating and Cooling. a Case Study From the 'Shallow Geothermal Potential Maps' project.

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Abstract

Polish Geological Institute – National Research Institute (PGI-NRI) is conducting a project entitled "Shallow Geothermal Potential Maps", focused on developing pilot GIS-based information layers. This project aims to deliver specialized planning tools that support both quantitative and qualitative evaluation of geological and thermal conditions in Poland. The maps and databases developed as part of the project are intended to support the efficient design of ground source heat pump (GSHP) installations. They also assist local authorities in assessing the extent to which low-temperature geothermal energy can meet the heating needs of specific regions or urban areas. The maps are derived from 3D models of shallow geothermal units extending to a depth of approximately 300 meters, enabling further analysis. The project data can be used as input for evaluating the geothermal energy potential beneath various types of buildings, including residential buildings using borehole heat exchanger (BHE) technology. An example of such an analysis is presented in a case study of a large housing district in Warsaw, Poland, with approximately 20,000 inhabitants. In this case, 57 scenario variants were analyzed for 156 buildings, with the results visualized in both 2D and 3D. A summary in the form of charts and tables was prepared, allowing the classification of buildings into four categories based on their energy demand and geothermal capacity. For each building, the most suitable GSHP implementation variant was identified. For buildings where GSHP systems could not fully meet the heating demand (i.e., less than 100% coverage), complementary solutions were proposed.

Keywords: shallow geothermal energy, ground source heat pumps, renewable heating and cooling, GIS, 3D modeling

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Evidence From Investigations for New Nuclear Power in Bradwell, Essex, England: Pre-Holocene Estuarine Deposits From Two High Sea Level Events

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Abstract

At Bradwell, Essex, UK, recent investigations ahead of a potential new nuclear power station yielded evidence for two pre-Holocene estuarine deposits beneath the Holocene salt marsh. These were investigated to enable the assessment of seismic hazard near to a known fault that may have caused an earthquake in the late 1800s. From a ground engineering perspective, we show that there was no evidence of ground movement since deposition of Bradwell Channel Unit A (correlated using amino-acid geochronology to the penultimate interglacial - MIS 7, c. 240 ka BP). Furthermore, it suggests that a fairly high possibility of encountering older sequences with different strength / stiffness when building nuclear infrastructure on Holocene salt marshes. This study has additional implications for offshore installations and palaeochannel locations – i.e. that we might expect multiple generations of palaeochannels with different geotechnical properties at similar elevations. Preservation of different age deposits at similar elevations also points to limited uplift since c. 240 ka BP. Scientifically, ground investigation ahead of building energy transition infrastructure has allowed new understanding to be developed. This study fills both spatial and temporal gaps at this location by providing information that is not available except through ground investigation. The preservation of penultimate interglacial (MIS 7) deposits is surprising because peak sea level during this highstand event was lower than during MIS 5e. These deposits can also provide tiepoints for understanding uplift and subsidence histories due to past glacial loading during MIS 6, or subsidence of the adjacent sedimentary basin.

Keywords: Nuclear, Salt marsh, Estuary, Geochronology, Seismic hazard assessment

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Criteria and Methodology for Locating Underground Thermal Energy Storage in the Soil and Rock Mass Using Closed Systems

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Abstract

This study presents the development of a comprehensive methodology for assessing the suitability of locations for underground thermal energy storage (UTES) in soil and rock mass using closed systems - Borehole Thermal Energy Storage (BTES), Pit Thermal Energy Storage (PTES), Tank Thermal Energy Storage (TTES), and Energy Foundations/Thermal Geostructures (EF/TG). The project was carried out by the Polish Geological Survey (PGS) as part of a national strategic task aligned with the Polish geothermal roadmap and broader energy transition goals. The primary objective is to establish geological, technical, and environmental criteria that assess the feasibility of closed UTES systems. Key factors include lithological homogeneity, excavatability and drillability of the geological medium, thermal properties (conductivity and volumetric heat capacity), presence and variability of groundwater, terrain morphology, and potential adverse geological-engineering conditions. The methodology also incorporates spatial analysis using GIS tools, integration of surplus heat source data, and legal/regulatory framework review. Preliminary analyses focus on areas adjacent to industrial facilities, waste heat sources, and district heating networks. Results will support the creation of a ranking of potential UTES locations and be shared via PGI-NRI's geoportals, enabling open access to suitability maps and data layers. This work contributes to the development of a unified framework for implementing scalable, seasonal thermal energy storage in Poland, supporting decarbonization strategies and enhancing the resilience of local energy systems.

Keywords: Underground Thermal Energy Storage, Thermal Geostructures, Thermoactive Engineering Constructions, Closed Loop Systems

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Geological and Thermal Data Integration for Shallow Geothermal Potential Assessment in Poland Using GIS Tools

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Abstract

The Polish Geological Institute – National Research Institute (PGI-NRI) is conducting a project entitled "Shallow Geothermal Potential Maps", which aim is to support the development of ground source heat pumps as a green source of heating and cooling. This project represents the first nationwide initiative aimed at creating a comprehensive shallow geothermal database, with the goal of optimizing the planning of ground source heat pump (GSHP) systems and ensuring their environmentally safe installation and operation.

The main objective of the project is to develop Shallow Geothermal Potential Maps based on 3D geological models and the thermal properties of the ground. This involves several stages, including large-scale data storage and processing using modern software tools that apply GIS geoprocessing methods—such as ModelBuilder in ArcGIS Pro or Python scripts (NumPy). The collected data includes laboratory and field thermal conductivity tests, thermal response tests, as well as geological and hydrogeological datasets.

The developed database will be presented, along with its structure and possible applications. The dataset enables multi-criteria analyses by integrating geological, thermal, and technical parameters. Relationships between individual data components—such as geological layers and thermal conductivity—will be highlighted to illustrate how the integrated system supports planning, decision-making, and the optimization of shallow geothermal energy use.

Keywords: database, renewable energy sources, ground source heat pumps, thermal conductivity, GIS

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Assessment of geological and engineering conditions in a selected area of the southern Baltic Sea: A Case study of the Baltica 2 OWF in Poland

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Abstract

Offshore wind farms are a key element of the energy transformation, bringing numerous ecological benefits. In line with the development towards a low-emission economy, the first farms in Poland are currently being built. The challenge at the beginning of the investment was the insufficient knowledge of the geological and engineering conditions of Polish marine areas, which is why it was very important to design and conduct detailed in situ and laboratory tests. According to the geological and mining law in Poland, the test results should be presented in the geological and engineering documentation, which specifies, among other things, the geological and engineering conditions of the construction site. The analysis of geological and engineering conditions in the area of the Baltica 2 OWF was carried out based on the results of research conducted in 2021-2024. The geological and engineering layers were described taking into account stratigraphy, genesis and lithology, and then based on the physical and mechanical properties of the complexes. In general, the lithological profile in the Baltica 2 area consists of five main units: Holocene marine soils, Pleistocene fluvioglacial and lacustrine soils and two layers of till. The conditions in the substrate of the planned investment are influenced by strongly consolidated tills and boulders, which may constitute an obstacle during construction. Glacitectonic deformations and erosion processes were also observed. Due to the variability of geological and engineering conditions in this area, the design of foundations requires an individual approach.

Keywords: engineering-geological conditions, geological documentation, offshore wind, Baltic Sea

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Borehole and Aquifer Thermal Energy Storage Developments and Opportunities

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Abstract

Aquifer Thermal Energy Storage (ATES) and Borehole Heat Exchanger (BHE) systems are key technologies in space heating and cooling of buildings. Hence, following high adoption levels in the Netherlands, in urban areas they substantially occupy subsurface space, both with their wells as well as beyond thermally and hydraulically. In addition, during installation and operation, there are further interactions with existing infrastructure. ATES systems require permeable, often confined aquifers for efficient bidirectional water flow and thermal exchange. BHE systems (sometimes embedded in geo-structures) rely on closed-loop boreholes, utilizing conduction has heat transport process rather than groundwater pumping. Their design is more flexible, allowing deployment in less permeable lithologies. However, high-density installations of both type of systems can lead to thermal interference between systems, reducing efficiency and affecting long-term subsurface temperature regimes. As urban areas densify and adopt these systems, strategic spatial planning becomes essential to avoid conflicts and ensure sustainable use of the subsurface. Developments are ongoing in the following areas and are the subject of this contribution. 1. Thermal zoning/planning and depth regulations exist in the Netherlands. Developing integrated subsurface use simulation tools can aid the increasing density of use. 2. Installing in locations with existing subsurface infrastructure: impacts on foundations have been quantified. 3. Mapping and characterizing resources. 4. Novel technologies to install systems where otherwise it would not be possible; and 5. Increasing temperatures to store more energy in the same space.

Keywords: BHE, ATES,

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Numerical Forward and Inverse Simulation of Heat Production and Heat Storage in Heterogeneous Targets

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Abstract

Direct-use geothermal systems encompass both production of heat from subsurface reservoirs and storage of heat in shallower aquifers. While both rely on the same physical principles, the geological targets differ significantly in terms of property ranges and how they are utilized. Deep aquifers are typically used for continuous heat production, whereas shallow aquifers are often employed for seasonal thermal energy storage and both contribute to dynamic, multi-component energy systems. These differences require tailored modelling approaches to accurately assess performance, recovery efficiency, and the spatial extent of thermal influence—particularly in densely developed areas where spatial constraints are critical. Recent advances in simulation capacity enable the rapid simulation of large-scale models that preserve realistic geological heterogeneity. These forward models offer valuable insights into subsurface fluid flow and thermal dynamics. Despite access to extensive datasets, uncertainties in subsurface properties persist. Geophysical techniques are therefore essential for validating forward simulations and enabling inverse modelling, which can refine estimates of key properties. In this work, we highlight recent developments in both forward and inverse modelling, using a deep geothermal production system and a high-temperature aquifer thermal energy storage system (HT-ATES) both located on the Delft campus. Our simulation approaches integrate the latest geological insights and heterogeneity characterization for each system type.

Keywords: Geothermal energy, Heat storage, simulation, forward modelling, inverse modelling

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Influence of Water Content and Void Ratio on Thermal Properties of Two High-Plasticity Clays

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Abstract

The efficiency and long-term performance of Underground Thermal Energy Storage systems rely on the accurate characterisation of the host medium's thermal response. In this study, we investigated the thermal conductivity, diffusivity, and volumetric heat capacity of two high-plasticity clayey marls sampled at Dubičná and Třebenice (Czech Republic), representative of common Central European subsoils. We examined these thermal properties in relation to soil structure, water content, and porosity using three complementary methods: the thermal needle probe, Hot Disk transient plane source, and optical scanning. Tests were conducted on both undisturbed and reconstituted samples to isolate the effects of the soil's natural structure from the intrinsic material behaviour. Laboratory results were validated against in situ profiles obtained from a 15.5 m exploratory borehole. Thermal conductivity typically increases with water content. However, our experiments revealed the opposite trend: with water content increasing from ~28% to 50%, thermal conductivity decreased from 1.45 to 0.70 W·m-1·K-1. This was attributed to the dominance of void ratio increasing (soil swelling) over fluid bridging (due to saturation). Our research shows that standard thermal models, which assume λ rises with water content, overpredict λ in these saturated swelling soils, and provides measured λ–e and λ–w relationships for design use.

Keywords: thermal diffusivity, void ratio, UTES, clay, thermal conductivity

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Predicting the Future – the Role of the Engineering (Hydro)geologist in Developing Credible Performance Requirements for Energy Infrastructure

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Abstract

There is a vital role for engineering geologists, and hydrogeologists, in managing ground risk in the design of energy generation infrastructure as society adapts to a changing world. Current practice requires characterisation of present day ground conditions to inform design and construction, however there is an increasing focus on predicting and quantifying future conditions. Existing energy generation infrastructure must be adapted to make it resilient to greater climatic extremes. There is also an opportunity to incorporate suitable performance criteria and adaptability into design for new infrastructure. Whilst there has always been a balance to be struck between robust management of ground risk, constructability and financial implications for construction and operation, the envelope of uncertainty is becoming increasingly wider over the life of new energy infrastructure. This is particularly pertinent when considering the role of groundwater in design. Using the new nuclear power plant Sizewell C, currently being constructed in Suffolk, UK, as a worked example this paper considers the degree to which uncertainty can be constrained. It also discusses the barriers to establishing a common approach across the industry, regulatory and technical challenges and what role ground engineering practitioners can play in addressing them.

Keywords: Hydrogeology, Nuclear, Adaptation, Design, Uncertainty

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Revival of an Abandoned Hydropower Project: Challenges, Adaptive Strategies and Learnings from the 120 MW Rangit-IV Project, Sikkim, India

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Abstract

Hydropower construction in the young and tectonically active Himalayan mountains is an intricate interplay of geological unpredictability and engineering expertise. NHPC Limited undertook the responsibility of reviving a decade-long abandoned project and to carry out balance construction works. Upon entrustment, project components necessitated extensive inspection to frame rehabilitative measures before commencement of the excavations. The underground structures had cavities and hollows behind structural steel supports, detached shotcrete layers and calcite leaching. Head Race Tunnel (HRT) was partially inundated, demanding dewatering and re-support of deteriorated stretches. Additionally, the foundations of the dam and powerhouse were only partially built, and the extent and effectiveness of prior ground improvement works were unknown, posing challenges for safeguarding the foundations against seepage and differential settlement. Key tasks focused on rehabilitating the abandoned underground and surface structures, along with planning for adaptive excavation and rock support for the remaining works. Critical challenges in HRT were- squeezing ground, heavy seepage, large cavities along with methane occurrence. This paved the way for innovative measures and improvisation techniques for safer and faster excavation. At the surface, optimized design changes and site-specific ground treatment ensured the integrity of the dam and powerhouse foundations concurrent to concrete placement. This paper highlights the role of engineering geology in retrospective inspection, foundation mapping, ground improvement, rock support planning and execution. It emphasizes how close collaboration among geologists, engineers, and field teams enabled the safe and resilient completion of this complex Himalayan hydropower project, also providing valuable lessons for revival of such abandoned projects.

Keywords: Hydropower, Himalaya, HRT, engineering geology, rehabilitation



Squeezing ground condition and flexible false Lattice Girders supports in HRT

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Aligning pre-existing geodata with project-acquired information for offshore infrastructures

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Abstract

The availability of pre-existing geodata is rapidly increasing for multiple offshore regions with intensive infrastructures. The North Sea is an example of a region where pre-existing geodata provide major opportunities for improving safe installation and economic operation of offshore infrastructures. This paper focuses on considerations for aligning pre-existing geodata with offshore project-acquired information for ground models up to 100 m depth below seafloor. Specific examples from practice are presented, including their added value and challenges. Data alignment requires, besides data quality assessment, selection of reference scales or reference methods. This selection typically considers the immediate needs for the ground model for the project at hand. This often means that some transformation of geodata will be required for alignment with the selected reference scale. Methods for such transformation include elicitation procedures for engineering judgment, Bayesian statistics, data enhancement technologies and data regularization. For the Dutch offshore, pre-existing data are currently available in the following repositories: DINOLoket, BROloket, NLOG and RVO (https://offshorewind.rvo.nl/) websites. Repositories are being expanded or newly developed to host new and generally voluminous data types. Accessibility is a key requirement for big data analyses. This development will be accelerated by data-driven methods like geotechnical data derived from UUHR seismic reflection data, AI-assisted horizon interpretation, AI fault detection and AI data interpolation. For data alignment, the use of Large Language Models (LLMs) for inquiring geodata repositories is taking a flight.

Keywords: pre-existing geodata, offshore ground modelling, data alignment, Bayesian transformation method, AI-assisted interpretation

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Foundation of Photovoltaic Panels in Heterogeneous Soils: Loess and Antropic Soil Deposit

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Abstract

The construction of photovoltaic parks has gained momentum in recent years in Romania. Due to the fact that in order to have a profitable photovoltaic park, large areas of land are needed, finding large areas, which are not agricultural land that would be taken out of the agricultural circuit, becomes an important factor for the location of these parks. The present paper shows the foundation conditions for a photovoltaic park with an area of approximately 60ha, located in the eastern part of Romania, on the right bank of the Danube (Cernavoda)-Black Sea canal, near Ovidiu. The park would be divided into two surfaces, one of them having as foundation soils loess or loessoid soils, in their natural state and will be built on the slope of the canal, the other surface being placed on a deposit of material, resulting from the excavations necessary for the construction of the canal. The deposit is more than 50 years old and is made up of excavated chalk material, loesss and loessoid soils. In both areas, the foundation will be made indirectly by the ramming system of foundation process, consisting of metal bars, with an H-shaped profile, driven into the ground by vibration or with the help of hydraulic presses. The foundation through this system can be difficult due to the nature of the foundation ground. If in the case of the natural loessoid soil there are no difficulties to arise, in the case of the loessoid soil, mixed with chalk, from which the organized filling is made, difficulties may arise both in the calculation of the bearing capacity and during the ramming process. Thus, in the same location, the foundation conditions for both the natural land and the anthropogenic deposited material could be studied.

Keywords: photovoltaic panel, loess, soil deposit

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Dynamic analysis of geospatial information using GIS for the selection of renewable energy sites in Korea

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Abstract

The selection of the renewable energy site involves some critical factors such as surface geology, engineering geological conditions, and terrain, which can be analysed using GIS (Geographic Information Systems). Physical properties of rock including weathering grade and soil depth were used for basic information for long-term stability of the sites. Potential area located in mountain area were chosen and simple and fast calculation using quickly updated terrain data at each step with GIS was conducted through the safer routes which were acquired from the engineering geological map created based on the geological condition of the ground. An additional analysis module was developed for the selection of other renewable sites such as wind farm, considering any potential geohazards such as landslide, and subsidence because the risk usually increases during rainy season. Both static and dynamic analysis of geospatial data including both geological and physical properties of rock using both borehole data and other data from the site investigation provide suitable site for renewable energy. Recycling of the materials from solar panel and wind farm after closing the site, could also be partly linked to the geoinformation, i.e. distance between the renewal energy site and the collection center for the recycling.

Keywords: geospatial, GIS, renewable energy, site selection, engineering geological map

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Designing Critical Seafloor Infrastructure Against Sediment Gravity Flow Hazards: Constraining Sedimentary Processes to Propose Mitigation Strategies

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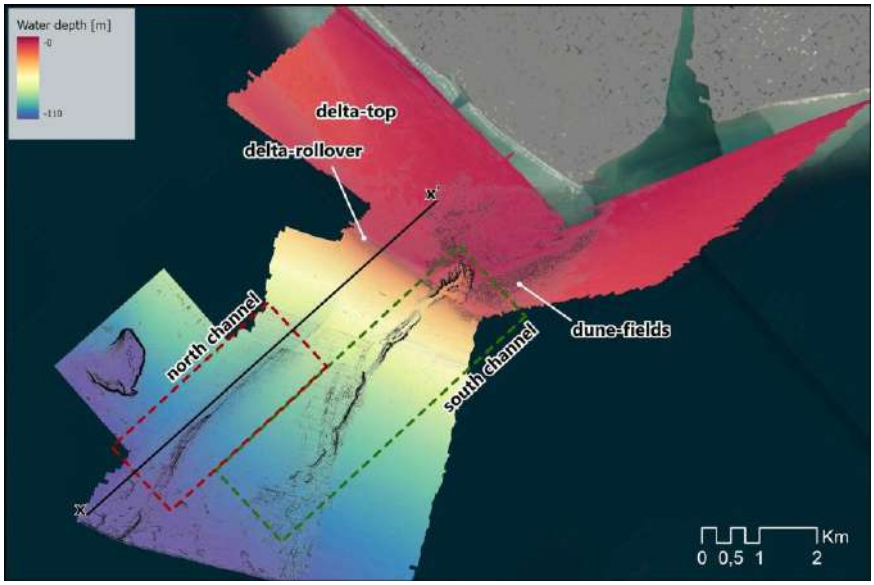
Abstract

Sediment gravity flows are the world's largest sediment movements, consisting of mixtures of sand, mud, and water that episodically travel down subaqueous slopes. They are reported to damage or destroy critical seabed infrastructure along the world's continental margins, such as internet cables, pipelines, or windfarm anchors. However, due to their large scale and inaccessible environments, little is known about their triggering mechanisms, behaviour, and interactions with engineered objects. This makes the design and maintenance of offshore structures extremely challenging. Using repeated bathymetric surveys spanning over a decade, we reveal patterns of erosion and deposition in a submarine channel where turbidity currents have impacted, and continue to impact critical seafloor infrastructure. We compare the erosion patterns through time to external triggers like typhoons and earthquakes, and conclude that episodic increased sediment supply during typhoons is an important priming condition but far from a universal predictor of catastrophic events. By analysing yearly to weekly seafloor change, we are able to constrain the extent of erosion, predict future patterns, and propose effective preventative strategies. We demonstrate that erosion and deposition along the submarine channel is driven by knickpoint migration, with areas of localised catastrophic erosion while in other parts of the channel net deposition occurs. This highlights the need for large-area surveying and an integral sedimentary system approach in order to design offshore infrastructure effectively, tailored to these dynamic and challenging environments.

Keywords: submarine channel, turbidity current, bathymetry, knickpoints, submarine landslide



Overview of the river mouth and coastal zone with bathymetric data available at the study location around the northern submarine channel and the southern submarine channel.

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Investigation Shaft for Testing the Foundation Bedrock, Patagonia Hydropower Project.

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[2] Universidad Nacional de La Plata (UNLP), La Plata, Argentina
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Abstract

In Patagonia, a concrete face gravel filled dam is being constructed. Many investigations have been conducted to evaluate the foundation of the high concrete structures (powerhouse and spillway) in soft rock. The foundation bedrock formation is a continental sedimentary rock, which includes mudstone, claystone, siltstone and sandstone, with variable volcaniclastic content. To define the top of the rock and observe the rock lithology and quality below the 20 m thick alluvium, seismic lines and a targeted drilling program were completed. The drilling was initially proposed with HQ diameter (core diameter: 63.5mm), but given there was core loss and poor recovery, it was increased to PQ (core diameter: 96mm). Some weak blocky layers were identified and correlated among the resulting drilled core. Based on these results, it was warranted to construct an investigation shaft, aiming to corroborate or discard the existence of the weak layers and to take undisturbed samples for laboratory direct shear testing to have a better understanding of their behavior and parameters. The shaft was completed with 27 piles, 4 reinforcement rings, and superficial protection of the rock to prevent slaking. It reached a depth of 33 m, and water was pumped out of the excavation. The lithologic contacts were documented through all the perimeter of the shaft, leaving representative windows exposed for future observation. In each weak blocky layer 40x40x60 cm cubic undisturbed samples were collected and sent for shear strength testing. In this presentation we are going to describe the excavation and logging methodology and compare the correlations observed in the core to the direct observation from the exploration shaft.

Keywords: Shaft, undisturbed samples , Soft rocks, Direct Observation, Direct Shear



Drone view of the investigation shaft during construction

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Enhancing Operational Resilience in delivering Renewable Energy: Integrating Multidisciplinary Approach for Geohazard Mitigation in Geothermal Fields

Elaine Marie Pena[1], Roy Anthony Luna[1], Ramon Quebral[1], Kate Trishia Papina[1]

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Abstract

Climate change is increasingly affecting the Philippines, bringing more intense and frequent hydro-meteorological events in recent years. With the country being highly vulnerable to natural hazards, it is imperative that proactive hazard mitigation strategies be employed to ensure the stability and continuous operation of geothermal power facilities despite adverse weather conditions. This study presents three case studies from geothermal production fields in the Philippines, where cascading geohazards—including earthquake-induced slope weakening, prolonged rainfall-triggered landslides, and flooding associated with landslide dam breaches—have caused significant operational disruptions and infrastructure damage. In one case, a breached landslide dam upstream triggered debris-laden flow that obstructed a critical drainage structure, resulting in unexpected flooding despite relatively low recorded rainfall at the facility. A multidisciplinary approach was employed, integrating hydrologic and hydraulic modeling, landslide inventory mapping, and geotechnical assessment to evaluate hazard interactions and identify vulnerable areas. The results highlight how initial triggering events can initiate a series of interrelated processes, where slope instability, sediment transport, and drainage blockage collectively amplify the impacts on geothermal infrastructure. Risk-based assessments were conducted to support the prioritization of mitigation measures, enabling more efficient allocation of resources. The findings underscore the importance of adopting a systems-based approach to geohazard assessment, supported by collaborative efforts among technical disciplines and stakeholders. Such approaches are essential in enhancing the operational resilience of geothermal facilities and ensuring the sustained delivery of clean and renewable energy under increasing climate variability.

Keywords: geohazard assessment and mitigation, geothermal energy, risk reduction, cascading geohazards, geohazard mitigation



Sequence of cascading geohazards in a geothermal field following an earthquake and typhoon in 2017: (a) development of ground cracks due to seismic shaking, (b) slope weakening and landslides, (c) debris flow affecting geothermal steam lines, and (d) resulting damage to geothermal infrastructure.

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Performance of High-Temperature Aquifer Thermal Energy Storage under Layered Geological Conditions: Effects of Density Compensation

Yifan Li[1], Tomochika Tokunaga[1], Jiaqi Liu[1]

[1] The University of Tokyo, Tokyo, Japan

Abstract

Aquifer thermal energy storage (ATES), an emerging sustainable technology, utilizes the heat-storage characteristics of aquifers to meet heating and cooling demands. In high-temperature ATES (HT-ATES) systems, temperature-induced density differences between injecting hot water and cooler ambient groundwater can cause free thermal convection, leading to heat loss and low thermal recovery. Salinity-based density compensation can be applied to reduce the density contrast and suppress convection. This study evaluates the influence of aquifer–aquitard layering and repeated operational cycles on the HT-ATES performance. A coupled flow, heat, and solute transport model was developed in FEFLOW, and benchmarked against the numerical study of Van Lopik et al. (2016) as a reference case. Wellbore mixing effects were neglected because the estimated wellbore volume was much smaller than the injected and extracted water volume. Additional scenarios were introduced by varying the number of aquifer and aquitard layers while maintaining constant overall horizontal/vertical transmissivities. All cases were simulated for ten operational cycles, each cycle consisting of injection, storage, extraction, and rest stages. The results show that increasing the number of aquifer layers improves thermal recovery efficiency. However, the benefit of density compensation becomes less pronounced as the aquifer becomes more layered, suggesting that geological layering can partly reduce the need for salinity-based control. Over repeated cycles, both thermal and salt recovery efficiency gradually increase and approach an asymptotic value. These findings highlight the importance of aquifer layering in controlling thermal and salt recovery. Further discussion is still needed regarding the practical management of salinity compensation.

Keywords: Aquifer Thermal Energy Storage (ATES), FEFLOW, Density compensation, Thermal recovery efficiency

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A Standardized InSAR Workflow for the Monitoring of Underground Gas Storage Operations

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Abstract

Underground Gas Storage (UGS) facilities represent a key component of the European energy system, providing seasonal flexibility, supply stabilization and resilience in line with the aims of the European Green Deal and the REPowerEU strategy. Ensuring safe and efficient operations requires robust monitoring frameworks capable of detecting and interpreting ground displacement related to reservoir pressure variations. This paper proposes an integrated Earth Observation (EO) methodology combining Multi-Temporal Interferometric Synthetic Aperture Radar (MTInSAR) data with UGS operational measurements to characterize surface displacement dynamics across different UGS reservoir types (depleted fields, aquifers and salt caverns). The approach relies on freely available displacement time series from the European Ground Motion Service (EGMS). InSAR measurements are harmonized, filtered and analyzed to extract spatial and temporal deformation behaviors. Cross-correlation techniques are then applied to compare the InSAR displacement time series with UGS injection/withdrawal cycles and climate variables, allowing the separation of signals due to UGS from those caused by environmental or climatic processes. Additional statistical tools, including Principal Component Analysis (PCA) and K-means clustering, help to identify areas governed by distinct deformation mechanisms, even in complex settings where multiple phenomena overlap. This paper summarizes the range of deformation scenarios that can be encountered in different UGS environments, emphasizing the distinctive behaviors of each reservoir type and geological context. Based on these observations, the research proposes a set of standardizable best practices for InSAR UGS monitoring worldwide, providing a transferable, scalable and cost-effective workflow.

Keywords: InSAR, Underground Gas Storage, EGMS, Cross-Correlation Analysis, Surface Displacement

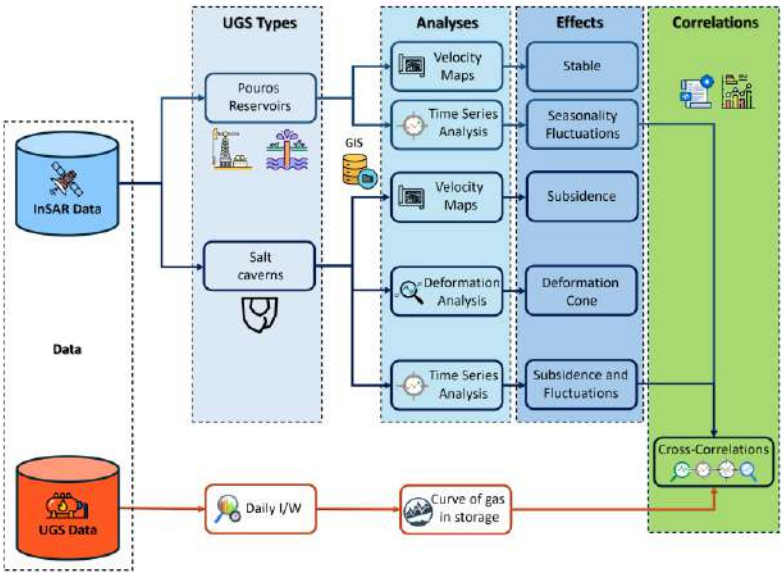

Fig.1 - Flowchart representing the development of the work.

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Characteristics of Deep Dutch Clay Formations Derived From Laboratory Measurements and Geophysical Logging Data

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Abstract

In the Netherlands, disposal of high-level radioactive waste in poorly indurated clay formations is considered at depths between 200 and 1000 m. However, intact core material is very rare within these depths. Therefore, lithostratigraphy and properties of these layers are poorly characterised. In Spring 2022, 64 high-quality cores and 49 sediment samples were extracted from the DAPGEO-02 borehole at depths between 362 and 415 m b.g.l. beneath Delft. A coring program was coupled with geophysical logging (gamma ray, resistivity, spontaneous potential, single point resistance, induced polarization, sonic P-wave velocity, PS suspension, nuclear magnetic resonance, electromagnetic induction) and CT scanning. Geophysical logging enables the estimation of key formation properties using empirical correlations, which is valuable when coring is not feasible. Using the logging data from DAPGEO-02 and direct laboratory measurements on the core materials and sediment samples, this study aims to evaluate the reliability of a few conventional relationships used to interpret logging data. Lithological sequence is reconstructed using the sediment samples. Formation boundaries and depth shift of logs are accurately determined using characterization tests, CT scans, and logging data. Fining-up and coarsening-up sequences are clearly identified. Comparing GR and NMR logs with CEC, GSD, and XRD clay mineralogy helps explain log variations. While existing GR log empirical relations may overestimate clay fraction, NMR derived clay-bound water follows similar variation trends with clay content and CEC, with moderate correlation coefficients. Therefore, comparison with laboratory studies indicates that direct use of existing correlations may yield inaccurate predictions and requires validation against laboratory studies.

Keywords: Geophysical logging, Geological disposal, Clay formations, Empirical correlations, Core characterisation

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Submarine Landslides Against a Deformable Cable: Insights From Centrifuge and DEM-LBM Modelling

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Abstract

The offshore energy transition employs an extensive network of sea cables as part of its support infrastructure. Sea cables are frequently laid directly on the seabed or with minimal burial depth, leaving them exposed to geohazards or anthropic interactions. These interactions pose a risk of them being snapped, deformed, or broken, resulting in costly operations and compromising the energy distribution. In this work we study the interaction of an analogue system of a submarine landslide and a sea cable in a plane-strain configuration. This configuration is explored both in a physical and a numerical model, where the immersed grains are led to push a spring-like obstacle. The physical model is tested in a geotechnical centrifuge, varying the tilting angle and allowing the visualization of two main interaction mechanisms: one where the cable displacement occurs by either the accumulation of soil behind the cable, or another where grains over- and under-flow around the cable. Moreover, the numerical model is simulated within the DEM-LBM framework, allowing a direct visualization of the particle and fluid kinematics. In this model, the competition between grain and fluid forces allows to identify the significant role of pore fluid pressures as a function of the landslide velocity. The insights from both models provide a comprehensive overview on the governing interactions on a deformable cable, paving the path for its implementation by the design practice and potential development of mitigation measures for this type of critical infrastructure.

Keywords: Landslides, Offshore infrastructure, Centrifuge modelling, DEM

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Experimental Characterization of the Thermal and Mechanical Properties of the Cutter Soil Mix Wall Material

Marco Gerola[1], Jacco Haasnoot[1], Korneel de Jong[1], Oskar de Kok[2], Francesco Cecinato[3]

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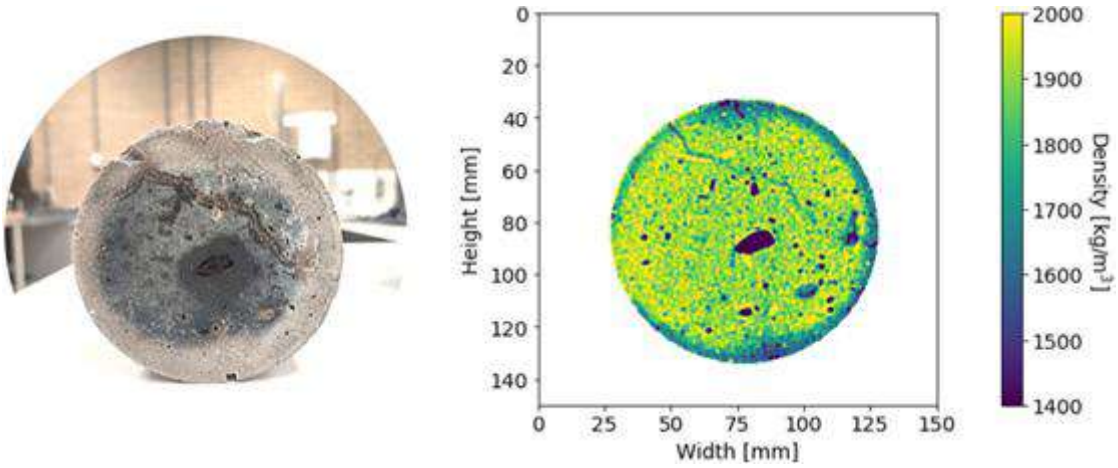
[3] Università degli studi di Milano, Milan, Italy

Abstract

Cutter Soil Mixing (CSM) is a comparatively new method used to build (permanent) cut-off and retaining walls. In this process, native soil is blended in place with a cementitious binder slurry by means of dedicated mixing equipment, producing a mortar-like composite in which the soil grains behave as aggregates. For the first time, this technology has been integrated with energy geostructure systems—geostructures that serve a dual function: providing structural stability and facilitating the exchange of shallow geothermal energy for building heating and cooling. This novel application, termed the CSM energy wall, has been implemented in a full-scale pilot project in Amstelveen, the Netherlands. Given the novelty of applying CSM technology for geothermal purposes, the thermal properties of CSM materials, needed for the thermal design of the energy wall, remain poorly documented in the literature. This paper addresses this gap by characterizing these properties using 11 cylindrical core samples (10 cm in diameter) extracted from the installed CSM energy wall. After 3 months, these samples underwent computerized tomography (CT) scanning to assess density distribution and were also subjected to disk tests to determine thermal conductivity and volumetric heat capacity. CT-scanning revealed a generally homogeneous density distribution within the samples, influenced more significantly by the cementitious matrix than by the in situ low-density soils (e.g., clay and peat). The thermal measurements were likewise consistent, giving a mean thermal conductivity of 0.95 W/mK and a mean volumetric heat capacity of 2.79 MJ/m³·K. These values are likely conservative estimates, as partial drying of the specimens after sampling may have reduced their degree of saturation relative to in situ conditions. In addition, unconfined compression tests were conducted, yielding an average unconfined compressive strength (UCS) of 9.2 MPa.

Keywords: Cutter Soil Mix energy wall, Energy Goestructures, Geothermal energy, Laboratory testing, Thermal properties



Comparison between a real cross section and the corresponding processed image from CT scan test of the UC2 sample.

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Sediment ageing and corrosion around piles in marine conditions: Impact on operational stability and decommissioning feasibility

Hannes Claes[1], Katreine Blomme[2], Jeroen Soete[1], Hadrien Rattez[3], Georgios Anoyatis[4], Ruben Snellings[1], Rudy Swennen[1], Stijn Francois[1]

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Abstract

Longterm use of steel piles is hampered by corrosion, particularly in harsh marine conditions. Aside from wall-thickness loss, accelerated fatigue damage and reduced stiffness, corrosion is associated with precipitation of iron (hydr)oxides in sediments surrounding piles. Coinciding with iron (hydr)oxide precipitation, sediment ageing may result in carbonate precipitation. Petrographic observations on piles from the port of Zeebrugge, supported by SEM-EDX and XRD mineralogical analyses and geochemical modelling, illustrate how carbonate-oxide cements result in crust formation at the pile-sediment interface. While corrosion alone leads to decreased pile-soil stiffness and lowered friction, cemented crusts counteract those effects. The petro-mineralogical analyses and simulations demonstrate that host sediment type plays a crucial role. Under typical marine conditions aragonite shells dissolve. Oxidation of steel in the sediment leads to locally increased pH, favoring carbonate precipitation. The co-occurrence of dissolved Fe and supersaturation with calcite results in local iron (hydr)oxide-carbonate cementation. Although interactions of corrosion and ageing are complex, they can lead to changes in stability during operation while potentially hampering later efficient decommissioning. These effects need to be considered when modelling for stability, life cycle and risks related to pile installation, operation and decommissioning, of particular importance in offshore windmill farms.

Keywords: Windmills, Piles, Ageing, Stability, Decomissioning

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Geomechanics of Low-mature Continental Shale under Real-time High-temperature Heating-Loading Coupling Conditions

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Abstract

As a critical strategic alternative for stable and increased crude oil production, China's continental shale oil is predominantly of low-medium maturity and requires thermal upgrading for effective exploitation. However, a poor understanding of the mechanical properties of shale under high temperatures has restricted the large-scale development of shale oil in China. This paper investigated geomechanical properties of low-mature continental shale under various real-time heating-loading coupling conditions (25°C, 200°C, 350°C, and 550°C) in the case of low-mature continental shale YK01 (with a vitrinite reflectance Ro value of 0.66%) from the Yanchang Formation of the Ordos Basin, China, utilizing an independently upgraded meso-scale high-temperature loading-observation-acquisition system. The results showed that as heating temperature increased, the average uniaxial compressive strength (77.30~121.89 MPa) and elastic modulus (3~5 GPa) increased first and then decreased, with the highest at 200°C and the lowest at 550°C, respectively. New fractures generally initiate at the ends and propagate toward the middle of the specimen at 25°C and 200°C and show brittle failure, but they tend to initiate in the middle of the specimen and extend toward the ends under 350°C and 550°C, with notable plastic deformation, indicating a softening effect of high temperature. The fracture surface roughness varied consistently with uniaxial compressive strength as the heating temperature was lower than 350°C, while it increased significantly at 550°C, probably due to plastic damage. The findings provide experimental references for in-situ thermal upgrading of low-maturity continental shale oil, with key structural and mechanical parameters available for numerical simulation of shale oil exploitation.

Keywords: Low-mature shale, Mechanical properties, Real-time heating-loading coupling, Fracture evolution, Fracture surface roughness

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Lessons from the PRACLAY Heater Test in Boom Clay for Geological Disposal of Radioactive Waste in Belgium

Arnaud Dizier[1], Temenuga Georgieva[1], Jan Verstricht[1], Ygee Larion[1], Adriaan Campo[1], Dries Nackaerts[1], Xavier Sillen[2], Mieke De Craen[1], Maarten Van Geet[2], Séverine Levasseur[2]

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Abstract

The Boom Clay is a poorly indurated clay characterized by low permeability, strong retention capacity for radionuclides, and self-sealing properties. These characteristics make it a promising host formation for the geological disposal of high-level and long-lived radioactive waste in Belgium. However, repository construction will create an excavation damaged zone around underground openings, while heat emitted by the waste will generate thermo-hydromechanical (THM) perturbations that may potentially alter the clay's favourable properties. Understanding these processes and their long-term evolution is therefore essential.

To investigate these effects under representative conditions the large-scale PRACLAY Heater Test was developed in the HADES Underground Research Laboratory, located 225 m in the Boom Clay Formation in Mol, Belgium. The experiment is designed to study the combined impact of mechanical disturbances and thermal loading under representative conditions. A 40 m long gallery was heated with the aim of maintaining for ten years a constant temperature of 80°C at the interface between the lining and the surrounding clay.

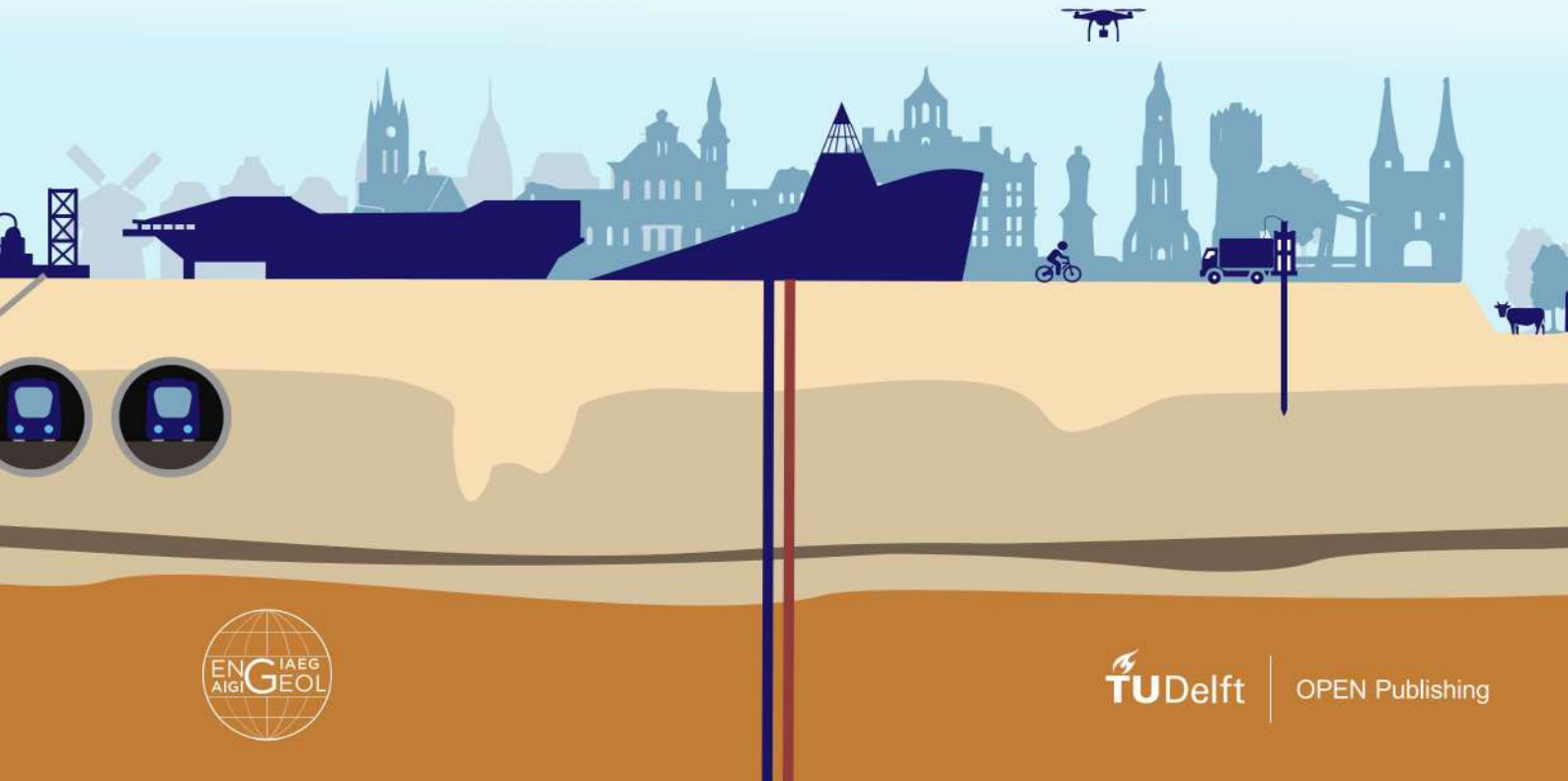
Over ten years of steady-state heating, a comprehensive dataset was collected. The results have largely confirmed previous laboratory and in situ findings while providing new insights into the THM behaviour of the Boom Clay. The unique scale and duration of the experiment offer valuable information on the coupled processes governing the response of clay formation to thermal loading. This contribution presents the objectives, implementation and main outcomes of the PRACLAY experiment, highlighting its relevance for process understanding, model validation and repository design.

Keywords: Boom Clay, PRACLAY Heater Test, THM, Geological Disposal

5. Responsible use of the (sub)surface



Emphasis on successes, failures, and forensic analyses in geotechnical engineering. Special attention to challenging environments and prestigious projects. Engineering Geology focus on mining ores, rare earths and aggregates, induced geohazards, (post)mining risk management, resilient infrastructure, dredging and compensation for nature, building-with nature and smart bio-geomaterials.



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Utilization of Cosmic-ray Muons for Subsurface Cavity Detection in Shield Tunneling: Addressing Infrastructure Challenges

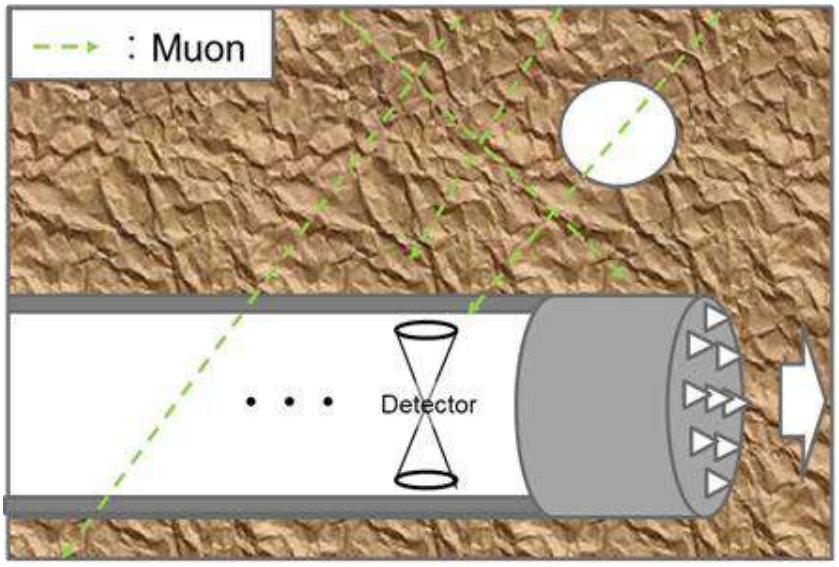
Koki Sakita[1], Hayato Takeshita[1], Norikazu Kinoshita[1], Jian Chen[1]

[1] Shimizu Corporation, Tokyo, Japan

Abstract

Road cave-ins resulting from shield tunneling have emerged as a critical issue. This study investigates the potential use of cosmic-ray muons to identify cavities that could cause such accidents. Based on simulations using a Monte Carlo code that enables the reproduction of muon transport, a cavity can be identified by the ratio of muon count rates measured with and without the cavity using an idealized muon detector. Consequently, systematic uncertainties, evaluated by comparing simulations with measurements, can be neglected in the cavity assessment. The cavity was clearly identified using a 2s criterion for statistical uncertainty.

Keywords: Cosmic-ray muon, Geophysical exploration, Geophysical exploration, Shield tunneling, Monte Carlo simulation



Cross sectional view of cavity detection in shield tunneling using cosmic-ray muon

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Characteristics and Mechanisms of Three Special Types of Rockburst in Deep Engineering Projects on the Qinghai-Tibet Plateau

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Abstract

As one of the world's most tectonically active regions, the deep-buried tunnel engineering on Qinghai-Tibet Plateau frequently faces rockburst disasters. Conducting comprehensive field investigations alongside rock mechanics experiments, numerical simulations, and theoretical analysis, this study systematically examines the developmental characteristics and failure mechanisms of three distinctive types of rockburst in this plateau region: "temperature-induced rockburst","ejection-burst rockburst" and "epigenetic-superficial modification rockburst." The findings are summarized as follows:

(1) Temperature-induced rockburst is driven by the coupling effect of high ground stress and geothermy. Within the temperature range of approximately room temperature to 120 °C, increasing temperature enhances rock brittleness and raises the rockburst propensity index. When thermal stress couples with excavation-induced secondary stress, tensile spalling or tensile-shear bursting modes are prone to occur.

(2) Ejection-burst rockburst is predominantly controlled by intense tectonic compression. It mainly occurs in rock masses within tectonic suture zones characterized by extensive concealed fissures and significant squeezing deformation. Energy release in such events typically follows a "granular ejection-burst" pattern and is often accompanied by sudden jumps in acoustic emission energy rates.

(3) Epigenetic-superficial modification rockburst is strongly influenced by recent geomorphic evolution processes. It commonly emerges in localized high-stress zones within 300–500 m horizontal depth at valley slopes or within high-stress pockets at valley bottoms, exhibiting classic stress-controlled structural rockburst characteristics.

This research elucidates the differential formation mechanisms of rockburst under the unique geological conditions of the Qinghai-Tibet Plateau, providing theoretical foundations for rockburst prevention and mitigation in deep engineering projects both on the plateau and in surrounding regions.

Keywords: Qinghai-Tibet Plateau, Rockburst, Special types, Mechanism

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Unusual geological instability conditions induced by the excavation of artificial caves: A case study of the Carrascal caves

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Abstract

The Carrascal Caves are located approximately 10 kilometres west of Lisbon, Portugal. They result from the artificial excavation of a nodular limestone layer with a high clay content, deposited between layers of compact limestone dating from the Cretaceous period. This material was used for several purposes, including the reconstruction of Lisbon's downtown following the 1755 earthquake. From the 1970s onwards, the land above the caves has been progressively occupied by illegal constructions, and the area is currently undergoing urban redevelopment. Following a collapse in April 2022 that affected a house and part of a road under construction, the stability conditions of the area were analysed. The study was based on surface geological mapping, which included both the characterisation of geological features and the identification of the main instability issues. The results indicate that the study area is prone to vertical ground movements, which can lead to the collapse of large blocks inside the cave galleries. These instability problems outline an extremely hazard scenario for resident population and local traffic. The factors controlling block dimensions are stratification and two sets of orthogonal sub-vertical joints, which are highly continuous and extremely wide. Recommendations are issued for priority actions to reduce the identified risks.

Keywords: Artificial caves, Stability conditions , Ground collapse, Limestone, Hazard

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Geotechnical Conditions for Construction in the Belgrade Metro Line One „Sava Alluvium“ Section

Dragoslav Rakic[1], Nemanja Stanic[2], Pavle Manasijevic[2], Nino Salcin[2]

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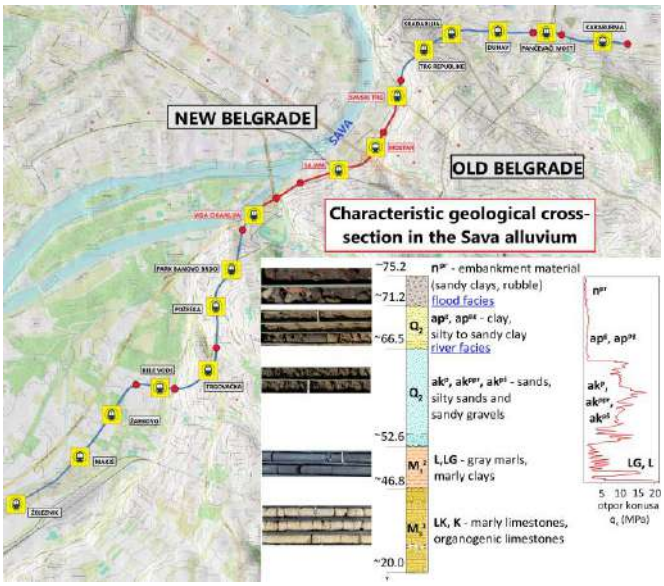
Abstract

Since 1973, a number of studies related to the construction of the Belgrade Metro have been conducted in order to find possible solutions to major traffic issues in Belgrade. However, only in 2019. the alignments of the future Metro Lines 1 and 2 were defined in The Metro Construction General Design. The total alignment length is 45.3 km, with 45 metro stations designed for construction.

The Belgrade Metro Line One (Phase 1) shall be constructed in five sections: Makiš, Banovo Brdo, Sava Alluvium (Savski Aluvion), Centar and Danube Alluvium (Dunavski Aluvion). The Sava Alluvium Section alignment will be 3770 m long, including three tunnel sections, four metro stations and three shafts. The site conditions are complex given the various Cretaceous sediments of marly-clayey and carbonaceous composition overlain by the Miocene marly-carbonaceous complexes, whereas the surface of the ground is covered by the Quaternary sediments (alluvial sediments of the Sava river developed in the floodplain and channel facies as well as deluvial sediments to a lesser extent, Fig. 1).

Tunnelling and deep excavations in urban areas are the most challenging engineering works because in addition to potential excavation problems, deep excavation can also pose challenges to the stability of the adjacent structures. This, together with the characteristic geological structure and the complex construction, is the reason the rock mass geotechnical zones and categories along the Metro alignment as well as the rock masses behaviour during excavations and the method of geotechnical modelling of the metro stations and shafts in the paper.

Keywords: Belgrade metro, Sava alluvion, Geotechnical terrain zoning, Geotechnical modelling, Diaphragm stability



Representative geological cross-section in the Sava alluvim along Line 1 Belgrade metro

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Responsible Construction in Underground Works: More than just Sustainable Development and Engineering

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Abstract

In recent years there has been a growing interest in labelling construction works ‘sustainable: or the use of the word “sustainability”. The word sustainability has been used with quotation marks as the definition is as varied within the industry as are the site-specific considerations of underground works. The primary focus of such efforts within companies, working groups and learned societies has been the emphasis on “sustainable” construction. The use of recyclable or renewable materials that are included within the projects with a view to minimizing the amount of waste production and a reduction of the energy footprint. As an industry, we need to look more holistically at the logistical chain, the operations, the type of contracts, etc. within a risk management framework. One also needs to consider the environment and the socio-economic aspects of a project. As such, the author proposes that such relevant working groups, committees, divisions etc. within learned societies should re-name their groups to “Responsible Construction Practices”. Sustainability is only a part of this overall effort to be responsible towards the public, the owners, the client(s), and the contractor(s). This paper aims at defining the components of responsible construction for underground works with a view to broaden the scope of sustainable development projects beyond the materials that are used as part of the projects. In this way, the responsible construction framework can incorporate ‘sustainability’ and other aspects of projects that will yield positive returns for all stakeholders and the build environment / planet.

Keywords: Responsible Construction,, Sustainability , Underground Works, Holistic Project Management, Resilient Infrastructure

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From Geological Evaluation to Geotechnical Design: Integrating Rock Mass Behaviour in Tunnelling Without Sole Reliance on Classification Values

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Abstract

This study proposes a methodological framework that integrates rock mass behaviour into geotechnical design for tunnelling, moving beyond exclusive reliance on rock mass classification values. Although classification systems like RMR and Q have been widely used to estimate support requirements and GSI to evaluate rock mass properties, their numerical ratings alone often fail to represent the complex and variable behaviour of rock masses under excavation-induced stresses. This work stresses the importance of understanding failure mechanisms and geological structures that govern tunnel behaviour for making informed design decisions. The approach starts with an engineering geological evaluation that identifies rock mass types and anticipates their behaviour under specific site conditions. By analyzing dominant failure mechanisms, designers can define an appropriate support philosophy and select design parameters that accurately reflect the ground response rather than depending solely on classification-derived assumptions. This method improves early decision-making in support design, construction planning, and contractual documentation. Case studies reveal that rock masses with identical classification ratings can behave very differently during excavation, highlighting the limitations of relying only on rating systems. The paper advocates a behaviour-based classification that incorporates structural and in situ geological features to guide support selection and dimensioning. Rock mass classification ratings remain valuable when applied appropriately within this broader framework. Ultimately, this work reinforces that tunnel design must be firmly linked to geological understanding. Integrating behavioural insight results in more robust, adaptable, and context-sensitive designs, enhancing tunnel stability and safety through predictive engineering practices.

Keywords: tunnelling behaviour, geotechnical design, rock mass classifications, failure mechanisms, engineering geology

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Squeezing Prediction in Rohtang Tunnel Through Semi-Analytical Approaches

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Abstract

The construction of underground structures can encounter various geotechnical challenges, such as squeezing and rock bursting. These problems are influenced by several factors, including overburden height, rock material properties, rock mass characteristics, and tunnel size. The 8.8 km long Rohtang tunnel is one of the road tunnels constructed at a very high altitude and passing through an overburden of approximately 1900m. The geological strata comprise of metamorphic rock such as phyllitic quartzite, quartzitic phyllite, biotite mica schist, and migmatitic gneiss. As it passes through high overburden, the tunnel is expected to encounter stretches with squeezing and rock-bursting conditions. Many empirical, semi-analytical, analytical, and numerical modelling approaches are available to analyze squeezing conditions in underground structures. A comprehensive study was carried out using semi-analytical approaches for predicting squeezing conditions in the Rohtang tunnel. The tunnel strain parameters were determined to predict squeezing using a semi-analytical approach. The relations have been proven between tunnel strain, overburden, stiffness and uniaxial compressive strength of rock mass, rock mass classification, and squeezing conditions. The paper highlights a comparison of semi-analytical approaches for predicting various squeezing conditions with respect to overburden depth, tunnel stress, tunnel strain, and compressive strength of rock mass. Further, the individual dependency of rock mass number N (Q without SRF), modulus of rock mass and uniaxial compressive strength (UCS) of rock mass in squeezing conditions has also been discussed.

Keywords: Squeezing, Semi-analytical approach, Overburden height, Tunnel strain, Metamorphic rocks

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Numerical Modeling of Tunnel Deformation near the Panagopoula Landslide in Greece using Finite Element Methods

Panagiotis Alexopoulos[1], Nikolaos Depountis[1], Spyros Lainas[1], Panagiotis Pelekis[2], Apostolos Mesbouris[3]

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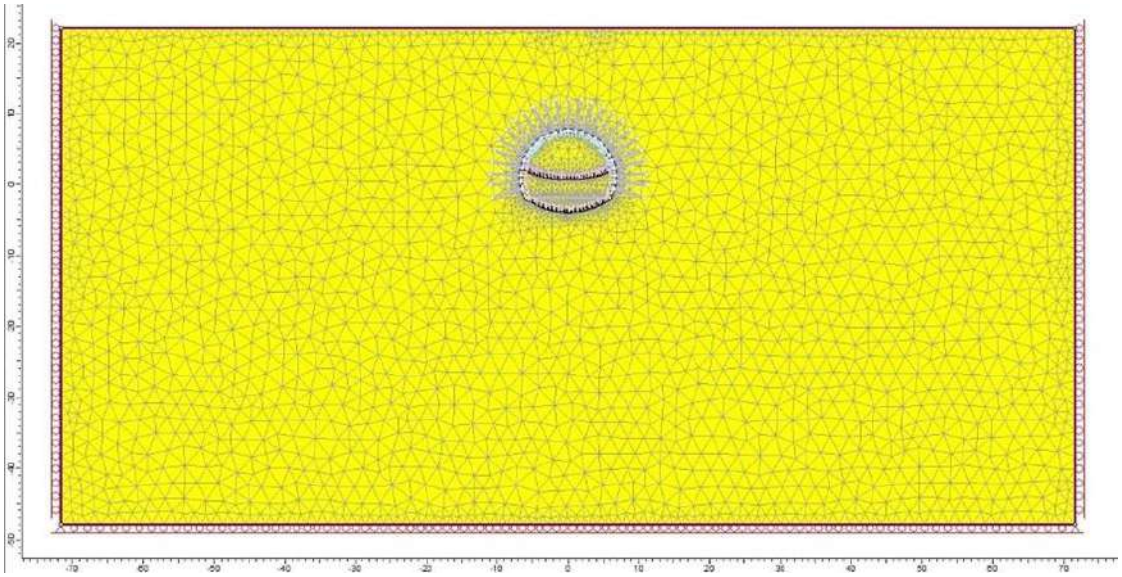
Abstract

This study focuses on the analysis of ground deformations using Finite Element Analysis (FEA) during the excavation of the south branch of twin tunnel T26, constructed adjacent to the Panagopoula landslide—one of the largest landslides recorded in Greece. The tunnel, part of the Elefsina–Korinthos–Patras motorway that connects Athens with Patras, comprises two separate branches (north and south), each serving one traffic direction. Excavation was carried out through rocky and semi-rocky formations of the Alpine basement, which characterizes the broader study area. The geological profile along the tunnel alignment was categorized into ten distinct geotechnical units. Two-dimensional finite element analyses, assuming plane strain conditions, were performed using RS2 software from the RocScience Academic Bundle. The primary objectives were to evaluate ground deformations and displacements, and to assess the suitability of the applied excavation and support methods in relation to the geotechnical conditions of each tunnel segment. For selected cross-sections representative of the various geotechnical units, initial elastoplastic analysis was performed using the convergence-confinement method and empirical relationships to estimate unsupported tunnel deformations. The coefficients derived from this analysis served as input parameters for the subsequent two-dimensional FEA. The two-dimensional analysis aimed to assess tunnel wall deformations, convergence, and the effectiveness of temporary support systems in each geotechnical unit. Additionally, the study evaluated whether the selected excavation and support classes were appropriately matched to the geotechnical conditions encountered at the analyzed tunnel faces.

Keywords: Numerical modelling, Tunnel deformation, Excavation, Temporary support, Displacement



RS2 Cross section of the GU-II (c) geotechnical unit

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Deformation and Failure of Rock Mass in Deeply Buried Railway Tunnel Under High in Situ Stress

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Abstract

Guanshan railway tunnel, located in Gansu Province, China, is a deeply buried diorite rock mass tunnel under high in situ stress. In contrast to the favorable rock mass classification predicted during the investigation phase, post-excavation conditions revealed substantial changes in the rock mass parameters and structure, uncovering degraded and anisotropic rock mass conditions. The degradation and anisotropy of rock mass is described and analyzed based on the statistic analysis of the rock mass discontinuity in field. Meanwhile, borehole camera is adopted to further observe the progressive deformation and failure of rock mass in an intervals after excavation. As one of the hard and brittle plutonite, diorite is with a relatively high uniaxial compressive strength (UCS), which is obviously larger than the in situ stress. However, the deformation and failure of diorite rock mass happened predominantly. Based on the evidence obtained by the borehole camera, the micro fracture or rock mass discontinuity that is closed under high in situ stress re-opens and develops quickly after the excavation, leading to a deterioration in the stability and structural quality of the rock mass. To investigate the deformation and failure process, uniaxial compressive test is designed with rotations of the sample. The uniaxial pressure is lower than the uniaxial compressive strength (UCS) of diorite. These findings indicate that the deformation and failure of the rock mass is caused by structural degradation, which is induced by changes in field stress after excavation.

Keywords: rock mass, deformation and failure, diorite, stress field

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The Use of ShapeMetriX, a Digital Photogrammetry Tool as Part of Rock Mass Characterization in Tunneling at Polihali Transfer Tunnel, Lesotho

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[2] University of KwaZulu-Natal, Durban, South Africa

Abstract

The Lesotho Highlands Water Project (LHWP) is a bi-national project between the government of the Kingdom of Lesotho and the Republic of South Africa (RSA) aiming at transferring water from Lesotho to South Africa due to the scarcity of water in South Africa. The transfer of water from Lesotho to South Africa has been considered as one of the largest water transfer schemes in Africa. The LHWP Phase 2 comprises the construction of the Polihali Dam, a 38 km long Polihali Transfer Tunnel (PTT) and an Oxbow Hydropower Scheme. Tunneling, as an underground operation, presents several risks such as rock falls and rock bursts, primarily during construction stage. Thus, the acquisition of adequate geological and structural data is essential in any tunneling operation. This paper presents the use of a digital photogrammetry system (3D ShapeMetriX) to collect, analyse and interpret geological and discontinuity data in the PTT. ShapeMetrix was used to produce a 3D model of the tunnel face at PTT, which was used to carry out geological and discontinuity mapping, analysis of the discontinuities and demarcation of lithological boundaries. The results show that the use of ShapeMetriX at PTT demonstrates a fast and effective way of obtaining and analysing geological and discontinuity data during tunnel construction. The capabilities of ShapeMetriX include geometric analysis, stereographic analysis, joint set spacing distribution as well as lithological distribution. The data obtained from ShapeMetriX can be incorporated in other software like RocTunnel3, for stability analysis.

Keywords: Lesotho Highlands Water Project, Polihali Transfer Tunnel, ShapeMetriX, 3D modeling

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Engineering Geological Insights for TBM Machine Selection in Thessaloniki's Urban Tunnel Design

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Abstract

Assessing subsurface conditions is essential for the successful execution of underground works like metropolitan tunnels, particularly in selecting the appropriate Tunnel Boring Machine (TBM). This study presents a methodology for TBM selection applied to the Thessaloniki's in northern Greece, leveraging an engineering geological database developed within the framework of the Tunnel Information and Analysis System (TIAS) (AGS, 1999; Marinos et al., 2013). The analysis focuses on two areas-the western region and the eastern one-highlighted in Figure 1. Key parameters evaluated include grain size distribution, permeability characteristics, sticky behavior of cohesive soils and clogging risk. A typical tunnel depth of 10-20 meters, common in metropolitan projects, is considered. In both areas, excavation is expected to primarily encounter fine-grained sediments of Quaternary and Neogene age with low hydraulic conductivity values (below 1.0×10^{-5} m/sec). However, in the western area, localized occurrences of loose, sandy Quaternary materials may pose a risk of subsidence during tunneling. The clogging risk of cohesive soils was evaluated using the method of Thewes & Burger (2004), while Geodata S.p.A. (1995) demonstrate a low to moderate tendency for stickiness in both areas. Control of surface and foundation-level deformations was considered a critical factor-alongside the aforementioned parameters-especially in the western section where subsidence-prone soils are present. The selection of a closed-type Earth Pressure Balance Machine (EPBM) was favored not only due to the prevailing low-permeability conditions but also because of its ability to manage face pressure and minimize ground movements. Although Slurry TBMs could be beneficial in more permeable zones of the western area, the overall geological and geotechnical conditions support efficient EPBM operation along the tunnel alignment. Targeted soil conditioning measures are recommended-particularly in zones containing loose or more permeable Quaternary sediments.

Keywords: TBM seletion, Urban tunneling, Engineering geological database, Geotechnical analysis, Quaternary and Neogene deposits

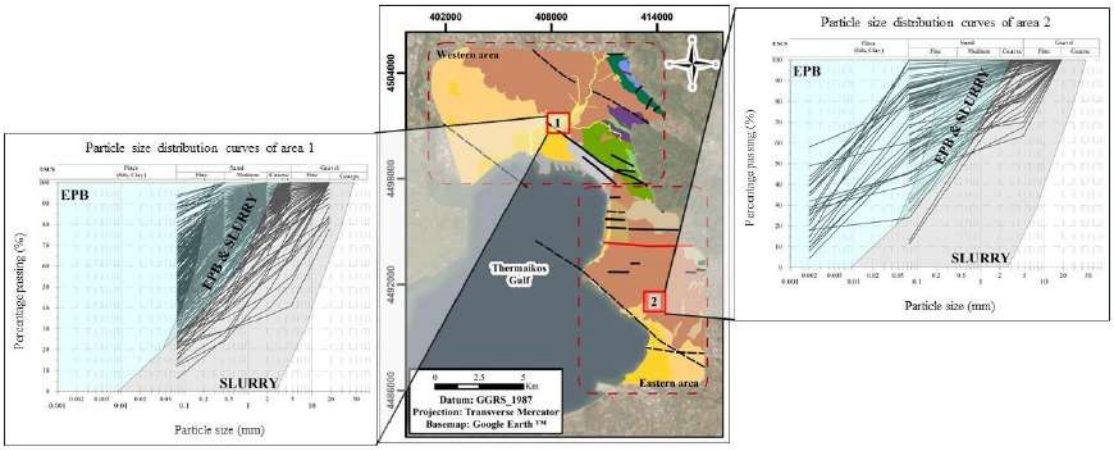

Figure 1. Engineering geological map of Thessaloniki city (for detailed engineering geological map refer to Kokkala and Marinos, 2022) illustrating eastern and western regions (dashed rounded rectangles) and particle size distribution curves for the depth of 10-20 m in two distinct representative areas, along with EPBM and slurry TBM suitability limits from Langmaack (2002) (Kokkala, 2023)

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Disaggregable Metagabbro Encountered During Tunnel Excavation: Tests for its Geological and Geotechnical Characterizaiton

Felipe Santos[1], Wilson Iyomasa[1], Marcos Saito de Paula[2], Letícia Vicente[3]

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Abstract

This study presents the results of tests conducted by the Institute for Technological Research on disaggregable rock samples collected during road tunnel excavations in the Serra do Mar region, Sao Paulo, Brazil. In the excavation front using the Sequential Excavation Method, a 18 m section was identified containing metagabbro, a metamorphic rock exhibiting anomalous behavior upon contact with water. Petrographic and X-ray diffraction analyses revealed that the original olivine gabbro had undergone intense hydrothermal alteration, resulting in mineralogical substitution. The infiltration of hydrothermal fluids into microfractures within olivine crystals led to the formation of serpentine needles and vermiculite infill, both of which, upon absorbing water, impart expansive (swelling) behavior to the metagabbro. Uniaxial Compressive Strength (UCS) test on intact specimen indicated a strength of 85 MPa. To evaluate expansion stress, another cylindrical specimen was dry-machined, inserted into metallic sleeves, and subjected to gravitational water infiltration. Expansion stress reached 1.7 MPa after two hours, as measured by load cells. Following the expansion test and subsequent oven-drying of the specimen, another UCS test yielded a reduced strength of 63 MPa and a P-wave velocity of approximately 3,200 m/s was measured on the same specimen. However, direct exposure of the unconfined samples to water resulted in complete disintegration within minutes, forming coarse sand-sized granules.

Keywords: Tunnel, Metagabbro, Rock expansion tests, Serra do Mar, Brazil



Metagabbro that disaggregates upon water exposure.

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Experimental Study of Surface Subsidence from Shallow Tunnel Excavation

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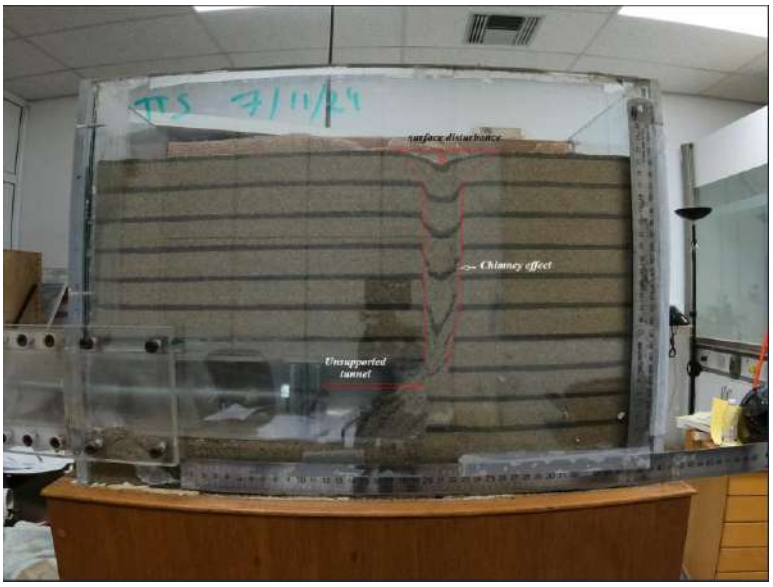
Abstract

In recent decades, there has been a rapid increase in tunnel construction and drilling technologies. However, constructing a tunnel in an urban area is a complex issue due to the risk of tunnel failure, which can cause ground surface subsidence. For the study of the chimney phenomenon, various analytical mechanisms have been used in the past. Nowadays, numerical modeling provides a powerful tool for investigating the failure mechanisms and simulating the kinetic behavior of the tunnel face. However, difficulties may arise from the assumptions about computational model parameters. Using scale models of an experimental sandbox device, this study aims to investigate the instability of the tunnel face in the mechanism of subsidence induced by shallow tunnel excavation. The model box has two moving parts: a semicircular rigid surface P1 that moves inward or outward, representing the tunnel chamber, and a vertical moving boundary P2, parallel to the tunnel axis, that reduces lateral pressure on the tunnel boundary. In the geotechnical analysis, the 2 cm movement of the P2 device within the soil mass led to the identification of a failure plane with an inclination of 45 + φ/2 = 66°, close to the theoretical angle of 63.5° defined by the active pressure mechanism. Numerical simulations were used to validate the experimental results, showing good agreement with the observations.

Keywords: Surface Subsidence , Proportional sandboxes, Near the Surface Tunnel, Chimney Effect, Shallow Tunnels



Sandbox analogue test simulating disturbance from shallow tunnel excavation

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Application of Geological Models in the Project Study of the Lamiako Underwater Tunnel in Biscay (Spain)

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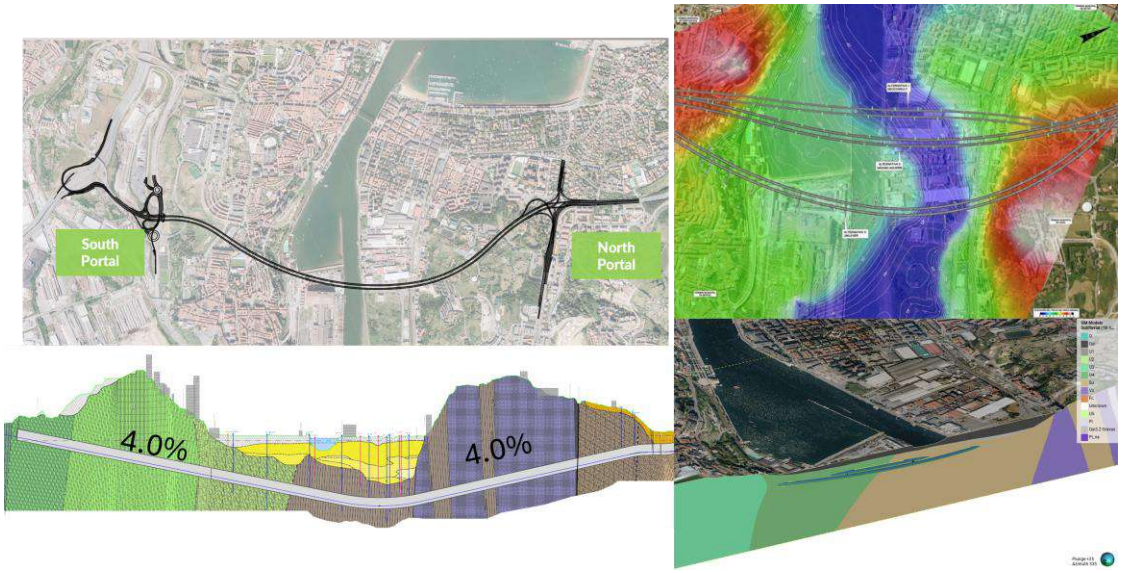
Abstract

The Underwater Tunnel of Lamiako, promoted by Biscay Regional Council (Bilbao, Spain), is a 3,2-km long twin tube road tunnel, to be drilled completely in rock. Its construction is planned to begin in 2026. This project has made extensive use of geological models, supported by a comprehensive set of field data. At the study early stages, digital models permitted to detect relevant subsurface features (as a paleochannel) and select the layout alternative. Additionally other models have been used in this stage, as S-waves speed models from geophysical studies .Further on, the use of Leapfrog Works 3D modelling software (Seequent) has facilitated the decision making regarding specific questions concerning the tunnel design. The model integrates a wide range of borehole information along a 5 km x 800 m area, facilitating thus the interpretation of terrain features. Subsequently the tunnel geometrical tentative definition was inserted in the model, allowing the analysis of critical zones, such as those with reduced rock cover under a circa 40 m soil layer, and the adoption of measures. The model has been used also for the interpolation of mechanical variables of the terrain, as RMR (Rock Mass Rating) and RQD (Rock Quality Designation), geo-statistically, by means of radial base functions. The model has allowed to visualize the project, and help in the design, as in the excavation, mainly in rock, of a great trench giving access to the tunnel north portal. It has also permitted the elaboration of a hydrogeological model, supported on the terrain geological frame.

Keywords: tunnel, Leapfrog model, Biscay region (Spain), integration of data, visualisation



Left top: tunnel plan layout; left bottom: profile; right top: digital model; right bottom: geological model

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Use of Hydrogeological Models in the Project Study of the Lamiako Underwater Tunnel in Biscay (Spain)

Jordi Font-Capo[1], José María de Ortuzar[2], Miguel de Ortuzar[2], Alejandro Tello Martínez[3]

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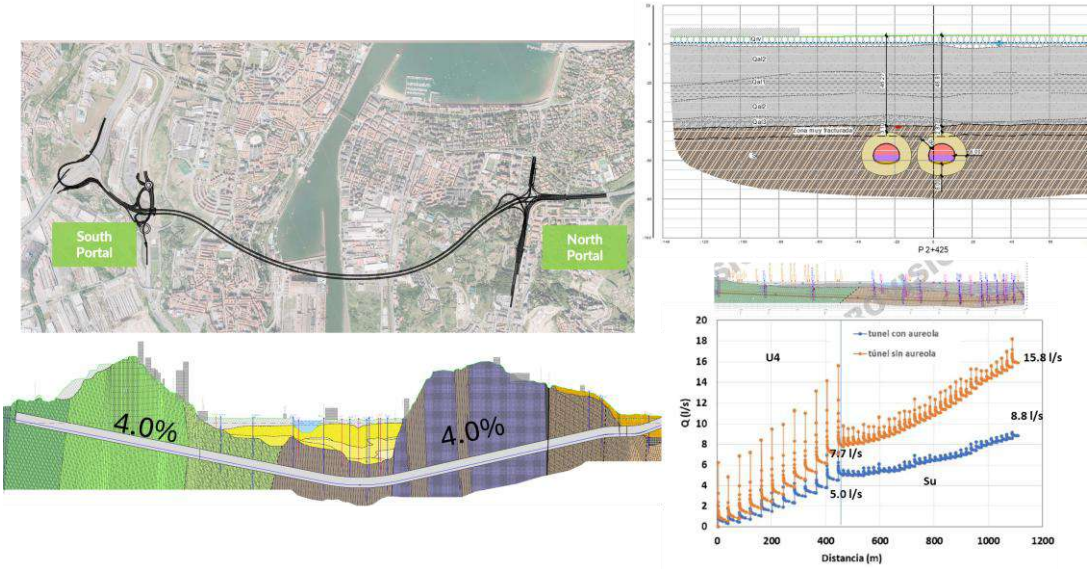
[2] Biscay Regional Council, Bilbao, Spain
[3] Freelance, Melbourne, Australia

Abstract

The Lamiako Underwater Tunnel, promoted by Biscay Regional Council (Bilbao, Spain), is a 3.2-kilometre twin-tube road tunnel, which will be excavated entirely through rock. Its construction is planned to begin in 2026. The tunnel will cross Bilbao estuary. Its layout is situated, to a great extent, below sea level, whereas other section of it crosses volcanic and flysch formations, where the water table is shallow in several points. These circumstances have led to their analysis in detail. Thus, in the project study, two hydrogeological models were built. In the present paper one of them will be described, which had been elaborated with the software program FEFLOW, and was used to address specific design issues, supported on a geological model and on a broad set of field data, collected over a long period of time. The model covers a great area (more than 5 x 1 km) centred on the tunnel plan layout and is aimed at predicting the water inflow in the tunnel along several excavation phases (transient state), and after completing excavation (steady state). Of special interest in the model is the analysis of the effect on the water inflow of the injection with grout of a rock annulus around the tunnel. The model permitted to evaluate the inflow and the pumping requirements.

Keywords: hydrogeological model, boundary conditions, tunnel inflow, construction, Biscay Region (Spain)



Left top: tunnel plan layout; left bottom: profile; right top: tunnel section with aureole; right bottom: water inflow with and without aureole

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Re-Profiling for Over Squeezing Segmental Lining

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Abstract

The T26 Tunnel is 5588 m (km: 216+260 - 221+848) long on the Ankara-Istanbul High Speed Railway route and was designed for a speed of 250 km/h. When completed, the tunnel will shorten the travel time between Istanbul, Türkiye's largest city, and its capital Ankara by 26 minutes. Serious excavation and deformation problems were encountered during the excavation work in the tunnel, and therefore both conventional and Tunnel Boring Machine (TBM) excavation methods were applied. In the squeezed ground conditions, the deformations in the segment linings caused depressions on the surface, and as a result, the TBM got stuck; therefore, the excavation work in the tunnel was stopped. During additional researches performed before starting the excavation work again, the segment linings 147 m behind the TBM were replaced. In this study, the re-profiling works applied for re-excavation in the T26 Tunnel and removal of the TBM are presented. Landslides, high seismic activity, groundwater conditions and extremely weak rock mass characteristics along the tunnel route complicate tunnel construction work. For this reason, drillings were carried out from inside the tunnel to understand the excessive excavation and ground profile behind the segment linings, and the stresses affecting the tunnel support were determined by back analysis method based on the cracks and failures in the segment linings. With the compiled data, a re-profiling method was developed employing the principles of the New Austrian Tunneling Method (NATM) for the regions where the segment linings failed. Optimizations were made in re-profiling supports due to the complex geological and geotechnical conditions in the T26 Tunnel. Re-profiling and TBM extraction operations in the tunnel were completed on January 22, 2020 with approximately 500 days of work and the excavation face was reached.

Keywords: High-speed railway tunnel, Squeezing rock, TBM, NATM, Numerical analyses

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An Insight into Water Curtain Efficiency in Underground Unlined Hydrocarbon Storage Caverns

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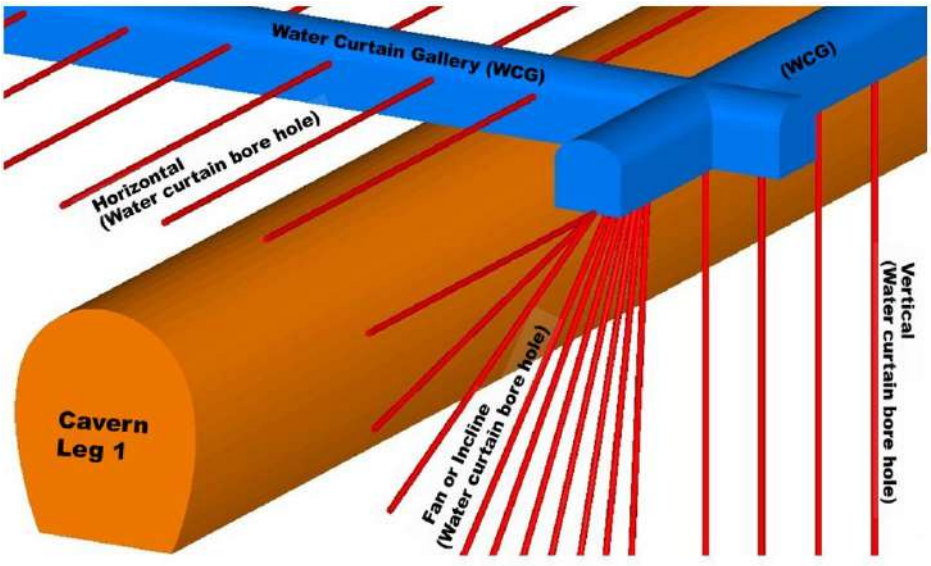
Abstract

The construction of unlined underground rock caverns for hydrocarbon storage is inherently challenging due to uncertainties in geological conditions. The fundamental storage principle of such unlined caverns is the hydrodynamic containment of the stored product. Water curtain efficiency test is the key method to evaluate the tightness and reliability of water curtain system. Using efficiency test results from three different hydrodynamic condition stages, together with the critical pressure threshold for water curtain efficiency assessment, zones of low efficiency within the tested rock mass are to be identified. This is achieved through systematic evaluation of pore and fissure water pressure propagation characteristics, together with continuous groundwater level monitoring within the project boundary and quantitative seepage measurements inside the caverns. To address these deficiencies, supplementary additional boreholes required to be drilled in the low-efficiency zones. Finally, follow-up tests are conducted to assess the improvement in efficiency resulting from the newly drilled boreholes. The test results indicate that the water curtain efficiency test can reliably and accurately identify low-efficiency zones within the rock mass. The implementation of additional boreholes significantly increases the water pressure in these previously low-efficiency boreholes, thereby enabling the cavern to satisfy the required tightness criteria for safe containment of the product. This paper presents an evaluation of water curtain efficiency test in a recently constructed underground hydrocarbon storage cavern located on the west coast of India.

Keywords: Water Curtain Efficiency Testing, Water Curtain Bore Hole, Water Curtain System, Critical Pressure, Hydrodynamic Containment



Typical arrangement of different components of water curtain system (WCS)

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Weathered and Unweathered Consolidated Clay in Tunnel, Changes of Physical Properties

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Abstract

The M0 motorway is one of the most important highways in Hungary; however, construction of its northwestern sector has not yet begun. Two tunnels are planned; a detailed investigation of the geological conditions is essential to understand the risks associated with tunnel construction, as it directly influences stability, construction methods, costs, and safety. The planned tunnels would pass through formations of the Oligocene Kiscell Clay, which is an overconsolidated tough clay. This formation is a relatively common geological unit in the Buda Hills. The properties of the clay have a very broad range in terms of physical parameters. It has relatively weak weathered units and unweathered fresh lithologies with high strength. This study aims to present and compare the physical properties of these lithologies and describe relationships between weathering and loss of strength using ultrasonic pulse velocity tests, strength tests, and density parameters.

Keywords: weathering, clay, physical properties, strength, ultrasonic pulse velocity

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Rock mass erodibility in pressurized hydraulic tunnels

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Abstract

This paper presents a methodology to assess the erosion risk of rock masses along pressurized hydraulic tunnels. Erodibility is particularly critical during plant operation in the absence of tunnel lining, and in the presence of drainage systems through the lining. Water flow through hydraulic connection holes can erode solid particles from the surrounding rock. Erosion risk is quantified by combining an Erosion Potential Index (P) with a hydraulic trigger factor related to water flow velocity. The methodology is based on geological and geotechnical investigations on site and in the laboratory. The index P is defined by five key parameters: chemical dissolution, distance between defects, thickness of seams or shear zones, fragment size distribution in shear zones, and susceptibility to slaking. Spatial arrangement and frequency of shear zones are determined via borehole-core inspection and analysis of ATV and gamma-ray logging. The hydraulic trigger factor accounts for the water's erosive capacity, establishing a critical velocity threshold beyond which erosion occurs. This method is specifically tailored for Pumped Storage Plants (PSP), where dynamic pressure oscillations inside pressurized tunnels, reaching tens of bars within seconds, occur multiple times a day. While validated on a real hydraulic tunnel within a specific geomechanical context, the methodology is designed for broad applicability across diverse geological conditions and tunnel sizes.

Keywords: Rock mass erosion, Hydraulic tunnel, Pumped Storage Power Plant

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Structural Large Deformation in Deep Hard Rock: Phenomenon Characteristics, Failure Mechanisms, and Evolutionary Laws

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Abstract

As engineering projects such as transportation infrastructure, hydropower development, and mining advance into deep underground environments, anomalous time-dependent large deformations frequently emerge in high-strength bedded or foliated hard rocks. The conventional binary paradigm based on material properties—attributing brittle rockbursts to hard rocks and plastic squeezing to soft rocks—along with continuum mechanics theories, faces fundamental challenges in elucidating such catastrophic phenomena. To unravel the underlying mechanisms, this study aims to reveal the physical constitutive relations and spatiotemporal evolution laws of structural large deformation in deep hard rock. Breaking through the traditional plastic rheological framework, this research incorporates interface mechanics and eccentric compression stability theory. Based on the macroscopic deconstruction of typical large-deformation cases in deep engineering globally, a dynamic evolution model characterizing the transition from a "continuous elastic medium" to a "discrete structural assembly" is established. The results demonstrate that the onset of structural large deformation is not governed by the plastic yielding of the rock matrix, but strictly follows a progressively cascading constitutive process: normal unlocking, shear debonding, eccentric bending, and geometric buckling. Its macroscopic volumetric dilation originates from the nonlinear superposition of microscopic interfacial physical dilatancy and the eccentric lateral deflection of discrete rock slabs. Driven by deep high stress, the fractured rock mass undergoes multiple structural reconstructions from "transient cantilever beams" to "stable three-hinged arches." This mechanism creates a spatial illusion of being "fractured yet uncollapsed" and evolves into long-term "pseudo-rheological" characteristics on a temporal scale. Furthermore, the support reconstruction provided by the residual root blocks after spalling reduces the effective free span of the interior sub-layer rock slabs, triggering a quadratic amplification in their buckling stiffness, which ultimately arrests the progressive disintegration and achieves system self-stabilization.

Keywords: Deep engineering geomechanics, Structural large deformation in hard rock, Bedded rock mass, Eccentric buckling, Self-stabilization mechanism

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Hydrogeochemical Characteristics of Shallow Water in the Gushan Tunnel Area and Implications for Tunnel Engineering

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Abstract

Understanding the recharge sources and hydrochemical evolution of shallow water is essential for assessing groundwater conditions in tunnel areas. This study investigated the hydrogeochemical characteristics, recharge sources, and anthropogenic influences of shallow water in the Gushan Tunnel area, Fuzhou, southeastern China. A total of 25 samples, including stream water, fissure water, and anthropogenically influenced water, were analyzed for major ions, hydrogen and oxygen stable isotopes, Sr concentrations, and 87Sr/86Sr ratios. The samples had pH values of 6.07–7.47 and total dissolved solids (TDS) concentrations of 16–238 mg/L, indicating predominantly weakly acidic to neutral, low-mineralization water. Na+ and Ca2+ were the dominant cations, HCO3- was the dominant anion, and HCO3-Ca·Na was the principal hydrochemical facies. Major-ion compositions indicate that granite silicate weathering and shallow water–rock interaction are important controls on water chemistry. The δ2H and δ18O values generally plot near the meteoric water line, indicating that precipitation is the primary recharge source. Similar hydrochemical and isotopic characteristics of fissure water and stream water suggest a possible hydraulic connection. One anthropogenically influenced sample (GS-25) showed elevated TDS and Sr concentrations and a lower 87Sr/86Sr ratio than natural waters. These results provide a hydrogeochemical basis for understanding groundwater conditions and supporting groundwater monitoring and environmental protection during tunnel engineering.

Keywords: Gushan Tunnel, Shallow water, Hydrogeochemistry, Hydrogen and oxygen stable isotopes, Strontium isotopes

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Unexpected Geology as Part of the Hosingen Bypass Project in Luxembourg: Examples of the Importance of Geotechnical Investigation

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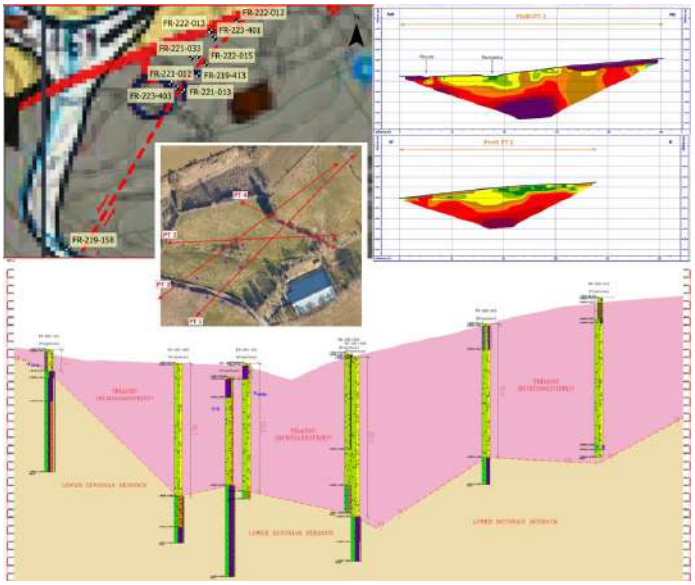
Abstract

Two engineering structures are to be built as part of the Hosingen bypass project in Luxembourg. Based on the topography and geological map, the rock was assumed to be shallow and only two exploration boreholes were planned for each structure by the project owner for the initial geotechnical studies. For the first structure, these boreholes revealed the presence of unconsolidated material and the rockhead at a much greater depth than anticipated. It was therefore decided to carry out a supplementary geotechnical campaign comprising a larger grid of boreholes and geophysical surveys. These investigations revealed a sedimentary fill up to 20m thick covering an area of 10,000m2. It is a conglomerate containing rounded pebbles ranging in size from a few centimeters to more than ten centimeters, with reddish clay cement. The pebbles are aligned horizontally, indicating that the fill post-dates the deformation of the underlying Devonian rocks. Electrical tomography revealed the presence of several faults with different orientations where the fill is the thickest. These faults appear to have formed a tectonic sedimentary basin, creating favourable conditions for the as yet unknown infilling of Triassic rivers and protecting them from the general erosion of the Mesozoic cover. In view of the new geotechnical data, the viaduct, initially planned with shallow foundations, has doubled in length, necessitating the installation of piles more than 25m long. For the second structure, the presence of the deconsolidated conglomerate necessitated the completion of additional piles deeper than those already in place, to reach the sound bedrock throughout and ensure a uniform level of support for the foundations. This highlights the need to carry out a complete and consistent geotechnical investigation at the planning stage of the project but also a competent geotechnical monitoring during the construction phase, to avoid unpleasant surprises and additional costs.

Keywords: Geotechnical investigation, Geotechnical monitoring, Unexpected geology, Bridge foundations, Piles



Summary of investigation which were carried out

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How the Application of the Observational Method Can Help Optimize the Supports: Three Examples of Projects in Luxembourg

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Abstract

The observational method was applied to optimize the supports for 3 projects in Luxembourg: the extension of an underground car park in Luxembourg, the bypass of Hosingen and the PC21 cycle path in Cinqfontaines. For each project, geotechnical calculations were carried out to verify the stability of the walls, considering the different load cases depending on the locations. Several scenarios were envisaged, based on the results of the geotechnical investigations, each corresponding to a type of support to apply. Then, as the work progressed, an in-situ analysis of the rock was carried out. Regular monitoring made it possible to classify the rock in one of the predefined cases at each stage, making it possible to secure the rock faces without losing time or stopping the works. For the car park in Luxemburg, several very specific constraints had to be considered, in particular the presence of archaeological remains and a monument to be preserved in situ. In addition, the existing car park had to remain in use. For the bypass of Hosingen, the method was used in a highly folded and faulted context, with slopes up to 25m high. The PC21 was constructed on a steep slope where few outcrops were accessible before excavation. By making it possible to check the exact geological conditions of the rock as the work progressed, and to adapt the securing required to the situation encountered, the application of the observational method made it possible to optimize the work and limit costs while guaranteeing completion deadlines.

Keywords: Observational method, Rock slopes stability, Excavation works optimisation, Faulted area



View of the rocky trench at Hosingen with the various supports optimised for the geological conditions encountered

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Engineering Geology and the Asset Management of 3000 Km of Track Embankment

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Abstract

ProRail, the Dutch infrastructural manager of 7,000 km track on ~3,000 km of railway embankments, initiated a project focussed on railway embankment stability. Although most of these embankments were constructed over a hundred years ago and still function effectively, recent calculations revealed concerns regarding their stability. To ensure safe future use of the embankments, it has been determined that any modifications to the tracks or embankments must be preceded by thorough investigations. At the start of the project in 2020, predictions were made regarding increased future usage of the Dutch railway tracks. Combined with the impacts of climate change, this led ProRail to recognize the necessity of gaining a better understanding of railway embankment stability. Unfortunately, the available information regarding the subsurface and embankments was limited, demanding a novel approach to investigate all embankment slopes in a cost-effective way. Therefore, the Stochastic Subsoil Schematization (SSS) approach was deployed for characterizing and parameterizing embankment composition and natural subsurface. This approach was combined with an automated workflow to assess slope stability. In the Netherlands, a wide range of geospatial data is available such as geological maps, ground elevation information, Cone Penetration Test data, borehole records and groundwater table measurements. This data served as the foundation for the SSS-procedure. Multiple subsoil scenarios were developed per segment, with stability calculations for each embankment slope conducted in D-Stability and automated using Python. With this, the stability of the ~3,000 km of railway embankment could be estimated, and the results were visualized in GIS for clear presentation.

Keywords: asset management, slope stability, railway embankment, Stochastic Subsoil Schematisation

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Measuring and Prioritising Sustainable Development Goals (SDGs) on a Mass Earthworks Project in Kent, UK.

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Abstract

Eastern Quarry is the main development site of a network of former quarries and industrial sites that together form the area known as Ebbsfleet Garden City sitting between the River Thames and the A2/M2 motorway some 30 miles east of London in Kent, UK. The choice of Ebbsfleet for an international railway station in the 1990s initiated a series of sub-regional and local planning policy initiatives that enabled major mixed-use planning applications to come forward. This legacy project of mass earthworks requiring re-engineering of up to 30m fill thickness has been in progress since initial inception in 2001, and is now the site of three new mixed-use villages – Castle Hill, Alkerden and Western Cross – connecting existing villages in the area with the adjacent Blue Water Shopping Centre and other local amenities. Through more than 20 years' involvement with the project we present the story of engineering the 260ha brownfield site, reusing the chalk overburden (mixed Thanet Sand and Lambeth group materials) with near zero offsite waste. The implication and understanding of sustainability, resilience and regeneration within the ground engineering industry and engineering projects has evolved in a similar timeline to this project, and therefore this paper takes a critical retrospective look at what a best practice approach means. This paper explores down-scaling of the high-level SDGs into project-level indicators to try and find a compelling way forward for the industry to consistently measure impact and objectively prioritise.

Keywords: Earthworks, Sustainable Development Goals, Ground model

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Multi-source Monitoring and Surveying Data for collapse risk identification of inner-city quay walls in Amsterdam, The Netherlands

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Abstract

Historical quay walls in low-lying delta cities are increasingly challenged by ageing materials, changing load conditions, and long-term ground deformations. In the inner-city of Amsterdam (The Netherlands), a dense network of masonry quay walls founded on timber piles requires continuous prioritization to manage collapse risk at municipal scale. This paper presents a multi-source monitoring-based framework that integrates conventional (ground-based) and innovative (remote-sensing) techniques with damage information collected during in-situ surveys to support the identification of potentially critical quay walls. Displacement information derived from terrestrial instruments (acquired in both vertical and horizontal directions) and satellite Multi-temporal Interferometric Synthetic Aperture Radar (MT-InSAR) recorded along the line-of-sight (LOS) are combined with qualitative indicators describing damage conditions (e.g. deformations and cracks on apron or wall façade) and kinematic behaviour (e.g. tilting, bulging) observed during in-situ inspections. Rather than aiming at detailed structural and stability verification of the single retaining structure (quay wall), the proposed analysis focuses on extracting consistent patterns between observed damage and recorded displacements, posing the base knowledge for developing a methodological procedure that allows the investigation of existing cause-effect relationships and the identification of the most probable collapse mechanisms. The results achieved highlights how multi-source monitoring and surveying sources can be jointly interpreted to support, at municipal scale, risk-informed decision making and the planning of mitigation strategies for historical retaining structures.

Keywords: Quay walls, Terrestrial monitoring, MT-InSAR monitoring, Damage, Failure mechanisms

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Significance of Geomodel Study in Engineering Projects

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Abstract

The Dinipro metro project with a length of 17.5 km was commenced in 1978. The middle portion (KM.13+100–15+350) is still incomplete. When the geomodel study, comprising model of Geology, Hydrogeology, Engineering geology, and Geotechnics in four dimensions, is not identified properly; problems are inevitable. Reliability of each model is dependent function of the former. However, each model may feedback. Geological-Hydrogeological model: The 2.5km long section takes place within migmatite (Pcm) overlain by a thick and highly pervious alluvium (Qa) deposited in an oxbow lake. The unit Qa has direct hydraulic connection with the perennial river Dinipro (q>1000m3/s). The unit Pcm was identified as granite (Pcg) which is isotropic and impervious whereas migmatite is anisotropic and relatively pervious. The water-ingress is being pumped out at a rate≥6000m3/day for decades. The mean advance ≤5cm/day. Engineering geological-Geotechnical models: Since the former models are improper, these models aren't dependable. This section is incomplete in terms of timing, environment, safety-security, and cost (TESC) either. The author's team was involved in the project in 2020 and informed the decision markers in the first day of field study obeying the proverb "A simple solution to a well-defined problem is more convenient than an advanced solution to an unidentified simple problem.". It was recommended to realign the centerline 0-300 m SW to bypass the Qa. Then, a strong rock-tunnel boring machine (D=5.6m) was recommended to complete the project in one year and at a cost <10% of the amount spent by 2020.

Keywords: Geomodel , Geotechnics , Alignment selection , Optimization , Civil design



Migmatite has been interpreted as granite although they are extremely different from engineering point of view. Hence, subvertical open layering contacts have direct hydraulic connection with Dinipro river throughout the alluvium. The mis-nomenclature made impossible the tunnel-construction at an acceptable time and cost.

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Quantitative Risk Analysis of Cliff Instability Hazards Impacting Coastal Infrastructure and Communities

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Abstract

Cliff instability and erosion hazards along the south and east coast of England, UK, are increasing due to extreme weather and climate change posing significant risks to infrastructure and communities. Between Dawlish and Teignmouth, South Devon, repeated cliff failures have caused disruption and line closures of an important rail link which runs below the coastal cliffs. On the east coast at Hemsby, and south coast Isle of Wight, cliff top homes have been severely impacted by cliff instability and recession destroying properties and community wellbeing.

To address these issues quantitative risk analysis (QRA) can be used for risk management and decision making which will become increasingly important in the future. Risk can vary greatly over a site and understanding where to focus resources for effective cliff and asset management is critical. Information on cliff behavior, hazard characteristics, existing mitigations and associated environmental factors provide a multifaceted spatial and temporal integrated approach for QRA.

The paper illustrates the methods and approach to quantify risk outcomes due to climate change and the cost benefits of risk reduction measures to protect infrastructure assets and communities in the future.

Keywords: Risk, Hazards, Cliff instability, Cliff failure, Climate change

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Numerical Analysis of the Flow Process During the Collapse of the Historical Archive of the City of Cologne

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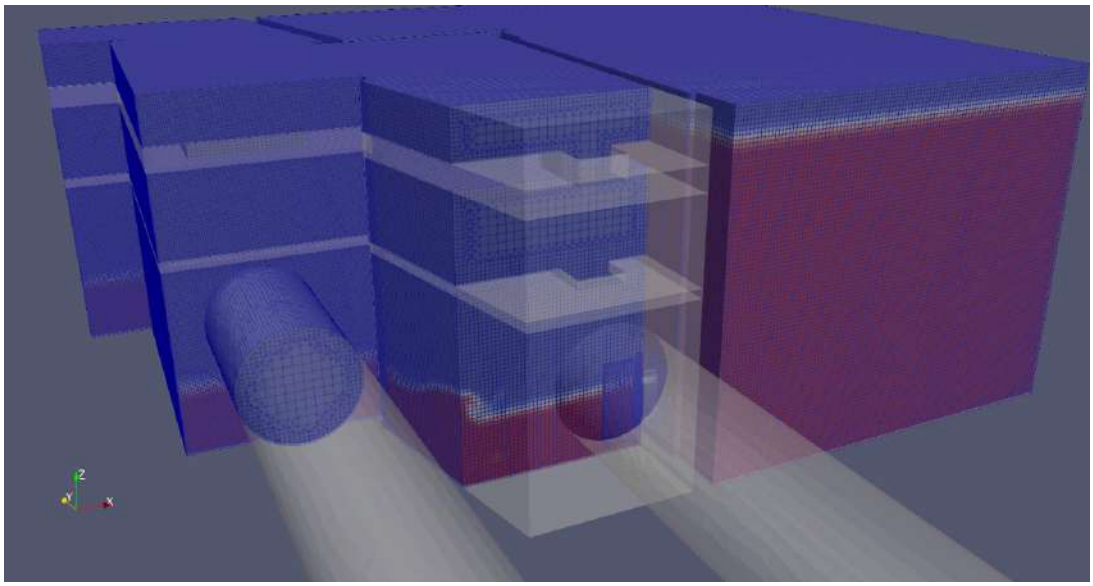
Abstract

Computational Fluid Dynamics (CFD) is increasingly used in geotechnics for the simulation of flow processes. Unlike simple estimations CFD can provide 3D flow descriptions including complex multi-physics flow and boundary conditions. Here, CFD has been employed to investigate the underground fluid transport (solid-water mixture) leading to the collapse of the Historical Archive of the City of Cologne on March 3, 2009. The flow of the soil-water mixture through the explored fluid transport channel around the defect located in the slurry wall, was simulated using the open-source CFD software OpenFOAM. The results help in reproducing and understanding the processes that led to this disaster. The fluid dynamics uses the averaged transport equations for mass and momentum (Reynolds-averaged Navier-Stokes equations, RANS), considering turbulence, if appropriate, as well as material properties of the mixture, such as density and viscosity. The OpenFOAM multiphase solver interFoam employs the Volume-of-Fluid (VOF) method to capture the interface between the fluid and the surrounding air. The simulation geometry is spatially discretized with a numerical grid of approximately 2.9 million grid cells (orthogonal hexahedral elements) in conjunction with well-resolved boundary layers on solid walls, especially in the vicinity of the defect. 3D simulations with different fractions of soil material and water were conducted to analyze their influence on the flow process through the defect (cross-section of approximately 1.5 m²) into the excavation pit. Using CFD it was possible to gain insights into the flow dynamics underlying the mechanisms of the collapse and validate it by comparing to established findings.

Keywords: Numerical Methods, Geotechnical Aspects of Underground Construction, Safety and Serviceability in Geotechnical Design



Snapshot of the three-dimensional model of the fluid-containing geometry overlaid with the numerical grid.

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Numerical Assessment of Groundwater-Driven 3D Dielectric Property Variability and Its Impact on GPR Response in Railway Subgrade Monitoring

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Abstract

Seasonal groundwater table fluctuations significantly influence the mechanical and hydraulic behaviour of railway subgrades and simultaneously alter the dielectric properties governing Ground Penetrating Radar (GPR) response. The effect of seasonal moisture redistribution on GPR-based railway subsurface monitoring were investigated using three-dimensional finite-difference time-domain simulations at 1 GHz and 400 MHz. A simplified railway model comprising a 0.30 m ballast layer over a 0.50 m sandy subgrade was evaluated under three hydrogeological states: dry reference conditions, fully saturated subgrade due to elevated groundwater table, and saturated subgrade with partial ballast void saturation representing upward moisture intrusion. Monitoring performance was quantified using four metrics: interface two-way travel time, interface envelope amplitude, detectability index, and depth of investigation. Results demonstrate that subgrade saturation produces systematic travel-time increases and attenuation effects, with substantially larger distortions at 1 GHz than at 400 MHz. Partial ballast saturation amplifies high-frequency variability, increasing reflection strength but reducing penetration stability. In contrast, the 400 MHz band maintains more consistent detectability and depth of investigation under wet conditions. These findings indicate that GPR monitoring performance is strongly conditioned by hydrogeological state and that frequency selection and velocity calibration must account for seasonal groundwater table variability to avoid systematic misinterpretation. Lower-frequency acquisition provides greater robustness during elevated groundwater table conditions, whereas higher-frequency systems offer enhanced resolution under dry states but reduced resilience during moisture redistribution.

Keywords: Ground Penetrating Radar, groundwater table fluctuations, FDTD, railway infrastructure monitoring, Forward Modeling

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Greenfield Finite Element Modelling for Damage Assessment of Axially Rigid Buildings under Groundwater-Driven Slope Movements

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Abstract

This study presents the results of a numerical analysis aimed to investigate the ground movements induced by groundwater table rise in drained soil conditions on slopes and the deformation patterns associated with axially rigid, shallow-founded buildings located along the slope for a preliminary assessment of the potential induced damage. Slope geometry is examined using a multi-step elastoplastic finite element approach. The numerical simulations reproduce progressive groundwater rise, generating incremental greenfield displacements and strains with the progressive reduction of the factor of safety. The deformation parameters are quantified through greenfield displacements and strains evaluated at different positions along the slope. Damage categories (e.g., slight, moderate, severe) are inferred by correlating computed deformation parameters with established limiting-strain thresholds consistent with an axially rigid structural model. Results demonstrate that increasing pore water pressures significantly amplifies ground displacements whereas the spatial distribution of damage-related strains is primarily controlled by the evolving kinematics of the slope. The modelled ground displacements evidence that a predominantly translational behaviour in the central portion of the slope which may coexist with rotational components near the crest and toe, which govern strain concentrations and the most critical zones for damage onset and development for buildings resting on. Unlike previous studies mainly focused on slope stability, this work explicitly integrates building deformation parameters and damage categorisation within groundwater-driven slope failure scenarios. These preliminary results achieved represent an initial step towards developing a quantitative methodology for screening building damage risk.

Keywords: Groundwater rise, Slope, Finite Element Model, Greenfield deformation, Building damage

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Combining Cone Penetration and Geophysical Data for Site Characterization near a Railway

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Abstract

Rail traffic generates vibrations propagating from the track to the neighbouring environment, adversely affecting residents and sensitive facilities. The propagation of vibrations is influenced by the heterogeneous subsurface. To assess and mitigate the vibrations, it is important to investigate and characterise heterogeneity of the ground near the railway. Using solely cone penetration tests in large-scale site investigation requires many testing locations and therefore is costly in finance. This article presents a programme jointly using cone penetration and geophysical data to characterise a site near a railway. Comparisons are made between site characterisation using the combination of data and that using the cone penetration data alone. The results demonstrate the effectiveness of combining cone penetration and geophysical data in uncertainty reduction. The proposed method can provide an optimal data acquisition scheme for large-scale site investigation.

Keywords: Cone penetration tests, Geophysical tests, Heterogeneity, Railway, Site investigation

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Reliability-based Calibration of Characteristic Values for Railway Embankment Stability Assessment

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Abstract

Stability assessment of railway embankments is predominantly performed using two-dimensional (2D) deterministic methods in engineering practice, in which three-dimensional (3D) soil heterogeneity is usually ignored. Such simplification may produce unreliable or even biased assessment results. This study develops a reliability-based method for the calibration of design parameters, which can be further used to benchmark such simplified stability calculations. The study has utilized the Random Finite Element Method (RFEM) to calibrate the characteristic values for the 2D deterministic stability assessment of a railway embankment. In the proposed method, anisotropic spatial variability of the soil shear strength is modeled using random fields, and the Monte Carlo Simulation method is adopted for uncertainty propagation and quantification. Each RFEM analysis comprises 500 realizations, based on which the probabilistic distribution of the load bearing capacity is estimated, allowing the characteristic values of soil strength parameters to be calibrated against the design load value corresponding to a target reliability level. The results show that the incorporation of 3D soil spatial variability yields a reliability-informed design load, and the calibrated characteristic values turn out to be considerably higher than the 5-percentile soil properties in many cases.

Keywords: characteristic values, railway embankment stability, Random Finite Element Method, reliability analysis, soil spatial variability

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State-of-the-art Ground Understanding for Modern Need Urban Development on the Deltaic Soils of Zuidplaspolder, Netherlands

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Abstract

The Zuidplaspolder in the Netherlands is located in the Rhine-Meuse Delta and has a typical deltaic (very) soft subsoil. Due to peat harvesting in the past the current polder level is about 5 to 6 m below sea level and is located behind dikes near the lowest point of the Netherlands. Based on the need for housing, municipality Zuidplas is developing a new village with about 8,500 houses in the Zuidplaspolder, called Cortelande. As part of a modern sustainable development it will be developed with the latest ground bounded requirements, such as stringent post-construction residual settlements requirement, application of energy storage in the subsoil and dealing with the latest insights of climate change adaptation. The subsoil of the polder presents interesting geotechnical and hydrogeological challenges and changes due to its complex stratigraphy with typical clay-and-peat-rich Holocene subsoil conditions and fluvial geomorphology of meandering rivers. Furthermore, it is formed by anthropogenic influences such as historical peat harvesting turning the polder into a lake, which was later drained again, as the first mechanically (our famous windmills) drained polder of the Netherlands. This article highlights the importance of an early and thorough understanding of all historical subsoil conditions to minimize geotechnical risks later in the project. Early full understanding is key at each stage of the development to achieve the best value, but particularly during the start-up. It explains how Engineering Geology contributed to sustainable development and mitigation of climate change in the Zuidplaspolder. Using the knowledge for a custom made and risk driven geotechnical investigation strategy. The surveys are then used for (3D) ground layering and the project's geotechnical parametrization. In this way a through geotechnical base was formed to support initial decision-making for resilient urban and infrastructural development directly, in climate-sensitive regions, susceptible by land subsidence and sea level rise.

Keywords: Zuidplaspolder, Rhine-Meuse Delta, Geology , Archeology, Geotechnical parametrization

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Environmental Sustainability of Heavy Industry Mega Construction Integration Fabrication Yard and Quay Wall Project on Immediate Surrounding at Apapa

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Abstract

The investigation was carried out at heavy industry mega construction integration fabrication yard at Apapa Lagos Nigeria to look at the possible negative impact the project might have on the immediate environment. Phyisico-chemical parameters, Cation, Anion, heavy/traces metal as well as hydrocarbon were analyzed. The physico chemical analysis conducted on the sediment samples showed that the sediments had pH value that ranged from 8.2 to 8.6, with a conductivity value that ranged from 4,000 to 4,820 µs/cm and Total Organic Content (TOC) that ranged from 0.10% to 0.51%. The analysis result showed that the soil had pH value that ranged from 8.2 to 8.6, with a conductivity value that ranged from 254.0 to 310.0 µs/cm and the exchangeable cation content showed that the soil had sodium content that ranged from 43.82 to 51.60 mg/kg, Calcium ranged from 5.30 to 9.22 mg/kg, Magnesium from 4.79 to 7.69 mg/kg, Potassium from 1.01 to 2.51 mg/kg and Manganese from 0.39 to 0.45 mg/kg. The noise level during the sampling period varied from 61.8 to 75.4 dB(A). The values recorded were all below the federal ministry of environment limit lower limit of 90.0 dB (A) for 8-hour noise exposure. The results were justified with World Health Organization limit for quantitative comparison. Based on the observed high level of environmental and safety compliance, the heavy industries –mega construction integration fabrication yard and quay wall project activities could be rated to have high environmental and safety compliance.

Keywords: Heavy metal, physic-chemical, hydrocarbons, sediment, , Ambient Air Quality, Soil characteristic, surface water, Meteorological data.

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Adaptive Design of Emergency Spillway Repairs at the Akosombo Dam: Integrating CFD and FEM Under Time Constraints

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Abstract

The Akosombo Dam Spillway No. 2 repair project addressed an urgent engineering challenge following severe erosion of the downstream rock foundation during a major spillage in October 2023. The 2023 spilling event at Akosombo Dam Spillway No. 2 resulted in severe scour of the downstream rock foundation, creating an urgent need for both immediate stabilisation and a long-term protection strategy. This paper presents the multidisciplinary adaptive design approach used to develop and construct a temporarya permanent remedial measure under extreme time, material, and logistical constraints. The primary goal was to ensure structural stability and mitigate further erosion before the 2024 rainy season, with a permanent solution planned later. A parallel workflow combining site investigations, geological mapping, hydraulic assessments, structural design, and geotechnical analyses was adopted to support rapid decision-making. For the permanent solution, an integrated modelling framework was developed, combining Computational Fluid Dynamics (CFD), three-dimensional scour modelling, and Finite Element Method (FEM) analyses. CFD simulations were used to evaluate jet trajectories, impact pressures, and hydraulic loading conditions, while calibrated scour models assessed the evolution of erosion under different spilling scenarios. These outputs were incorporated into a PLAXIS 2D geotechnical model to evaluate global stability, structural performance, and the effects of progressive scour on the remedial works.

The final design consists of an enhanced reinforced concrete protection slab integrated with a palisade retaining wall system and scour protection measures founded on the underlying rock mass. Model calibration against the 2023 event increased confidence in hydraulic loading assumptions and rock mass behaviour, while sensitivity analyses confirmed stability under conservative scour conditions. The project demonstrates how the combination of CFD, scour prediction, and geotechnical FEM modelling can be effectively integrated within an adaptive design framework to deliver resilient dam infrastructure solutions under conditions of geological uncertainty, operational constraints, and increasing hydrological extremes.

Keywords: Dam Safety, Multidisciplinary Design, Computational Fluid Dynamics, Finite Element Modelling, Scour Modelling



The Akosombo Dam with its two spillways (on the right).

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Concrete Over-Consumption in Non-Displacement Piles in Dikes Due to Concrete Pressure

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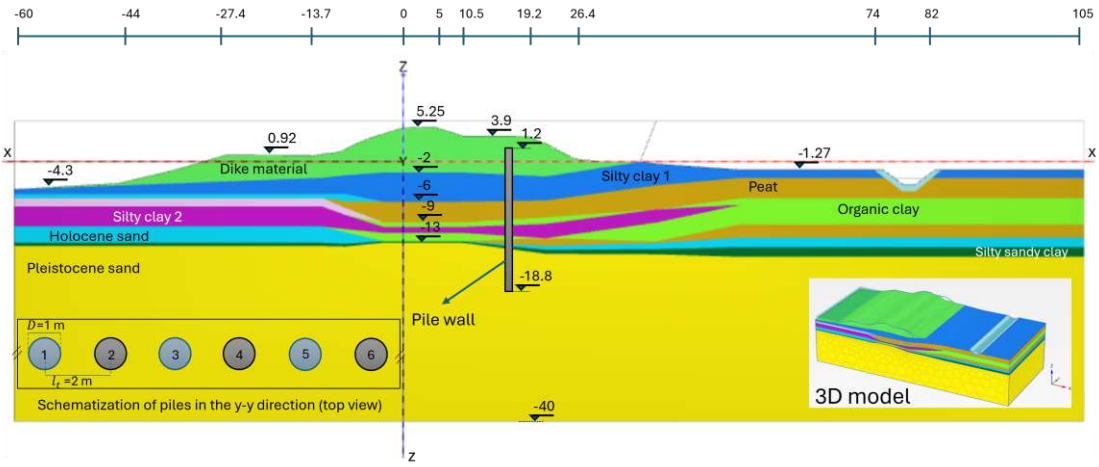
Abstract

In dike reinforcement projects in the Netherlands, non-displacement pile walls are frequently used to enhance slope stability while minimizing disruption to nearby infrastructure. However, when installed in soft soil conditions such as clay or peat, these piles often exhibit concrete over-consumption. This phenomenon is partly attributed to the lateral pressure exerted by fresh concrete on the surrounding soil, which may deform the borehole and increase the required concrete volume. Despite its practical relevance, this mechanism remains underexplored in current design practice. This study investigates the impact of concrete pressure on soil deformation and over-consumption during pile installation. Using both axisymmetric and three-dimensional finite element models, compared to data from the Lekdijk reinforcement project, we simulate borehole deformation across various soil profiles and concrete pouring rates. Results show that in soft soils, rapid concreting can induce significant horizontal deformation, up to 10 cm at the dike toe, and lead to concrete over-consumption exceeding 25%. In contrast, stiffer soils such as silty and clayey layers reduce both deformation and material excess, often keeping over-consumption below 10%. Furthermore, while reducing the concrete pouring rate can mitigate deformation, it may result in early setting of the concrete before casing extraction is completed, potentially forming vertical gaps that compromise hydraulic integrity. These findings highlight the need to optimize pouring rates based on subsoil conditions, balancing construction efficiency, cost, and dike stability.

Keywords: dike reinforcement, non-displacement piles, soft soils, finite element modelling, concrete over-consumption



Effect of concrete pressure in displacement-piles in the Lekdijk case in Plaxis 3D

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Marine Geotechnics Numerical Software FssiCAS for FSSI Problem-Features and Typical Applications

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Abstract

A great number of offshore structures had been constructed worldwide in the past decades, but their stability were always seriously threaten by the extreme ocean waves or seismic waves. Developing reliable methods for evaluating the stability of offshore structures is a major international challenge. The seawater–marine structure–seabed foundation system is inherently a coupled system, and its stability must be assessed by considering the complex interactions among these components. However, a reliable evaluation framework that fully accounts for these coupled interactions has only emerged in the past decade. We will present a Chinese marine geotechnics numerical software FssiCAS, which is specially developed as well as is the first numerical modelling software worldwide for the problem of fluid-structure-seabed interaction (FSSI). The main features and function will be first introduced, and then some typical applications involving coastal breakwater, offshore wind turbine, subsea floating tunnel, River-crossing tunnel etc., will be given to illustrate the abilities of the software FssiCAS

Keywords: Marine geotechnics, Numerical modelling, Chinese software FssiCAS, Fluid-Structure-Seabed Interaction, Offshore wind turbine

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Application of Monitoring-Guided Controlled Grouting Uplift Technology for Green and Low-Carbon Tilt Correction of High-Rise Buildings

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Abstract

Differential settlement and inclination of existing high-rise buildings may develop under weak ground conditions with localized subsurface voids, compromising structural safety and serviceability. Conventional demolition, reconstruction, or large-scale foundation replacement may involve substantial material consumption, construction waste, and site disturbance. This study presents a monitoring-guided controlled grouting uplift method based on green and low-carbon principles for the tilt correction of a high-rise building in Mengshan County, Guangxi, China. Engineering geological investigations were first conducted to identify the principal factors responsible for differential settlement and inclination, and a three-dimensional FLAC3D model was subsequently developed to evaluate ground deformation and the effects of subsurface voids on the building response. Based on the investigation and numerical analysis, a targeted reinforcement-first, uplift-second treatment scheme was implemented using low-pressure, staged injection of an environmentally friendly composite grout. Real-time deformation monitoring was used to dynamically adjust the grouting process and control uplift magnitude and uniformity. Following treatment, the building inclination ratio decreased from 6‰ to 0.3‰, demonstrating a significant tilt-correction effect. By preserving the existing load-bearing structure, the in-situ treatment reduces the need for large-scale demolition and foundation replacement and helps reduce material consumption and construction waste. The integration of engineering geological investigation, numerical modelling, and monitoring-guided grouting enables safe, controllable, and low-disturbance treatment of differential settlement in existing buildings.

Keywords: differential settlement, engineering geological characterization, controlled grouting uplift, numerical modelling, low-carbon rehabilitation

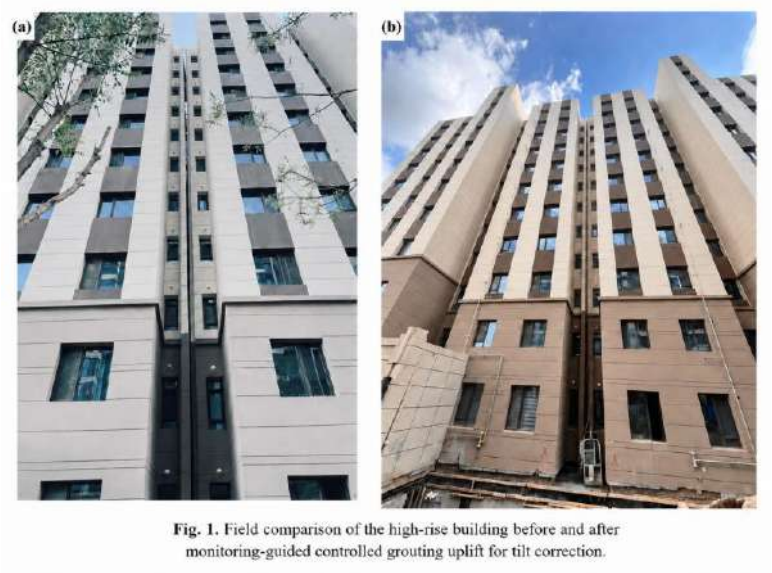

Fig. 1. Field comparison of the high-rise building before and after monitoring-guided controlled grouting uplift for tilt correction.

Fig. 1. Field comparison of the high-rise building before and after monitoring-guided controlled grouting uplift for tilt correction

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The Fehmarnbelt Tunnel Trench Dredging and Reclamation Project

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Abstract

The Fehmarnbelt Tunnel Trench Dredging and Reclamation Contract (TDR), a Design and Construct contract executed by Fehmarn Belt Contractors (FBC), comprises large-scale dredging works and the reuse of excavated materials for the construction of dikes and reclamation areas. The geological complexity of the project area, characterized by several types of fine-grained soils, combined with the scale of the earthworks, poses a range of engineering challenges. This presentation provides an overview of the project and the TDR scope, followed by a description of the geological units encountered within the dredging areas. Their engineering characteristics are discussed in relation to dredging operations and the reuse of dredged materials. Particular attention is given to challenges associated with the occurrence of boulders within glacial till deposits. The implications of hydraulic methods, such as Trailing Suction Hopper Dredgers (TSHDs), and mechanical methods, including Backhoe and Grab Dredgers, are considered in relation to the reuse of dredged materials and the project's performance-based requirements. A key message is that model parameters should not be regarded as soil properties, but rather as values selected for specific engineering purposes. Understanding the geological origin of the soils, the planned dredging and reclamation operations, and the intended reuse is fundamental to the successful delivery of large-scale dredging and reclamation projects involving fine-grained soils.

Keywords: Offshore, Dredging, Reclamation, Beneficial Use, Tunnel

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Initiatives for the Effective Utilization of Excavated Rock Containing Geogenic Heavy Metals and Metalloids in Japan

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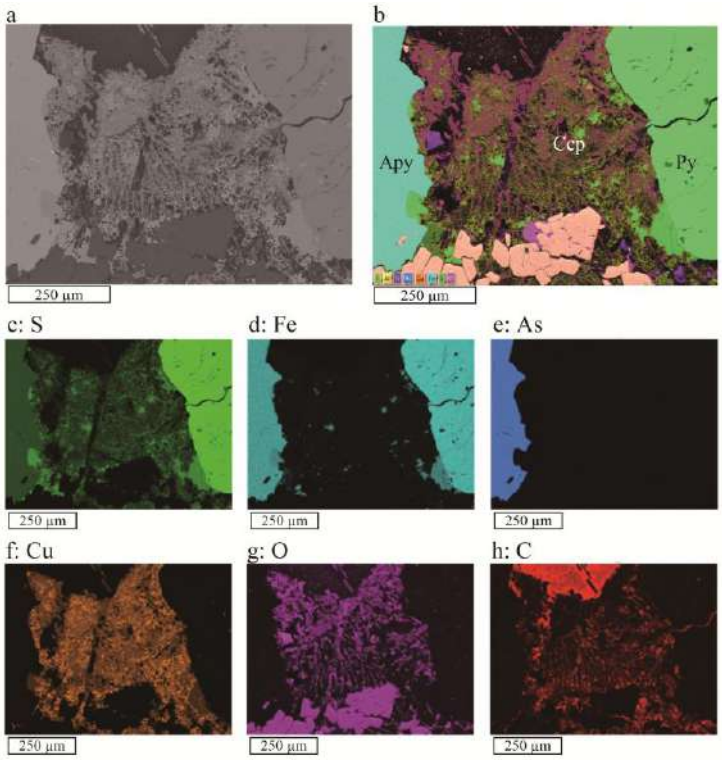
Abstract

In Japan, there are initiatives to effectively utilize excavated rock generated from large-scale public works as construction materials, such as embankments, from the perspective of reducing environmental impact. Excavated rock is utilized by implementing rational countermeasures based on environmental safety assessments. This paper introduces the technical manual that summarizes this series of processes in Japan. Furthermore, as part of recent research, it introduces attempts to elucidate the leaching mechanisms of geogenic heavy metals and metalloids in excavated rock using electron microscopy.

Keywords: environmental impact reduction, excavated rock, geogenic heavy metals and metalloids, acidic water, scanning electron microscopy (SEM)



Selective reactions occurring in chalcopyrite due to galvanic interaction, observed via SEM. Apy: arsenopyrite; Ccp: chalcopyrite; Py: pyrite; a: SEM-EDS electron image; b: electron image with elemental mapping; c–h: individual elemental maps.

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Influence of Petrographic Characteristics on the Physical-Mechanical Properties of Crystalline Rocks: Quality of the Aggregate Produced

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Abstract

This research falls within the context of the sustainable use of resources and aims to optimise the production process of aggregates by understanding the petrographic characteristics that influence their mechanical behaviour. Therefore, studying the performance of the produced aggregate is relevant to the region's economic and technological development, as it provides criteria for selecting materials to optimise production and improve product quality. Geologically, the study area forms part of the Santa Inês Intrusive Suite, consisting of fine-to medium-grained Proterozoic leucocratic hornblende/biotite granites with irregularly distributed outcrops. This is a highly valuable area for aggregate production. After defining the sampling points for each mining front, tests were conducted on the rock and aggregate. A petrographic study was performed, including mineralogy, textural and microstructural aspects, and degree of alteration. The aggregate's physical and mechanical properties were characterised according to international standards, including specific gravity, water absorption, Los Angeles abrasion, and crushing value. The results revealed that the textural (e.g. elongation of quartz grains) and compositional features (e.g. basaltic intrusive bodies) identified in the study did not influence the quality of the aggregate produced.

Keywords: petrographic characteristics, physical properties, mechanical properties, crystalline rocks, aggregates

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Application of Scheelite Residues as a Components in Soil-Cement Mixture for Base Pavement Layer

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[2] Federal University of Rio Grande do Norte, Natal, Brazil

Abstract

Civil engineering, especially transportation infrastructure, is one of the largest consumers of natural resources, as well as a generator of waste. To overcome this situation, research has been conducted worldwide on the reuse and recycling of waste for use as pavement layers. Among the various materials used as layers, in pavement construction, meanly in base layer, soil-cement is a widely adopted alternative. This solution involves selecting a granular material whose characteristics are improved through chemical stabilization by mixing it with cement. The rigidity achieved through this stabilization allows for the use of thinner asphalt pavements. Given the global trend of reusing materials in civil engineering applications, the aim of this study was to reuse scheelite residues (coarse and fine waste) — a by-product from the processing of the mineral, of which only 0.8% is utilized as a source of Tungsten (W) — as a component in a soil-cement mixture. Previous studies have demonstrated the applicability of this residue as a sub-base layer. In this study, physical tests such as granulometry, Atterberg limits, and physical-chemical dosing were performed to obtain a mixture composed of 85% coarse residue, 15% fine residue, and 8% cement (85C15F+8CE). This mixture achieved an average simple compressive strength of 2.39 MPa, meeting the minimum value recommended in the DNIT standard of 2.10 MPa, demonstrating the applicability of the material for use as a base pavement layer.

Keywords: Sustainability, Reuse, Pavement, Scheelite, Waste



Pile of scheelite coarse residue

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Quantification of Chert in Concrete Structures to Reduce Bias in Alkali-Reactive Aggregate Assessment through Forensic Examination

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Abstract

Reliable condition assessments are essential for managing concrete structures affected by alkali-silica reaction (ASR). Expansion in ASR-affected concrete results from the chemical potential of the material and is influenced by the aggregate lithology and concrete mixture properties. It is commonly assessed by linking expansion to the degree of internal damage, based on laboratory testing. However, in the absence of documentation from the time of construction, a forensic investigation was necessary to recover the original mixture design and identify the alkali-reactive constituents. Petrographic examination was carried out to determine the origin and composition of the aggregates. The alkali-reactive component, was according to existing guidelines identified as chert/flint. However, accurately quantifying the volume of alkali-reactive aggregate proved challenging. In existing structures, standard petrographic methods are limited. Sampling and preparation processes introduce bias, as sections are typically taken from 'areas of interest'. This approach often leads to an overestimation of both damage and reactive aggregate content, making it unsuitable for assessing the overall reactive fraction. To improve representativeness, a new method was proposed to quantify chert on polished cross-sections of larger specimens. This was compared with conventional thin section analysis to assess sampling requirements and statistical reliability. Validation was carried out by extracting and cleaning coarse aggregates and identifying them using descriptive nomenclature. Image analysis on polished sections allowed for direct identification and quantification of chert particles within the coarse aggregate fraction. The proposed method contributes to more consistent and representative quantification of reactive aggregates, addressing key limitations in current ASR assessment practices.

Keywords: Alkali-Silica Reaction, Aggregate assessment, Sampling bias, Representative quantification , Chert

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Assessment of Environmental Impacts of Limestone Aggregate Mining with the Life Cycle Approach

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Abstract

Global interest in mining and sustainability is steadily increasing today. During this process, adopting sustainable practices and minimizing environmental impacts are of great importance. Aggregate is the general name for natural materials such as sand, gravel, and crushed stone used in the production of concrete and asphalt. The structural growth and development of a country, its increasing population, and the necessity of industrial and infrastructure investments make aggregate one of the mandatory strategic natural raw materials worldwide. The purpose of this study is to evaluate the environmental impacts of mining activities at a quarry located in Cebeci Village, Sultangazi District, Istanbul, where limestone is produced as aggregates. First, the geology of the quarry area and its surrounding area has been examined. Then, using the life cycle assessment (LCA) method, 1 ton of aggregate production was accepted as the functional unit and the activities in the aggregate quarry were included in the system. These activities include excavation and blasting, loading and transportation, crushing and sieving and transportation to the stockpile. It was found that the global warming potential of limestone aggregate quarrying is 1.98 kg CO2 eq./ton aggregate. It was observed that the most significant contributors to the increase in global warming potential were the electricity supplied to meet the high energy demands of heavy machinery and equipment used in mining activities and the diesel fuel consumed.

Keywords: Aggregate mining, limestone, life cycle assessment, environmental impact

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Circular Materials for Urban, Civil Engineering Purposes

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Abstract

The larger the city becomes, the more complicated the supply of aggregates for construction of hard-made surfaces such as streets, parking places, bike lanes and industrial areas. Circular economy and better planning of available resources are important keys to solving much of the ever-increasing needs of aggregates. This Swedish project takes a holistic view on the problem and includes such topics as circular procurement, dimensioning of roads, suitable test methods for quality control and factory production control, legislation, climate impact, how to build in practice and how to follow up, maintenance etc. One of the overall goals of the project is to make circular materials easier to use and more commonly applied, primarily in municipal infrastructure. Sixteen partners are directly engaged and represent cities/municipalities, contractors, material suppliers, energy producing companies, research institutes and landscape architects. Of primary focus are materials such as ash from incineration of municipal waste, crushed concrete (e.g. inorganic, non-metallic construction and demolition waste), crushed asphalt (i.e. not milled asphalt from larger roads). The project has built several test sites which will be presented. In general, the subbase, or bottom part of it, has been replaced with some of these waste materials. People directly involved in building the test roads have been interviewed and the information shared in e.g. technical reports. The project is rather big (and technologically broad) and will not be possible to present in all its details in a short abstract but can also be followed here on the website: ri.se/sv/circulara-anlaggningsmaterial

Keywords: aggregates , waste, circular economy, construction, sustainable infrastructure



Construction of a test road with different secondary materials

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Using concrete plant waste as reclaimed aggregates in concrete: new opportunities

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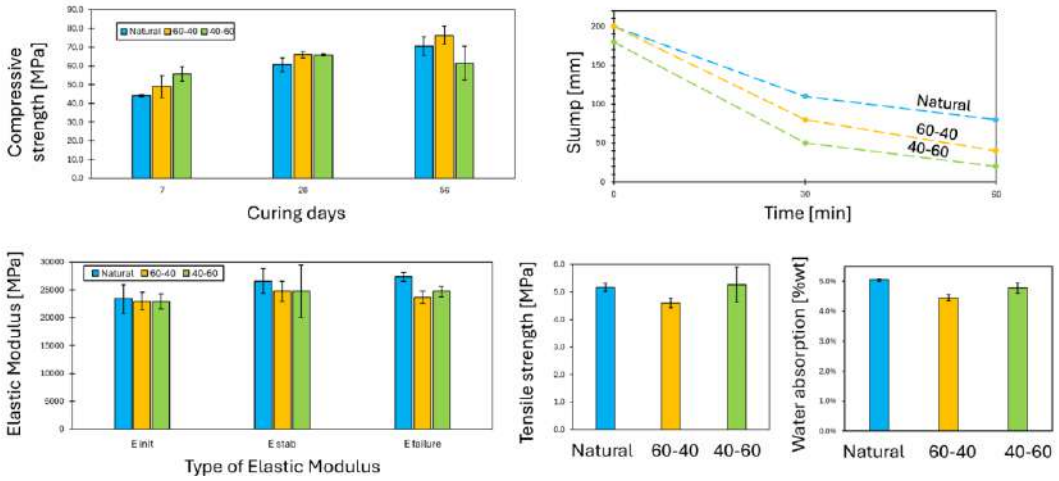
Abstract

Circularity of materials is part of the solution for sustainable development. In concrete formulations, concrete plant waste can be used as reclaimed aggregates (RA). This opportunity reduces the need for natural aggregates, thereby limiting the impact of the construction sector on the environment. The European norm (NBN EN 206) now allows to substitute 5% of natural aggregates by reclaimed ones. This study addresses the impact of such a substitution on concrete properties.

Three formulations were investigated. The reference composition contains 100% natural aggregates. The other formulations include 5% RA with 0/6mm and 6/20mm fractions, respectively with proportions 60-40% and 40-60%. Both fresh and hardened (28 days) concrete samples were tested. The workability and density of concrete with 5% RA is lower. Indeed, RA are coated by a very porous hardened cement layer. It lowers the density of aggregates, and hence of concrete, but also water tends to occupy the pore space in the cement layer. In particular, workability is reduced by 25% after 30 minutes and by 50% after 1 hour. However, after 28 days, no significant difference was observed for the water absorption, elastic modulus, compressive strength and tensile strength (Fig. 1). Such results show that a fraction of reclaimed aggregates with various size distribution can be used in concrete formulations. It opens new opportunities for developing circularity in certified concretes by increasing the content of RA, by variating their grain size distribution (increase fine fraction) or by investigating techniques to remove the cement layer.

Keywords: Reclaimed aggregates, Sustainable concrete, Fresh-Hardened concrete , workability, Water absorption



Evolution of properties on fresh and hardened concrete in function of RA's substitution and grain size distribution

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Planning Aggregate Supply in İstanbul, Türkiye

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Abstract

Sustainable management of aggregate resources is increasingly acknowledged as a key component of regional development, particularly within the European Union's environmental and land-use frameworks. İstanbul, Turkey's most populous and rapidly urbanizing city, faces mounting pressure to secure a stable and sustainable supply of aggregates to meet the growing demands of its construction sector. Over the past three decades, urban expansion has pushed residential development into former quarry zones, turning once-remote extraction sites into areas of environmental tension. Concurrently, the depletion of nearby high-quality reserves and a range of regulatory, logistical, and ecological constraints have underscored the urgent need for a strategic planning approach. This study provides a comprehensive assessment of aggregate resource planning in İstanbul. It begins with an overview of existing resource distribution and extraction zones, identifying key challenges such as land-use conflicts, environmental degradation from surface mining, and the limited integration of quarry operations into urban planning. The study also explores sustainability-oriented solutions, including the use of environmentally responsible mining practices, digital monitoring technologies, strategic relocation of quarrying activities, and enhanced stakeholder involvement. Through this multi-dimensional analysis, the study highlights the importance of long-term, cross-sectoral coordination to ensure that aggregate supply systems remain economically viable, environmentally sustainable, and aligned with the city's broader development goals. The findings are intended to support both policymakers and industry stakeholders in shaping forward-looking policies. In alignment with these priorities, Republic of Türkiye Ministry of Energy and Natural Resources, through MAPEG, is currently conducting aggregate resource planning studies for the İstanbul province.

Keywords: aggregate, sustainable planning, istanbul, turkey

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Automated Classification of Natural Aggregates Using Paired Polarized Light Microscopy

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Abstract

Reliable identification of natural aggregate types is essential for ensuring the quality, durability, and performance of concrete. Traditional petrographic methods based on plane-polarized light (PPL) and cross-polarized light (XPL) microscopy provide valuable insights into mineralogical composition and texture, yet they remain heavily reliant on expert interpretation and are often limited by subjectivity and time constraints. This study proposes an automated classification approach that leverages image-based machine learning techniques to identify natural aggregate types using paired PPL and XPL thin-section images. High-resolution microscopic images were acquired for various aggregate types commonly found in structural concrete. A convolutional neural network (CNN) architecture was trained on paired PPL–XPL image data to learn discriminative features associated with mineral texture, birefringence, and microstructural patterns. The training dataset was manually annotated based on expert classifications, and several preprocessing and augmentation strategies were employed to improve generalization. By combining complementary information from both lighting conditions, the model enhances classification performance. The developed model achieved high classification performance across multiple natural aggregate types, demonstrating the feasibility of combining polarized light imaging and machine learning for rapid, objective, and reproducible petrographic analysis. Beyond accurate classification, identifying the specific type of aggregate plays a crucial role in predicting potential durability issues—such as Alkali-Silica Reaction (ASR) in reactive siliceous aggregates or poor freeze-thaw resistance in certain porous types. This approach offers a significant advancement toward digital petrography workflows by reducing dependence on manual evaluation, enabling standardized classification, and supporting faster decision-making in aggregate sourcing and concrete mix design.

Keywords: Artificial Intelligence, Segmentation, Aggregate characterization, Digital petrography, Mineral identification

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Global Outlook on Aggregate Supply: Challenges and Opportunities

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Abstract

The global demand for aggregates—such as sand, gravel, crushed stone, and recycled materials—continues to rise due to rapid urbanization, population growth, and expanding infrastructure, especially in developing regions. As a heavily used construction material, aggregates are vital for roads, buildings, and essential infrastructure. However, this growing demand presents serious challenges in resource availability, environmental sustainability, and supply chain efficiency. Natural reserves are depleting in many areas, while access to new quarry sites is limited by land-use conflicts and environmental regulations. Transportation costs often exceed production costs, particularly in urban regions lacking nearby sources. In earthquake-prone and low-income countries, substandard materials and poor construction practices further elevate safety risks. Despite these challenges, the aggregate industry holds significant potential for innovation and sustainable transformation. Advancements in recycling technologies, circular economy practices, and integrated planning approaches offer promising solutions. Utilizing construction and demolition waste, enforcing quality standards, and fostering collaboration among engineers, geologists, policymakers, and civil society can improve supply resilience. Digital technologies—such as GIS mapping, remote sensing, and real-time monitoring—are transforming aggregate management. These tools enable better forecasting, environmental impact assessment, and logistics optimization, supporting more sustainable operations. Ultimately, this study highlights the importance of multidisciplinary, strategic, and digital approaches in aggregate planning. In megacities and fast-growing areas, long-term sustainability and socio-economic resilience depend on innovation, smart governance, and coordinated planning.

Keywords: Aggregate supply, Quarry planning, Circular economy, Environmental impact, Supply chain optimization

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A Novel Method for Alkali-Silica Reaction Mitigation in İstanbul's Aggregates: Understanding Reactivity and Treatment

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Abstract

This study presents a novel method for mitigating alkali-silica reaction (ASR) in concrete by thermally treating clay-rich aggregates sourced from the Trakya Formation in Istanbul. Aggregates from two quarries-one on the European side and one on the Asian side of Turkey-were examined to evaluate the generalizability of the method. Petrographic analysis revealed that ASR gels formed predominantly within the binder phase, associated with microcrystalline quartz rather than coarse grains. To mitigate ASR, the aggregates were thermally treated at 800 °C for 30 minutes. XRD analysis indicated the elimination of chlorite and calcite and a significant reduction in muscovite content, while DTG-TG and XRF analyses confirmed phase transitions and loss of volatiles. These changes resulted in the formation of amorphous phases with pozzolanic potential. ASTM C1260 expansion tests demonstrated that untreated aggregates showed significant expansion-above the 0.2% limit-within 14 days. In contrast, thermally treated aggregates remained well below this threshold even at 28 days. Thin-section observations further confirmed the reduced gel formation and absence of internal cracking in treated samples. This approach differs from conventional ASR mitigation strategies that rely on supplementary cementitious materials (SCMs) added to the binder. Instead, it activates reactive clay minerals within the aggregate itself, eliminating the need for additional materials. While effective for aggregates containing muscovite and chlorite, its applicability is limited to aggregates with similar compositions. The results suggest that in-situ thermal treatment offers a practical, scalable, and sustainable alternative for ASR control in clay-bearing aggregates used in concrete infrastructure.

Keywords: Alkali-silica reaction (ASR) mitigation, Thermal treatment of aggregates, Sustainable construction materials, Concrete durability, Pozzolanic transformation

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Failure Mechanism Analysis of Granite-Backfill Bio-Composites Under Hydromechanical Cyclic Loading: Implications for subsurface Infrastructure

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Abstract

This study investigates failure mechanisms in granite-porous backfill composites under hydromechanical loading conditions, combining triaxial cyclic tests (9 MPa confining pressure; 0-9 MPa osmotic pressures), acoustic emission (AE) monitoring, and 3D CT scanning to advance damage assessment for mining and resilient infrastructure. Results demonstrate that increasing osmotic pressure reduces AE energy but elevates the AE Damage Index (DAE, distinguishing tensile/shear microcracks) from 0.32 to 0.55, while 3D fracture visualization reveals osmotic pressure broadens crack inclination ranges (63°-85° to 49°-80°) and lowers average angles, indicating shear failure dominance. Two key correlations were established: (1) Under dry conditions, energy dissipation damage (DED) relates to DAE via DED= a/(DAE+ bσ3) + c, identifying tensile-to-shear failure transitions; (2) Under seepage, DAE and visual damage (DV) follow DV = aDAEb (b<0), validating cross-method damage assessment. These findings prove osmotic pressure intensifies interface cracking - critical for tailings dam stability and post-mining risk management - while the mathematical correlations enable reliable damage prediction in high-pressure environments like deep mining or underground storage. The consistent damage progression laws across natural and engineered geomaterials not only aid forensic analysis of geotechnical failures but also provide quantitative tools for designing resilient infrastructure resistant to pore pressure fluctuations. By linking microscale damage indices to macroscale failure modes, this work offers practical solutions to enhance the durability of subsurface structures facing complex hydromechanical challenges.

Keywords: Hydromechanical coupling, Damage index correlation, Mining backfill stability, Shear-tensile failure transition, Resilient subsurface infrastructure

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Long-Term Durability of Aggregates: An Overview of Abrasive Tests

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Abstract

Standardized tests are available to assess the durability of aggregates. These tests employ various methods and enable the estimation of the applicability of different rock types in the construction industry. The current study extends these limits and provides an overview of the long-term durability of aggregates by performing additional rotations that extend beyond the limits of the standards. Namely, the European standard (EN 1097-1:2023) requires 12,000 rotations during micro-Deval tests to evaluate the quality of aggregate, while Los Angeles tests (EN 1097-2:2020) require a few hundred (500) of rotations. Our experiments aimed to expose aggregates to higher abrasive stress. Namely, 10 or 20 times more rotations were applied, and the performance of volcanic rocks under these extended abrasions was assessed. Regression analyses were made to evaluate the behaviour of these lithologies and to estimate the reliability and limitations of standardized abrasion tests.

Keywords: aggregate, duranilty, laboratory testing, micro-Deval



Andesite aggregate after 120,000 rotation in micro-Deval drum

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Sustainable Application of Calcium Carbide Residue and Lime for Stabilisation of Soft Marine Clay: Strength and Microstructural Analyses

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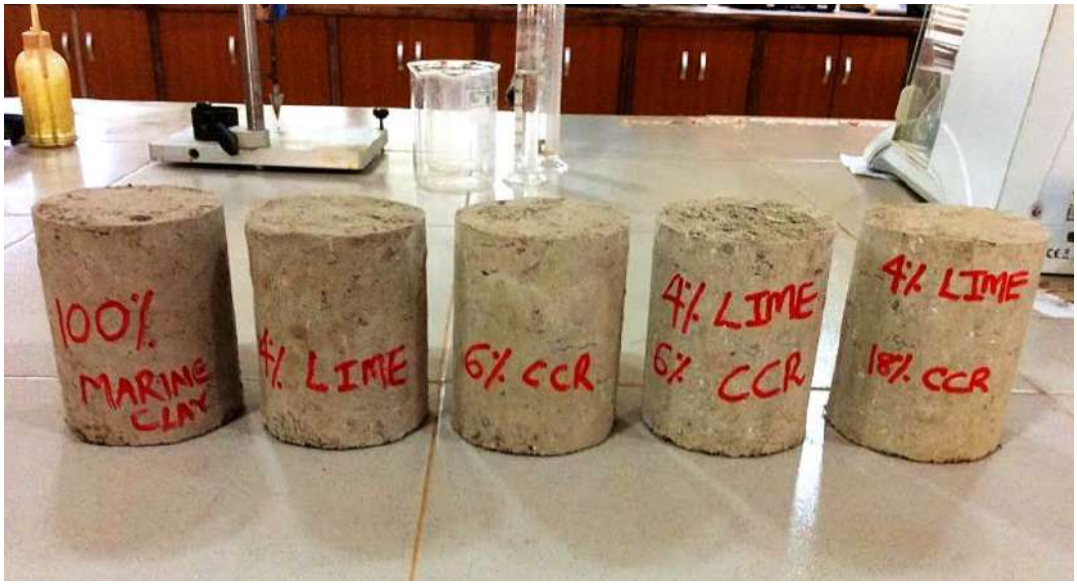
Abstract

The shift towards environmental sustainability and cleaner production has inspired civil engineers and policymakers to evaluate the possibility of using supplementary cementitious materials (SCMs), such as calcium carbide residue (CCR), wholly or in part, with traditional stabilisers to improve the engineering properties of expansive soil. This paper, therefore, investigates the sustainable application of CCR and lime for stabilisation of soft marine clay (SMC). For this purpose, the SMC sample was initially treated with 4 wt.% lime and then admixed with varying dosages of CCR (0%, 3%, 6%, 9%, 12%, 15%, and 18%). A series of unconfined compressive strength (UCS), Atterberg limits, and California bearing ratio (CBR) tests was conducted on the SMC-lime-CCR mixtures after soaking ages of 3, 7, 14, and 28 days. Microstructural analyses were conducted by carrying out scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDX) on the stabilised soil samples. The UCS results indicate that the addition of 12 wt.% and 18 wt.% CCR to the SMC-lime mixtures increased the unconfined compressive strength by 529.9% and 601.30%, respectively, after a soaking age of 28 days. Similarly, the CBR value increased by 558% and 602%, respectively, for the same dosages of CCR and soaking age. The SEM results indicate that the degree of distribution of cementitious reaction products is controlled by the CCR dosage, while the EDX results indicate that the percentage of calcium, silica, and aluminium in the soil matrix can be linked to the progression of pozzolanic reactions.

Keywords: Expansive soil, Calcium carbide residue, Soil stabilisation, Strength, Lime



Laboratory preparation of the SMC and SMC-lime-CCR samples for geotechnical tests.

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Limestone is Superior to Hard Rocks in Asphalt and Concrete

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Abstract

The Los Angeles Abrasion Test has been included in relevant specs to select aggregates for concrete and road pavement internationally since 1920s. Hardness is not strength or toughness. It is the ability to scratch other materials. Glass, which is made of essentially SiO2 with hardness (H) of about 7, scratch iron (H@4) plate easily. But the glass is quite brittle due to lower strength and toughness. Moreover, bitumen and hard rocks (silicates and groundmass of basalt) are all negatively charged and they repel each other. Fine to cryptocrystalline limestone, has distinct superiority over siliceous and silicate rocks as aggregate in asphalt, subballast, ballast, and concrete. Toughness is the ability to withstand shock loading without fracture and it is the main concern in selection the of proper aggregate source, which in turn to prolong the useful life of asphalt, ballast, suballast, concrete platform roads, and concrete. Particularly during the last 30 years the hard rocks are extensively used in wearing course and concrete roads by disregarding toughness, affinity, and physical-chemical interactions of calcite with bitumen and cement minerals. Limestone [chief mineral of which is calcite (CaCO3)] is major ingredient in cement production. It provides Ca2+ which is the main cation for four major cement minerals. The chemical-physical processes in concrete continue forever between limestone aggregate and cement which in turn the strength noticeably increases with time. The memorized desperation continues since 1920s. Fortunately, the authors' team has convinced many customers at home and abroad through practical field application since particularly 1988.

Keywords: Limestone, Asphalt, Affinity, Cement minerals, Cation exchange



Limestone aggregate is superior to siliceous and silicate aggregate in terms of economic lifespan for asphalt pavement and concrete

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Economic Prospects and Industrial Profiling of Residual Clays around Southwest Nigeria for Sustainable Development.

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Abstract

Residual clays are important industrial and engineering materials whose properties are largely controlled by parent rock composition and intensity of weathering. This study investigates the economic feasibility and characterization of residual clay deposits from selected locations in Ekiti State, Southwest Nigeria. Twenty-six representative samples were collected across the study area. Physical, geotechnical, mineralogical, and clay mechanical tests were carried out on the samples. The physical tests include specific gravity, grain size distribution analysis, and Atterberg limits, while geotechnical tests include compaction tests, California bearing ratio, and direct shear tests. All tests were carried out according to the British Standard BS 1377 procedures with modifications where necessary, to evaluate their industrial, engineering, and environmental suitability. Results show that the clays are predominantly fine-grained, with clay contents ranging from approximately 30% to over 90%, negligible gravel fractions, and variable proportions of silt and sand. Based on the Unified Soil Classification System, most samples fall within the CL (low plasticity clay) and CH (high plasticity clay) groups. Liquid limits (33–69%) and plasticity indices (13–46%) indicate moderate to very high plasticity, reflecting differences in clay mineral composition and degree of weathering. Bulk unit weights (14–18 kN/m³), porosity values of 40–50%, and moderate shear and compressive strengths are consistent with residual clays formed in situ under tropical weathering conditions. High-plasticity clays are suitable for ceramic and refractory applications, while fine-grained, low-permeability clays are appropriate for landfill liners, environmental barriers, and sealants. Mineralogical composition suggests dominance of kaolinite with subordinate illite and smectite, supporting potential applications in pharmaceuticals, filtration, and bleaching processes. Overall, the abundance and favorable properties of Ekiti State residual clays highlight their economic viability and relevance for sustainable industrial development, contributing to local resource utilization and alignment with circular economy principles and Sustainable Development Goal 9.

Keywords: SDG goals, residual clay, economic prospects, industrial use, kaolinite

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Microstructural Origins of Volumetric Instability in BOF slag

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Abstract

The high extraction rate of natural aggregates for the concrete production is depleting the natural sources of river sand and gravel. Therefore, developing sustainable alternatives for concrete aggregates is crucial. Simultaneously, during the steel production, basic oxygen furnace (BOF) slag is generated at a rate of about 200 million tons annually worldwide, and it is commonly disposed of in landfills. When used as concrete aggregate, BOF slag has been shown to improve the mechanical properties of the concrete for instance, providing a promising alternative to natural aggregates. However, its use in the construction industry is limited due to its volumetric instability, primarily attributed to the presence of free lime, which expands in contact with water, leading to concrete cracks and failure. While this phenomenon has been extensively studied at the macro scale, micro-scale investigations remain limited. This study provides a detailed microstructural analysis of BOF slag to identify free lime as well as other instability mechanisms. X-ray diffraction (XRD) and Scanning Electron Microscopy (SEM) were employed for materials characterization, revealing belite, calcium ferrite, and wustite as primary phases. Free lime was observed on the microscopic scale, as well as Mg-rich phases that show a similar but slower expansion reaction, which are likely the main damage mechanisms.

Keywords: BOF slag, Converter slag, Volumetric instability, Free lime, Magnesium oxide

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Characterization and Evaluation of the Refractory Properties of Kitibi Clay Deposits, Iwo, Southwestern Nigeria

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Abstract

The properties of the Kitibi clay deposit were evaluated to determine its suitability for industrial applications. Twenty (20) samples were collected from excavation sites in Kitibi Village in Osun State. The characterization process included mineralogical, chemical, and geotechnical analyses using techniques such as X-ray Diffraction (XRD), X-ray Fluorescence (XRF), specific gravity, moisture content, particle size analysis, Atterberg limits, compressive strength, water absorption test, and bulk density. The results revealed that the liquid limit of the clays ranged between 38.3% to 53.7%, the plastic limit ranged between 19.7% to 25.7%, and the plasticity index ranged from 18.6% to 32.4%. The clays have high moisture content (7.9% - 18.4%), are well-graded, and exhibit medium to high plasticity, pointing to the presence of clay minerals like montmorillonite and illite. The engineering properties of the samples indicate that the samples have high porosity (11.59% to 14.44%), low void ratio (13.11% to 16.88%), and low compressive strength (0.96- 1.40N/mm2). The chemical composition of the clays is similar to that typical for kaolinite. However, the potassium oxide content is unusually high (3.21% to 5.55%). Mineralogically, kaolinite is the dominant clay mineral while smectite occurs in small amounts, and the non-clay mineral identified includes quartz, mica, feldspar, and sillimanite. The evaluation demonstrates that the clays meet the required standards for use in various industrial applications such as ceramics, bricks, landfill liners, and refractories in environments with low mechanical stress. The clays must also be washed before use to reduce the potassium oxide content.

Keywords: compressive strength, montmorillonite, X-ray Diffraction (XRD), X-ray Fluorescence (XRF), refractory

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Mechanical Performance and Technical Suitability of Carbonate Quarry Waste for aggregate production: The Süttő Travertine Case Study

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Abstract

Sustainable mining has become a strategic priority in the current context of increasing demand for raw materials and growing environmental constraints. In Hungary, with specific reference to the Süttő area selected as the study site, this research investigates the valorization of extractive waste materials as a means to reduce environmental impact and promote circular economy principles. The study focuses on the potential reuse of quarrying waste derived from carbonate rock exploitation evaluating its suitability as aggregate for civil and building applications. A comprehensive experimental program was carried out to characterize the physical and mechanical properties of the waste materials. Laboratory investigations included the determination of bulk density and particle density to define mass volumetric properties, as well as a detailed grain size distribution analysis through sieve testing. Mechanical performance was assessed using the Los Angeles test and the Micro-Deval test to quantify resistance to fragmentation and wear under dynamic loading conditions. In addition, grain morphology was evaluated through shape and flatness indexes, parameters that significantly influence compaction behavior and interlocking capacity. The percentage of fine particles was also measured to assess potential effects on workability, durability, and overall aggregate performance. The results provide a technical basis for assessing the feasibility of reusing extractive waste as construction aggregates, contributing to reduced landfill disposal, lower consumption of primary raw materials, and the advancement of sustainable mining practices in the Süttő region.

Keywords: Extractive waste valorization, Mechanical characterization, Sustainable mining, Circular economy

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Quantification in petrographic analysis: from aggregates to concrete

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Abstract

Researchers characterizing construction materials use a range of standards to test aggregates from a physical and mechanical point of view. Petrography is applied aiming to determine the lithological classification of the rock, as well as the mineralogical composition of the gravel or sand to be used in concrete. There are national and international standards that establish guidelines for these classifications. However, when aggregates for concrete are being assessed, the petrographer needs to focus on the mineral composition present in rocks from quarries and in the particles from natural deposits to unravel the presence of deleterious components, namely certain forms of silica and some carbonate rocks. This analysis leads to the classification of the aggregate into classes (usually I, II, and III) depending on the presence of the reactive components. The main limitation of the standards used internationally is the lack of a threshold above which an aggregate is classified as potentially reactive. On the other hand, petrographers contribute to the diagnosis of the cause of deterioration of a concrete element, namely, in identifying the occurrence of chemical reactions between the components involving the aggregates. In this regard, a huge amount of work has been developed in Canada to create an index that can reflect the degree of deterioration found in cores extracted from a damaged structure. The present work aims at summarizing the methods currently used and discussing the possible improvements that can be made to suggest further details that can make the petrographic methods more useful and appealing for concrete researchers and structures stakeholders.

Keywords: Aggregates, Standards, Petrography, Concrete, Quantification

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Multi-Hazard Assessment for Man-Induced Geohazard – Cavity Collapse and Fooding Hazards

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Abstract

Several natural hazards are likely to affect the same surface areas in urban sites. Therefore, the risk assessment and associated management remain crucial for local and national authorities, policymakers, and planners. This paper focuses on multi-hazard evaluation and proposes a methodology for considering the interaction between two hazards: sinkholes and flooding. In fact, flooding can play a key role in triggering the collapse of the underground cavities. The paper presents the method to adjust the level of individual hazards by incorporating their interactions. The adjusted hazard value is calculated as the product of the initial hazard level and the interaction level of this hazard with another hazard. A multi-hazard index (MH) is used that allows to compare different areas, sectors and scenarios with several hazards. It is defined according to the following equation: MH = sum of the (Had-i) for n hazards. with n the number of hazards identified on the site studied and Had-i is adjusted hazard level of hazard i (H_i). In the second part of the paper, the proposed methodology is applied to a case study from the northen of France where chalk underground mines affected regularly by flooding. The main finding is that the interaction between two or more hazards can increase both their intensity and risk level. In conclusion, the methodology based on multi-hazard assessments and the multi-hazard index can be used in areas exposed to multiple hazards to identify locations where interactions between hazards are significant.

Keywords: geohazard, ground movement, flooding, mine, interaction

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Integrated Geomechanical and Geohydrological Assessment of Quarry Floor Stability in the ENCI Limestone Quarry (The Netherlands)

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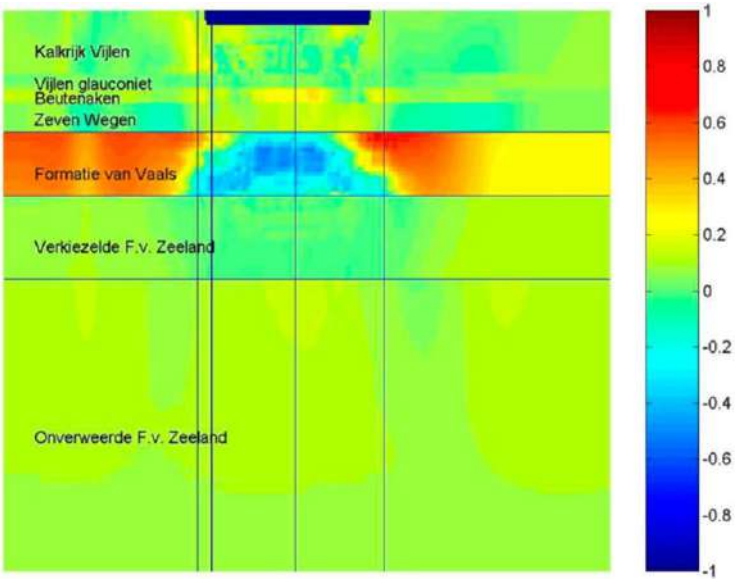
Abstract

This study presents an integrated geomechanical and geohydrological methodology to assess and manage quarry floor stability during deep excavation in the ENCI limestone quarry in Maastricht, the Netherlands. In 2002, unexpectedly high groundwater inflow from the underlying Carboniferous strata raised concerns about floor failure, environmental impact, and operational safety. To support ENCI's request for deeper mining permission, a multidisciplinary investigation was conducted combining geological mapping, core drilling, groundwater monitoring, high-resolution seismic imaging, ductility testing, in-situ stress measurements and numerical modelling. Emphasis was placed on the behaviour of the Vaals Formation, a low-permeability siltstone aquiclude that hydraulically separates the Cretaceous limestones from the pressurized Carboniferous groundwater system. Laboratory tests and hydrofracturing measurements demonstrate that the Vaals Formation behaves brittle under relevant stress conditions, leading to micro-cracking and significant permeability increase when vertical stresses are reduced by excavation. Geohydrological modelling shows that excavation below –10 m NAP causes vertical effective stresses to fall below Carboniferous pore pressures, triggering horizontal strain cracking and potential fault reactivation. Probabilistic FLAC simulations confirm that excavation deeper than –10 m NAP results in loss of sealing capacity and uncontrolled groundwater inflow. The study concludes that safe excavation is feasible down to –10 m NAP only when compensation rock weight is applied immediately after extraction. The integrated methodology provides a robust framework for evaluating geostability risks in similar quarry and mining environments.

Keywords: Geomechanics, Limestone, Open quarry, Grondwater pressure, Quarry floor stability



Correlation between horizontal eff. stress and Poisson's ratio

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A Holistic Approach to the Coal Aftercare: The Limburg Coal Mining District, in the Netherlands

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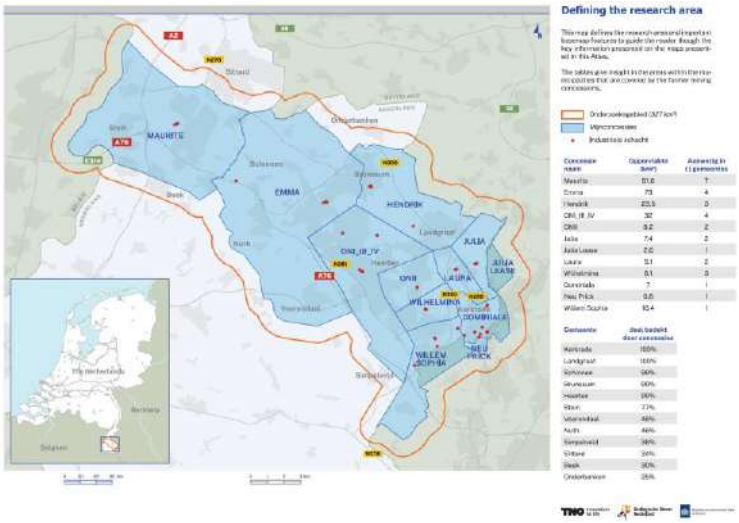
Abstract

Coal mining in Limburg, the Netherlands, occurred between the late 19th century and the 1970s. Its legacy persists across 234 km² of densely populated former mining zones. In 2014, the Ministry of Economic Affairs launched an investigation into the coal mining after-effects in South Limburg. Since then, evolving subsurface and policy conditions have increased the need to understand after-mining effects. From the previously identified potential after-effects we focus on sinkholes and other surface deformation due to their strong potential for damaging infrastructure and buildings. We develop a multidisciplinary framework integrating satellite geodesy, hydrogeology, historical mining records, geological and geomechanical models to locate zones of potential after-effect occurrence. This approach allows us to assess subsurface vulnerability and surface deformation patterns. As a foundational step, we created an Atlas to define the key components of potential exposure to after-mining effects and to facilitate the dissemination of historical and newly acquired knowledge to a broader audience. To estimate the spatial distribution of these effects, we apply two complementary methodologies: a bottom-up and a top-down approach. The bottom-up approach starts with subsurface characterization, including geological layering, historical mining configurations, and hydrogeological conditions. Geomechanical modeling is applied to simulate stress redistribution and collapse potential. Satellite-based InSAR data is then used to refine these models by detecting surface displacements. The top-down approach begins with large-scale InSAR analysis to identify anomalous surface movements. These are then correlated with subsurface features using geological and hydrogeological datasets, enabling targeted investigations. Here, we present the ongoing development of a framework to assess vulnerability, and results obtained with elements of this framework. This integrated modular setup accommodates for annual updates of InSAR data and ongoing improvements in geological and hydrogeological models. This framework will also serve as the basis for the assessment of other after-effects towards an integrated risk signaling system.

Keywords: sinkholes, coal mining, Multidisciplinary framework, surface deformation, InSAR



Map outlining the research area and key factors related to former mining concessions (shaded in blue) in the Netherlands. It highlights municipalities affected by historical coal mining activities, locations of industrial mine shafts (red circles), and includes a table summarizing concession names, operational periods, and the number of municipalities covered by each. This overview supports spatial analysis and enhances contextual understanding of after-mining effects presented in the Atlas.

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An Integral Quarry Policy for the Municipality of Valkenburg aan de Geul

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Abstract

Under the municipality of Valkenburg aan de Geul there are approximately 270 hectares of underground passages, which were created as a result of centuries-long buildingstone extraction. The vast majority of the quarries do not (yet) pose an acute threat to the surface in terms of rock mechanical safety. In addition, the quarries where roof and/or pillar instability occurs are being structurally monitored by experts. As part of its municipal duty of protecting the people and territory, the municipality has installed a digital warning system in the two largest municipal quarries, with which any movements in the bedrock are registered 24/7. The municipality is increasingly confronted with questions about the public meaning of the underground limestone quarries. Up until now, the main concern has been safety issues concerning the rock mechanical stability of the underground spaces to ensure that those who work there, visit them and live over them are protected against unforeseen calamities. This traditional concern is currently being matched by questions in the field of appreciation, management and preservation (heritage and nature conservation), and contemporary (touristic) use. Currently, the main question seems to be: "What should we do with this historical underground?" How can we achieve a situation in which, on the one hand, good and safe use is guaranteed and, on the other hand, a plausible basis for decision-making exists with regard to cultural heritage and nature management. Based on the above-mentioned problems, the municipality of Valkenburg aan de Geul has drawn up an integral quarry policy, which sets out how this form of historical mining can be dealt with in the future.

Keywords: historical mining, cultural heritage preservation, nature preservation, post-mining risk management, monitoring

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Geotechnical Hazards of Historical Mining - The Important Legacy of our Shared Mining History.

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Abstract

Across the United Kingdom and in many parts of Europe, coal mining underpinned the Industrial Revolution, triggering breakthroughs in transportation and the earth sciences—most notably stratigraphy, born of the need to map seams and predict conditions underground. By the late 19th century, miners and geologists were already correlating rock layers from pit shafts to outcrop, laying the foundations of modern geology. Yet many recorded and unknown mines sit within a "zone of influence" of the surface, and over time void collapse, slow settlement and mine entries can make former workings a serious liability. Subsidence deforms buildings and infrastructure, mine-water rebound can flood basements, and legacy shafts and adits allow gas migration, and create additional stability risks—all of which complicate brownfield redevelopment. Designing any new structure therefore demands a rigorous grasp of subsurface conditions, while post-failure repairs hinge on knowing exactly what's gone on underground. As Europe shifts to renewables, specialist geotechnical expertise in abandoned mines is dwindling — and with it our ability to safeguard future development on these critical sites. It is therefore imperative that knowledge is captured and shared regarding how to identify, asses and safely develop over these areas.

This paper presents a series of case studies illustrating how man-made mining geohazards are identified and quantified, the challenges of risk assessment in areas of incomplete mining records, techniques for ground investigation, modelling and remedial works.

Keywords: Geohazards , Mining Legacy , Knowledge Transfer

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An Engineering Geology Framework for Lithium Open Pits in Australian Pegmatites

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Abstract

The global shift toward a low-carbon economy is driving rapid growth in lithium demand, with hard rock pegmatite-hosted deposits emerging as key sources. Open pit mining of these deposits presents distinct engineering geology challenges due to the steeply dipping nature of the orebody, complex structural settings, and variable weathering and hydrogeological conditions. This paper provides a synthesis of engineering geological controls on slope stability in hard rock lithium deposits, supported by examples from active operations in Australia.

A case study from a short-life open pit lithium mine in Australia highlights the importance of engineering geology in design and managing slope instability. The steeply dipping pegmatite orebody is hosted in weak, foliated phyllite, with flexural toppling identified as the dominant failure mechanism. Instability was exacerbated by elevated pore pressures and limited data. The engineering geology model was updated using field observations and failure back-analyses. This informed updated slope stability analyses, which revealed the potential for deep-seated toppling even at shallow inter-ramp angles.

This paper demonstrates the critical importance of the conceptual engineering geology model. This model should then be tested and updated based on site investigation data and observations during operations. It underscores the sensitivity of slope stability to structural and groundwater conditions, as well as the importance of slope monitoring and risk management in complex lithium-bearing terrains.

Keywords: Pegmatite, Lithium Deposits, Open Pit Mining, Slope Monitoring, Conceptual Model

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Evaluating the Geological Setting and Mechanical Behavior of Iron Ore Tailings for Sustainable Filtered Stacking Disposal Design

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Abstract

The use of filtered stacking for tailings storage is increasingly adopted due to its significant environmental benefits, including reduced water usage and minimized risk associated with tailings dam failures. This method not only conserves water resources but also enhances the overall safety and sustainability of tailings management. The tailings, the fine-grained waste materials produced by mining operations, present unique challenges. They exhibit distinct material behavior and can be operationally intensive, often in challenging environments, which pose several risks that need to be evaluated and mitigated. This paper addresses geological and geotechnical risks and focuses on assessment of the mechanical properties that influence tailings behavior. In the study, field data were gathered to assess geological characteristics and possible geohazards of the chosen tailings disposal site in The Middle East. Moreover, a laboratory program including index and triaxial testing was conducted on tailings samples to identify and assess the mechanical properties that influence their behavior. This is crucial for understanding how the tailings will perform in real-world conditions. The findings of this paper highlight the importance of understanding the geological setting and the mechanical properties of the tailings that can help to optimize the design and operation of filtered stacking disposal. The results of this research contribute to the development of more reliable and sustainable tailings management practices, enhancing the stability and performance of tailings stacks and ultimately improving safety and environmental outcomes. This research underscores the necessity for ongoing research and innovation to address the complex challenges associated with tailings disposal.

Keywords: Tailings Storage Facilities (TSFs), Filtered Stacking Disposal, Mining risk management, Geohazards, Critical State Soil Mechanics (CSSM)



Location overview of the future Tailings Storage Facilities (TSFs) in The Middle East: estimated disposal volume is close to 100 Mm3.

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Improved Methodology for Post-Mining Risk Assessment in Wallonia (Belgium) and Application to Former Mining Areas

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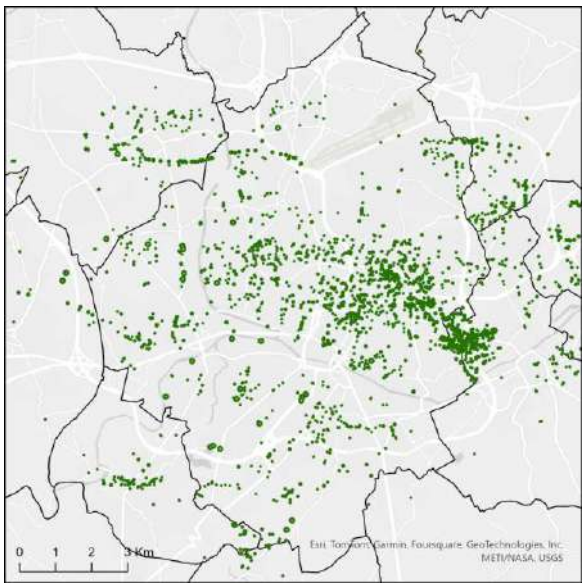
Abstract

Wallonia is the Southern part of Belgium and must deal with many consequences of its former mining industry. These consequences (such as subsidence or remaining sub-surface works as mine shafts) created precedence which have led to many impacts on land planning process and physical works. This led the authorities of Wallonia to impose pre-mining policies to prevent post-mining risks.
For the past 30 years, Geological Survey of Wallonia and its partners led have been engaged in many projects to gather data regarding:
- The geological contexts of Wallonia, mainly focused on the mined areas: of which the best example is the review of the geological map of Wallonia;
- Underground objects including mine shafts, mines, quarries or karstic phenomena.
These studies resulted in post-mining hazard assessment and associated cartography, useful to prevent ground collapse and to grant security for people and land planning. Public authorities inventory now these data for each cadastral plot in Wallonia in a Subsoil Information Fiche (SIF) devoted to all economic actors or ordinary citizens.
To improve policies of public security, land planning and economical attractiveness of Wallonia, an updated post-mining risks assessment is now needed, including the vulnerability of exposed targets including people, buildings or infrastructures.
In this paper, we will describe a new methodology for post-mining risk assessment and will apply it to one large former mining area of Wallonia. The results will also show the real post-mining risk to which people and structures are exposed and the consequences on public policies.

Keywords: Post-mining risks, Mine shafts, Risk assessment, Hazard management, Ground collapse



Map of hazard zones map which are induced by old mine shafts in this former mining area of Wallonia (Belgium) and general overview of their footprint that impacts this region.

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Predictive Rock Mass Qualification in Limestone Quarries: An Integrated Approach Using Geological Strength Index and Specific Drilling Energy

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Abstract

Assessing rock mass quality is a significant challenge within the quarrying industry. This issue is notably pronounced within the Carboniferous limestone formations of the Tournai's region (Belgium), where significant geomechanical heterogeneity is caused by karstic weathering and complex fracturing. This variability compromises the quality of raw material, necessitating a robust and predictive methodology for rock mass qualification prior to blasting to optimise material destination. This study presents an integrated approach combining traditional geomechanical mapping from outcrops with real-time analysis of drilling logs. The Geological Strength Index (GSI) is employed as a key parameter for geomechanical qualification, determined through field observations of rock mass fracturing and alteration. Additionally, the downhole hammer drill, equipped with a Measurement-While-Drilling (MWD) system, provides high-resolution data, incorporating parameters such as weight on bit, rate of penetration, and rotation torque. From these parameters, a specific drilling energy index (E') is continuously calculated. This E' index is analogous to specific energy and directly proportional to the rock strength, allowing for the delineation of weathered zones. However, it does not clearly highlight structural fracturing. The study demonstrates a consistent trend between the visually evaluated GSI values and the mean E' index calculated on a hole-by-hole basis, where lower rock mass quality systematically corresponds to a lower drilling energy index. This relationship facilitates high-resolution, in situ prediction of rock mass quality. By integrating the GSI-based spatial zonation with the continuous E' profiles, a predictive three-dimensional block model is generated, enabling optimised blast design and selective excavation.

Keywords: Rock mass quality, GSI, Measurement-While-Drilling, Specific drilling energy

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Subsurface Modeling 3D Using Geophysycal Methods for the Prospect of an Non-Metalic Open Pit Mine, Guanacaste, Costa Rica

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Abstract

In Costa Rica, exploration of non-metallic mineral deposits is commonly based on geological mapping and structural analysis, while geophysical methods and 3D modeling are often applied in hydrogeology, geothermal, geotechnical, metallic mining studies, etc. However, in areas like non-metallic, or with limited outcrop exposure, these approaches may not adequately define the geometry and continuity of geological units, increasing uncertainty during early exploration stages. This study integrates geological mapping, structural analysis, Electrical Resistivity Tomography, Seismic Refraction Tomography, SPT boreholes, and 3D geological modeling to characterize a non-metallic deposit in Guanacaste, Costa Rica. The 3D model was constructed from limited outcrop data, projected using structural interpretations and validated with geophysical results. It reveals interbedded sandstones and basalts affected by dextral strike-slip faulting and intruded by an igneous body. Electrical Resistivity Tomography correlates well with mapped contacts, delineating the intrusive geometry and fault continuity. Seismic Refraction Tomography constrains overburden thickness. Overall integration of geological and geophysical data reduces subsurface uncertainty and improves early-stage exploration and deposit characterization. These results demonstrate the effectiveness of integrating traditional geological methods with geophysical techniques and 3D modeling for reducing interpretative uncertainty in complex volcanic-sedimentary environments, particularly where exposure is poor and subsurface conditions are heterogeneous. This integrated workflow enhances predictive capability, supports more robust geological models, and provides a transferable framework for other non-metallic mineral exploration projects in comparable terrains, improving exploration efficiency and reducing geological risk assessment in early exploration stages..

Keywords: Seismic Refraction Tomography, Electrical Resistivity Tomography, Subsurface 3D modeling, Open pit.,

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In-situ Monitoring and Analysis of Sediment Plume Dispersion from Scaled Deep-Sea Mining Vehicle Operations

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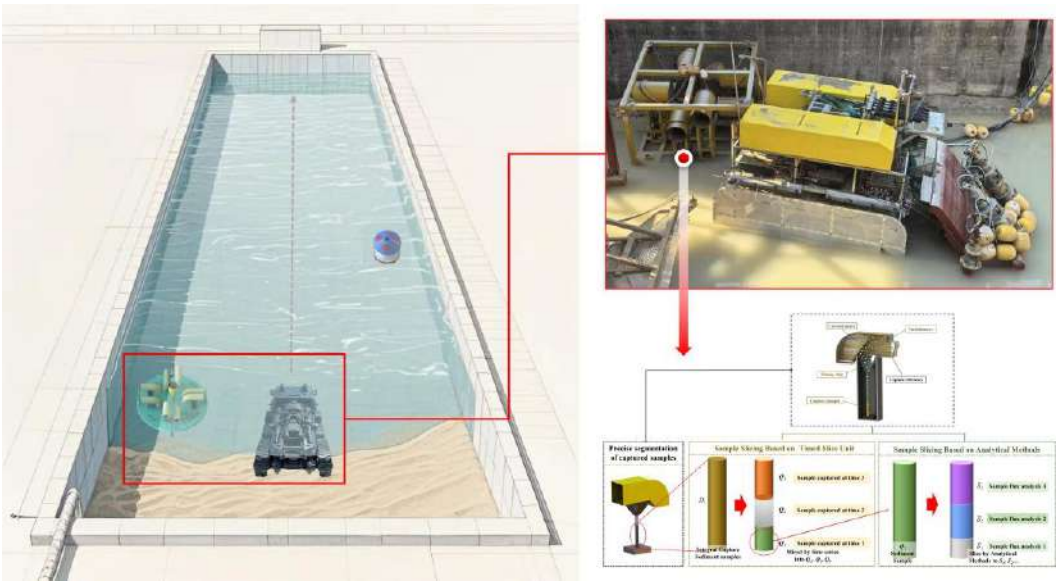
Abstract

Sediment plumes generated by deep-sea mining pose significant environmental risks and represent a major constraint on the industry's development. Current observation methods are limited in their ability to directly capture the temporal evolution of transported plume particles, hindering accurate assessment and prediction of plume transport and dispersion. In this study, we conducted scaled-down simulations of deep-sea mining operations in a controlled harbour pool environment, varying mining truck speeds and ore collection power. A self-developed sediment plume capture and monitoring system was employed for in-situ observation of plume transport and particle capture. This enabled detailed tracking of the formation and transport evolution of sediment plumes. Results showed that under low-power operation, the dominant particle size shifted from 30–55 μm to 45–75 μm, with a 32% increase in transport flux compared to high-power conditions. The influence of ore collection power and vehicle speed on plume particle evolution was systematically analysed. Three key parameters—flow velocity, turbidity, and particle size—were used to characterize plume dynamics and provide insights into sediment transport processes. These findings contribute to a more precise understanding of plume behavior, offering valuable data for improving environmental assessments and informing sustainable deep-sea mining practices.

Keywords: deep-sea mining, plume dispersion, scaled-down simulations, sediment trap,



Schematic and field photographs of the scaled-down simulations test and subsequent in-situ sample analysis diagrams

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Two-Stage Quantitative Risk Assessment of Water–Sand Mixture Inrush Based on Disaster Process Continuity

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Abstract

Water–sand mixture inrush (WSMI) poses a typical geological hazard in deep coal mining. This study proposes a two-stage quantitative risk assessment framework consisting of initiation and migration stages to characterize the progressive development of WSMI. For the WSMI initiation stage, the critical hydraulic condition governing seepage instability of loose roof materials is defined. The critical hydraulic gradient is adopted as a theoretical threshold to determine whether static hydraulic conditions are sufficient to trigger particle mobilization and material loss. For the water–sand migration stage, the energy dissipation characteristics of water–sand transport are theoretically analyzed under the coupled effects of pathway geometry and particle gradation. Consequently, an energy-based analytical model describing the along-path energy loss during migration is established. The proposed criterion indicates that a catastrophic hydraulic connection occurs only when the initial potential energy of the source material exceeds the cumulative energy dissipation along the transport pathway. By integrating the two-stage criteria, quantitative risk zoning of WSMI during fault crossing of the first mining panel in the study area is achieved. The proposed framework provides a process-oriented method for hazard evaluation and offers a practical scientific basis for disaster prevention and risk management in deep underground mining.

Keywords: Water–sand mixture inrush, critical hydraulic gradient, energy dissipation, quantitative risk assessment.,

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Fault-Influenced Overburden Deformation in a Steeply Dipping Submarine

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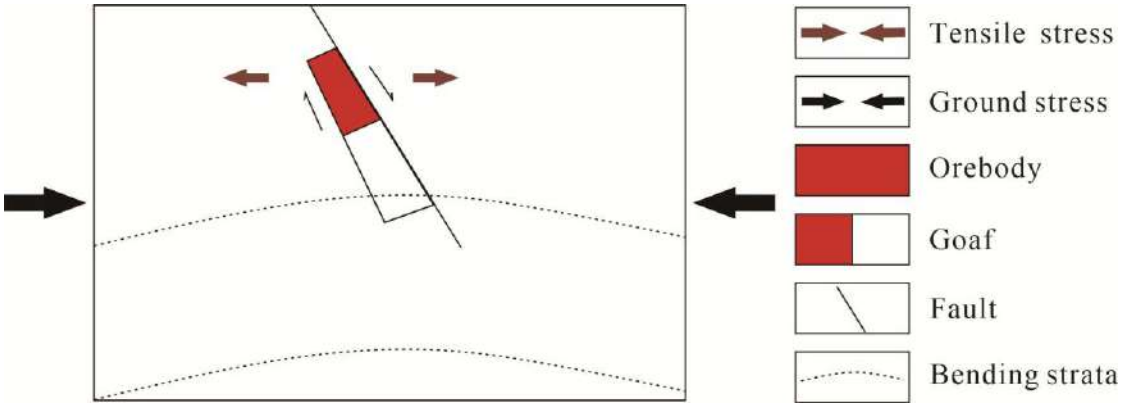
Abstract

Seabed mining operations have been found to induce significant movement and deformation in overlying rock strata, posing serious threats to mining safety. The presence of geological faults further complicates these deformation patterns. This study utilized geophysical surveys and the continuum-based discrete element method (CDEM) to investigate how fault activity influences rock deformation and failure. The results demonstrate that: (1) Acting as mechanically weak zones, faults exerted a pronounced barrier effect on deformation propagation and stress redistribution within the surrounding rock, leading to markedly divergent displacement patterns on either side of the fault plane. Comparative analyses between single-fault and double-fault models revealed an 18–22 % expansion of the damage zone under the latter, together with significantly intensified deformation and failure; (2) The double-fault model exhibited a larger maximum cumulative vertical displacement and a spatial shift in the location of peak deformation, thereby posing a heightened threat to mine safety; (3) Acting as an orebody substitute, backfill effectively constrained surrounding-rock deformation, enhanced its load-bearing capacity, and delayed the overburden subsidence. Nevertheless, backfill only reduced the amplitude of deformation; it could not entirely prevent settlement. These findings provide essential theoretical insights and foundational knowledge for safer submarine mining practices.

Keywords: Submarine mine, Steeply inclined ore body, Fault effect, Overburden deformation, Discrete element method of continuum mechanics



Schematic diagram of the uplift phenomenon of the rock mass in the hanging wall

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Investigation of Fracture Evolution and Groundwater Flow in High-Position Overburden Under Longwall Mining

Wei Qiao[1], Mengnan Liu[1], Xiangshen Meng[1], Xianggang Cheng[1], Peichao Feng[2], Mengke Cui[2], Junpeng Yang[2]

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Abstract

Intensive longwall mining with large extraction heights in northwestern China has aggravated overburden damage and altered its hydraulic behavior, making the evolution of fractures and permeability in high-position strata a key concern for water hazard prevention. Mining-induced fractures may activate confined aquifers, increasing the risk of water inrush. To address this problem, in situ monitoring was first conducted to investigate the interaction between mining-induced fractures and groundwater within a high-position confined aquifer (HPCA). Subsequently, physical and numerical simulations were carried out to examine the coupled evolution of fracture development and fluid migration. Based on these results, a dynamic seepage model of mining overburden was established to predict water inflow from the HPCA. The results indicate that a confined separation layer forms above the water-conducting fractured zone in the high-position overburden. The horizontal permeability beneath the HPCA is markedly enhanced, allowing groundwater to migrate laterally along the separation layer. As mining advances, the water-filled separation layer progressively connects with vertically developing fractures along the coal wall. Furthermore, the proposed seepage model divides the hydraulic evolution of high-position overburden into four stages: initial formation of the separation layer, rapid development of the separation layer, initial formation of longitudinal water-conducting fractures, and further development of these fractures. The predicted comprehensive permeability, expressed as a function of advance distance, shows good agreement with the observed variation in water inflow. This study enhances the understanding of the coupled evolution of fracture networks, overburden permeability, and hydraulic hazards under longwall mining conditions.

Keywords: high-position overburden, rock mass mining structure, overburden permeability, separation layers, water inrush

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Rheological Behavior of Grouted Sand Aquifers in Mitigating Mining-Induced Groundwater Hazards

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Abstract

Mining activities alter the original stress and seepage equilibrium of subsurface rock masses, potentially triggering geological hazards characterized by obvious time-lagged responses and posing long-term challenges to the safety of underground workings. The previous studies primarily focus on instantaneous failures induced by mining disturbances, while the long-term rheological behavior of disturbed strata—particularly the delayed instability and hydraulic pathway evolution of overlying aquifers—and its role in hazard evolution remain insufficiently understood. This study conducted fluid–solid coupled physical model tests and large-deformation shear experiments to investigate the time-dependent responses of stress, pore pressure, and structural evolution in grouted sand aquifers under mining disturbances. Results show that post-mining strata responses exhibit a staged evolution characterized by stress increase, stable fluctuation, intensified fluctuation, and gradual attenuation, indicating pronounced rheological regulation over long-term structural adjustment. Shear experiments further reveal significant stress relaxation and delayed self-adjustment behavior in grouted strata, suggesting that rheological processes dominate the continuous reconstruction of structural stability after disturbance. The observed responses indicate that grouted strata remain in a long-term adjustment stage after mining, highlighting the importance of evaluating post-grouting stability from a time-dependent perspective. This study provides a mechanical basis for the long-term prediction of mining-induced geological hazards.

Keywords: Mining-induced hazards, Grouted aquifers, Long-term response, Post-grouting stability

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Risk Assessment of Water-Sand Mixture Inrush in Deep Mining Based on 3D Geological Modeling

Rui Guo[1], Wanghua Sui[1], Jinxi Liang[1]

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Abstract

Water-sand mixture inrush (WSMI) disasters in underground coal mining refer to the disruption of the original equilibrium state within the source area. To address the limitations of risk assessments that rely on discrete borehole data and struggle to accurately characterize spatial variations in faults and strata morphology, this study proposes a risk assessment method based on 3D geological model constrained attribute field reconstruction. By constructing a high-precision 3D geological model of the study area, the spatial relationships between strata and faults are characterized. Key indicator data are extracted from the attribute fields, effectively reducing the assessment errors caused by discrete borehole distribution in deep mining. A comprehensive evaluation method based on improved combination weight and cloud model is applied to the panel No. 1305 of the Wanfu Coal Mine to assess the WSMI risk level. The results demonstrate that the proposed method effectively identifies risk mutation features in structurally developed zones and coal seam outcrops. It significantly enhances the spatial resolution and geological interpretability of risk assessment, providing a reliable technical pathway for the prevention and control of WSMI disasters in deep mines.

Keywords: Mine water hazard, 3D geological modeling, Water-sand mixture inrush, Attribute modeling, Risk assessment

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Hydrological Reorganisation in Mining-Subsided Lowlands

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Abstract

Mining-induced subsidence in low-relief landscapes does not automatically generate surface inundation. Its environmental consequences depend on how deformation reorganises near-surface hydrology through the formation of closed depressions, reduced hydraulic gradients, altered flow paths and modified groundwater persistence. Conventional threshold-based assessments and models trained directly on observed inundation inventories are limited in their ability to anticipate future activation, as they either oversimplify process linkages or rely on circular validation.

This study reframes post-mining inundation as a problem of hydrological reorganisation and introduces a transparent, process-based Retention Potential Index (RPI). Six hydro-geomorphic predictors representing storage capacity, runoff impedance, flow convergence, substrate retention, deformation history and groundwater state were integrated on a common 10 m grid. The 2025 inundation inventory was excluded from all stages of predictor development and model calibration, serving exclusively as an independent validation dataset. In the 119.98 km² Bogdanka mining domain, the morphology-dominant RPI variant achieved strong discriminative performance (AUC = 0.866). Spatial block validation confirmed robustness (mean AUC = 0.822; Spearman r = 0.470, p = 0.0017). The resulting zonation identified 4.04 km² of confirmed inundation and 2.69 km² of high-priority potential zones. Terrain morphology functions as the primary control on retention activation, whereas geology and groundwater modulate water persistence. The framework provides a reproducible and auditable GIS-based screening tool for field verification, drainage management and spatial planning in actively deforming lowland mining regions.

Keywords: hydrological reorganisation, retention potential, GIS multi-criteria analysis, mining subsidence, independent validation

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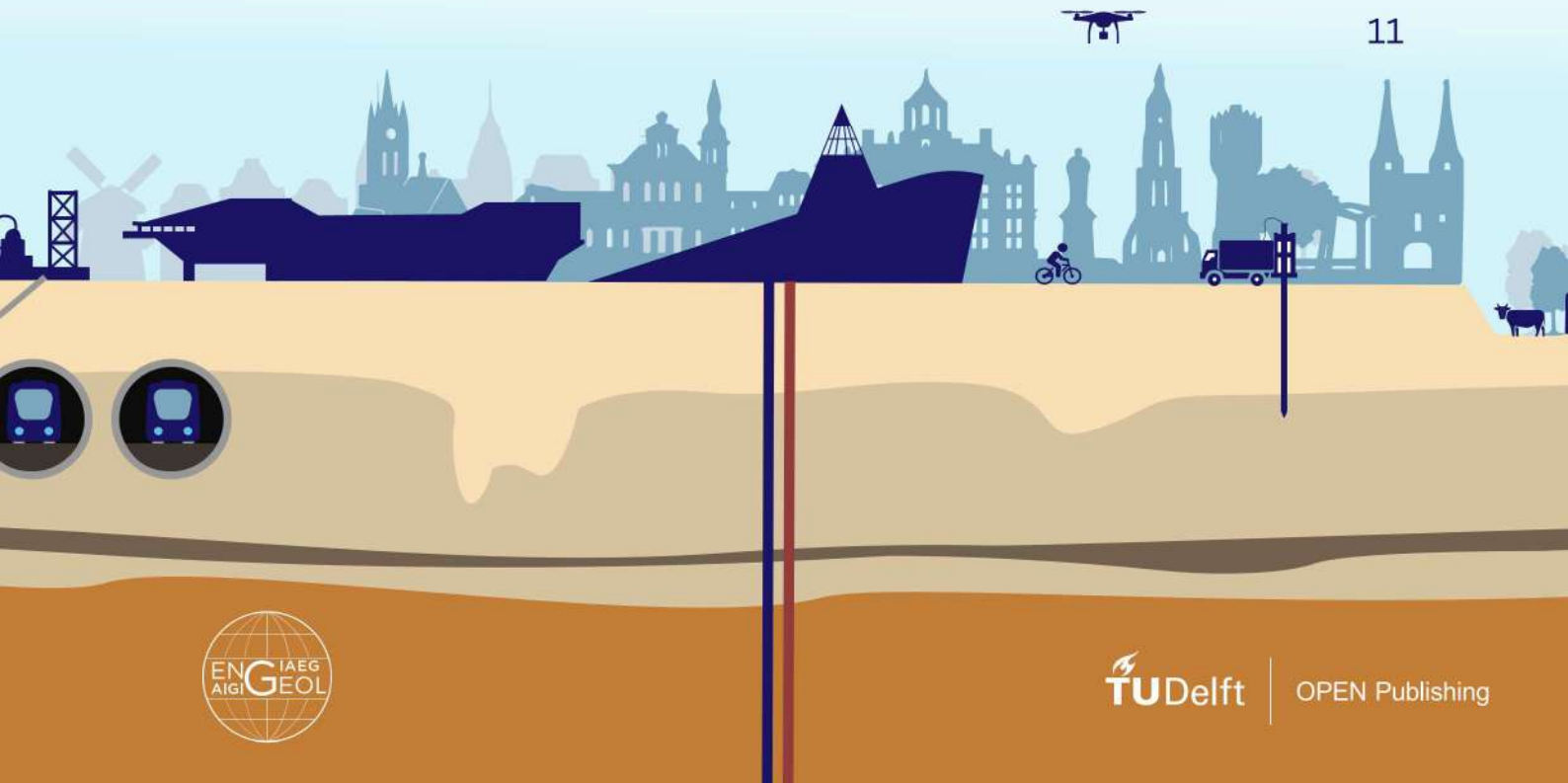
6. Geoenvironmental engineering

Engineering Geology for a virtuous clean water cycle and circularity in waste management. Focus areas include landfills, tailings dams, desalination, contaminant transport and treatment, innovative microplastic removal techniques, and sludge recycling.



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Microseismic Evidence of Deep-Sea Methane Release Driven by Tropical Cyclone-Induced Seafloor Warming

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[1] Ocean University of China, Qingdao, China

Abstract

Seafloor sediments serve as a major carbon reservoir and can release significant amounts of methane when disturbed. Under the influence of global warming, rising sea surface temperatures have led to prolonged tropical cyclone activity, transmitting substantial energy into the deeper ocean. This may have potential impacts on methane release from the deep seafloor. However, direct observational evidence of how successive tropical cyclones affect deep-sea methane release remains lacking. Here we conducted this study in the northern South China Sea, combining in-situ observations of seafloor microseisms and tropical cyclones to identify and confirm the characteristics of microseismic signals associated with both tropical cyclones and methane release events. Analysis of these records revealed a clear connection between tropical cyclone activity and seafloor gas emissions. We observed active methane release on the seafloor in this region and found that tropical cyclones significantly enhanced the intensity of these emissions, primarily due to cyclone-induced increases in seafloor temperature. These findings underscore the significant role of tropical cyclones in regulating seafloor methane release. The observed link between atmospheric disturbances and subseafloor carbon reservoirs suggests that tropical cyclones must be carefully considered in studies of climate change and marine geological hazards.

Keywords: Microseismic, Methane Release, Tropical Cyclone, Deep-Sea, Climate Change

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Using plants to improve bearing capacity of soft dredged sediments

Azad Goli[1], Ivy Raeijmakers[1], Joey Boganen[1], Mark Biesheuvel[1], Leon Van Paassen[1]

[1] Boskalis, Papendrecht, Netherlands

Abstract

Very soft soils are a significant challenge in construction and reclamation projects. Traditional methods, such as mechanical pumping, chemical treatments or the installation of perforated vertical drains, are often costly, energy-intensive, and environmentally invasive, and typically require access for heavy equipment in order to be implemented. In this study we investigate the potential of plants to increase bearing capacity, as an innovative, sustainable, and cost-effective solution. Large scale tests were performed in depots filled with dredged sediments, where dewatering rates, water content, shear strength, and bearing capacity were monitored under various conditions with and without plants. Results demonstrate that this approach not only addresses the technical challenge of creating accessibility, but also offers substantial environmental benefits, including carbon sequestration, bioremediation, and ecosystem restoration.

Keywords: Phragmatis Australis, Sustainability, Bearing capacity, Plants, Dewatering



Depot to be filled with dredged sediments and plants

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Living Reefs, Engineered by Worms: Structural Performance of Sabellaria Alveolata

Reiner Treur[1], Dominique Ngan-Tillard[1], Leon van Paassen[2], Ellen Meijvogel-de Koning[1], Arjan Thijssen[1]

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[2] Boskalis, Papendrecht, Netherlands

Abstract

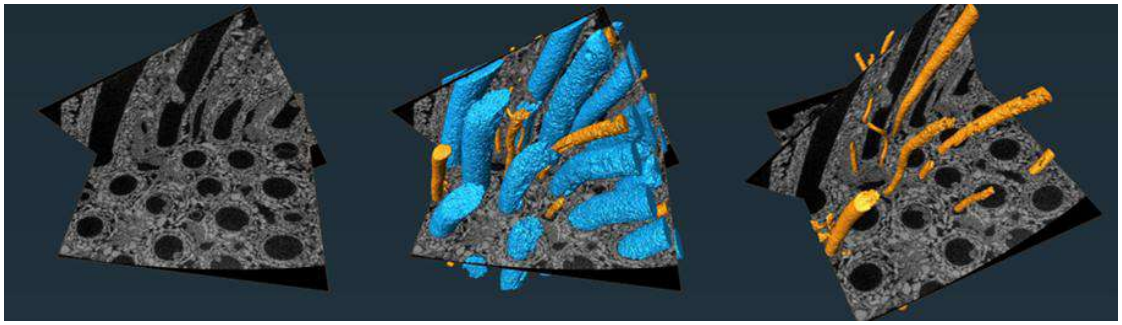
As interest grows in ecosystem-based coastal protection, the sandcastle worm Sabellaria alveolata (SA) is gaining attention for its potential engineering value. This polychaete constructs large reef structures from sand particles filtered from the water, which can enhance biodiversity and provide storm surge protection. However, little is known about the material and structural properties of these reefs. A recent study aimed to address this gap through comprehensive structural and mechanical analysis.

Structural characterization was performed using a range of imaging techniques, including environmental scanning electron microscopy, optical microscopy, CT scanning, laser diffraction, and powder X-ray diffraction. Results revealed that the reefs consist of tubes that first grow along hard substrates, then curve upward into reef blocks. These tubes often terminate in a tooth-like cap that prevents sand infiltration and optimizes orientation to prevailing currents for feeding and sand capture. On the microscopic scale, the tubes have a layered composition: an organic inner sheath, a middle layer of flat grains, and an outer layer of flat or rounded grains, all bound by a porous organic adhesive. The grain sizes show a trimodal distribution, with a dominant size around 1 mm.

Mechanical testing included oedometer, shear box, unconfined compressive strength (UCS), and slake durability tests. These showed variability in strength and stiffness depending on the orientation of testing and tube layer composition, with the inner layers demonstrating greater mechanical strength.

These findings contribute valuable knowledge toward understanding SA reef mechanics and support their potential role in sustainable coastal engineering and habitat enhancement.

Keywords: bioconstruction, sandcastle worm, micro-CT scan, micro-structure, mechanical resistance



EPOS-NL trial sub-scan of Sabellaria Alveolata honeycomb sand castle. Left, cross-sections parallel and perpendicular to the bio-tubes showing the neat arrangement of sand grains and shell fragments. Middle and right: bundles of large and small bio-tubes constructed by parents and offspring, respectively. Cube size: 28x28x24 mm3. Voxel size: 0.019 mm.

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Identifying possible methane emission risk related to abandoned oil/gas wells in the built environment of the municipality of Rotterdam

Ard den Outer[1], Rodriaan Spruit[1], Marc Breddels[1], Kees de Vette[1], Erik Gerlag[1]

[1] Municipality, Rotterdam, Netherlands

Abstract

In the year 2020 the Engineering Office of the municipality of Rotterdam was alerted on methane emissions occurring during construction works in Rotterdam-IJsselmonde. The methane emission from the subsurface occurred to such a high level that inhalation resulted in a state of dizziness and nausea for workers. Because the incidents happened in the vicinity of abandoned oil and gas wells, it was considered that the emission could be related to the wells. Since these incidents, an extensive Health, Safety and Environment research program has been initiated with the aim to assess the risks of abandoned wells for the built environment of Rotterdam. The outcome shows that a relation of the excess methane emissions with old wells is plausible and at least a 'very high' level of monitoring is needed in the built environment of the City of Rotterdam, rather than the current 'high' monitoring regime applied by the SodM, to detect hazardous emissions in time.

Keywords: methane, emissions, risk, degradation, oilwells

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Evaluation of Radon Content in Soil Using Artificial Intelligence

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Abstract

Radon measurements of the air in the soil in a 40m deep borehole were combined with meteorological data and evaluated using artificial intelligence. The purpose of the study is to analyze the factors influencing radon levels. Neural networks were employed for this purpose. After training the neural networks, a high coefficient of determination was achieved both in the training and in the forecast (test) phase if weekly or monthly averages are used. The most influential parameters on radon content were identified using a correlation matrix. The main reasons for the large variation in radon values observed in laboratory experiments without meteorological influences were primarily the environmental conditions of decay such as water/air and the grain size or decomposition degree of the rock. When recalculating and predicting radon values, these factors must be taken into account. Otherwise the large deviations cannot be explained.

Keywords: radon, neural networks

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National-Scale Soil Erosion Risk Mapping in Zambia Using the Revised Universal Soil Loss Equation (RUSLE)

Nikolaos Antoniadis[1], Constantinos Nefros[1], Constantinos Loupasakis[1]

[1] National Technical University of Athens, Athens, Greece

Abstract

Soil erosion poses a significant threat to agriculture and land sustainability across sub-Saharan Africa. In this study, we assess the extent and spatial distribution of soil erosion in Zambia using the Revised Universal Soil Loss Equation (RUSLE) model. This model incorporates environmental parameters, including rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover-management (C), and support practices (P) to estimate average annual soil loss across the landscape. To achieve this, we integrated a Digital Elevation Model (DEM), satellite-based precipitation data, global soil databases, and land cover maps within a GIS environment. Furthermore, high-resolution orthoimages were used to identify and digitise existing conservation practices (e.g., contour farming, terracing), to accurately assess the P-factor. Results showed that the majority of the country is characterized by very low erosion susceptibility. However, critical erosion hotspots were identified in areas lacking conservation measures, exceeding tolerable soil loss thresholds. The study results confirmed that areas implementing erosion control exhibited significantly reduced soil loss, highlighting the effectiveness of these land management strategies. The derived spatial erosion patterns provide valuable insights for prioritising conservation measures and sustainable land use planning in Zambia.

Keywords: Erosion, Zambia, RUSLE, Land management, Conservation practices

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Fungal Application for Mitigating Erosion and Shallow Landslide: Impact of Penicillium chrysogenum on the Properties of Clayey Soil

Ali Hajian[1], Kimia Saber Sichani[2], Solveig Tosi[3, 4], Massimiliano Bordoni[5], Valerio Vivaldi[5], Antonio Gambarani[5], Matteo Giganti[5], Laura Pedretti[5], Claudia Meisina[5]

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[5] Department of Earth and Environmental Sciences, University of Pavia, via Ferrata 1, 27100 Pavia, Italy, Pavia, Italy

Abstract

Sustainable ground improvement techniques are gaining attention in engineering fields as a response to increasing water-related hazards such as slope instability and soil erosion. Fungi-soil improvement is one of the nature-based solutions that offer promise for the mitigation of landslides and erosion in an environmentally responsible manner.

This study examines the impact of Penicillium chrysogenum on some of the physical, hydrological, mechanical, and hydromechanical properties of a remolded clayey soil collected from the northern Apennine region prone to erosion. This experiment was conducted in laboratory conditions. Investigated results include Atterberg limits, soil water retention curves, and suction stress characteristic curves obtained using the HYPROP and WP4C devices, aggregate stability by using the wet sieving apparatus, water repellency as measured by the water drop penetration time test, and shrinkage limits, shear parameters, and consolidation features derived from direct shear and oedometer tests. Also, Scanning Electron Microscopy was used to observe the soil at a microscale, providing insights into fungal interactions and their growth patterns within the soil matrix.

The results highlight the potential of using microorganisms, particularly fungi, for soil improvement, with a focus on geohazards such as landslide and erosion mitigation strategies. This study supports the use of fungal-based soil treatment as a sustainable and effective strategy for enhancing slope stability and reducing erosion risk.

Keywords: Bio-inspired technique, Penicillium chrysogenum, Soil improvment, Mechanical and Hydrological Properties, Mitigation of Geohazard

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Impact of Trichoderma Asperellum on Hydrological and Mechanical Properties of a Silty Clay Soil on Mitigating Rainfall Induced Shallow Landslide.

Kimia Saber Sichani[1], Ali Hajian[2], Solveig Tosi[3, 4], Massimiliano Bordoni[5], Valerio Vivaldi[5], Antonio Gambarani[5], Matteo Giganti[5], Laura Pedretti[5], Claudia Meisina[5]

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[5] Department of Earth and Environmental Sciences, University of Pavia, via Ferrata 1, 27100 Pavia, Italy, Pavia, Italy

Abstract

Nature-based solutions (NbS) are gaining recognition as sustainable, eco-friendly strategies for enhancing soil stability and mitigating land degradation processes such as shallow landslides and erosion. In this context, mitigation of geohazards based on using fungi offers promising potential, and this study investigates the influence of a fungal species, Trichoderma asperellum, on the hydrological and mechanical behavior of silty clayey soil. The soil samples, collected from a landslide-prone area in the Northern Italian Apennines, were treated with Trichoderma asperellum under controlled laboratory conditions. Various laboratory tests were conducted to assess the changes in soil properties, including Atterberg limits, soil water retention curves utilizing HYPROP and WP4C devices, aggregate stability, shrinkage limit, and water repellency by the water drop penetration test. In addition, mechanical behavior was assessed through oedometer and direct shear tests and hydro-mechanical tests by suction stress analysis. Microstructural observations were conducted using scanning electron microscopy to examine fungal-soil interactions at the particle scale. This work contributes to the growing field of NbS by demonstrating the potential of Trichoderma asperellum as a mitigation method. The findings emphasize the fungal-based amendments as promising solutions within the field of engineering, particularly for enhancing slope stability, controlling erosion, and promoting sustainable soil management practices.

Keywords: Fungal Treatment, Trichoderma asperellum, Mechanical and Hydrological Behaviors , Reduction of Geohazard, Silty clay soil

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Multi-Scenario Land Use and Carbon Storage Assessment in the Yellow River Delta under Climate Change and Resource Development

Zekun Wang[1], Xiaolei Liu[1, 2, 3], Shaopeng Zhang[1], Xiangshuai Meng[1], Hongjun Zhang[3], Xingsen Guo[1, 4]

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[2] Laboratory for Marine Geology, Qingdao Marine Science and Technology Center, Qingdao, China
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[4] Department of Civil, Environmental, and Geomatic Engineering, University College London, London, United Kingdom

Abstract

Land use and land cover change (LULCC) is a key driver of carbon storage changes, especially in complex coastal ecosystems such as the Yellow River Delta (YRD), which is jointly influenced by climate change and resource development. The compounded effects of sea-level rise (SLR) and land subsidence (LS) are particularly prominent. This study is the first to integrate SLR and LS into a unified simulation framework, employing three IPCC AR6 climate scenarios (SSP1−26, SSP2−45, SSP5−85) and InSAR-derived LS data to assess future inundation patterns. Based on local land use and ecological protection policies, three strategic scenarios—Ecological Protection Scenario (EPS), Natural Development Scenario (NDS), and Economic Growth Scenario (EGS)—are constructed. The Patch-Generating Land Use Simulation (PLUS) and the Integrated Valuation of Ecosystem Services and Trade-offs (InVEST) models are applied to simulate LULCC and carbon storage dynamics under these scenarios. Results show: (1) Over the past 30 years, land use in the YRD has expanded seaward, mainly converting grasslands and wetlands to drylands and culture areas. (2) Carbon storage exhibits strong spatial heterogeneity, with LULCC since 1990 to 2020 causing a net carbon loss of 2.22 × 106 t. (3) Inundation risk is closely tied to LS, especially under low sea-level scenarios. Under the EGS, significant carbon loss and severe inundation are projected by 2030 and 2060. This research offers a novel compound-driving simulation approach, providing scientific insights for coastal spatial planning and carbon sink enhancement in subsidence-prone delta regions.

Keywords: carbon storage, land use and land cover change, seawater inundation, Ecological Protection Scenario, global climate

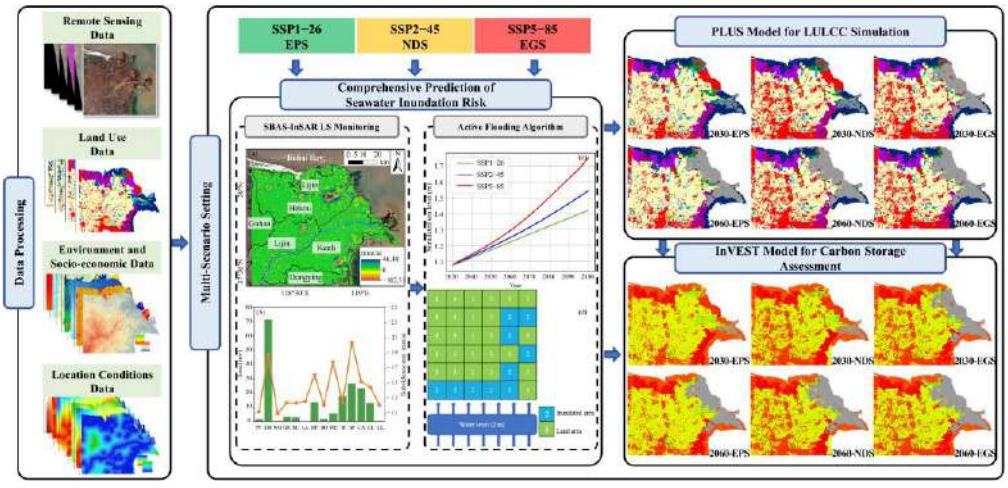

Figure. Research framework for multi-scenario land use and land cover change (LULCC) simulation and carbon storage assessment in the Yellow River Delta (YRD) considering seawater inundation risk. (a) Land subsidence (LS) rate inversion; (b) Subsidence of each land use type; (c) Future sea-level rise (SLR) projections; (d) Active flooding algorithm principle. (EPS: Ecological Protection Scenario; NDS: Natural Development Scenario; EGS: Economic Growth Scenario; PF: paddy field; DR: dryland; WO: woodland; GR: grassland; RC: river and canal; LA: lake; RP: reservoir and pond; BO: bottomland; WE: wetland; TF: tidal flat; SP: salt pan; CA: culture area; CL: construction land; UL: unused land).

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Sorption Characteristics and Geochemical Assessments of Clay-Shale Materials as Landfill Liners: Implications for Low-cost Wastes Containment System

Moshood Tijani[1], Akinade Olatunji[1], Oluwanisola Ayodele[1]

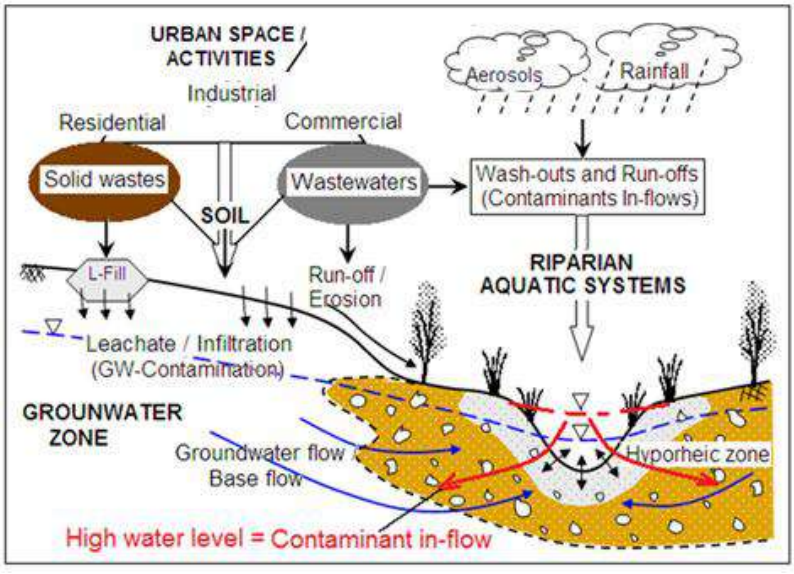
[1] Department of Geology, University of Ibadan, Ibadan, Nigeria

Abstract

This study examines the sorption characteristics and geochemical assessments of selected clay-shale materials from Anambra Basin, SE-Nigeria in order to determine their suitability as landfill liners. The intent is to assess the capacities of these clay-shale materials to remove contaminant trace metals from waste leachates and in order to prevent contamination of the underlying groundwater system.

Three clay samples were analysed for bulk chemical composition using the Atomic Adsorption Spectrometer (AAS) while the mineralogical compositions were determined using X-ray diffraction (XRD) technique. Batch adsorption studies were conducted to investigate the effects of contact time and initial concentrations on the adsorption (removal) of Cu, Zn, and Pb by the clay materials. The sorption characteristics were analysed by Langmuir and Freundlich adsorption isotherms. The results of the bulk chemical composition revealed high content of SiO2 (45.49-55.50%) and Al2O3 (18.60- 32.80%). The samples were rich in quartz, feldspar and mica group and had high CEC of 6.98-7.62 meq/100g. The sorption data fitted well with the Freundlich adsorption isotherm model and revealed about 5-10% reduction in adsorption capacity of the samples resulting from 200% increase in metal concentration. All the metals exhibited 94-98% removal within 4-5 hours of reaction time suggesting effective sorption capacity. In summary, the clay materials exhibited acceptable geochemical properties and high adsorption capacities for removal of contaminant metals from aqueous wastes. Hence the clay materials are suitable for application as landfill liners subject to appropriate beneficiation to enhance the hydraulic properties to the required specification for optimum performance as liners.

Keywords: Landfill Liner, Clay-shale, Sorption Isotherms, Geochemical Asessment, Trace Metal Sorption



Conceptual diagram depicting contaminant sources and movement dynamics in an urban catchment

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Engineering Geological Properties of Effluent Contaminated Clay Soils and the Influence of Charcoal as Barrier Material

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Abstract

Experimental studies on the effect of industrial effluent contaminated clayey soil and the impact of charcoal as barrier material was investigated. The physico-chemical properties of the effluent were characterized, and soil parameters (pH, particle size distribution, consistency limits, and hydraulic conductivity) were determined before and after four-weeks of effluent-soil interaction. The same suite of tests was then repeated on soil samples incorporating charcoal as barrier material. Contamination caused a decrease in soil pH, changes in clay mineralogy, and a shift toward finer particle sizes (suggesting flocculation or dispersion). Consistency limits increased, while hydraulic conductivity rose substantially by 249.50% in undisturbed samples and 173.18% in Proctor-compacted samples relative to uncontaminated values. These alterations indicate impaired barrier performance, likely from chemical interactions that enlarge pores or disrupt the chemistry of the soil. However, post-charcoal data significantly displayed reversal in the geotechnical properties of the soil when compared to that of post-contaminated soil.

Keywords: Contamination, Hydraulic Conductivity, Effluent , Prosopis juliflora, Geotechnical changes

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Landfill Settlements Under Conditions of Enhanced Waste Biodegradation

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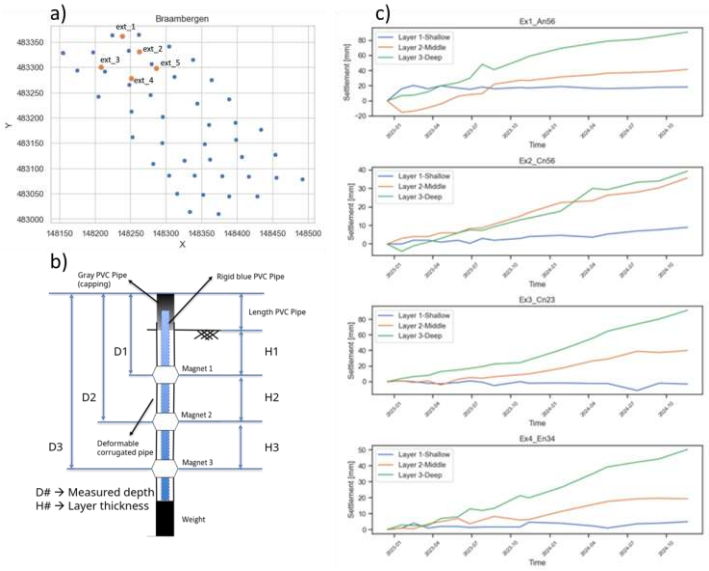
Abstract

Geomechanical stability and biodegradation processes in organic wastes are primary drivers of landfill settlement. Biodegradation and settlement are closely linked through mass transfer and transport processes, particularly influenced by percolating water and leachate flow. Gas landfill overextraction or air injection accelerate biodegradation, resulting in increased mass loss via the gas phase. This study monitored surface and subsurface settlements at two aerated landfill sites (Braambergen and Wieringermeer) in the Netherlands between 2017 and 2025. Settlement plates were used for long-term surface tracking on both sites. At the Braambergen pilot, additionally five extensometers were installed in 2022 to measure settlements across three waste body layers. Additional data included leachate and gas production rates and waste composition. The deepest landfill layers exhibited the highest cumulative settlements (40–80 mm), followed by intermediate layers (10–30 mm), while shallow layers remained largely stable. Surface elevation changes measured via Leica GS18i GPS ranged from 0 to 250 mm. Settlement plates revealed significant spatial variability: cumulative settlements ranged from 0.3 to 1.2 m at Wieringermeer and 0.1 to 0.55 m at Braambergen (2017–2022). The highest subsurface settlements occurred near aeration wells and slopes, suggesting enhanced biodegradation in these regions due to enhanced air intrusion during overextraction. Notably, GPS-derived surface settlements exceeded total subsurface settlements detected by extensometers, suggesting potential consolidation of soil layers beneath the landfill base. Overall, settlement monitoring using plates and extensometers proved effective in assessing (depth-dependent) landfill response to measures enhancing waste biodegradation.

Keywords: Biodegradation, Infiltration, Settlement, Overextraction, Air injection



Braambergen settlements captured by extensometers. a) Location of extensometers at the Braambergen pilot site (orange dots) together with settlement plates (blue dots). b) Generic extensometer profile used at the Braambergen pilot site. c) Settlements of the three different waste layers from extensometer 1 to 4.

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Promoting morphological diversity to support resilience and ecological functionality of a freshly infilled reconstructed wetland in the Venice Lagoon

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Abstract

Since 2020, Venice has been protected from extreme flooding by mechanical barriers at the inlets between the Adriatic and the lagoon, but this heavy infrastructure is only part of the solution to mitigating and adapting to climate change. Wetland reconstruction is also integral to maintaining a healthy lagoon system and preserving the unique city.

Yet salt marsh area in the Venice Lagoon has shrunk by ~75% in the past century, and of the remaining salt marsh, almost half has been artificially reconstructed with mixed success in comparison to natural marsh subjected to comparable environmental forcings - in terms of erosion and eco-morphological traits including quota relative to average water level, tidal channel density, halophytic vegetation cover and diversity.

The Vital initiative, a partnership between academic research, a community NGO, a local business and technical experts, is developing techniques of “working with nature” to promote greater ecological functionality of reconstructed marshes and innovative protocols and tools for monitoring key biotic and abiotic parameters, such as channel evolution and drainage, derived from studies of natural marsh eco-morphodynamics.

Promising results are emerging from the first interventions carried out in 2023 to promote channel formation that replicate tidal creeks on natural marsh and contribute to improved drainage and associated plant colonisation. This is being demonstrated via seasonal topographical surveys using drone technology to track substantial reduction of the extension of waterlogged area and subsequent geometrical analysis.

Keywords: saltmarsh, reconstruction, ecological functionality

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Assessing the potential of Carbon Sequestration via Enhanced Rock Weathering in Costa Rica

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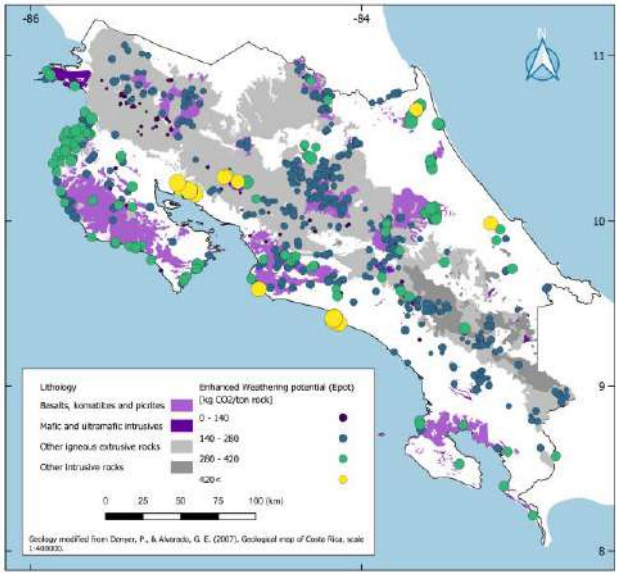
Abstract

The escalating climate crisis demands effective CO2 capture and storage strategies, and Negative Emissions Technologies (NETs) have become the trending topic on climate mitigation research. This research evaluates the potential of enhanced rock weathering (ERW) as an innovative carbon sequestration method to apply in Costa Rica. The Project determines the technical viability of long-term carbon fixation using the country's geological resources and extensive agricultural fields, taking advantage of the optimal climatological conditions of the tropics to enhance a natural process and quantify the carbon uptake it causes. We identify high-magnesium igneous rock units in Costa Rica such as picrites and basalts, through geochemical literature review, then characterize them petrographically and geochemically to assess their suitability as a raw material for applying ERW. Through laboratory experiments we quantify weathering rates of the pulverized rocks and their impact, determining CO2 fixation potential and nutrient release for soils. Ultimately, we estimate the CO2 sequestration potential (in tons per hectare per year), evaluating its viability as a sustainable NET. This research provides crucial data on ERW's effectiveness when applied as basalt rock dust in Costa Rican agricultural fields, combining earth sciences with environmental technology to contribute to global climate change mitigation efforts.

Keywords: Carbon sequestration, Enhanced Rock Weathering, Basalt, Costa Rica , Climate mitigation



Whole-rock geochemical data processed using the Epot equation for CO2 sequestration capacity, following Renforth (2019). Symbol sizes are scaled according to the calculated Epot values for each site, representing the kilograms of CO2 potentially removed through enhanced rock weathering.

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Groundwater Extraction-Induced Geohazards and Geodiversity Loss in Protected Volcanic Crater Lakes of Central Mexico

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Abstract

Volcanic-bound crater lakes in central Mexico are critical repositories of geo- and bio-diversity, containing unique microbial ecosystems, sedimentary archives, and rock/mineral assemblages of significant scientific and cultural value. Several of these systems, Rincón de Parangueo, La Alberca, Lake Cuitzeo, and Lake Pátzcuaro, are located within Protected Natural Areas (PNAs). Despite their conservation status, they are increasingly impacted by unsustainable groundwater extraction, resulting in lake desiccation, sediment exposure, and hydrogeological instability. As part of a PAPIIT-IG101325-funded research project (UNAM), we conducted field investigations, remote sensing analysis, and soil/hydrological data synthesis across these sites. The results reveal soil desiccation, fracturing, differential compaction, and subsidence in carbonaceous and evaporitic sediments, as well as degradation of microbialite structures. These changes not only compromise the geoheritage and ecological integrity of these PNAs but also represent diffuse geohazards, including slope instability and water quality deterioration due to disrupted aquifer/lake dynamics. This study emphasizes the disconnections between legal protection and hydrological vulnerability. While these crater lakes are nominally protected, the lack of integrated water resource management threatens irreversible geodiversity/biodiversity loss and poses increasing geological risks to the surrounding communities. We advocate for the inclusion of lacustrine crater systems in geohazard assessments, groundwater regulation policies, and geoheritage monitoring frameworks, particularly in protected areas experiencing high anthropogenic pressure.

Keywords: Protected Natural Areas, groundwater overextraction, geodiversity loss, volcanic crater lakes, Central Mexico

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Water Balance and Chloride Mass Balance Assessment of the Kragge Infiltration Pilot

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Abstract

In the Netherlands a long-term experiment is being carried to actively reduce the emission potential from landfill waste bodies. At the Kragge landfill, a pilot is performed to test enhanced leaching by recirculating treated leachate on one of the cells. We present an analysis of the water and chloride mass balance based on long-term time series and a recently developed modelling approach. Using this approach we have an accurate mass balance, showing that the landfill Cell 3 is hydrologically connected to its neighbouring cell: about 22 % of the infiltrated leachate discharged through the drainage system of Cell 4. While the water storage in Cell 4 remained close to the initial storage, the water storage in Cell 3 consistently shows an increase, which is still ongoing after 6.65 years, about 44 % of the infiltrated water remains in the waste body of cell 3. The mass of chloride in Cell 3 remains constant because of the recirculation of leachate. On Cell 4, the chloride mass decreases because of the flushing with fresh rainwater. The approach gives accurate results for the change in mass and water. However, the absolute magnitude of remaining chloride mass and water storage in the waste body remains uncertain.

Keywords: Landfill after-care, Leachate, Infiltration, Emission Potential

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Geological and Geo-electrical Characterization of Hydrocarbon Contaminated Soils in Gokana, Ogoni, Rivers State, Nigeria

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Abstract

Early years of oil exploration and production in the Niger Delta witnessed several oil spill incidents due to weak environmental regulations. These spills seep into the ground exacerbated by pervious soil which encourage contaminant migration downwards until groundwater is intercepted, where the oil exists as free phase. The full extent as well as 3-dimensional distribution of the contamination is determined by Site characterization to provide information that is required for conducting risk assessments and for designing and implementing remediation systems. Intrusive methods of soil characterization involving boring are expensive, time consuming and expose the pristine subsoil and groundwater to further contamination. This paper is focused on the use of non-intrusive Electrical Resistivity Tomography (ERT) in delineating contaminated areas. A criss-crossing network of Vertical Electrical Sounding (VES) was acquired and analyzed using RES-3D and Earth-Imager softwares to generate geo-electric ground models. Resistivity signature for mature oil contamination was determined as cutoff and used to discriminate between hydrocarbon contamination and other geo-electric horizons. Predictions of ERT were validated by soil boring. Results suggest that ERT with its minimum footprint and negligible cost can become a standard method for the assessment and delineation of hydrocarbon polluted site. The ground models can be further used to compute precise volumes of materials to be remediated and bring clarity to the contaminated soil structure and enable a precise remediation intervention.

Keywords: Characterization, Remediation, Geological, Geo-physical, Tomography

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Continuous Ultrasonic Monitoring of Curing-State Evolution in Tung Oil-Stabilized Sand

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Abstract

Low-carbon ground improvement increasingly uses biopolymer-based treatments, but curing in non-cementitious treated soils remains difficult to track with discrete endpoint tests. This study uses ultrasonic transmission to monitor tung oil-stabilized sand through hardened-state measurements and continuous P-wave records. Hardened specimens show a biphasic acoustic response near 6 wt% tung oil: P-wave velocity (V_p) increases from 246.71 to 1824.05 m/s, while an attenuation proxy, expressed as the apparent inverse quality factor (Q_app^(-1)) decreases from 0.081 to 0.0260 up to 6 wt%. Above this content, V_p changed little, whereas Q_app^(-1) increased again. This pattern is consistent with a shift from contact bonding toward pore-filling dissipation. For the continuous records, a Gaussian-smoothed V_p curve and a sustained velocity-growth threshold of 0.1% h−1 identify the onset of active curing and entry into an acoustic plateau. The method defines acoustic curing-state markers for stabilized sand. Because the bonding and pore-filling interpretation is inferred from acoustic evidence, these markers should be calibrated with mechanical or microstructural measurements before being translated into application-specific criteria.

Keywords: Tung oil-stabilized sand, Non-destructive evaluation, Continuous p-wave monitoring, Apparent inverse quality factor, Curing-state identification

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Effects of Root–Crack Dynamics on Soil Infiltration During the Growth Period Across Seasons

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Abstract

Reliable measurement of soil infiltration is fundamental in geotechnical engineering, especially when evaluating slope stability. Although vegetation is widely recognised for enhancing environmental resilience, the impact of plant roots on soil permeability remains debated in the literature. In addition, desiccation cracks play a critical role in modifying infiltration behaviour, particularly under seasonal changes. This study explores the coupled effects of root development and crack formation on infiltration rates across different seasons. Infiltration rates were measured directly in both bare and vegetated plots over a six-month observation period using the double-ring infiltrometer method. The interaction mechanisms between root development and crack dynamics were quantified through the Root Area Ratio (RAR) and Crack Identification Factor (CIF), assessed using a minirhizotron imaging system. The results demonstrate that as vetiver roots developed, they substantially altered crack characteristics, reducing 2 times lower CIF and producing a more irregular crack network compared to bare soil. Statistical analysis revealed positive correlations between both RAR and CIF with infiltration rate, suggesting that root proliferation and crack presence jointly facilitate water entry into the soil. Compared with the bare zone, the vegetated area exhibited markedly higher final infiltration rates, approximately 2.7 times greater in the summer dry period. The results indicate that infiltration was controlled by both surface cracking and vegetation-induced soil structure. Although bare soil exhibited higher CIF, vegetated plots showed higher infiltration rates, particularly during the dry summer period. This suggests that root-induced macropores and improved pore connectivity enhanced infiltration independently of visible surface crack.

Keywords: Crack, Double ring test, Root growth, Water infiltration,

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Sustainable Soil Permeability Reduction Using Microbial Bio-Clogging

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Abstract

Bio-clogging via microbial activity provides an eco-friendly alternative to conventional geotechnical seepage control. Although promising, its practical application remains limited by uncertainties related to bacterial concentration, nutrient supply, and treatment duration under field conditions. This study evaluates the influence of microbial bio-clogging on the hydraulic behaviour of coarse-grained soils during both nutrient application and post-treatment phases. Laboratorium testing were performed to examine permeability reduction processes associated with bacterial attachment and the production of extracellular polymeric substance (EPS). The results show that progressive microbial colonisation and EPS accumulation caused pore constriction and partial blockage within the soil matrix, leading to a substantial decrease in saturated hydraulic conductivity. Hydraulic conductivity decreased from approximately 1x10-4 m/s to 1x10-6–10-7 m/s within 10 days of treatment. The reduction achieved was comparable to that of conventional seepage mitigation techniques, such as bentonite grouting and cement. Furthermore, the sustained low permeability after nutrient withdrawal indicates the durability and structural stability of the biofilm matrix. These findings confirm the prospect of microbial bio-clogging as an environmentally sustainable ground improvement strategy for field-scale geotechnical applications.

Keywords: Bio-clogging, Extracellular polymeric substances (EPS), Microbial ground improvement, Permeability reduction,

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Assessment of water quality in the Xichu-Laja River Basin using multivariate statistical analysis and water quality indices: a longitudinal study

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[1] University of Guanajuato, Guanajuato, Guanajuato, Mexico
[2] Technical University of Darmstadt, Darmstadt, Hesse, Germany

Abstract

This longitudinal study in the Xichu–Laja River Basin (central Guanajuato, Mexico) evaluates spatial and temporal variations in water quality within a mining-impacted region characterized by Pb–Ag–Zn sulfide deposits. The objective was to assess contamination patterns using an integrated hydrogeochemical and statistical approach. A total of 86 water samples were collected during two monitoring campaigns (2013 and 2018), allowing evaluation of temporal variability. Field parameters were measured in situ, and dissolved metal concentrations were determined by atomic absorption spectroscopy. Four distinct hydrogeochemical zones were identified based on water types. Multivariate statistical analyses, including Principal Component Analysis, revealed Cd, Cu, Fe, Hg, Mn, Pb, and Zn as the main potentially toxic elements controlling water quality, while correlation analysis clarified their interrelationships. Arsenic was detected in approximately 80% of samples. Hydrogeochemical interpretation indicates that contamination results from both anthropogenic sources—mainly urban wastewater discharge and acid mine drainage—and natural processes such as the weathering of mineralized rocks. Hydrochemical facies were defined using Piper diagrams, and Schoeller diagrams illustrated spatial evolution along the basin flow path. Spatial interpolation (Inverse Distance Weighted) identified the area near La Aurora Mine tailings (Zone 3) as the most critically impacted. Water quality indices (WQI, Cd, HPI, HEI) show progressive deterioration downstream: Zones 1 and 2 remain suitable for drinking and irrigation, whereas Zones 3 and 4 are unsuitable without treatment. These findings highlight the need for continuous monitoring and targeted remediation strategies within the Sierra Gorda Biosphere Reserve.

Keywords: Mine tailings, Potentially Toxic Elements, Spatial distribution, Water Quality Index, Xichu Mining District

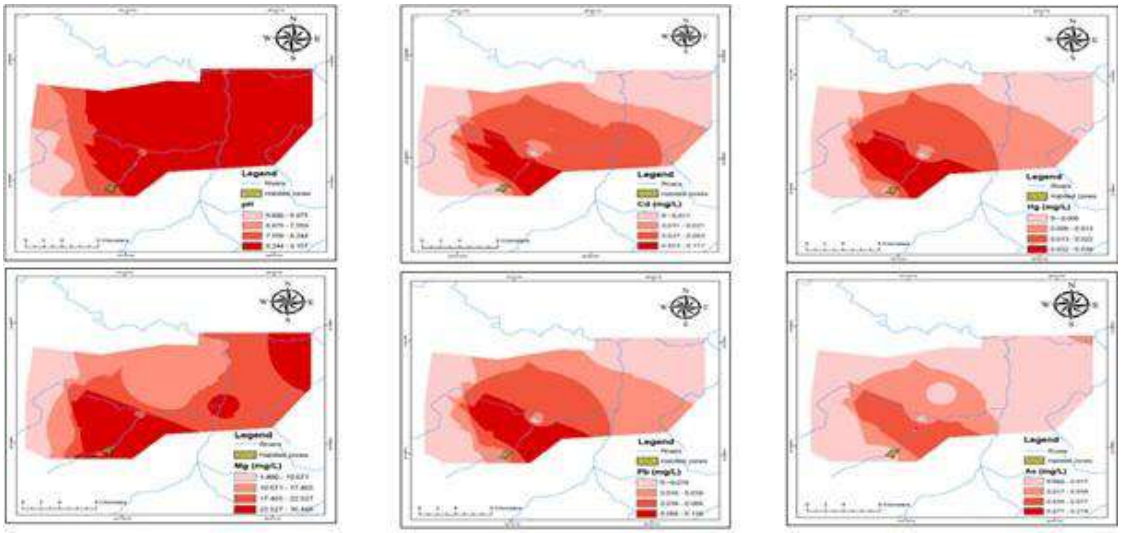

Figure 5. Spatial distribution of contaminants in the XLRB

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Hydrogeochemical Modeling of Metal Mobility in Mining-Impacted Reservoirs in Palo Colorado, Mexico

Armando Guerrero Aguilar[1, 2], Alma Hortensia Serafín Muñoz[1], Christoph Schüth[3]

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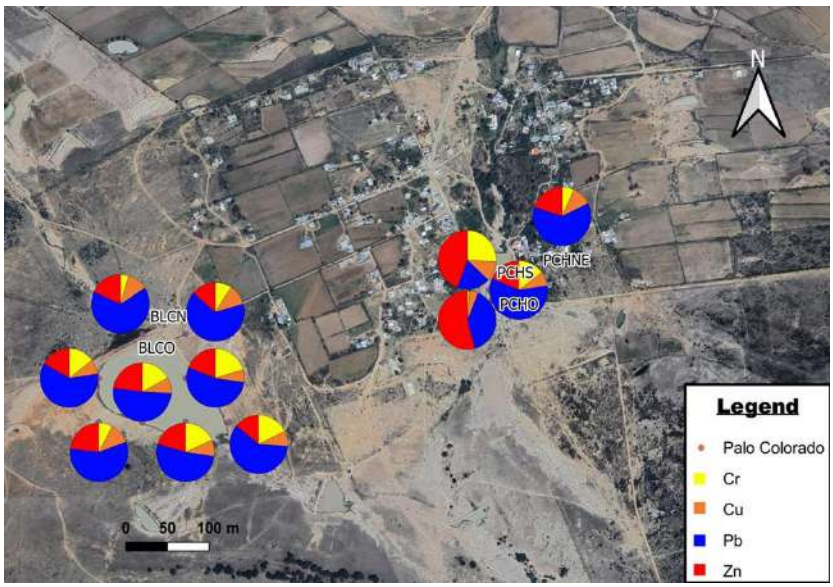
[2] Technical University of Darmstadt, Darmstadt, Hesse, Mexico
[3] Technical University of Darmstadt, Darmstadt, Hesse, Germany

Abstract

This study presents a hydrogeochemical modeling approach to evaluate the mobility, speciation, and environmental behavior of potentially toxic elements (PTEs) in surface water reservoirs impacted by legacy mining activities in Palo Colorado, Guanajuato, Mexico. Field sampling and laboratory analyses, including ICP-MS and ion chromatography, were conducted to characterize water and sediment chemistry. Geochemical modeling was performed using PHREEQC v3 and Hydra/Medusa to simulate equilibrium reactions, speciation, and saturation indices under varying physicochemical conditions. Results indicate that water chemistry is primarily controlled by carbonate weathering and evaporation processes, while the mobility of trace metals such as Al, Pb, and Hg is strongly influenced by pH, redox potential, and alkalinity. Some potentially toxic elements, such as Al, exceed the maximum permissible limits of the Mexican normativity of 0.20 ppm. Other elements like Ba, Cd, Pb, and As are also present in the water samples. Saturation index calculations suggest that iron oxides and carbonate minerals play a key role in regulating metal mobility through precipitation and adsorption mechanisms. Scenario simulations demonstrate that slight variations in pH and redox conditions can significantly enhance the release and transport of contaminants. The integration of geochemical modeling with field and laboratory data provides a robust framework for understanding contaminant dynamics in mining-impacted environments. This study highlights the importance of predictive modeling for environmental risk assessment and supports the development of mitigation strategies in vulnerable communities exposed to contaminated water resources.

Keywords: Geochemical modeling, PHREEQC, Mining impacts, Hydrogeochemistry, Contaminant mobility



Distribution of PTEs in the water bodies of Palo Colorado

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Performance Evaluation of Chitosan-Treated Black Cotton Soil with Indigenous Bacteria via Bio-Cementation

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Abstract

Black cotton soil (BCS) is an expansive clayey soil characterized by its higher montmorillonite content. Due to the presence of swelling minerals, BCS exhibits swelling-shrinkage behaviour and poor load-bearing capacity. While traditional methods like lime and cement stabilization are commonly used to improve the engineering properties of BCS, they pose several environmental concerns. Stabilization of BCS in a more sustainable manner by using a biopolymer (viz., Chitosan) and the additional application of the Microbial-Induced Calcite Precipitation (MICP) technique has been investigated in the present study. For the MICP treatment, an indigenous bacterium, i.e., Methylobacterium radiotolerans (MRT) has been used. Proctor compaction and unconfined compressive strength (UCS) tests were carried out in the laboratory on the treated as well as untreated samples. For the biopolymer treatment, different doses of chitosan (i.e., 0.08%, 0.16%, 0.24%, 0.32%) were considered. Based upon the results obtained, 0.24% was found to be the optimum chitosan dose, using which the combined biopolymer-MICP treatment was carried out. It was found that the UCS value of BCS treated only with chitosan increases significantly from 157.32 kN/m² to 678.46 kN/m². Additionally, the maximum dry density (MDD) improved from 15.2 kN/m³ to 16.6 kN/m³, while the optimum moisture content (OMC) decreased from 22.10% to 20.16%. When the optimum percentage of chitosan was combined with MICP treatment, a further strength improvement of around 19% was obtained. This 19% increment in UCS with inclusion of MICP is found to be insignificant considering the cost aspect.

Keywords: MICP, Soil stabilization, Chitosan, MethyloBacterium Radiotolerance, Black cotton soil

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Earthquake-triggered landslides and mountain carbon storage

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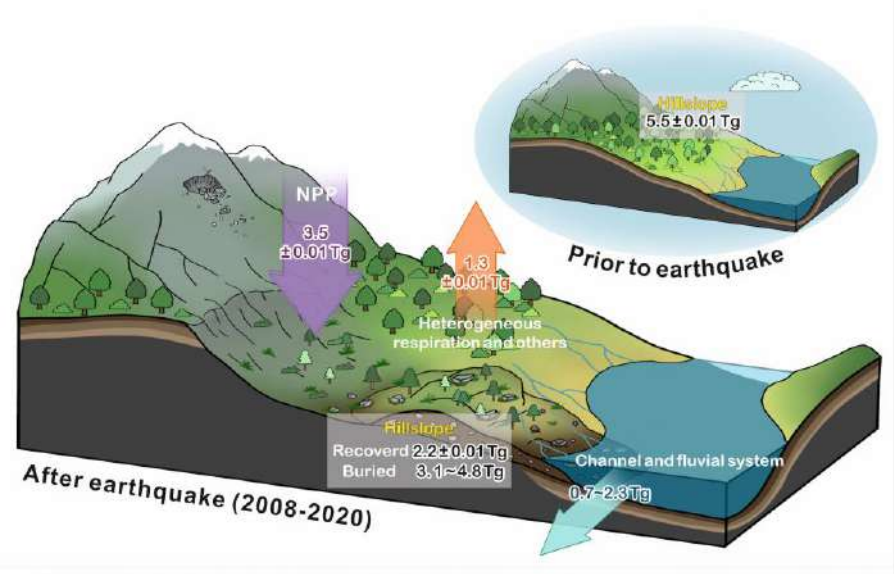
Abstract

Earthquakes and seismically induced landslides accelerate carbon export from mountains by eroding hillslope soil carbon, yet their net contribution to terrestrial organic carbon cycling remains incompletely understood. Here, we use the 2008 Mw 7.9 Wenchuan Earthquake, which generated one of the largest landslide volumes in recent history, to quantify an organic carbon mass balance that accounts for storage, loss, and transport within the ensuing sediment cascade. By integrating field measurements, laboratory analyses, remote sensing, landslide inventories, machine-learning-based carbon stock mapping, and carbon balance modelling, we assess the post-earthquake carbon budget across the Longmenshan region. Our results show that earthquake-triggered landslides mobilized organic carbon from pre-existing vegetation and soils. However, thanks to post-event revegetation and extensive intermontane sediment storage, much of this carbon was retained within landslide deposits rather than being rapidly exported downstream. As a result, the earthquake boosted the regional hillslope carbon mass by approximately 10%. We demonstrate that earthquakes and landslides can function as carbon capacitors: they mobilize and bury organic carbon during coseismic slope failure, store it temporarily within landslide deposits and sediment cascades, and gradually release it through erosion, decomposition, and fluvial transport. This capacitor effect regulates carbon storage and discharge across mountain belts over time, providing a direct link between seismic activity, post-seismic sediment dynamics, ecosystem recovery, and the terrestrial carbon cycle. This study highlights the long-term environmental significance of earthquake-induced landslides in tectonically active mountain belts.

Keywords: Mass movement, Organic Carbon, Sediment and carbon budget, Earthquake triggered landslides



Overview of hillslope organic carbon (OC) budget triggered by the 2008 Wenchuan Earthquake

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Radiological Risk Assessment as an Engineering Geological Tool for Sustainable Phosphate Mining in Northwestern Nigeria

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[2] University of Ibadan, Ibadan, Oyo, Nigeria
[3] Ajayi Crowther University, Oyo, Oyo, Nigeria

Abstract

Engineering geological characterization of phosphate deposits is fundamental to sustainable mine planning, occupational safety, and environmental risk management. This study evaluates the mineralogical characteristics, naturally occurring radioactive materials (NORM), and radiological hazards associated with phosphate mining in the Sokoto Basin, northwestern Nigeria. Representative phosphate and intercalated shale samples were collected from five active mine sites (P1–P5). Mineralogical compositions were determined using X-ray Diffraction (XRD), while uranium (U), thorium (Th), and potassium (K) concentrations were analysed using Inductively Coupled Plasma Mass Spectrometry (ICP-MS). Phosphate mineralization occurs as nodules within shale horizons at depths of 0.25–7.0 m and is dominated by fluorapatite, calcite, smectite, and quartz, whereas shales are composed mainly of smectite, quartz, calcite, palygorskite, and kaolinite. Phosphate grades (P_2O_5 = 0.29–22.29 wt.%) indicate low- to medium-grade deposits. Radiological hazard assessment revealed that all shale samples satisfied internationally accepted safety limits for radium equivalent activity, hazard indices, gamma index, and annual effective dose. In contrast, phosphate samples from selected mine sites exceeded recommended thresholds for radium equivalent activity, external and internal hazard indices, gamma index, and annual effective dose, indicating elevated long-term occupational exposure risks. The findings demonstrate that engineering geological investigations should integrate radiological characterization into mine planning and operational risk assessments to support safer extraction practices and sustainable phosphate resource development. This work contributes to post-mining risk management by providing a framework for identifying NORM-related hazards and informing evidence-based occupational health protection in phosphate mining environments.

Keywords: Engineering Geology, Phosphate Mining, Naturally Occurring Radioactive Materials (NORM), Radiological Risk Assessment, Occupational Health

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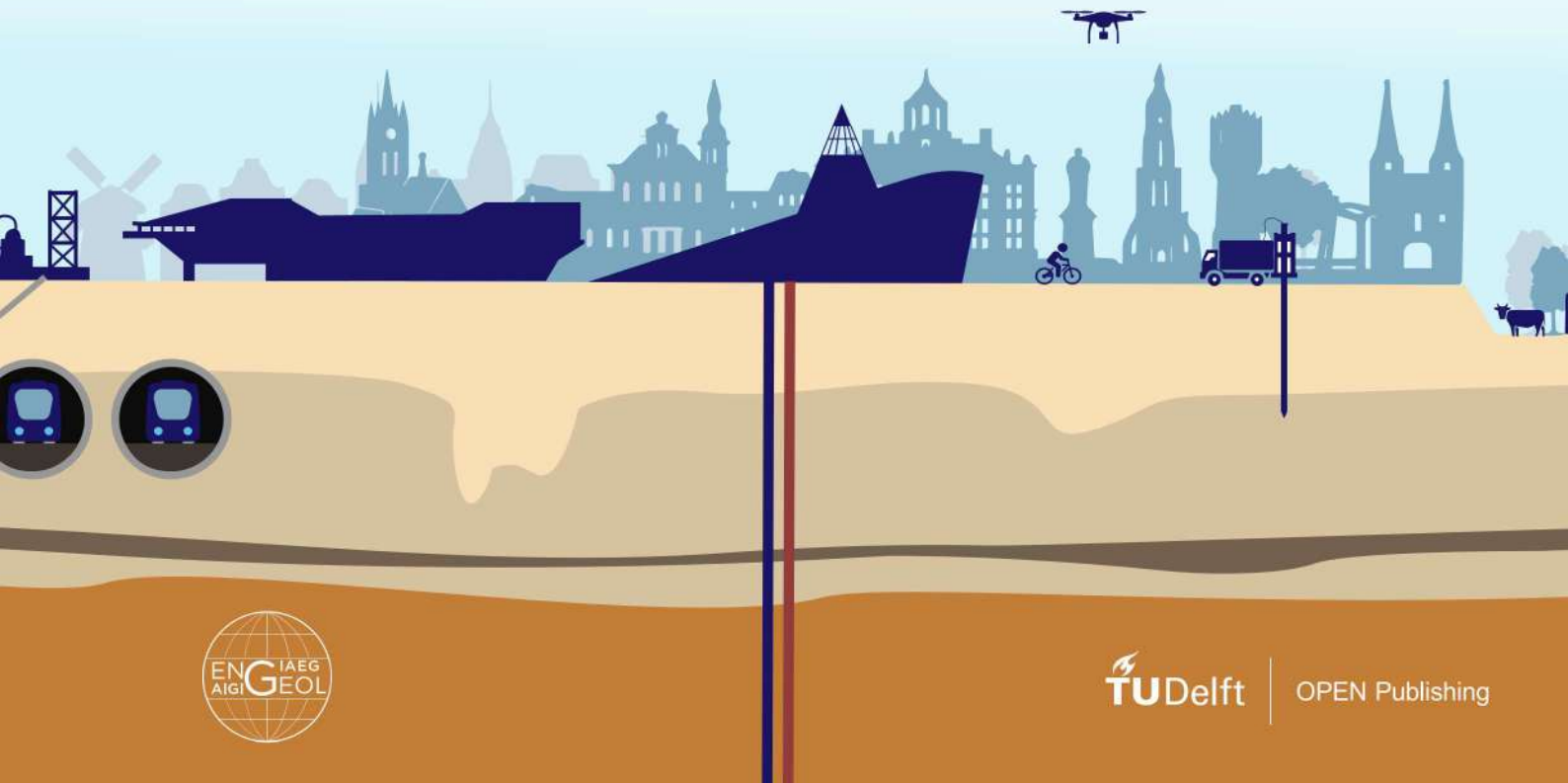
7. Engineering Geology for preservation of heritage

Highlight of Engineering Geology techniques for the characterization and preservation of geological, archaeological and industrial sites combined with policy and management. Special attention to building stones and ancient mines.



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Cliffs of Moher, Ireland Geohazard Assessment

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Abstract

Located on the west coast of Ireland, the Cliffs of Moher rise above the Atlantic Ocean as part of the Burren and Cliffs of Moher UNESCO Global Geopark. The impressive 214m high siltstone and sandstone cliffs are one of Ireland's most popular tourist hotspots. Battered by frequent, intense storms caused by climate change, the geohazard assessment provided insights into the mechanisms and impacts of erosion, identified areas at risk and fed into future development plans at this protected natural site. Site walkovers and investigations and a range of digital tools created a 3D model of the cliffs, with detailed information which allowed us to assess the behaviour of the rockmass at the inaccessible cliff edge and face. The subsequent 3D Ground model created used information and data from a series of visual assessments, field mapping and Unmanned Aerial Vehicles (UAV), topographic and geophysical surveys. Including over 370 million data points, the model provides an overview of the condition and structure of the overburden and rock at the cliff edge and face. This enhanced digital data formed the basis of stereographic, kinematic and slope stability analyses. Our interactive 3D cliff model can be updated through ongoing monitoring, helping the client track and assess the effects of climate change by analysing ongoing erosion, and inform any future potential developments. We also carried out a geohazard assessment to provide insights into the mechanisms and impacts of erosion, identify areas at risk and feed into future development plans at this protected natural site.

Keywords: Climate , Geology, Geohazard, GeoPark, Coast



Cliffs of Moher, Co. Clare, Ireland

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Influence of Lithology and Saturation on the Mechanical Behaviour of Chalk Rocks in Northwestern Europe

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Abstract

The Chalk rock plays a key socio-economic and cultural role across Northwestern Europe, serving as a major aquifer—supplying around 50% of England's and 25% of southern Belgium's groundwater—and shaping iconic landscapes such as the Étretat cliffs. Its cultural significance is reflected in historic constructions like the Beauvais Cathedral and the UNESCO-listed Champagne cellars built in former underground chalk quarries. However, chalk formations are increasingly affected by geomechanical instability, with sinkholes and coastal cliff collapses becoming more frequent due to environmental and climatic changes. This study investigates the relationships between mineralogical, petrographic, and mechanical properties of three distinct chalk lithotypes: a highly porous white micritic chalk from the Mons Basin (≈40% porosity), an argillaceous chalk from Cap Blanc-Nez, and a cemented chalk from Flamborough Head, UK (both ≈20% porosity). Permeability measurements (5.3, 0.4, and 0.2 mD respectively), pore size distribution from Nuclear Magnetic Resonance (NMR), Mercury Intrusion Capillary Pressure (MICP), and Brunauer–Emmett–Teller (BET) methods, and partial saturation tests (via exposure to 63%, 88%, and 98% relative humidity) revealed significant lithological control on water uptake. Cemented chalk absorbed the most water, while micritic porous chalk showed minimal saturation. Mechanical testing (uniaxial compressive and Brazilian tensile strength) showed strength decreases with increasing saturation, with argillaceous chalk exhibiting the greatest sensitivity. Our ongoing work explores correlations between microtexture, petrophysical properties, and mechanical response to water content. These findings emphasize the critical role of lithology in predicting chalk behavior under environmental change and guiding the preservation of chalk-related geoheritage.

Keywords: chalk, water saturation , petrophysics, uniaxial compressive strength, microtexture

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Identification of unstable rock blocks in a hand-excavated historic tunnel wall using millimeter-wave radar

Masahiko Osada[1], Masatomo Nose[1], Yuta Uesaka[1], Yota Togashi[1]

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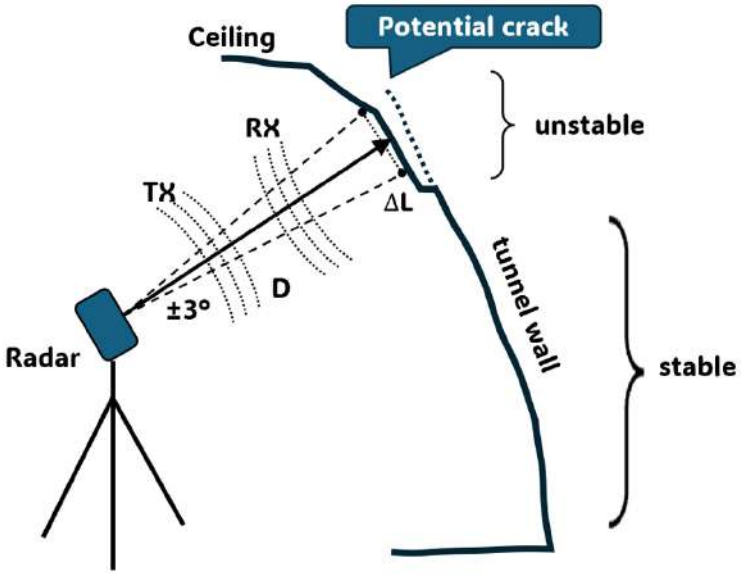
Abstract

The historic site “Yoshimi Hyaku-Ana” in Saitama Prefecture of Japan has underground tunnels excavated by human power in a grid pattern. The host rock is a porous tuffaceous sandstone of Miocene age. About 80 years have passed since the tunnels were excavated, and weathering has progressed on the tunnel walls, causing rocks to fall from the tunnel tops and sidewalls. Currently, public access to the site is restricted. In order to ensure the safety of tourists for the reuse of the tunnel as a historic site, it is necessary to take measures such as identifying and removing unstable rock blocks. This study employed a millimeter-wave radar to detect potentially unstable rock blocks susceptible to rockfall by investigating small displacements on the order of tens of micrometers in the direction perpendicular to the tunnel wall. Our findings indicate that the amplitude of displacement was significant in the rock mass assessed as clearly unstable. Furthermore, when displacement was measured along the crisscrossing scanlines including tunnel intersections, a tendency for displacement to increase near the intersections was observed. This result aligns with our experience that rockfalls occur more frequently around tunnel intersections.

Keywords: The Yoshimi Hyaku-Ana, millimeter-wave radar, a porous tuffaceous sandstone, unstable rock block, small displacement



Schematic diagram showing millimeter-wave radar measuring the tunnel wall surface.

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Long-term Preservation Strategies for Cultural Heritage on Active Landslides using Advanced Remote Sensing Technologies

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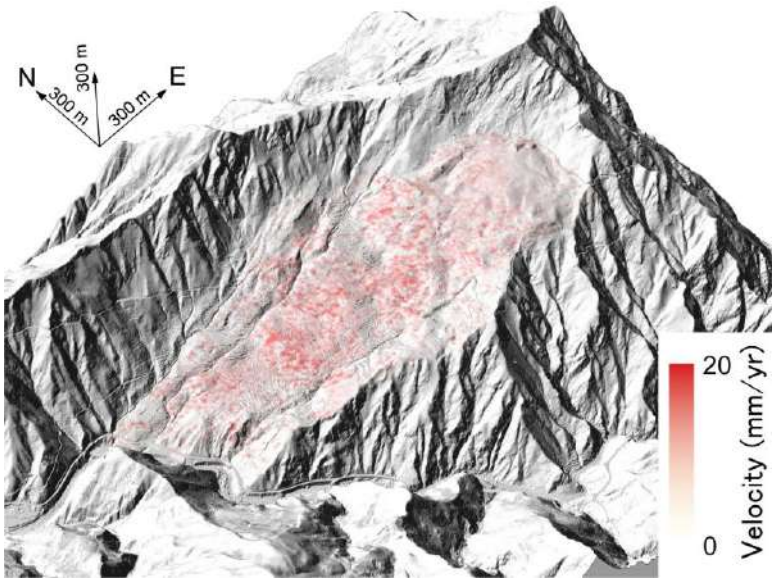
Abstract

Historical cultural heritage sites located on slopes may appear stable at present, but they are at risk of significant damage over the long term due to gradual ground deformation. Climate change has the potential to accelerate this risk, making the monitoring of slopes that host important cultural properties crucial for risk assessment. On the other hand, the remarkable advancement of remote sensing technologies allows for highly effective risk assessment of cultural heritage on slopes. In the warm and humid mountainous regions of East Asia, there are terraced fields with historical and cultural value, many of which are formed on landslides. As a result, they are often exposed to the risk of destruction due to landslide activity. This presentation introduces efforts to acquire fundamental data for long-term future predictions aimed at preserving culturally and historically valuable reclaimed farmlands located on active landslides. These efforts utilize GNSS observations, InSAR observations from various satellites, and remote infrared camera monitoring.

Keywords: Landslide, Heritage, InSAR, Remote Sensing, Slope Hazard



Westward surface displacement velocity of the Senjo landslide observed by ALOS-2/PALSAR-2

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Engineering Geological Study for the Preservation of Petroglyphs at Mata Ngarahu, Rapa Nui (Easter Island)

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[3] Ma'u Henua, Rapa Nui, Chile

Abstract

The petroglyphs of Mata Ngarahu, which are located at the ceremonial village of Orongo, are among the most iconic cultural heritage artifacts on Rapa Nui (Easter Island). The Orongo site is located on a narrow strip of land along the crater rim of the Rato Kau volcano, with steep coastal cliffs on the southern side plunging 300m down to the Pacific Ocean and steep slopes on the northern side down to the floor of the Rato Kau volcano caldera. The petroglyphs are carved into volcanic core stone boulders located at the crest of the steep coastal cliffs. The site and the boulders have been adversely affected by slope instability processes including soil creep and erosion, boulder toppling and falls and slides along rockmass discontinuities.

This paper describes the engineering geological study, including site visit, undertaken as part of a wider risk management plan being developed in partnership with the Ma'u Henua Polynesian Indigenous Community with support from the World Monuments Fund.

Keywords: Geohazards, Rapa Nui, Easter Island, Cultural Heritage, Petroglyphs



Photograph of petroglyph on a boulder at Mata Ngarahu, Orongo, Rapanui (Easter Island)

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Geological Domains of Building Stones in Heritage Monuments in India

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Abstract

India's architectural heritage is deeply intertwined with its diverse building stones, which have shaped structures ranging from ancient temples to modern landmarks. The building stones have been the enduring foundation of India's architectural legacy. It is the historical use of natural stone offers valuable insight into past civilisations, tracing their evolution from antiquity to the present. Grand palaces, temples, and rock-cut monuments stand as enduring testaments to artistic vision and engineering mastery, all unified by the resilience of stone. Over centuries, locally sourced stones from various geological formations have been integral to construction. India is home to 44 World Heritage sites, comprising 36 Cultural and 8 Natural Properties. These UNESCO World Heritage Monuments are positioned in different geological domains of India. Dimension stones used in these heritage monuments are natural stones that have been preferred and finished to specific sizes, shapes, colours, textures, and surface finishes or aesthetics, from these geological domains. Over time, many of these geological formations have gained widespread recognition, continued to serve as cultural landmarks, and retained substantial resource potential. Whether the different types of sandstone shaping Khajuraho temples, basalts in rock-cut monuments in Ajanta and Ellora caves, granites in temples of south India, or pristine white marble of the iconic Taj Mahal, each stone carries a unique story of resilience and aesthetics. The paper deals with the geological domains and their representative building stones used in heritage monuments through the ages. Identification and resource availability within these domains help in the preservation of heritage monuments.

Keywords: Building stones, geological domains, Heritage stones, Stone preservation, Architectural heritage

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Landslide hazard and risk assessment for conservation of underwater cultural heritage: a case study of the Green Island No. 1

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[1] Department of Construction Engineering, National Kaohsiung University of Science and Technology, Kaohsiung, Taiwan
[2] Green Energy and Environment Research Laboratories, Industrial Technology Research Institute, HsinChu, Taiwan
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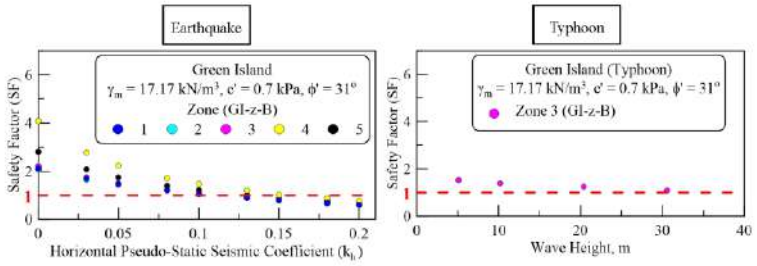
Abstract

Green Island is a volcanic island in the Pacific Ocean off the southeast coast of Taiwan. "Green Island No. 1" is an ancient shipwreck off the southwest coast of Green Island. It is located on a continental slope dominated by modern alluvial layers. The slope presents a high-angle inclination, 15 to 30 degrees, with a corresponding risk of slope failure. Green Island is located in an earthquake-prone region, and external disturbance factors, such as typhoons and the Kuroshio current, are likely to trigger slope failure and accelerate the deterioration of the shipwreck. This research evaluates the stability of the submarine slope. High-potential areas are examined by identifying high risk areas and assessing the potential for slope failure under different triggering factors including earthquakes, typhoons, and the Kuroshio current. The stability assessment revealed the following. (a) Landslides occur at water depths of 26-59 m during a magnitude 5 earthquake; (b) During a typhoon producing wave heights up to 20.4 m, the slope is close to failure. If soil liquefaction is considered, landslides may occur; (c) The Kuroshio current affects the overall surface-current regime. The sinking of the surface caused by the current eroding the loose sediments on the seabed slope should also be taken into account in stability assessment. We recommend developing a disaster prevention and early warning system that integrates geophysical detection technology, on-site sensor deployment, and numerical model simulations for accurate predictions.

Keywords: cultural heritage, landslide assessment, slope stability analysis, prevention strategy



Slope stability analysis results under different conditions.

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Forecasting Long-Term Creep in Valkenburg Calcarenite Mine Pillars: A Comparative Study of LSTM and Long Expressive Memory Models

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[1] National Technical University of Athens, Athens, Greece
[2] Delft University of Technology, Delft, Netherlands

Abstract

The Valkenburg limestone mines in the Netherlands, dating back to 1500, present a unique case study for examining the stability of calcarenite pillars subjected to long-term creep phenomena. Exploited using the room and pillar method, these mines have experienced collapses attributed to unregulated extraction practices and inherent material weaknesses. This paper leverages a comprehensive dataset from Fugro's fibre optic monitoring system, encompassing four years of observations across 81 pillars, to analyse the impact of various factors on pillar creep. Advanced machine-learning models are examined for time-series forecasting: Long Short-Term Memory (LSTM) networks, renowned for their gated memory cells, and Long Expressive Memory (LEM) models. Because creep unfolds slowly and demands capturing very long-range dependencies, LSTMs can struggle with exploding and vanishing gradients. For that reason, we benchmark their performance against LEM architectures. These machine learning models were used to unravel the complex interactions between temperature, precipitation, pillar geometry, and overburden thickness and afterwards make predictions. The findings demonstrate that these techniques can be effectively employed in mining engineering and underscore the importance of integrating advanced modelling techniques with geospatial data for improved risk management and stability assessment in soft rock mines.

Keywords: Soft rock, Underground mine, Long Expressive Memory, Machine Learning, Long Short-Term Memory

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Evaluation of stability in rock-hewn dwellings at a cultural heritage site: Cappadocia (Türkiye)

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[1] Nevsehir Haci Bektas Veli University, Nevsehir, Turkey

Abstract

The Cappadocia Region (Türkiye), has hosted numerous civilizations throughout history and possesses a cultural heritage spanning approximately 1500 years. The region is predominantly composed of weak ignimbrites interlayered with volcano-sedimentary sequences. Due to the ease of excavation of the pyroclastic rocks, countless rock-hewn dwellings and many underground cities have been excavated across the region. In the weak rock masses, locally intersected by discontinuities, stability problems are occasionally encountered. Furthermore, rapid weathering processes develop over time, threatening the integrity of many rock-hewn structures that constitute important cultural heritage assets, ultimately leading to their collapse and loss. Therefore, in order to preserve this cultural heritage for future generations, it is of great importance to conduct engineering geological investigations, analyze the stability conditions of these structures and implement appropriate engineering measures.

In the scope of this study, the geoengineering problems and the engineering geological studies carried out on these rock-hewn dwellings will be discussed. Moreover, numerical results from finite element analyses aimed at evaluating the stability of these rock-hewn structures will be shared. As a result of these investigations, it has been determined that the most critical engineering geological problems affecting the rock-hewn structures in Cappadocia are instabilities related to discontinuity-controlled failures and weathering-induced degradation. The chaotic configuration of these rock-hewn spaces complicates classical engineering geological assessments. Additionally, the cultural heritage status of the site and its natural beauty restrict the application of conventional engineering measures and remediation techniques. Consequently, site-specific engineering solutions, which are compatible with the historical texture are generally preferred.

Keywords: soft rock, cultural heritage, rock-hewn dwelling, stability, Cappadocia

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Settlements in Residual Soils. the Case of Chilandari Holy Monastery (Athos)

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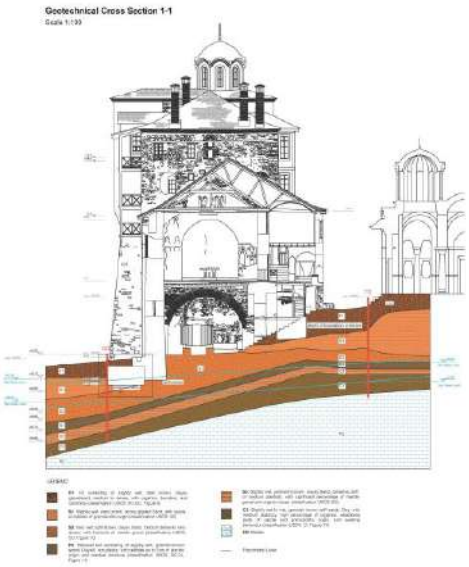
[1] Aristotle University of Thessaloniki, Thessaloniki, Greece

Abstract

The conservation and restoration of cultural heritage structures requires a complete and detailed analysis of the geological and geotechnical hazards that affect them. Thus, it is possible to clarify the failure mechanisms that act upon them or might be activated due to technical interventions and to carry out detailed planning of measures to mitigate their effect at a time scale longer than conventional construction works. In the present project, geological and geotechnical data from site investigation are presented and evaluated relating to the failure mechanisms affecting the foundation of the Holy Monastery of Chilandari mainly the western wing of the Monastery. The Monastery was founded on artificial backfill material followed by weathered soil formations - most probably residual soils of weathered granodiorite – that lay on top of granodiorite and marble rocks. Specifically, the project presents the results of the geotechnical investigation carried out via sample drilling in situ and laboratory tests and the formulation of the geotechnical model of the foundation area of Monastery. Based on the model, the nature and mechanical behavior of the foundation soil is investigated against mass movements, deformations and settlement. Finally, the main failure mechanism of the subsoil foundation of the Monastery is established and mitigating measures are proposed.

Keywords: Differential settlement, Residual soils, Swelling behaviour, Failure mechanisms, Mitigation measures



Geotechnical cross section

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Historical Mining Plans – Their Preparation and interpretation.

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Abstract

The need to record and archive plans of coal mines in the United Kingdom (UK) was only enshrined in law in 1872. Prior to this, plans were made and used predominantly for health and safety reasons. Plans were prepared often in poor conditions, with measurements made using a variety of tools leading to significant variation in quality and style. For the modern user the nature of these plans varies significantly in terms of quality, visual layout and the level to which the plans have survived the intervening period. The coal industry in the UK began to make attempts to codify the style and nature of these plans around the start of the 20th century. Eventually the notations, stylisations and layout of these plans became standardised. This incorporated earlier elements of mine plan preparation such as the use of colours, line type and other important key features. With the decline in coal mining (in the UK) and the increase in the development of brownfield sites; the need for professionals to fully understand the information presented on mine plan is increasingly important. The misinterpretation of mine plan may have significant financial costs at both investigation and construction stages. However, there is no formal course or presentation in textbooks covering this, with much industry knowledge being self-taught using historical sources. This paper discusses the style and notation used in the preparation of mine plans based upon historical sources and presents an invaluable resource for anyone undertaking mining risk assessment in formally mined areas.

Keywords: Geohazards , Mining Legacy , Knowledge Transfer, Preservation, Education

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Military Open Science for Coastal Heritage: From a Sustainable Monitoring Practice Towards a Preservation Policy Toolkit.

Georgios Drosos MSc DIC FGS HAFESS[1], Panagiotis Tripontikas MA[2], Kimon Papadimitriou Dr.-Ing.[3], Christos Tsatsanifos Dr PhD MSc DIC MASCE[4]

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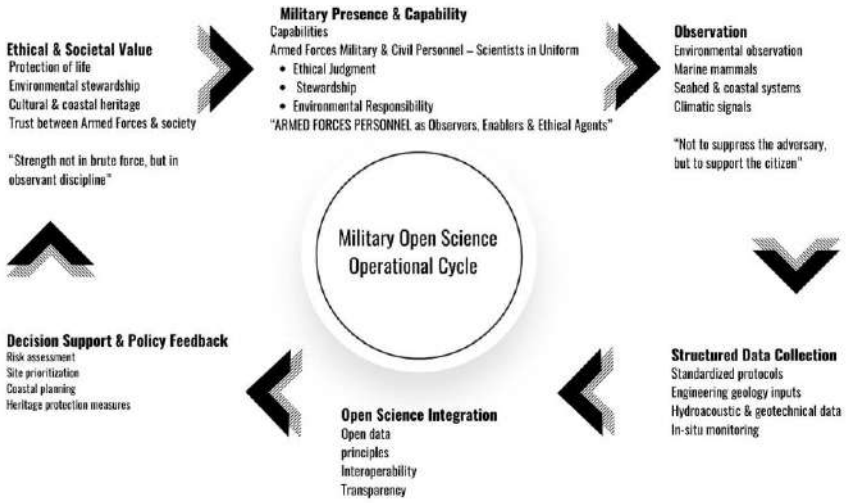
Abstract

The coastal zone is a dynamic boundary shaped by climatic variability and geological processes, hosting a rich mosaic of natural and cultural heritage such as shipwrecks, fortifications, port installations, lighthouses, and fragile ecosystems. The challenges for preserving such coastal and submerged sites require creative approaches in engineering geology. Our proposal is inspired by the continuum of historically important structures (e.g. ancient harbours, temples, settlements) along the Greek coastline -ranking 11th globally in length- which has demonstrated centuries of resilience to geological processes and climate changes. This enduring seafront legacy offers a living laboratory for engineering geology and sustainable coastal management. Military Open Science (MOS) is introduced as a pioneering technical and operational framework, built on military capabilities, and volunteerism. By leveraging military equipment, infrastructure, and applied techniques (e.g. sediment coring, hydroacoustic mapping, photogrammetry, sub-bottom profiling, structural integrity testing), MOS supports non-destructive recording and appraisal of coastal features. Systematic mapping of 20th-century war wrecks and deterioration monitoring of lighthouse and fortifications in Greece are employed as an example, unveiling historical networks as well as contemporary hazards. MOS enhances engineering geology's role through emphasis on sustainability, real-time monitoring, and qualitative in-situ evaluation, complementing traditional geotechnical calculations. The integration of the UNESCO Open Science Toolkit ensures standardization, transparency, and global scalability, outlining a new vision for sustainable coastal heritage management. By bridging military and scientific communities, MOS evolves challenges of access and documentation to opportunities for open, interoperable, and ethical oversight. Current approach can be replicated supporting heritage conservation in any particular area.

Keywords: War wrecks, Fortifications, Management model, Open science, Military capabilities



Military Open Science (MOS) Operational Cycle

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Rediscovering the Acequia Madre in Queretaro Mexico: Geophysical and Artistic Explorations of Urban Heritage

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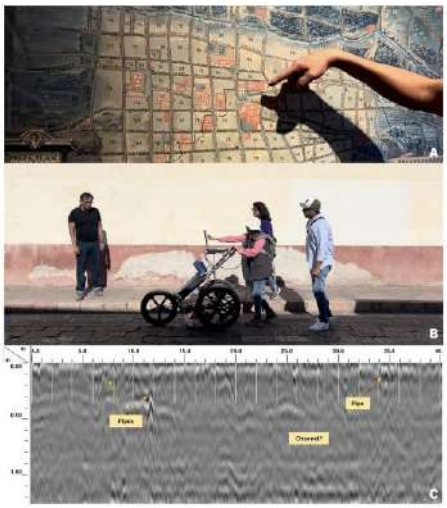
Abstract

Heritage conservation faces complex challenges when cultural infrastructures become buried, obscured, or rendered invisible by urbanization, often leading to their neglect or complete loss. While geophysical prospecting techniques, particularly Ground-Penetrating Radar (GPR), have been widely used to detect buried archaeological features globally, their application to historic infrastructure in densely urbanized settings remains limited in Mexico. Historical water management systems such as the Acequia Madre of Querétaro, a 16th-century canal buried beneath the city's colonial center, have received limited scientific attention despite their cultural significance. This study uses GPR surveys to locate and characterize subsurface remnants of the Acequia Madre, as part of a broader interdisciplinary effort that combines geophysical prospection, historical research, and artistic intervention. GPR profiles revealed several anomalies interpreted as segments of the original canal; however, many sections appear degraded or destroyed due to urban development and the lack of formal heritage protection/recognition. Beyond the geophysical findings, this research explores the possibilities of integrating scientific tools with artistic and historical approaches to activate public memory and urban heritage. Performative interventions in public space, workshops, and an exhibition were used to accompany the scientific results and invite community engagement, reimagining how hidden heritage can be made visible. This approach repositions the GPR method not only as an instrument of technical measurement but also as an interface between scientific knowledge, cultural memory, and civic participation. The results demonstrate the value of GPR prospecting in urban heritage studies and advocate for its expanded use in interdisciplinary engineering geology, particularly where infrastructure interacts with unrecognized historical layers.

Keywords: Water mangement, Archeology, GPR, Queretaro, Heritage



Interdisciplinary exploration of the Acequia Madre, a colonial water channel system that shaped the city's early urban development in Querétaro City, Mexico: (A) Historical map indicating the trajectory of the Acequia Madre, (B) Photograph of the Ground Penetrating Radar (GPR) survey conducted in public space, (C) Radargram obtained with a 400 MHz antenna, showing hyperbolic reflections interpreted as modern pipes and the channel. These results illustrate the value of geophysical techniques for highlighting cultural heritage in modern urban landscapes.

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Geodiversity and Urban Heritage: Identifying Vulnerable Areas through Spatial Interpolation using Geodiversity Index

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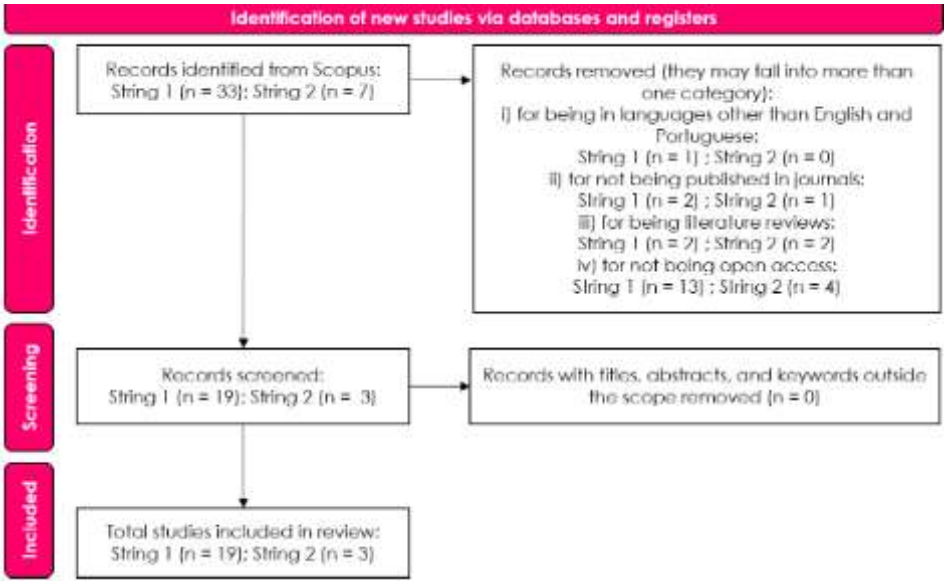
Abstract

Urban expansion and intensified land use have generated significant environmental transformations, including the degradation of natural landscapes and the progressive loss of geological heritage. Although studies on geodiversity have increased in recent decades, research specifically focused on urban environments remains fragmented, frequently addressing isolated abiotic elements without integrating their spatial relationships and cumulative significance. In this context, the conservation of geodiversity, comprising geological, geomorphological, pedological, and hydrological components, has become increasingly relevant in densely occupied areas subjected to strong anthropogenic pressure. This study presents a systematic literature review of case studies that apply geodiversity indices in urban and peri-urban contexts, with emphasis on spatial interpolation techniques, particularly Inverse Distance Weighting (IDW). The methodological procedures included the definition of inclusion and exclusion criteria, the selection of publications in English and Portuguese indexed in the Scopus database, and the organization of extracted data into a structured database. Both qualitative thematic analysis and quantitative bibliometric assessment were conducted. The results reveal a predominance of regional-scale applications of geodiversity indices, with limited methodological adaptations to address intra-urban heterogeneity and the integration of natural and built components. IDW emerges as a central technique for converting discrete index values into continuous surfaces, enabling the visualization of spatial gradients and the identification of areas vulnerable to anthropogenic impacts. The findings highlight methodological gaps and reinforce the importance of refining urban geodiversity assessment frameworks to support sustainable urban planning and geoconservation strategies.

Keywords: Geological Heritage, Inverse Distance Weighting, Spatial Analysis, Urban Planning, Vulnerability Mapping



PRISMA flow diagram illustrating the process of study selection for inclusion in the review.

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Natural Heritage Sites in Climate Changing Conditions, Example of the Devils Town (Serbia)

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Abstract

The need for protecting heritage sites is directed toward minimizing human influence and conservation of ambient conditions. However, erosion, mass movements, weathering and other geological processes affect all areas regardless of the level of protection. Additionally, climate change amplifies effects of these processes through shifts in temperature and precipitation patterns over short timescales, raising the question of how long specific landscapes can resist these impacts. Rather than occurring over geological timescales, we can hypothesize that dramatic landscape changes may unfold within our lifetimes. One such example is the nature park known as the Devils Town in southern Serbia. This site features fragile columnar landforms created by the interplay of erosion and weathered rock, which can be modelled as block-in-matrix material, wherein resistant andesitic blocks are embedded within a weak tuffaceous matrix. Using climate projections for Serbia under high-emission scenarios, trends in temperature increase, altered precipitation regimes, extreme rainfall frequency, and freeze–thaw cycles are analysed in relation to erosion and stability. Results indicate that while reduced freeze–thaw activity and partial drying may locally favour stability, increased temperatures, intensified rainfall extremes, and more frequent wetting–drying cycles are likely to accelerate weathering, erosion, and basal instability driven by groundwater fluctuations. The combined effects suggest a net increase in geomorphic activity and landform degradation over the 21st century. The study highlights the need for site-specific climate impact assessments and continuous monitoring of vulnerable geoheritage sites, emphasizing that effective protection and management strategies must integrate anticipated climate-driven changes alongside traditional conservation measures.

Keywords: Climate change, Natural heritage, Devils Town, Erosion, Monitoring

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Geotechnical Assessment, a Major Step for Heritage Valorisation of Underground Quarries - The Malogne Case Study in Belgium

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Abstract

The Malogne underground quarry is a remarkable example of industrial and geological heritage near Mons (Belgium), comprising more than 175 km of galleries excavated in phosphatic chalk using the room-and-pillar method. The site is currently being considered for its tourism potential through the development of a 1.3 km guided tour route. To ensure the safety of future visitors, a comprehensive geotechnical study was carried out to assess the structural stability of the selected pathway. The methodology was based on a multiscale and multisource approach. Historical and geological archives were first analysed to reconstruct the quarry geometry, extraction techniques, and known instabilities. Field investigations included systematic mapping of discontinuities, identification and classification of instability features, and visual inspections of pillar and roof conditions. The quality of the rock mass was evaluated using both the Rock Mass Rating (RMR) and the Geological Strength Index (GSI). The mechanical properties of the key lithologies (phosphatic chalk itself and the rocks of the footwall and hanging wall) were determined through laboratory testing under both dry and saturated conditions, in order to simulate extreme hydrogeological scenarios. Analytical calculations based on the tributary area method were performed to estimate the safety factor of individual pillars. These analyses were complemented by numerical modelling at both large and small scales to better understand local stress redistributions and roof behaviour. The results show that most of the proposed tour route lies within stable zones, with safety factors exceeding 1.6. Localised risks were identified, and targeted mitigation strategies were proposed. This case study highlights the crucial role of engineering geology in supporting the safe and sustainable valorisation of underground heritage.

Keywords: Underground quarries, Room and pillar, Chalk, Stability, Heritage



Picture of a typical pillar of the Malogne underground quarry (Tshibangu et al., 2024)

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Engineering Geological Models and Foundation Stability Assessment of the Grade I listed Clifton Suspension Bridge, Bristol, UK.

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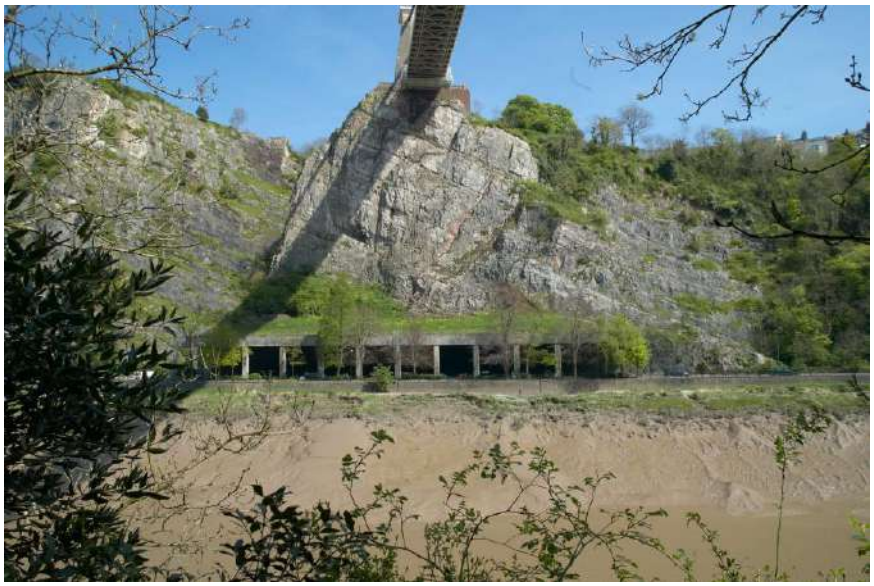
Abstract

The 214m span Clifton Suspension Bridge is a Grade I listed enduring British icon, originally designed by Isambard Kingdom Brunel with construction completed in 1864, after his death. Yet this wonderful bridge continually sets engineering challenges that must be addressed in a sympathetic and understanding manner. Despite the apparent stability of the bridge foundations and of the high rock slopes that support them, there is a long history of rock fall and deeper-seated instability in the slopes of the Clifton Gorge that neighbour the bridge location. In this context the strength and stability reserve of the foundations to the abutments and of the bridge chain anchorages were identified as areas that required assessment. This paper describes the work, which commenced in 2010 with a ground investigation campaign, to evaluate the foundation stability reserve under bridge loading cases. Engineering geological models have been developed for each abutment, which were used as the basis for the foundation stability evaluations, and both 2D and 3D discrete element method numerical analyses. The paper concludes with an overview of the results of the assessments and a summary of the improved understanding of the ground, its interaction with the bridge foundations and how residual risks are being managed through ongoing inspection and maintenance.

Keywords: Rock engineering, Geological model, Rock slope, Slope stability, Heritage



Clifton Suspension Bridge - West Slope

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Weathering-Induced Changes in Khondalite: An Implication to Assessing Deterioration of Ancient Structures at Ratnagiri (Odisha, India)

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Abstract

Rocks were possibly the oldest construction materials used by human beings. Several structures made up of rocks get degraded over time because of the influence of ongoing weathering processes. Therefore, the status of the degree of deterioration of rock materials in an ancient structure needs to be evaluated. Ratnagiri is an archaeological site in the state of Odisha, India, which is rich in the ruins of large and prominent Buddhist monasteries. The oldest ones apparently date back to 5th century CE. At Ratnagiri, several ancient structures and sculptures are made up of a metamorphic rock called khondalite which is a prominent rock type in the Eastern Ghats region of India. Destructive rock testing for characterizing these materials found in the archaeological as well as heritage site of Ratnagiri is, in general, prohibited. Moreover, weathering grade categorization of khnodalite does not seem to have gained much attention in the past. In such a situation, evaluation of weathering grades of equivalent rock materials in nearby natural outcrops becomes absolutely necessary and this is done in the present investigation. How far the common six-fold weathering classification is applicable to khondalite materials is evaluated and substantiated by macro-and microscopic observations, and rock strength tests. The degree of deterioration of khondalite is comprehensively assessed in this study. No fresh/unweathered khondalite was present on the outcrops. However, Grade II to Grade III/IV materials were frequently observed. The assigned weathering grades were substantiated using photomicrographs also. The P-wave velocity was found to be as high as 4316 m/s in Grade II khondalite and depicted a drop of more than 30% as weathering intensified. This was found to be equivalent to a 57% drop in terms of uniaxial compressive strength of the concerned khondalite. Rock failure modes with reference to weathering grades were also scrutinized.

Keywords: Heritage Site, Khondalite, Weathering Classification, Macro-and Microscopic Observations, Strength Tests

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Surface Strength Test of Stones, Application of Duroskop

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Abstract

Laboratory testing of engineering structures is often hampered by sampling difficulties (e.g., historic monuments, tunnels), and strength tests require sufficient size and quantity of samples. On-site non-destructive surface strength tests provide quick and reliable information on material properties. The present study focuses on the application of one tool, the Duroskop, in the surface strength test of stone. It is a testing tool that has a similar principle to the Schmidt hammer; it detects rebound values of tested surfaces, but it is a much smaller and more sensitive device. 40 cm2 of stone surfaces were tested, and on each surface, 10 readings were recorded. Tested stones represent carbonates from highly porous Miocene limestone, travertine. Results of Duroskop rebound test suggest that this tool can be used to assess the strength of low durability rocks. Porous limestone has the lowest rebound values, which are followed by andesite tuff. The highest rebound was measured on basalts, but micro-crystalline (compact) limestones also provided high Duroskop rebound values. The test results are compared with Schmidt hammer rebounds. The performed tests indicate that Duroskop is a sensitive non-destructive strength testing tool that provides useful information on the strength parameters of the stone surfaces.

Keywords: surface strength, non-destructive testing, Duroskop, Schmidt hammer



Testing surface strenght of a limestone wall with Duroskop

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Ultrasonic Analysis of the Parthenon's Structural Stones and Grouted Joints

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Abstract

A non-destructive ultrasonic method was employed to evaluate the physicomechanical properties of the Parthenon's marble and the integrity of its grouted joints. A total of 600 ultrasound velocity measurements were recorded—320 to characterize the marble and 280 to assess joint condition—using a PUNDIT device with 54 kHz P-wave piezoelectric transducers. Properties of Dionysos ("new") and Pentelic ("old") marble were examined in both parallel and perpendicular orientations relative to bedding or schistosity. Transducers were spaced 10 cm apart, with successive rows 3 cm apart, and a canvas was used to ensure accurate positioning. The results revealed compatibility between the two marble types. Notably, higher values of shear modulus and dynamic elasticity were observed along the bedding/schistosity compared to perpendicular directions. Despite superficial deterioration—such as cellular corrosion and gypsum crystallization—the core structure of the marble remains unaffected. While surface damage alters the relief irreversibly, it does not compromise internal mechanical strength. The integrity of the joints also proved satisfactory. Open cracks generally measured less than 2 cm in depth, with few exceeding 5 cm. Though crack width could not be quantified due to equipment limitations, only capillary cracks were detected along joints, indicating sound overall cohesion.

Keywords: Ultrasonic , Parthenon, grouted joints



A)Ancient and Ancient marble measurement canvas for joint filling control, B)Ancient and new marble measurement canvas for joint filling control.

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Investigation of the Weathering of Granite Building Stone by Salt Spray

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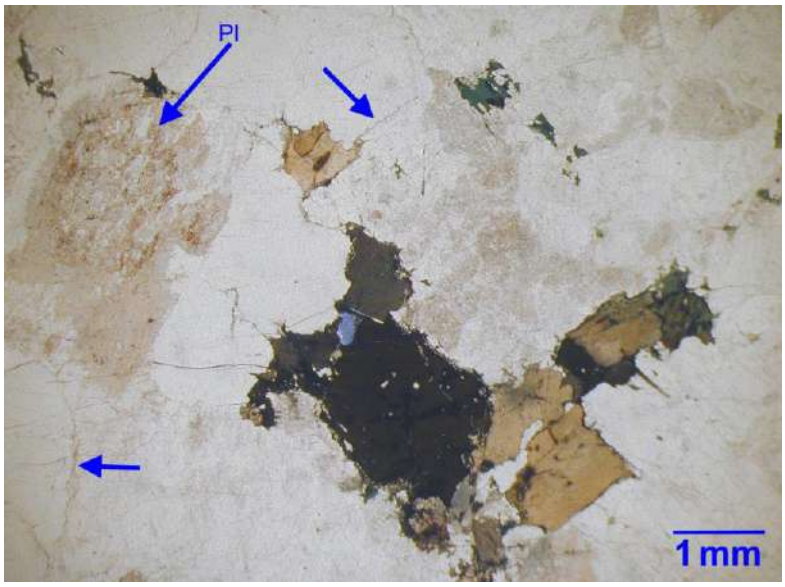
Abstract

Salt crystallization is considered one of the most powerful weathering agents, as it is the main stone degradation mechanism in marine environments, humid climates as well as in polluted environments, which are often acting together. Due to their relatively high durability among natural stones, granites are widely used in modern and historical monuments and buildings, in addition to cladding. This study aims to investigate the action of saline mist on selected Brazilian granitic natural stones by carrying out salt spray accelerated tests. During testing, specimens became partially covered by salt, which was most perceptible along surface microcracks. After completion, most specimens did not exhibit easily visible changes, however, comparison with pre-test conditions revealed various alterations, such as oxidation, detachment of biotite, and discoloration. Petrographic examination further revealed that deterioration was microscopically evident, characterized mainly by the intensification of iron hydroxide staining in previously altered plagioclase. These findings indicate that the action of saline spray in marine environments is slow but effective and highlight the importance of the initial degree of alteration of the rock on its deterioration, when used in the built environment.

Keywords: Granites, Saline aerosols weathering, Salt spray ageing test, Brazilian natural stones, Visual alteration patterns



Increased oxidation, indicated by the brownish hue of iron hydroxides associated with clay minerals in altered plagioclase and in microfracture infillings. Note the cavity in the biotite (blue area).

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Engineering Geological Characterization of Athagarh Sandstone for Heritage Conservation

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Abstract

The Athagarh Sandstone is widely used as a building material in historical monuments and heritage buildings all over the eastern part of India, especially in Odisha. Over a long period of time, natural weathering processes have significantly altered its mechanical behavior, which poses problems for structural stability and protection planning of heritage. From a technical geological perspective, quantification of loss of mechanical properties of Athagarh Sandstone with increasing degree of weathering is necessary to assess risk and to propose appropriate preservation measures. This study systematically examined the variation in the effective porosity, dry density, ultrasonic (P-Wave) velocity, uniaxial compressive strength (UCS) and Brazilian tensile strength (BTS) of the Athagarh Sandstone over weathering spectrum (slightly weathered to highly weathered). The results show a marked decrease in strength parameters, especially in UCS from 19.28 MPa (SW) to 7.61 MPa (HW), and increase in effective porosity from 10-12% for (SW) and 18-20% (HW) with progressive weathering. The study also shows the percentage of reduction of strength parameters with respect to weathering grade.

Keywords: Athagarh sandstone, Uniaxial compressive strength, Brazilian tensile strength, Strength reduction percentage

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Mechanical Degradation and Microstructural Evolution of Volcanic Tuff and Sandstone under Water Saturation and Freeze-Thaw Cycles

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Abstract

Porous rocks are often used in heritage sites, and in engineering structures are highly susceptible to environmental weathering, particularly water saturation and freeze–thaw (F–T) cycles. This study investigates the comparative mechanical and elastic evolution of volcanic rhyolite tuff and sandstone from North Hungary. Samples were subjected to four environmental states: air dry, water-saturated, 50 F–T cycles, and 100 F–T cycles. Physical properties (density, Vp, Vs) and mechanical parameters uniaxial compressive strength (UCS) and Brazilian tensile strength (BTS) were measured at each stage. Results indicate a "pore-filling effect" upon initial saturation, where dynamic Young's modulus (Edyn) increased by up to 25% for tuff, while UCS and BTS plummeted due to water weakening. Prolonged F–T exposure led to catastrophic degradation; by 100 cycles, tuff and sandstone retained only 12% and 16% of their initial UCS, respectively. Tuff exhibited significantly higher vulnerability due to its fragile, vesicular microstructure, losing 26% of its stiffness compared to 13% for sandstone. Statistical correlations between elastic and mechanical parameters reveal that while Edyn and Kdyn are reliable proxies for damage accumulation during frost action, they do not predict initial water-weakening in pyroclastic rocks. These findings provide critical data for predicting the longevity of stony cultural heritage and rock engineering projects in cold climates.

Keywords: Tuff, Sandstone, Uniaxial Compressive Strength, Brazilian Tensile Strength, Dynamic elastic parameters

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Geology, Microstructure, and Durability in Marmara Island (Prokonnesos) Marble: Accelerated Aging Tests and Implications for Cultural Heritage Sites

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Abstract

Marmara Island (Prokonnesos) marble has been an important building stone in the Mediterranean basin from ancient times to today. This study investigates the relationship between the durability characteristics of Marmara marble and deterioration mechanisms observed in historical monuments from an engineering geology perspective. Nine accelerated deterioration tests; wetting–drying, freezing–thawing, salt crystallization (Na_2SO_4 and $MgSO_4$), acid vapor (concentrated and diluted SO_2), thermal shock, UV irradiation, and climate chamber tests—evaluated changes in the physical, mechanical, and surface properties of the marble. The results indicated that salt crystallization, particularly with Na_2SO_4 and $MgSO_4$, was the most destructive mechanism, causing increases of up to 1600% in water absorption and 1550% in porosity, with flexural strength losses of up to 72%. Wetting–drying and freezing–thawing cycles also caused physical deterioration. The findings reveal a relationship between the mineralogical–petrographic characteristics of Marmara marble and deterioration patterns in historical structures. Graphite-, chlorite- and mica-rich gray–black bands act as preferential weakening planes, consistent with field observations of detachment, fragmentation and material loss along banded zones. The coarse granoblastic calcitic fabric and polygonal–interlobate grain boundaries increase susceptibility to microcrack development under salt and freeze–thaw stress. This is supported by accelerated aging results, particularly after salt crystallization, where P-wave velocity decreased by 40–55% and flexural strength losses reached about 70%. SO_2 aging and salt crystallization produced marked colour changes ($\Delta E \geq 5$), supporting field evidence of discoloration, black crust formation and aesthetic deterioration. These quantitative indicators (ΔE, Vp, surface roughness-Ra, porosity, flexural strength) are consistent with field-observed color change, efflorescence, flaking and material loss. Sensitivity to SO_2 supports black crust/color deterioration risk in urban atmospheres. In conclusion, this study establishes link between degradation conditions and microstructure-durability for Marmara Island marble, helping predict natural stone behaviour over its service life.

Keywords: Marmara Island (Prokonnesos) marble, durability, deterioration mechanisms, historical monuments,

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Examples of non-conventional use of geophysical methods for monumental heritage

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Abstract

It is well known that geophysical methods can contribute to the discovery of archaeological remains. Less widely known is the fact that they can also be applied to existing structures to reconstruct their history and to design effective conservation strategies. We present the case of two emblematic structures and the role played by geophysics in their investigation. The first structure is the Colosseum in Rome (Italy). One of the most interesting questions concerning the Colosseum relates to the causes of its differential collapse over the centuries, which today appears as a well-preserved northern sector (with four orders of arches still standing) and a much less preserved southern sector (with only two orders of arches remaining). A classical explanation for this difference attributes it to the heterogeneity of the foundation subsoil, which is volcanic in the northern part and alluvial in the southern part. Such heterogeneity may induce different local seismic responses in the two sectors. We will show how a series of geophysical investigations carried out on both the structure and its foundation soil can help to "unveil the mystery." The second case concerns the Eiffel Tower in Paris. Although it is the most photographed structure in the world, no public images of its dynamic response were previously available—that is, an accessible dynamic characterization was not accessible. Such characterization allows the study of structural ageing and supports the planning of structural interventions, including those involving secondary elements (e.g., elevators, antennas at the top, and similar components). We will show how, with limited equipment and a measure of ingenuity, it is possible to obtain a large amount of useful information about structures of this type.

Keywords: Colosseum, Eiffel tower, , ,

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From Deformation to Stabilisation: Long-Term Behaviour of Historical Salt Mine Chambers in the UNESCO-listed Wieliczka Salt Mine

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Abstract

The long-term preservation of underground cultural heritage represents a major challenge in engineering geology. Although historical mine workings commonly undergo continuous deformation long after mining ceases, it remains unclear whether such deformation reflects progressive deterioration or a natural evolution towards geomechanical stabilization. This question is particularly relevant for heritage sites, where engineering interventions may unintentionally disturb established stress conditions. This study investigates the long-term behavior of historical chambers located on Levels I and III of the UNESCO-listed Wieliczka Salt Mine (Poland), one of the world's oldest continuously preserved underground mining complexes. The analysis combines nearly three decades of precise underground and surface leveling observations (1992–2020) with detailed chamber inventories and three-dimensional excavation geometry. The results reveal a persistent but remarkably stable deformation regime despite cumulative subsidence locally exceeding 450 mm. Displacement trajectories remained nearly linear throughout the monitoring period and showed no evidence of acceleration, instability, or deformation regime shifts. The largest displacements were recorded within roadway systems and transition zones rather than directly above the principal chambers, indicating that excavation geometry exerts a stronger control on long-term deformation behavior than chamber volume alone. Historical chambers consistently exhibited lower deformation rates and more stable displacement patterns, suggesting progressive stress redistribution and long-term adaptation of the surrounding rock mass.These findings challenge the conventional assumption that ongoing deformation necessarily reflects increasing instability. Instead, the observations indicate that measurable deformation may coexist with long-term geomechanical stability. The study provides rare empirical evidence from a globally significant underground heritage site and offers new insights into the relationships among deformation, excavation geometry, rock mass stabilization, and heritage preservation.

Keywords: rock mass stability, mining heritage preservation, ground subsidence, geomechanical monitoring, Wieliczka Salt Mine UNESCO World Heritage

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General Situation of Cultural Relics Protection Projects in China and Typical Cases

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Abstract

China possesses a vast and diversified cultural heritage system. According to the national heritage surveys, the country holds 766,700 immovable cultural relics and 108 million sets of state-owned movable relics. In particular, 5,986 grotto temples and cliffside statues are distributed across 27 provincial regions, forming the world's most extensive, continuous, and well-preserved rock-cut heritage system along the ancient Silk Road. Affected by long-term geological evolution and human interference, over 70% of grottoes exhibit varying degrees of weathering, structural fractures, and deterioration. Over the past century, generations of Chinese researchers and engineers have promoted systematic grotto conservation, evolving from the early investigation phase before 1950, through the renovation phase (1950–1970) and the comprehensive conservation phase (1970–1990), to the rescue conservation phase and the preventive conservation phase in the 21st century. A series of interdisciplinary technologies, including dangerous rock removal, anchor reinforcement, fissure grouting, and targeted weathering control, have been successfully applied in typical grotto projects such as the Mogao Grotto, Yungang Grotto, and Maijishan Grotto, achieving effective risk mitigation and structural stabilization. By establishing standardized technical systems, integrating multidisciplinary theories, and promoting environment-coordinated conservation strategies, China has greatly advanced global stone heritage protection theories and engineering practices, providing valuable paradigms and sustainable technical references for the conservation of worldwide rock-cut cultural heritage.

Keywords: Cultural Heritage Conservation, Grotto, Rock mass structure, Engineering Geology, Preventive Conservation

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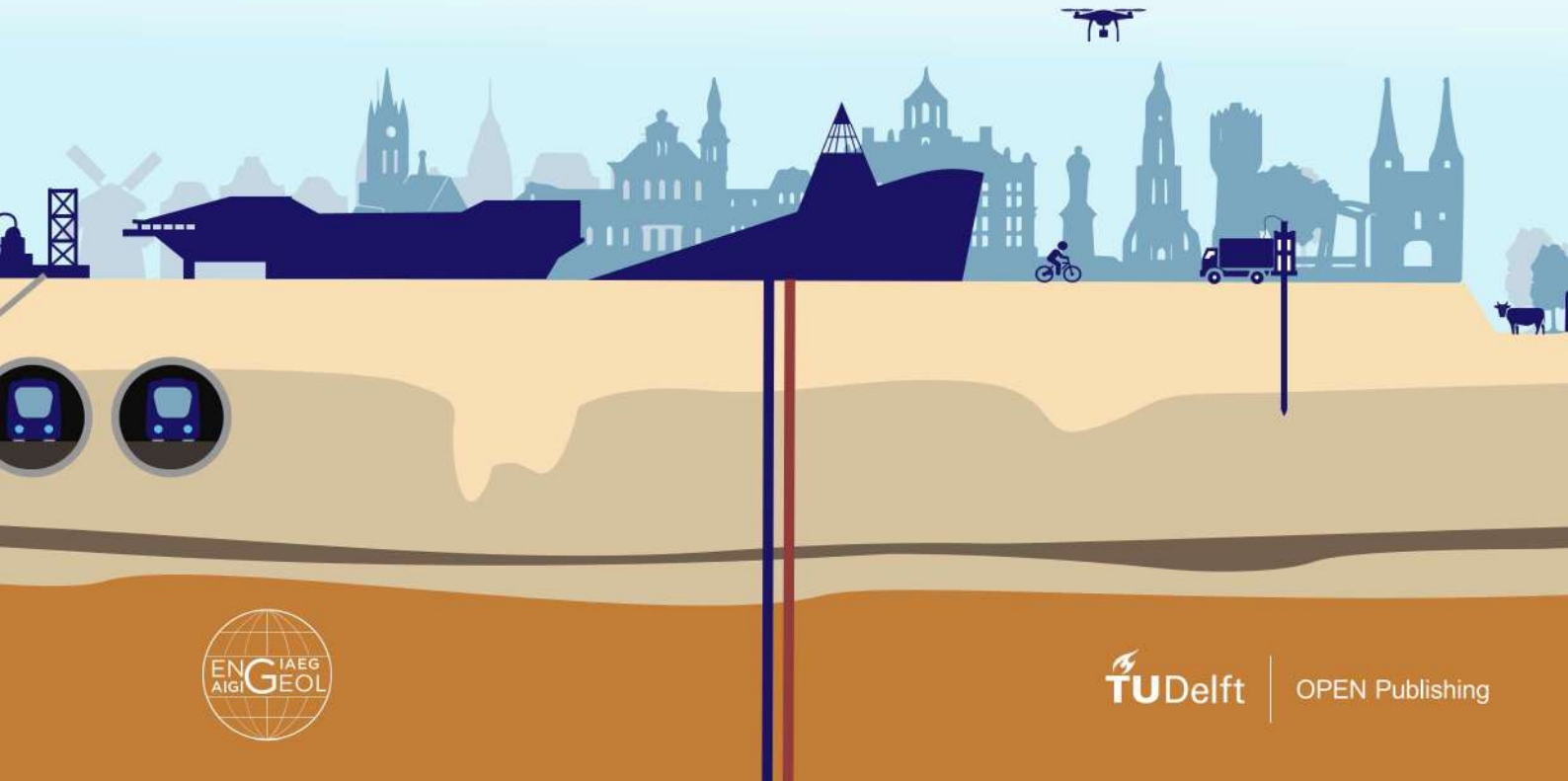
8. EG in the Digital transition and AI revolution



Focus on 3D geo-mapping, learning from big data sets, Artificial Intelligence, and Virtual and Augmented Reality in Engineering Geology.



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3D Rock Slope Monitoring with AI and a Single RGB Camera

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Abstract

Digital rock slope monitoring is widely applied to geotechnical risk management workflows, mainly along linear transportation infrastructure and mines. It is however difficult to monitor large extents at high-frequency with the existing technology and methods, due to both costs and often technical limitations. Some systems use 2D images (RGB, thermal, etc.) to identify surficial changes along rock slopes while some others rely on depth sensing technology using either long-range LiDAR scanning or digital photogrammetry. The former are low-cost and computationally-efficient systems but error-prone and incapable of quantifying the detected changes due to the lack of depth information. The latter provide more robust 3D detections but prove computationally-intensive and costly when applied at scale. Thus, a scalable, flexible and low-cost system that allows for 3D detection would widen the field of applications

In this work, we present a new high-resolution approach to 3D rock slope monitoring based on computer vision. It includes the comparison of time-sequential images captured by a fixed camera sensor targeting a certain rock outcrop area. The system uses the visual information of the images and the camera calibration parameters within a ViT (vision transformer) neural network to reconstruct the 3D geometry of each instance. The AI-generated point clouds are compared to each other providing 3D rockfall detection and quantification similar to those extracted by expensive depth-sensing systems. Applications on experimental natural laboratories indicate an RMSE between ground-truth and AI-generated point clouds lower than 8 cm, indicating promising advancements in rock slope monitoring with the inclusion of AI.

Keywords: Computer Vision, Artificial Intelligence, Vision Transformers, Monitoring, Rock Slope

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V-ROCK, a Virtual Reality Tool to Teach Rock Mass characterisation.

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Abstract

V-ROCK is a virtual reality (VR) project aiming to prepare Applied Earth Science and Civil Engineering students for real fieldwork. V-ROCK uses a rock outcrop from Bellmunt, NE Spain to achieve this overall objective.

First, we built a rudimentary VR environment that serves as the essential foundation for developing an engaging VR teaching tool. This tool immerses students in a digital twin of the Bellmunt rocky environment. Within the VR setting, students first learn how to secure their working surroundings, then are guided through a series of observations and measurements critical for characterizing a rock exposure.

To quantify the added value of the developed tool, we are integrating V-ROCK into three courses at both BSc and MSc levels in the field of engineering and geology. In these courses, the V-ROCK team quantifies the benefit of the virtual tool before and after real fieldwork. This surveying will allow us to improve the relevance of V-ROCK for various applications. The ambition of V-ROCK is to become a benchmark tool that boosts students' confidence when encountering real outcrops for the first time. This advantage will accelerate the acquisition of more in-depth scientific skills during essential real-world fieldwork. V-ROCK offers tailored teaching in a secure environment and contributes to inclusive education.

Keywords: Rock mass characterisation, Virtual Reality, Education



The V-Rock experience

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Enhancing Offshore Geotechnical Data Interpretation through AI-Based Outlier Detection: A Case Study on CPT in Wind Farm Development

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Abstract

In the context of digital transition in engineering geology, this study develops an AI-based framework to automate outlier detection in Cone Penetration Test (CPT) data, addressing the growing data volume and quality demands in offshore wind farm projects. CPT, widely used for seabed characterization, is prone to outliers due to equipment variability and harsh marine conditions, which compromise soil interpretation and design safety. This study implements a multi-scale Convolutional Neural Network (CNN) combined with a Bidirectional Long Short-Term Memory (BiLSTM) network to identify anomalies in large-scale CPT datasets. Results show high performance in terms of Area Under the Receiver Operating Characteristic Curve (AUC) across thresholds, allowing threshold tuning based on engineering risk levels. A balanced F1-score (the harmonic mean of precision and recall) of 0.7468 demonstrates a successful precision-recall tradeoff, supported by Focal Loss and class weighting strategies. It was demonstrated that CNN efficiently captures local signal variations while BiLSTM models temporal dependencies, reducing missed anomalies in noisy offshore data. This digital approach offers a consistent, scalable solution for seabed data analysis, supporting safer foundation design and enabling future integration with real-time monitoring and multi-source data fusion.

Keywords: CPT, offshore, CNN, LSTM, digital transition

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Pre-Event DEM-Based Deep-Seated Landslide Susceptibility Mapping Using a Vision Transformer in the Kii Mountains, Japan

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Abstract

This study evaluates deep-seated landslide susceptibility using pre-event LiDAR-derived DEM data from the 2011 Kii Peninsula heavy rainfall disaster. Terrain parameters representing gravitational deformation were calculated and used as inputs to compare a Convolutional Neural Network (CNN) and a Vision Transformer (ViT). Validation results show that ViT achieved higher classification accuracy (0.867) than CNN (0.837), with recall for the landslide class exceeding 95%. ViT effectively captured broader geomorphological context, whereas CNN emphasized local terrain features. Both models showed difficulty in distinguishing DSGSD, reflecting its intermediate geomorphic characteristics. Tests in unseen areas indicate the potential to identify terrain prone to future failure using pre-event topography alone.

Keywords: Vision Transformer, Landslide susceptibility map, Disaster prediction, AI, Influence factor

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Machine Learning-Based Prediction of Thermal Properties of Soils Using National PGI-NRI Thermal Database

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Abstract

This study aims to develop an advanced predictive model employing machine learning algorithms to estimate soil thermal conductivity and specific heat capacity. The model leverages archival datasets and the Polish Geological Institute's (PGI-NRI) Thermal Properties Database, which encompasses approximately 6,000 high-resolution measurements. The research addresses a critical need in geothermal engineering for accurate thermal property assessments relevant to the design of ground heat exchangers, thermal energy storage systems, energy foundations, and heat propagation simulations in subsurface environments.

The core hypothesis assumes that the use of selected algorithms (Support Vector Regression, Decision Tree, Random Forest Regressor, and Gradient Boosting) will provide accurate predictions and enable sensitivity analysis of contributing variables. The methodology includes data preprocessing, model training with hyperparameter tuning, and comparative evaluation of algorithm performance. Results will support the parametrization of archival units in the PGI-NRI Engineering-Geological Database (BDGI), enhancing their thermal profiles.

This work contributes to the digital transformation of engineering geology by integrating AI-based tools with geological datasets. The outcomes will strengthen the efficiency and adaptability of geothermal system designs, contribute to the expansion of the PGI-NRI Engineering-Geological Database (BDGI) and its Physical-Mechanical Properties extension (BDGI-WFM), and provide a valuable reference for both research and industry. The project aligns with the strategic goals of sustainable energy development and supports broader transitions in energy and data-driven environmental engineering.

Keywords: shallow geothermal potential, thermal parameters of soil, AI in geology, geological databases, urban geothermal

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Engineering-Geological Database (BDGI) - the biggest geotechnical dataset for urban areas in Poland

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Abstract

PGI-NRI, the Polish Geological Institute is managing the Engineering-Geological Database (BDGI), which was established in 2013 and continues to be regularly updated. This is a unique, continuously developed digital collection of borehole logs (currently over 418 420 boreholes) and laboratory test results from different regions of Poland (currently over 246 400 parametres) with a special attention to urban areas. The database is used for spatial analyses and preparation of engineering geological maps for spatial management and geotechnical design purposes. Thanks to the Engineering-Geological Database, 17 engineering geological atlases, covering the largest Polish cities and agglomerations, had been prepared by 2022 (work on two additional atlases is expected to be completed by the end of 2026). The information contained in the atlases provides support in assessing how suitable the land is for construction, choosing the best location for investment and planning how the land should be developed. These data are gathered, verified and shared via web browsers based on the PGI-NRI internal procedure. The result of the project, including all database components and series of maps, will be presented through the GIS web browser. The abstract has been prepared as part of a project, financed by the National Fund for Environmental Protection and Water Management, as a task of the Polish Geological Survey.

Keywords: database, geological boreholes, engineering geology, Engineering-Geological Database (BDGI), maps

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Combining Process-Based and Deep Generative Models for Modeling Non-Stationary Sedimentary Deposits in 3D

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Abstract

From managing groundwater to building foundations, characterizing sedimentary heterogeneities is essential to support subsurface activities. Despite substantial progress, geological modeling still struggles to reproduce the architecture and heterogeneity of sedimentary deposits while conditioning to data. Recent developments in deep generative models offer a promising path forward. A first challenge is obtaining the large number of 3D images needed to train such models. To address it, we used the Channel-Hillslope Integrated Landscape Development (CHILD) model, which simulates fluvial evolution over geological timescales using simplified physical processes. We generated 20,000 simulations of meandering deposits and used them to train a 3D generative adversarial network (GAN). An ablation study shows that techniques developed for generating large 2D images transfer well to 3D images of fluvial deposits: training remains stable, and the GAN produces diverse, non-stationary deposits with detailed structures, without mode collapse or memorization. But generating new images is only part of the challenge. To address conditioning, we evaluated several GAN inversion methods for fitting well data. We find that the GAN's latent space is often entangled, making conditioning difficult. However, updating the model weights during fitting significantly improves its ability to match data. This study shows that we are close to being able to use GANs in practical applications. But further effort is needed to build geologically plausible and diverse training datasets that support the development of foundational generative models, models that can then be fine-tuned to specific case studies and conditioning data.

Keywords: sedimentary heterogeneities, stratigraphic modeling, deep generative modeling, GAN, inversion

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Estimating 3D shallow S-wave velocity models from geophysical data based on deep neural network

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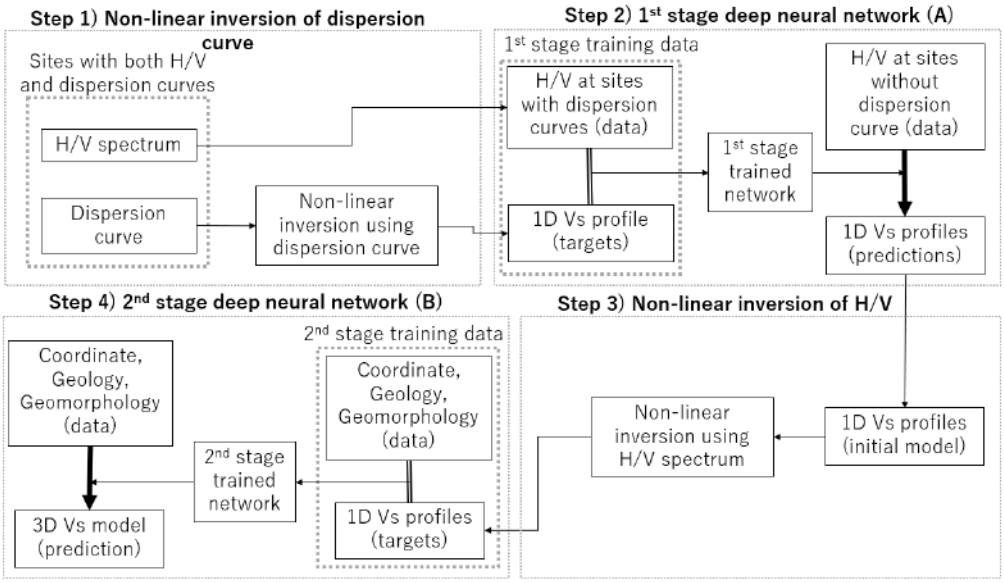
Abstract

We developed a method that estimates regional shallow three-dimensional (3D) S-wave velocity (Vs) models based on deep neural network (DNN). The method utilizes phase velocities and microtremor horizontal to vertical spectral ratio (mHVSR) obtained from geophysical measurements. Our DNN is composed of two stages since the number of sites with only mHVSR data is larger than those with both phase velocity and mHVSR data. The first stage DNN (A) predicts one-dimensional (1D) Vs profiles using training data pairs consisting of mHVSR and 1D Vs profiles analyzed from phase velocity data. The second stage DNN (B) predicts 1D Vs profiles using training data pairs consisting of regional surface information such as elevation, geomorphological classification, and geology etc. and 1D Vs profiles analyzed from phase velocity data and predicted by the first stage DNN (A). Estimation procedure for a 3D regional shallow Vs model can be summarized as four steps and two stage DNN. Our method predicted a three-dimensional (3D) model to 90 m deep with 200 m grid spacing from the eastern part of central Tokyo to the southeastern part of Saitama Prefecture, Japan, using phase velocity data, mHVSR and 1D Vs profiles open to public as digital data. The number of sites with dispersion curves obtained from active and passive surface wave methods was approximately 500. The number of sites with mHVSR was approximately 3200. The predicted 3D Vs model was well conforming to surface elevation, geomorphological classification, and geology, and clearly delineated geological features along with small rives on Pleistocene terrace covered with volcanic ash.

Keywords: Neural network, S-wave velocity, Surface waves, Microtremors, Horizontal to vertical spectral ratio



Four processing steps with two DNNs to predict three-dimensional S-wave velocity (Vs) model. Step 1) Non-linear inversion of phase velocity data to estimate 1D Vs profiles. Step 2) The first stage DNN (A) to predict Vs profiles from mHVSR spectra. Step 3) Non-linear inversion of mHVSR spectra to estimate 1D Vs profiles. Step 4) The second stage DNN (B) to predict Vs profiles from elevation, geomorphology, and geology etc.

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Digital Transition and Artificial Intelligence for Early Warning and Risk Assessment in Engineering Geology

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Abstract

Digitalization and artificial intelligence (AI) are transforming engineering geology by enabling more robust monitoring, risk assessment, and early warning for geohazards. This paper presents insights and practical results from two large-scale, EU-supported projects: 4G-MONITOR and CRISAFE. Both projects address the increasing complexity and frequency of geological hazards due to climate change and urbanization, focusing on the integration of sensor technologies, digital platforms, and AI analytics.

The 4G-MONITOR project develops and validates a modular IoT sensor network—using magnetic, gravity, and geodetic sensors—combined with AI algorithms for real-time detection of ground deformations and hazardous movements. Data fusion and edge computing approaches support early warnings in remote areas, with applications in landslide and infrastructure monitoring.

The CRISAFE project advances digital risk assessment and early warning for cascading multi-hazard scenarios (floods, earthquakes, liquefaction) in critical urban infrastructure. It applies harmonized, quantified methodologies for vulnerability analysis and integrates real-time sensor data with advanced visualization on IT platforms for infrastructure managers and first responders. AI-driven tools enhance risk communication and public awareness.

Combined, these projects demonstrate the transformative potential of digital transition and AI to deliver holistic, interoperable, and actionable solutions in engineering geology, supporting both scientific innovation and civil protection across Europe.

Keywords: geohazards, AI analytics, monitoring, risk assessment, early warning system

Figure 4. Rainfall monitoring field node with autonomous solar power supply and a protective enclosure for outdoor use.

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Integration of 3D Technology in Rock Slope Classification: A New Era

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Abstract

Traditional rock mass classification systems, such as the Rock Mass Rating (RMR) and the Slope Mass Rating (SMR), rely on empirical parameters derived from field observations, including rock strength, RQD, spacing and condition of discontinuities, groundwater conditions, and geometric relationships between joints and slope faces. These systems have long served as essential tools for assessing slope stability and remain central to engineering geology practice. However, their accuracy often depends on subjective field observations and limited spatial coverage. The integration of 3D point cloud technology, acquired through LiDAR or structure-from-motion techniques, offers a paradigm shift in how rock slopes are characterized. High-resolution 3D models enable the extraction of structural and morphological features, allow objective identification and discrimination of rock, soil, and mixed units, and provide accurate quantification of slope geometry and discontinuity patterns, which are used in empirical classification systems. This study presents a web-based, open-source framework that integrates high-resolution 3D point cloud data with automated segmentation and machine learning for rock slope classification and hazard assessment. By embedding traditional rock mass classification systems within a scalable, 3D-driven digital environment, the proposed framework aims to enhance the precision, repeatability, and transparency of slope stability and rockfall hazard assessment. Integrating 3D technology marks a significant step toward a more robust, data-driven approach for assessing slope stability and informing geotechnical design, marking the beginning of a new era in rock mass classification.

Keywords: Rock slope classification, 3D point cloud, Slope Mass Rating, Rockfall , Hazard analysis

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Integrating AI and Knowledge Graphs for Advancing Georisk Assessment

Sandra Paula Villacorta Chambi[1, 2], Ever Castillo[3], Michel NZikou[1], Alonso Otiniano[4], Katia Veronica Vila Mamani[5]

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Abstract

The integration of Artificial Intelligence and Knowledge Graphs (KGs) offers a structured approach to formalising and operationalising geoscientific knowledge for georisk assessment. This study presents an ontology-guided framework for constructing domain-specific KGs from heterogeneous and largely unstructured documents. Unlike open information extraction approaches, the proposed methodology relies on a controlled geo-schema that constrains entity recognition and relation extraction to predefined ontological classes and canonical predicates, improving semantic consistency, causal plausibility, and engineering interpretability. The workflow follows a modular extraction, transformation, and loading architecture that combines domain-adapted Named Entity Recognition, ontology-constrained triple generation, expert-in-the-loop validation, and graph deployment in a Neo4j environment. The approach is demonstrated through a case study in the Chillón, Rímac, and Lurín watersheds in Lima, Peru, where 20 technical documents were processed to generate a semantically structured KG encoding hazards, geological processes, triggering factors, exposed elements, and mitigation measures. Results indicate that ontology-driven constraints reduce semantic noise and improve relation validity, enabling multi-hop reasoning across causal and spatial dependencies. Rather than producing predictive susceptibility maps, the resulting KG serves as a structured knowledge infrastructure that enhances traceability, explainability, and interoperability within georisk workflows. The framework contributes to the digital transformation of engineering geology by providing a reproducible semantic layer aligned with the Findable, Accessible, Interoperable, and Reusable data principles, capable of supporting decision-oriented hazard analysis and integration with broader geoscience data systems.

Keywords: Artificial Intelligence, Knowledge Graphs, Georisk Assessment, Landslide Susceptibility, Semantic Data Integration

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Integrated Monitoring and AI-Based Forecasting of Landslide Activity in the Complex Terrain of Metsovo, Greece

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Abstract

This study investigates past and potential ground deformations in the landslide-prone area of Metsovo, one of the most touristic mountainous villages in Greece, using a combination of high-resolution satellite data and in-situ measurements. Monitoring is carried out using several in-place and portable inclinometers, which allow for detailed observation of subsurface displacements, as well as high-resolution multi-temporal interferometry data. Multi-temporal InSAR (MTInSAR) analysis over a nine-month period detected minor to moderate surface deformations, ranging from 5 mm/year to 2 cm/year, revealing localized instability across the entire Metsovo settlement. Inclinometer data confirmed subsurface movement rates (4–16 mm/year) in areas overlapping with MTInSAR-detected zones, indicating a good correlation between surface and subsurface movements. The area's geological and geomorphological complexity—including steep slopes, a heterogeneous flysch bedrock, and inconsistent hydro-meteorological data—presents significant challenges for modeling and prediction. To address these, a data fusion and AI-driven framework is proposed for further investigation and analysis of subsurface movements. This approach includes the integration of recent Sentinel-1 InSAR time series, inclinometric data, rainfall accumulation, and volumetric soil water content for enhanced deformation analysis and predictive modeling to forecast future landslide activity and establish automated alert systems. These innovations aim to improve early warning capabilities and support proactive risk management in the geologically complex terrain of Metsovo.

Keywords: Landslide, AI Forecasting, Monitoring, Ground deformation, Rainfall accumulation

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Combining LinkNet and Fourier Neural Operator with GPU Accelerated Computing to Forecast Rock Avalanche Motion

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Abstract

Rock avalanches are composed of large volumes of rapidly flowing rock fragments that can exceed 50 m/s in velocity and devastate extensive areas, posing a severe threat to people and infrastructure. Numerical models are essential for forecasting the associated hazards and risks, however, the runtime of most existing models limits their ability. While Deep Learning (DL) models can potentially address this limitation, the efficiency of most numerical models limits the data available for training DL. In the present work we have overcome this limitation using the GPU-based numerical model ORIN-3D (parallel simulatOR of landslIde motioN over 3D terrain), which provides large quantities of training data for DL. We compare LinkNet and Fourier Neural Operator (FNO) for forecasting the runout of rock avalanches, which accounts for the effects of topography, initial conditions, and path materials.

Utilizing ORIN-3D simulations derived from our database comprising 20 case histories and 100 synthetic cases. Both architectures demonstrate strong parameter interpolation on known terrains (especially FNO with a True Positive Rate (TPR): 96.3%, False Positive Rate (FPR): 0.7%). While cross-terrain generalization remains challenging, FNO significantly outperforms U-Net, achieves better generalization performance when temporal dimension is included in the architecture (TPR: 86.0%, FPR: 5.1%). Both architectures achieve significantly higher forecast speeds than ORIN-3D, with FNO being roughly 1000 times faster. This dramatic improvement is crucial for applications such as landslide risk analysis, where large scale rapid forecasts are essential.

Keywords: Rock avalanches, Surrogate modelling, ORIN-3D, FNO, LinkNet

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Probabilistic Assessment of Rainfall-Triggered Landslides through Gumbel Distribution and Machine Learning Modeling

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Abstract

Effective landslide hazard assessment plays a vital role in reducing disaster risks, particularly in regions like Cyprus that are prone to landslide events. The present study introduces an integrated framework for mapping rainfall-induced landslide hazards by merging statistical rainfall analysis, terrain susceptibility modeling, and a spatial risk matrix. We analyzed daily precipitation records from meteorological stations using the Gumbel distribution to model extreme rainfall and estimate return periods and exceedance probabilities. A critical threshold of 64.2 mm in 24 hours, identified through empirical evaluation, served as a benchmark for assessing landslide likelihood under extreme precipitation conditions. Terrain susceptibility was mapped using various Machine Learning models trained on a combination of topographic, geological, land-use data, and historical landslide occurrences. The resulting susceptibility map classifies areas into five categories—ranging from Very Low to Very High—highlighting vulnerable regions such as the Troodos Mountains and the districts of Paphos and Limassol. To capture the multi-dimensional nature of hazard, we developed a spatial landslide hazard matrix that integrates three key elements: rainfall exceedance probability, terrain susceptibility, and the conditional probability of landslides triggered by threshold exceedance. This approach produces a multi-class hazard map that reflects varying levels of landslide risk across Cyprus. Hazard maps generated for rainfall return periods between 5 and 50 years reveal a notable expansion of High and Very High risk zones as rainfall intensity increases. These findings offer critical insights for early warning systems, land-use planning, and risk mitigation strategies in landslide-prone areas.

Keywords: Rainfall-induced landslides, Hazard mapping, Gumbel distribution, Machine learning, Cyprus

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Deep Learning-Based Landslide Susceptibility Mapping Using 1D-CNN and Geospatial Data

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Abstract

Landslides are among the most destructive natural hazards, causing serious social and economic impacts and posing risks to lives and infrastructure worldwide. Often triggered by extreme weather they disrupt slope stability by altering hydrological conditions and soil saturation. As climate-related risks intensify, the demand for accurate prediction and prevention has grown, supported by advances in remote sensing and geospatial technologies. The present study investigates the application of a one-dimensional convolutional neural network (1D-CNN) to assess landslide susceptibility in the Alfeios River Basin (Peloponnese, Greece). The objective is to build a reliable deep learning model that integrates spatial and environmental data to identify landslide-prone areas. The 1D-CNN's performance is compared with Logistic Regression (LR), Naïve Bayes (NB), Gradient Boosting (GB), and a deep learning neural network (DLNN). Several landslide-related variables were used, including elevation, slope, aspect, curvature, topographic wetness index, lithology, soil cover, and proximity to drainage networks and faults. A landslide inventory of 229 mapped events was used as the positive class, while 229 non-landslide samples were extracted from stable areas to create a balanced binary classification dataset for training and validation. The Weight of Evidence (WoE) method was used to quantify variable contributions, while multi-collinearity tests ensure data reliability. Shapley Additive Explanations (SHAP) provide insights into model interpretability. The workflow covers data preprocessing, model training, validation, and the generation of susceptibility maps. Evaluation metrics include accuracy, sensitivity, specificity, and AUC. Results confirm that the 1D-CNN offers a scalable and interpretable solution for regional landslide hazard mapping using multisource geospatial data.

Keywords: Landslide Susceptibility, Convolutional Neural Network, Geospatial Analysis, Remote Sensing, Machine Learning

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Integrating Engineering Geological Data for Urban Geohazard Identification and Risk Mitigation of Thessaloniki's City, Northern Greece

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Abstract

This study presents the integration of an advanced engineering geological database to support urban geohazard assessment and risk mitigation in Thessaloniki city, northern Greece (Kokkala, 2023), placing emphasis on reducing geological uncertainty and enabling early-stage hazard-informed planning. Developed within the Tunnel Information and Analysis System (TIAS) framework (AGS, 1999; Marinos et al., 2013), the database consolidates extensive borehole and geotechnical investigation data from the city's fill deposits and sediments of Quaternary and Neogene age. As a representative database application, liquefaction susceptibility was assessed in the vicinity of Thessaloniki airport using Standard Penetration Test (SPT) and Cone Penetration Test (CPT) data (Figure 1). Subsoil profiles indicated alternating layers of sandy clays, silts, and medium-density sands. Two sub-areas were delineated based on proximity to a local stream, and their stratigraphic variability was analyzed using the Soil Behavior Type Index (Ic) and the criterion by Robertson and Wride (1998). Liquefaction potential index (LPI), vertical settlements, and lateral displacements were estimated under two seismic scenarios (M6.9-0.4g and M7.0-0.5g), simulating activation of the Anthemoundas and Gerakarou faults, respectively (Lin and Smerzini, 2022). Results indicated spatial heterogeneity in liquefaction response: coarse-grained dominance in sub-area A contrasted with fine-grained deposits in sub-area B. LPI values exceeding 5% were observed throughout the study area in most soil columns, indicating high to very high liquefaction potential. Additionally, vertical displacements ranging from 16 to 19 cm and lateral displacements up to 220 cm were estimated in some cases, under both seismic scenarios for the two sub-areas. While direct field validation of the estimated displacements is limited due to the absence of recent strong ground motions in the study area, the results align with findings from previous geohazard risk assessments in the broader urban area (Pitilakis et al., 2008; Papathanassiou and Marinos, 2018), further supporting the applicability of the adopted methodology.

Keywords: geohazards, liquefaction, CPT, SPT, stratigraphy

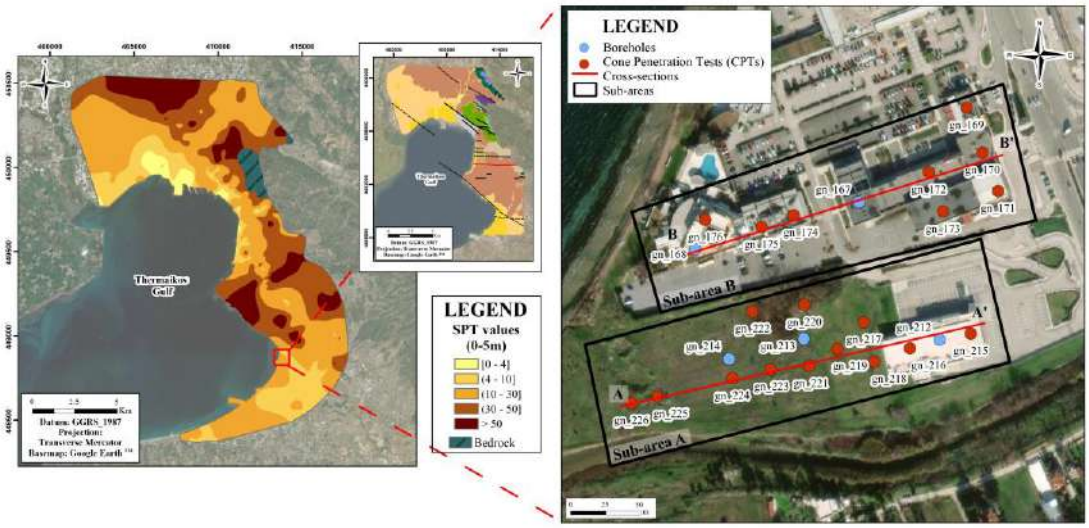

Figure 1. Spatial distribution map of SPT values for depth 0–5 m, presented alongside the updated engineering geological map of Thessaloniki (for detailed engineering geological map refer to Kokkala and Marinos, 2022). The figure delineates the study area used for urban geohazard mitigation (Kokkala, 2023)

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Data Driven Framework for Rainfall-Induced Landslides Dimension Assessment Using Machine Learning: Case Study from Northern Italy

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Abstract

Landslides are one of the most dangerous natural disasters in mountains and geologically sensitive areas, especially when they are caused by heavy rainfall.Because of the climate change, these kinds of disasters are happening more often and with more force in the area of interest and this means that we need better techniques for assessing risk and giving early warning. , Traditional susceptibility mapping usually only show where the landslides are likely to happen in the study area, but it does not always has the tools to figure out how big or far they might be.

This study offer a complete, data driven approach that combines probabilistic modeling with reliable prediction of important landslide characteristic, such as spatial extent, for improve the description of landslides caused by rainfall event. This method uses a variety of environmental and climatic factors, such as high resolution topographic data, lithological properties, land use patterns and rainfall metrics, to help us the better understand the many different ways that slope failures areas can be driven.

The paper uses a recent case of widespread landslides in northern Italy (May 2023 events in Emilia Romagna region, more than 80,000 landslides) to test and show how the framework works, using machine learning based methods (Random Forest algorithm) as data-driven method for relating the predictors with the response variable of the model, represented by landslides area.

The suggested framework offer a mechanisms to make land planning, infrastructure development, and disaster preparedness more resilient, especially in areas that are becoming more influenced by extreme weather events.

Keywords: Landslides, Random Forests, Prediction

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Sequential Bayesian framework for embankment settlement forecasting: automating the observational method

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Abstract

The reliable prediction of settlement beneath embankments is essential for safe and cost-effective infrastructure development. Traditional methods, such as Terzaghi's consolidation theory or Asaoka's graphical approach, often require extensive prior data, assume fixed soil behaviour, and offer limited adaptability during staged construction. This study presents a low-dimensional sequential Bayesian framework for real-time updating of settlement forecasts, formalizing the observational method within a probabilistic setting. The proposed approach begins with minimal early-stage monitoring data and incrementally updates predictions as new measurements become available, without full model recalibration. Settlement is represented using a parsimonious exponential-growth formulation, and posterior parameter distributions are updated sequentially using Bayes' theorem to quantify uncertainty at each stage. The framework is demonstrated using monitoring data from the Boddington embankment trial (UK HS2). Results show rapid early parameter correction within approximately 75 days of monitoring, followed by convergence toward stable long-term forecasts as additional data are assimilated. Predictive uncertainty contracts monotonically with record length, and end-of-record settlement magnitudes compare favorably with analytical consolidation estimates, although differences in settlement rate evolution are observed. The method enables meaningful forecasting from short monitoring windows and provides explicit uncertainty bounds to support risk-informed construction control and engineering decision-making.

Keywords: Embankment , Settlement , Bayesian , Modeling, Sequential

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Expert-Guided AI Protocol for Geological and Hydrogeological Conceptual Modelling

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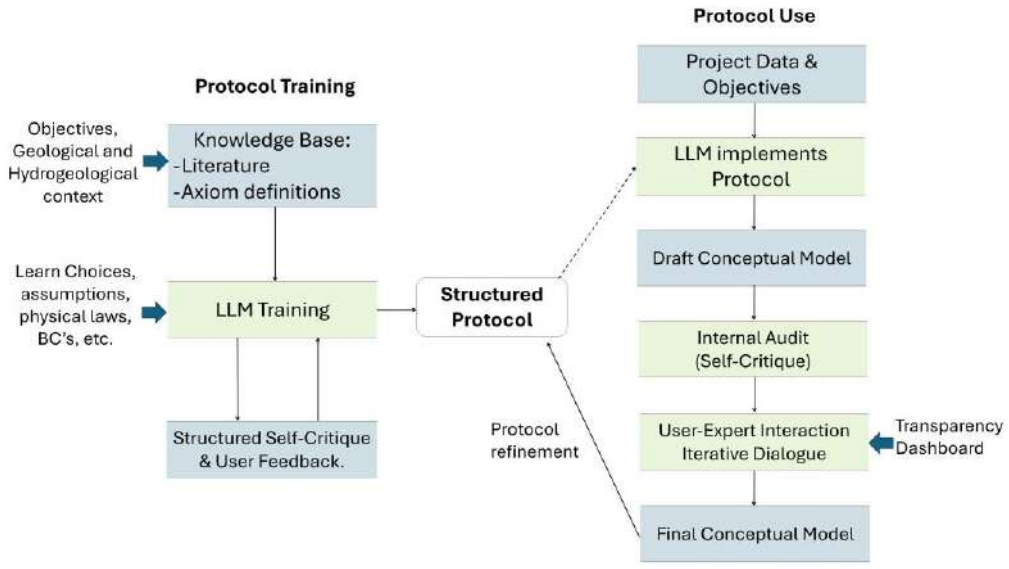
Abstract

In hydrogeological simulation, the development of the conceptual model is the most critical phase, providing a simplified representation of a complex subsurface reality. This foundational step frequently becomes a bottleneck, demanding extensive expert interpretation to navigate data ambiguity and justify inherent assumptions. To address these challenges, this study introduces a human-in-the-loop protocol for geological and hydrogeological conceptual modeling, which employs a Large Language Model (LLM) as an active reasoning partner to streamline and enhance this process. The protocol operates in a distinct sequence. The LLM is first trained to implement a structured protocol for geological and hydrogeological conceptual modeling, an approach that integrates literature review, axiom-based audits, and user feedback. When applied to a new project, the LLM generates a draft conceptual model that immediately undergoes an internal audit via structured self-critique using domain-specific evaluation criteria. The model is then presented to a human expert for an interactive and iterative dialogue, where expert knowledge is used to guide the model to its final state. This iterative dialogue is supported by a transparency dashboard of trackable metrics like uncertainty ranges, data source documentation and assumption tracking. to provide transparency. This facilitates active assumption analysis, treating assumptions not as static inputs but as variables to be tested. The entire interaction history, including these tests, serves as a new training case to refine the core protocol. This creates a dynamic tool that co-generates conceptual models with the expert, supports data-gap identification through systematic uncertainty tracking, and enhances the overall transparency of subsurface investigations.

Keywords: Protocol, Large Language Model, Conceptual Model



AI protocol workflow, from LLM training to expert-guided application and refinement.

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Improving Risk Communication through Visual Monitoring Bulletins: from Raw Data to Accessible Knowledge.

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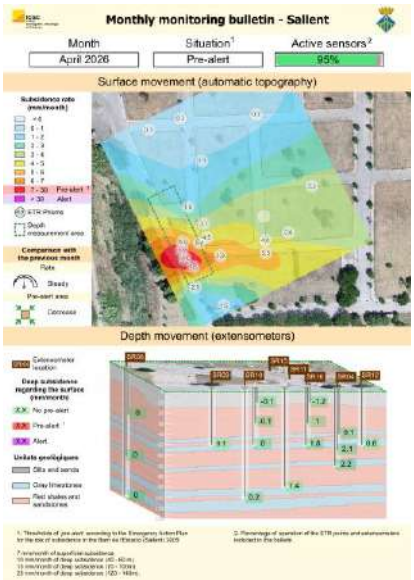
Abstract

A persistent challenge in risk management is bridging the gap between technical experts and non-technical stakeholders. This issue becomes particularly critical in monitoring projects targeting areas with active terrain instability. These initiatives depend on a broad array of contact and remote sensors that periodically measure key representative variables. Translating this complex sensor data into accessible information for non-expert audiences is no simple task. To address this, monitoring bulletins have been developed as a more intuitive and engaging alternative to conventional technical reports, which often rely heavily on text and line graphs. Producing these bulletins requires significant effort from the technical team. It demands a deep understanding of the underlying physical phenomena, along with the ability to synthesize and correlate multisource data. In addition, algorithms must be developed to clean and process the datasets, as well as to automate the generation of bulletins efficiently and consistently. Although this process involves a substantial initial investment of time and resources, once operational, the system supports timely and reliable publication. This, in turn, enables experts to redirect their focus toward higher-value tasks, such as analyzing trends and assessing the evolution of the monitored phenomena. Presented in a concise 2-3 page format, the bulletins visually communicate the current status and progression of risk factors. The aim is to communicate key insights and its interpretation clearly and accurately, tailored to the interests and comprehension of each audience. This paper shares our implementation experiences across multiple locations and highlights key lessons learned through real-world application.

Keywords: Risk communication, Geohazard monitoring, Sensor data, Automated reporting, Data integration



Monitoring bulletin for Sallent showing subsidence caused by historical mining activity.

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Assessment and Mapping of Sinkhole Hazard and Risk by Using a Machine Learning Approach: Guidonia–Bagni Di Tivoli Plain (Italy) Case Study

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Abstract

Sinkholes result from different concurrent or sequential processes such as hydrogeological processes like subsurface dissolution by groundwater flow, and mechanical processes like downward gravitational movement of the overlying material. Sinkhole occurrence in settled flat areas is a major geohazard that can cause relevant economic and social damage in terms of losses in human lives, and severe injuries to properties and activities. This work presents a sinkhole susceptibility and risk assessment mapping in Guidonia-Bagni di Tivoli plain (Central Italy), which is a travertine sinkhole-prone study area where sudden occurrences of sinkholes have occurred in past and recent times. In order to assess sinkholes hazard and risk, it is essential to map the spatial likelihood of these collapsing events with the aim of preventing damages and managing land-use activities in sinkhole-prone areas. Nevertheless, this is a complex and difficult task since the formation of sinkholes is often sudden and unpredictable. A point-wise sinkhole database was considered in Guidonia-Bagni di Tivoli, and a series of environmental sinkhole-controlling factors on this study area was analyzed, as related to its geo-litho-hydrological asset, i.e. travertine thickness, and to its terrain deformational scenario, i.e. ground motion rates derived from satellite InSAR imagery. A sinkhole susceptibility map was generated throughout the use of free and open-access ML (machine learning) algorithm - MaxEnt model – and it was combined with vulnerability and economic exposure data derived from cadastral inventories and market and income values, in order to provide a user-friendly sinkhole risk map of the Guidonia-Bagni di Tivoli area. Overall, results of this work demonstrate capabilities of open access machine learning models to assess sinkhole susceptibility for potential sinkhole areas, and provide a sinkhole risk map, along with information on urban environment, as a useful tool for urban planning and geohazard risk management.

Keywords: sinkholes, machine learning, Guidonia-Tivoli plain, risk, maximum entropy algorithm

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Enhancing Subsurface Model Flexibility through Telescopic Integration and Physics-Informed Machine Learning

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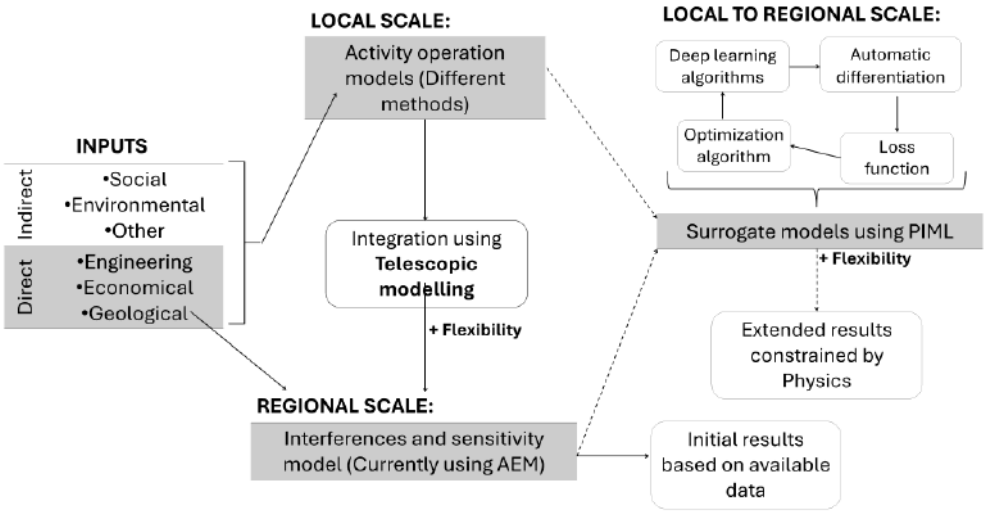
Abstract

Effective planning and management of deep subsurface energy systems, including geothermal extraction and natural gas storage, require modelling approaches that can incorporate site-specific details, represent interactions across scales, and manage uncertainty with limited data availability. This study presents two complementary strategies to improve the adaptability and utility of regional models: Telescopic Modelling and Physics-Informed Machine Learning (PIML). Telescopic Modelling combines detailed local simulations with broader regional models by integrating direct and indirect inputs, including hydrogeological, operational, and external constraints. These locally informed results, rather than being purely hydrogeological, reflect broader contextual influences. The outcomes are then integrated into a regional model developed using the Analytic Element Method (AEM) by defining boundary conditions that embed this rich local information. This approach enables the regional model to better reflect interactions between co-located activities while maintaining computational efficiency. In parallel, surrogate modelling using PIML is being planned to further enhance flexibility. The initial goal is to emulate groundwater flow (with view to also include as heat transfer and multiphase flow in the future). Both local and regional surrogates will be tested, and depending on their performance, one or both approaches may be adopted. Initial efforts will focus on Physics-Informed Neural Networks (PINNs) due to their ability to incorporate governing equations, making them suitable for training on datasets derived from multiple modelling methodologies. This diversity of input sources could allow the surrogates to generalize beyond the limits of any single simulation tool and compensate for the scarcity of deep subsurface data.

Keywords: Telescopic Modelling, Physics-Informed Machine Learning (PIML), Flexibility, Regional Models



Telescopic modelling integration, complemented by Physics-Informed Machine Learning (PIML), to enhance subsurface model flexibility

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Predicting Drought-Induced Desiccation Cracks in Regional Dykes Using Random Forest Models

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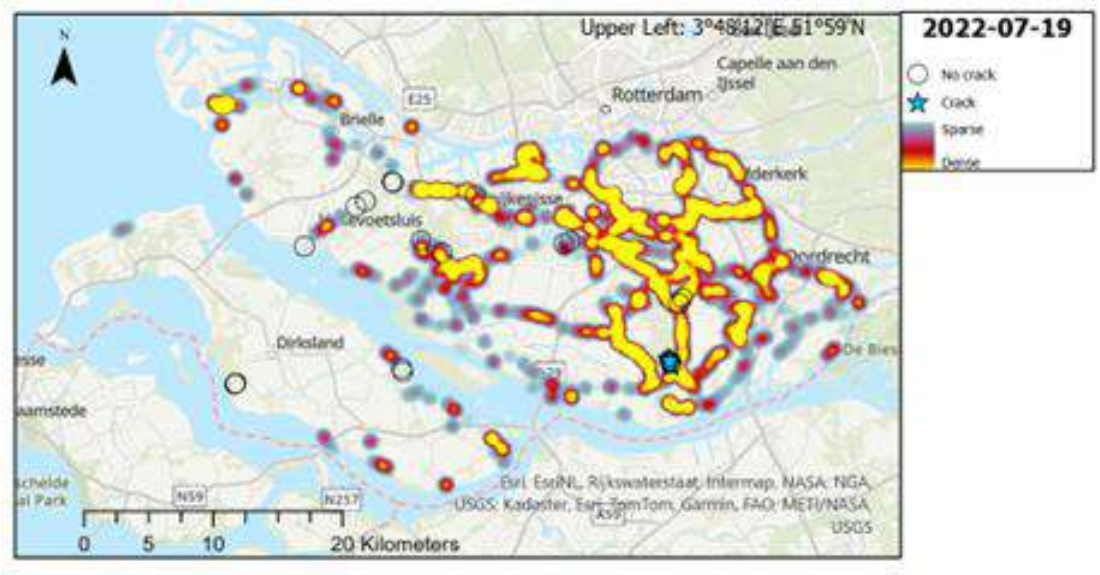
Abstract

Drought-induced desiccation cracks present a serious risk to the structural integrity of regional dykes, potentially compromising flood safety. This study explores the application of Random Forest machine learning models to predict such cracks within the jurisdiction of Waterschap Hollandse Delta (WSHD), building on earlier work by Chotkan (2021). The model uses environmental and geotechnical indicators, including Normalized Difference Vegetation Index (NDVI), cumulative precipitation deficit (CPD), soil stiffness, and slope aspect, to classify regions prone to cracking. Trained on observational data collected during drought inspections in 2020, 2022, and 2023, the model achieved a promising test accuracy of 82%. However, it suffers from significant overprediction, likely due to missing dyke-specific features and limitations in spatial data distribution. While the model identifies logical relationships between variables and crack presence, it cannot yet reliably localize cracks at a regional scale. The findings underline both the potential and limitations of applying machine learning for water safety applications. Future improvements should focus on incorporating dyke-internal soil data, enhancing drought stress indicators (e.g., using NDMI or soil moisture), and ensuring higher-quality and more diverse observational datasets. Despite its current shortcomings, the model represents a valuable step toward decision-support tools that could eventually aid in more efficient and proactive dyke inspections.

Keywords: Desiccation cracks, Random Forest, Machine learning, Dyke stability, Drought prediction



Comparison of the cracks predicted by for a single day and the observations of 1 month starting from that day. Showing a much higher amount of cracks being predicted than observed.

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Automation of Tunnel Support Detailing with AI-Assisted Programming

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[1] Ariel University, Ariel, Israel

Abstract

Drafting tasks in geological engineering are time-consuming and often highly repetitive, with tunnel support drawings being a representative example. Although such tasks may appear straightforward and intuitive to experienced engineers, translating drafting logic into executable code typically requires substantial software development effort. While modern CAD and BIM platforms provide programming and automation capabilities, their effective use has traditionally depended on skilled programmers rather than domain engineers. This paper presents a practical case study in which a geological engineer with only basic programming experience leveraged recent advances in artificial intelligence, specifically large language models, to develop a custom code for automating tunnel support drawings. The workflow generates detailed support layouts directly from the tunnel contour and a limited set of user-defined engineering parameters, such as bolt spacing, liner thickness, and support class. Crucially, the approach preserves engineering judgement by requiring the engineer to define all design parameters and to review the final outputs, while automating repetitive drafting operations. The results demonstrate a viable pathway for lowering the barrier to engineering automation. The proposed approach is readily extendable to similar repetitive drawing tasks across a broad range of geological engineering applications.

Keywords: Tunnel support, Artificial Intelligence, Automation

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Undocumented Decisions: The Hidden Risk of AI in Geotechnical Practice

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Abstract

Artificial intelligence adoption in geotechnical engineering has accelerated rapidly, with industry surveys reporting that 73% of engineering professionals now use AI tools, up from 35% in 2023. However, a significant portion of this adoption is undocumented: 78% of AI users bring their own tools to work without employer approval, and 52% are reluctant to admit AI use on important tasks. This creates a hidden layer of unverified, untraceable AI-assisted decisions embedded in geotechnical practice. Large language models fabricate soil parameters and misapply design formulas, producing output indistinguishable from expert analysis. A triple gap has emerged in the European context: no engineering-specific AI case law exists, professional indemnity insurers are inserting AI exclusions into policies, and regulatory frameworks from the Eurocodes to Belgian ten-year liability law predate AI entirely. The EU AI Act (Regulation 2024/1689), with high-risk obligations originally applicable from August 2026 and now subject to renegotiation under the Digital Omnibus on AI, is expected to impose documentation and logging requirements that current geotechnical practice cannot meet. Other European regulated sectors offer instructive contrasts: medical devices require conformity assessment under the MDR, aviation mandates full audit trails under EASA, and finance enforces five-year algorithmic decision records under MiFID II. Engineering has none of these. This paper argues that the geotechnical profession faces a closing window to establish voluntary documentation practices for AI-assisted decisions before mandatory compliance reshapes the landscape. The building blocks exist; what is missing is a coherent, domain-specific framework.

Keywords: artificial intelligence, geotechnical engineering, decision documentation, professional liability, EU AI Act

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AI-Based Prediction of Bulk Density and UCS from Rock Sample Photos: Validation Against Laboratory Measurements for Granite and Limestone

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Abstract

This study evaluates how well an image-based AI model can estimate bulk density (t/m³) and uniaxial compressive strength (UCS, MPa) compared with laboratory measurements for granite (n = 19) and limestone (n = 20) using specimen photos and location context. Agreement was quantified using bias, Bland–Altman limits of agreement (LoA), MAE, RMSE, Pearson correlation, and coverage of laboratory values within the AI uncertainty interval (AI ± uncertainty). Bulk density performance was lithology-dependent. Granite density showed near-zero bias (+0.0037 t/m³), tight LoA (−0.113 to +0.121 t/m³), low error (MAE 0.050 t/m³; RMSE 0.058 t/m³), and moderate correlation (r = 0.75). Limestone density had much larger scatter (LoA −0.544 to +0.491 t/m³) and higher error (MAE 0.217 t/m³; RMSE 0.259 t/m³; r = 0.64). UCS estimates were unreliable: the AI overestimated granite UCS (bias +68.46 MPa; r = −0.12) and underestimated limestone UCS (bias −31.35 MPa; r = 0.59), producing a wide combined LoA (−100.48 to +135.03 MPa). Uncertainty intervals were under-calibrated, with overall coverage of 43.6% for density and 30.8% for UCS. Overall, the AI shows potential for preliminary density screening, but laboratory testing remains essential for UCS.

Keywords: bulk density, uniaxial compressive strength, granite, limestone, artificial intelligence

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Non-Destructive Prediction of Marl Unconfined Compressive Strength Using Ensemble Machine Learning Models

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Abstract

This study investigated the feasibility of using machine learning to predict the unconfined compressive strength (UCS) of marl rock with easily obtainable non-destructive testing (NDT) parameters. A dataset comprising 178 marl samples collected from the laboratory reports of a major infrastructure project in Budapest was utilized. Three non-destructive variables, depth, density, and ultrasonic pulse velocity (UPV) were used to train four ensemble learning ML algorithms: Random Forest, AdaBoost, XGBoost, and CatBoost. Hyperparameter optimization was conducted using randomized search along with fivefold cross-validation to ensure that models provide the best results without overfitting. Models' performance was measured using the coefficient of determination (R^2), root mean square error (RMSE) and mean absolute error (MAE). Results showed that Random Forest is the most accurate among all the models. Random Forest achieved an R^2 of 0.88 on the testing dataset with low error values, highlighting strong generalization capability. SHapley Additive exPlanations (SHAP) analysis revealed that density is the most influential predictor of UCS, followed by UPV, while depth played a minor role. The findings of this study demonstrate that ML algorithms can effectively capture non-linear relationships in geotechnical data and provide a reliable estimation of UCS using only a few nondestructive parameters. The proposed approach offers a rapid, cost effective, and practical alternative to laboratory testing, particularly valuable for large-scale infrastructure projects.

Keywords: Unconfined compressive strength (UCS), Marl, Machine learning, Machine learning

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Geostatistical and Evolutionary Optimization Strategies to Assess Uncertainty and Spatial Variability in Engineering Geological Problems

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Abstract

Reliable engineering geological applications, such as liquefaction hazard assessment, need robust subsurface characterization methods capable of handling strong spatial variability, sparse site investigation data, and model uncertainty. In this study, two methodological families are compared and integrated for liquefaction hazard quantification in the Central Business District (CBD) of Christchurch, New Zealand: (i) geostatistical modelling and (ii) evolutionary optimization based on genetic algorithms (GAs). The geostatistical workflow is used to model the spatial variability of key CPT-derived parameters and to support uncertainty quantification and the construction of liquefaction hazard maps. In parallel, the GA-based workflow is adopted to optimize model parameters involved in liquefaction-related correlations and hazard estimation, with the aim of improving predictive performance under non-linear, multi-modal, and uncertain conditions. The study highlights the different but complementary roles of the two approaches. Geostatistics provides a rigorous framework for spatial estimation and uncertainty quantification, whereas GAs offer a flexible global-search strategy for calibration and optimization problems in which conventional gradient-based methods may be ineffective or unstable. Their combined application enables a more robust hazard assessment workflow by coupling spatial analysis with parameter optimization. The results, discussed with reference to the Christchurch CBD case study, show the added value of integrating geostatistical and evolutionary approaches for liquefaction hazard mapping in highly heterogeneous alluvial settings. The proposed framework is intended to support more reliable engineering geological modelling and more informed risk-management decisions in seismic-prone urban areas.

Keywords: Geostatistics, Kriging, CPTu, Genetic Algorithms, Soil Improvement Methods

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Integrating Deep Learning and Explainable AI (XAI) for Landslide Susceptibility Assessment: A Case Study of the Aring Road Alignment, Malaysia

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Abstract

Landslides represent a critical threat to road infrastructure, particularly in tropical, mountainous regions characterized by complex lithology and high precipitation. This study investigates multiple slope failures occurring along a new road alignment in Kelantan, Malaysia, which rendered the route unusable shortly after construction. To address the limitations of traditional assessment, a data-driven approach using Machine Learning was employed to evaluate landslide hazards. The study area traverses the geologically sensitive Aring Formation, comprising interbedded argillaceous, arenaceous, and volcanic rocks. A geospatial database was developed using high-resolution LiDAR DTM (0.5 m resolution), site investigations, and remote sensing satellite imagery (10 m resolution) to identify 17 landslide causal factors classified into 4 factor groups namely geological factors, geomorphological factors, hydrological factors, and land cover factors. A Convolutional Neural Network (CNN) was optimized to classify the alignment into five hazard levels, from "Very Low" to "Very High". To ensure engineering transparency, Explainable AI (XAI) techniques including SHAP (SHapley Additive exPlanations) and Integrated Gradients were utilized to quantify the global and local contributions of specific parameters to slope instability. The analysis revealed that slope gradient, ground moisture, and terrain ruggedness were the primary drivers of failure. ROC AUC analysis indicates that the model achieved high reliability value of 0.9845. XAI results confirmed that these triggers were exacerbated by the presence of relict landslide scars upslope and thick colluvial debris beneath the road alignment. The ML-derived hazard maps demonstrated that road realignment was unfeasible due to widespread susceptibility, leading to the selection of elevated bridge solution to decouple the roadway from unstable ground. This research highlights the efficacy of integrating deep learning with XAI to enhance decision-making in geotechnical risk management.

Keywords: Landslide, Convolution Neural Network, Explanation AI, Slope Failure

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Hybrid Methodology for Landslide Prediction Integrating Geotechnical Numerical Analyses, Satellite Remote Sensing Data and Machine Learning Algorithms

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Abstract

Landslides represent a major geohazard for mountainous and semi - mountainous areas, especially where adverse ground conditions interact with extreme rainfall, seismic loading and anthropogenic slope modification. This study presents a hybrid landslide prediction methodology currently under development, integrating geotechnical numerical analyses, satellite remote sensing data and machine learning algorithms within a physically interpretable predictive framework. The proposed workflow initially relies on the compilation and standardization of a historical landslide inventory, including the spatial extent of each event, landslide type, inferred failure mechanism, geological setting, available geotechnical information and the associated triggering factor. Satellite - derived datasets and Digital Elevation Models are then used to extract landslide conditioning factors. These variables are introduced into machine learning models to support landslide susceptibility assessment and the preliminary classification of terrain into slope response units. The resulting susceptibility units are not considered merely as statistical classes, but are interpreted in engineering - geological and geotechnical terms, considering lithological setting, geomaterial quality, hydrogeological conditions, geomechanical parameters and expected modes of failure. Subsequently, representative geotechnical ground models are developed for selected slope units and analysed under different triggering scenarios, including rainfall infiltration, pore - water pressure increase, partial or full saturation and pseudo - static seismic loading and dynamic analysis using selected earthquake acceleration time histories. Numerical outputs, such as the Factor of Safety, failure mechanism, critical triggering threshold and associated hazard rating, are intended to provide physically based calibration and validation targets for the learning - based component of the methodology. In this way, the proposed framework aims to bridge the spatial information provided by satellite remote sensing, the mechanical understanding offered by geotechnical slope stability analysis and the predictive capability of machine learning. The final objective is to support the development of a robust, physically consistent and computationally efficient methodology for regional – scale landslide prediction and slope hazard assessment.

Keywords: Landslide hazard prediction, hydrid modelling, AI, Numerical modelling

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AI-Assisted Integration of Geological, Geotechnical and Geophysical Data for Subsurface Interpretation, Prediction and Decision Suppor

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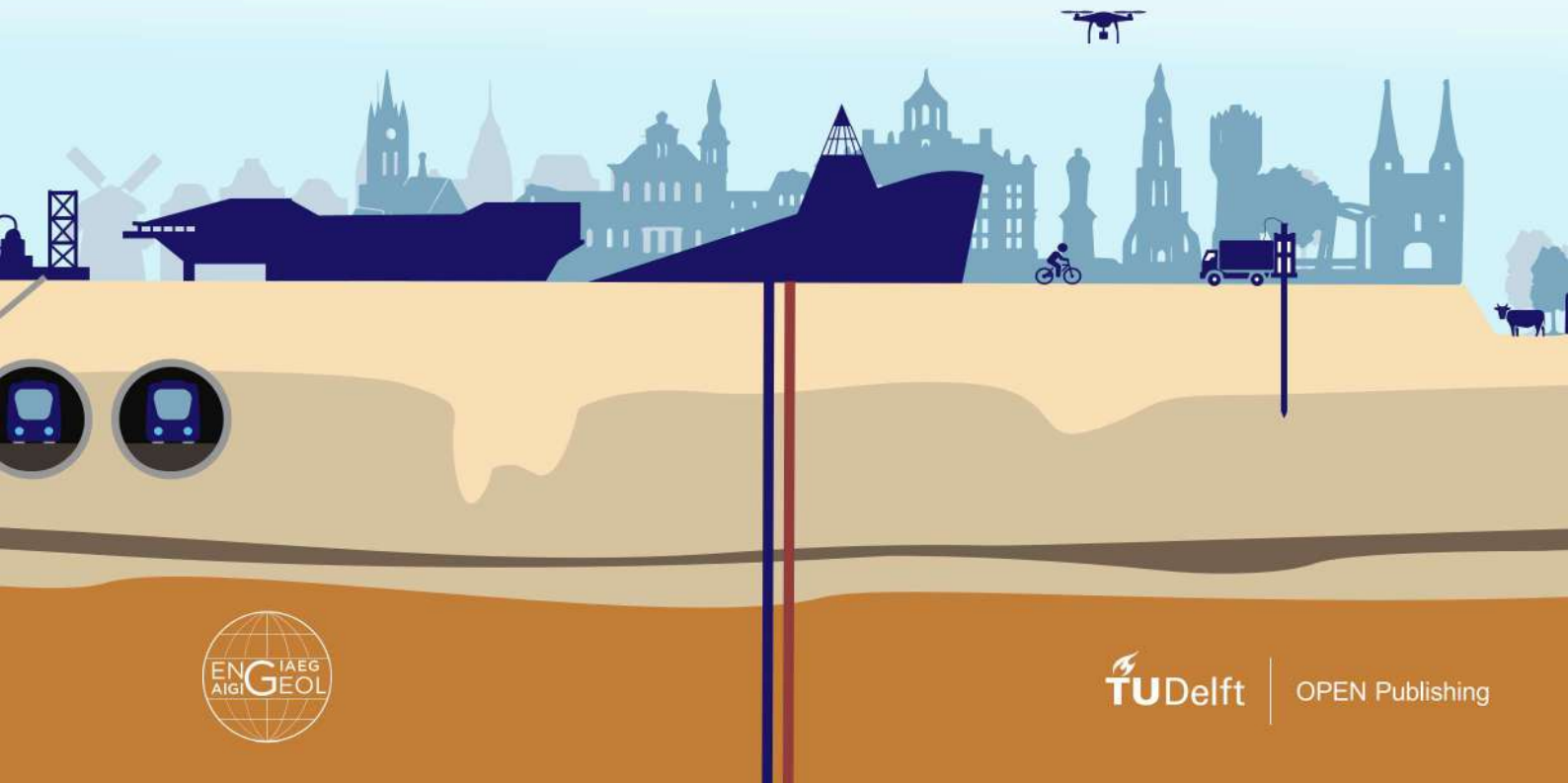
Abstract

Subsurface characterization relies on heterogeneous datasets including borehole logs, geological descriptions, geotechnical test results, geophysical surveys, laboratory data and previous site investigations. Differences in spatial resolution, format, completeness and reliability make their integration into a consistent geological model challenging. This contribution presents GeoHome AI, an AI-assisted framework under development for integrating heterogeneous subsurface information and supporting geological interpretation, prediction and engineering decision-making. The approach combines geological, geotechnical and geophysical data with machine-learning methods to identify spatial relationships, assess geological uncertainty and support predictions where subsurface information is incomplete. A key principle is that artificial intelligence complements rather than replaces professional geological interpretation. AI-generated predictions and uncertainty estimates are evaluated against borehole observations, geological context, geotechnical parameters and available geophysical information, with expert geological validation remaining an essential part of the workflow. The proposed framework is intended to support applications such as ground characterization, identification of geological boundaries and anomalous zones, interpolation between investigation points, preliminary assessment of subsurface conditions and optimization of further site investigations. The work discusses the methodological architecture of the developing system, requirements for integrating heterogeneous datasets, and the potential role of AI-assisted interpretation in engineering geology. Particular attention is given to transparent, uncertainty-aware outputs that can support rather than substitute engineering geological judgement.

Keywords: Artificial Intelligence, Engineering Geology, Subsurface, Geotechnical Data Integration, Geological Prediction

9. Boosting Engineering Geology

Added value of Engineering Geology. The **B**ulletin **o**f **E**ngineering **G**eology and the Environment: past, present, future. Innovations in Education and training in Engineering Geology. The **Y**oung **E**ngineering **G**eologists (YEG) and **W**omen in **E**ngineering **G**eology (WEG).



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Early Career Initiatives of the Engineering Group of the Geological Society (UK)

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Abstract

The Engineering Group of the Geological Society (EGGS) is one of the largest specialist groups in the Geological Society of London (GSL). EGGS, and associated Early Career Group (EGGS-EC), aim to promote engineering geosciences within the UK by promoting sharing and learning about ground engineering topics at evening lectures, field trips, conferences and seminars.

Who we are

The EGGS committee comprises volunteers forming several subcommittees who co-ordinate everything from monthly events to our Annual Conference and flagship Glossop Event. Our Chair, Anna Morley, steers the direction of the committee and broadly represents EGGS membership at mirror organisations such as the British Geotechnical Association (BGA) and the GSL itself. EGGS is also the UK national group and representative of the International Association for Engineering Geology and the Environment (IAEG).

What we do

EGGS organise events for members of all experience to attend and contribute towards. They're traditionally at the home of the GSL, Burlington House, allowing contributors to proudly present their work a historic building.

EGGS-EC boost early career engagement by organising regular photo competitions, providing formal and informal mentor opportunities, holding Chartership guidance events, and by promoting varied CPD opportunities (such as discounted fieldtrips, the Annual Conference CPD session and support with Glossop Award submissions).

A recent poll found that our members didn't engage with our former Facebook, Instagram or Twitter pages, so we've concentrated solely on increasing our LinkedIn presence. The EGGS LinkedIn page has over 2.6k followers and the EGGS-EC page recently surpassed 1.3k followers. Both continue to steadily grow year-on-year!

Keywords: Engagement, Early Career, Award, Committee, Collaboration



EGGS-EC Committee 2024 (Luke Johnstone, Jacob Bennett, Josh Dunlop, Hannah Newey)

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Enhancing Engineering Judgement in Dam Projects: Addressing the Engineering Geology Skills Gap in Australia and the Pacific Islands

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Abstract

Dam infrastructure projects in Australia and the Pacific Islands increasingly rely on geological interpretation to manage uncertainty and risk during site investigation, design and construction. In recent decades, however, the effective application of engineering judgement within engineering geology has weakened. This decline is driven by an ageing specialist workforce, limited succession planning, contraction of dedicated engineering geology education pathways and reduced opportunities for sustained field based learning. The consequences are evident in unreliable ground models, inefficient investigation programs and late stage design revisions that are frequently attributed to inherent ground risk rather than deficiencies in geological interpretation. Drawing on dam project experience from Australia and the Pacific Islands, working with multidiscipline teams, education evidence and published references, this paper reframes the commonly cited skills gap as a degradation of engineering judgement itself. Engineering judgement is treated as a critical technical risk control mechanism embedded within contemporary dam project delivery and regulatory frameworks. A structured, field centered mentorship and professional development framework is proposed to restore judgement in early career engineering geologists. The framework is designed for implementation within Australian and the Pacific Island institutional contexts and provides a practical pathway for strengthening engineering geology practice, ultimately improving dam project outcomes across the region.

Keywords: engineering geology, dam safety, engineering judgement, geological modelling, professional development

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Engineering Meets the Earth: Boosting Engineering Geology Education Through Field Training

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Abstract

This paper emphasizes the crucial role of fieldwork in enhancing Engineering Geology education, particularly for future Geotechnical Engineers. Geotechnical engineering combines Soil Mechanics, Rock Mechanics, and Engineering Geology, requiring a deep understanding of geological processes to predict ground behavior and develop accurate models for engineering applications. Educational approaches vary: geological departments prioritize ground investigation, data synthesis, and comprehensive geological modeling, while polytechnic departments emphasize geological characteristics and their relevance to civil engineering structures' stability. Historically, geology education for civil engineers lacked alignment with real-world engineering needs. Notable engineering failures, such as the Vajont and Malpasset dam disasters, underscored the necessity of integrating geological expertise into engineering practice. This catalyzed collaboration between geologists and engineers and the rise of interdisciplinary fields. Consequently, specialized MSc programs were developed to meet the growing demand for geotechnical knowledge through interdisciplinary curricula. Fieldwork, especially in joint teams of geotechnical engineers and engineering geologists, is highlighted as essential for training competent geoengineers. It allows students to apply theoretical knowledge in real-world settings, investigate diverse geological environments, and analyze past failures where geological conditions were misunderstood or overlooked. This paper presents the experience through field activities such as an 11-day European study tour for undergraduate civil engineering students and a 7-day MSc field trip tailored for aspiring tunnel engineers. These experiences reinforce the value of hands-on learning and interdisciplinary collaboration in developing professional skills in geoengineering.

Keywords: Fieldwork , Engineering Geology, Interdisciplinary Education, Geotechnical Engineering, Geoengineering

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Contributing to the future of Engineering Geology in Brazil: the experience of the Young Engineering Geology Brazilian Group

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Abstract

The young group of the Brazilian Association of Engineering and Environmental Geology (ABGE) began forming in 2018 during the XVI Brazilian Congress of Engineering and Environmental Geology (CBGE) and was officially created in August 2020.

With the goal of engaging more young professionals, the group organized technical discussions between junior and senior experts on topics such as engineering geology and the environment for tunnels, dams, roads, and mining. In its early days, the group chose the name ABGE Jovem (Young ABGE, in translation), created a logo, social media profiles, and defined its mission, vision and objectives.

Since then, ABGE Jovem has worked to bridge generations in engineering geology and the environment and encourage youth participation. A special membership category was introduced for students with reduced annual fees. The group has also offered job-market preparation courses in AutoCAD, QGis, and HEC-RAS, given university lectures, and contributed to the Portuguese translation of the Guidelines for the Development and Application of Engineering Geological Models on Projects. For 2025, it has planned a technical competition at the XVIII CBGE.

To ensure continuity, an official statute was established in 2022, defining elections every two years for a president, vice-president, secretary, YEG representative, and senior advisor. The senior advisor, the only board member over 40, plays a key role in connecting professional generations.

Keywords: Youth Engagement, Professional Development

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Rethinking Engineering Geology Education: Critical Thinking in an AI-Enhanced World

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Abstract

Written from the perspectives of an engineering undergraduate student and two professors at different career stages, this paper examines how artificial intelligence (AI) may accelerate the decline of critical thinking in engineering geology education. Uncritical pedagogy that emphasizes "established methods" and assumes "industry standards" risks training professionals who apply techniques without questioning their validity. Engineering knowledge exists as a three-dimensional network in which cognitive biases are encoded in its core. As the body of literature proliferates, older publications become entrenched in the core without critique: new knowledge critical of the core is ignored, while knowledge that perpetuates core biases reinforces the status quo. Knowledge transfer propagates these biases through bias amplification. When AI algorithms are trained on datasets that incorporate human interpretation, they replicate subjective decisions rather than transcend them, learning patterns in formalized human judgment rather than in the mechanical behaviour of engineering geology problems. Without deliberate critical judgement, such tools can reinforce prevailing assumptions and make it more difficult to imagine or justify alternative approaches. This represents bias amplification at scale, wrapped in the dangerous misconception of AI objectivity. AI enhances students' perception of learning but significantly reduces actual knowledge retention when used as a cognitive substitute. Professional engineering carries legal obligations that AI cannot fulfill. Licensed engineers bear personal responsibility regardless of the tools employed. Students must learn to interrogate data provenance, recognize empirical parameters as formalized judgments rather than physical measurements, grasp the limitations of empirical methods, and comprehend that AI amplifies rather than eliminates uncertainty.

Keywords: Engineering Geology, Artificial Intelligence, Engineering Judgment, Observational Method, Field Practice

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Geology for Engineers: Building a Better Foundation for Risk-Resilient Design.

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Abstract

Engineers involved in the design of construction projects come from various engineering backgrounds, but they share a common challenge: the structures they design are located on, in, or even below the ground. The ground—comprising soil and/or rock—often represents the greatest source of uncertainty in construction projects. As a result, it frequently poses the highest risks. The course discussed in this paper equips participants with the knowledge to manage these risks from an engineering geological perspective. It emphasizes the importance of thorough ground investigations and effective risk management based on the geological history of the site. The course aims to foster an understanding of how geotechnical site features are shaped by geological processes, and how this understanding can contribute to the success of construction projects. Participants gain practical insights into designing foundations in complex geological settings, including fundamentals of geology and rock mechanics. Basic skills are taught to help navigate spatial variability and unexpected soil conditions in ground and foundation engineering. The course also offers an optional one-day engineering geological fieldwork session to bridge the gap between theory and practice. The course is tailored to meet the specific needs of the Dutch market and highlights the potential impact of site geology on the design and execution of construction projects. The curriculum is carefully designed to strike a balance between the limited time available to cover such a broad topic and the goal of delivering meaningful value to participants. Experiences are shared and discussed.

Keywords: Education

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Women Engineering Geologists in the LAC Region Building Resilience: Experiences Facing Geohazards and Social Inequity

Sandra Villacorta[1, 2], Kimie Suzuki Morales[3], Judith Sullon[3], Alejandra Serey Amador[4, 5], Romina Celabe[6], Marisol Valerio[7], Monica Guzman[8], Liliana Corona[9]

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Abstract

This paper examines the role of women engineering geologists and geoscientists in disaster risk management (DRM) in Latin America and the Caribbean (LAC), giving insights into how equity, diversity, and inclusion (EDI) influence technical performance, governance, and long-term resilience in hazard-prone contexts. The review analyses selected country cases (Bolivia, Chile, Paraguay, and Peru), complemented by regional evidence from Brazil and Mexico, and draws on policy documents, institutional reports, professional initiatives, and applied community-based projects.

The review indicates that women professionals contribute to DRM not only through technical expertise in geohazard assessment and mitigation but also by sustaining continuity in territorial engagement, facilitating communication between technical and non-technical actors, and strengthening the social legitimacy of risk management measures. Across the analysed cases, women engineers frequently occupy bridging roles that connect scientific evidence, local knowledge, and institutional decision-making, enhancing the effectiveness and durability of geotechnical interventions. This review of cases also identifies persistent constraints that affect both equity outcomes and engineering practice. These include the underrepresentation of women in senior and decision-making positions, fragmented implementation of EDI initiatives, and limited availability of gender-disaggregated and longitudinal workforce data. Such factors reduce institutional capacity for knowledge retention, monitoring, and adaptive risk governance.

The findings indicate that inclusive participation, geoethical practice, and professional networks should be understood as core components of effective engineering geology and DRM. Strengthening gender-responsive data systems, leadership pathways, and professional coordination mechanisms is therefore essential to improve technical outcomes and societal resilience in the LAC region.

Keywords: Engineering Geology Outreach, Disaster Risk management, Geoscience Education, Equity and Inclusion, Geoethics

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Numerical simulation of gravity effects on lunar soil

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Abstract

As the main material form on the lunar surface, the mechanical properties and gravitational effects of lunar regolith directly affect the safety and feasibility of deep space exploration missions such as lunar landing detection, base construction, and in-situ resource utilization. Based on high-precision particle scanning data, this study adopted the Discrete Element Method (DEM) to construct multi-morphology particle samples containing 22 types of real particle morphologies of Chang'e-6 lunar regolith. Triaxial shear numerical simulations were carried out to explore the effects of gravitational fields (1 g, 1/6 g) on the macro-mesoscopic mechanical behaviors of lunar regolith. The results show that the 1/6 g gravitational environment leads to a decrease in the peak strength and strength parameters of the samples, a weakening of the volume dilatancy trend, a reduction in the coordination number, a decrease in the shear band inclination angle, a weakening of the vertical concentration of contact force chains, and a more significant anisotropy of the average normal contact force.

Keywords: Lunar soil, Mechanical behavior, Gravity, Numerical simulation,

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Engineering-Geological Assessment and Landslide Risk Mitigation along the famous Odontotos Railway in the Vouraikos Gorge, Greece

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Abstract

This study evaluates the engineering-geological conditions and landslide risks along the historic Odontotos Railway in the Vouraikos Gorge, Greece, an engineering feat completed in 1896. Connecting Diakopto to Kalavryta, this narrow-gauge railway traverses a tectonically active environment characterized by steep slopes and complex geological formations. The research focuses on mitigating risks from earthflows, debris flows, and rockfalls, which were significantly exacerbated following a devastating wildfire in 2023 that stripped the landscape of stabilizing vegetation. The methodological approach integrated detailed field mapping, laboratory testing of soil and rock samples, and the creation of a specialized Engineering Geological Map and a Slope Gradient and Geohazard Map. Slope gradients were classified to identify high-risk sectors, particularly those exceeding 65∘. Furthermore, 3D rockfall simulations were conducted using RocFall software to assess kinetic energy distributions and trajectory patterns. Results indicate that rock fragments of approximately 2.6 tonnes can generate kinetic energies up to 760 kJ, posing a direct threat to railway infrastructure. The study concludes by delineating critical locations and proposing technically substantiated protection measures—such as reinforced drainage and installation of specialized rock fall and debris flow barriers —to ensure the continued safety and functionality of this vital tourist corridor.

Keywords: Debris flow, Rockfalls, Mitigation, Protection, Railway

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Didactical Practices in Engineering Geology with Digital Maps: Expanding Integration with the Local Environment

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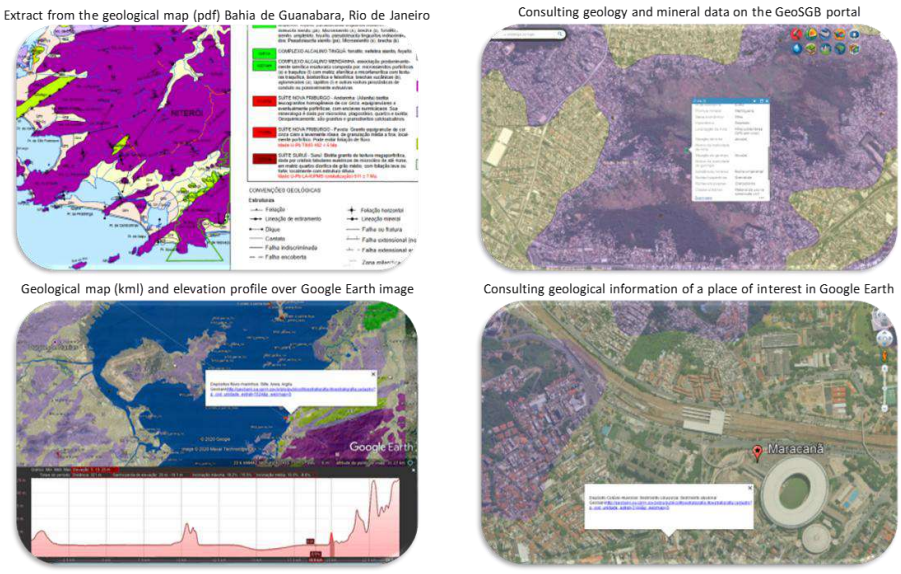
Abstract

Practices in engineering geology and environmental geology have always included activities with geological maps, seeking to present superficial geological diversity and its relationship with relief and human occupation. These activities in teaching Civil Engineering and Environmental Management and Analysis at the Federal University of São Carlos were based on printed maps. Recently, the usage of digital maps and geographic information system (GIS) maps by the Geological Survey of Brazil (SGB) started; this transition accelerated in the years with remote classes. Since the 2010s, the SGB has digitizing its collection and possess a range of cartography in different scales and formats. The active practices start with students in groups evaluating different regions of Brazil on 1:100,000 geological maps. Activities include map reading (unconsolidated materials, rocks, minerals, structures); evaluation of maps in Google Earth and the SGB's GIS environment (local occupation, relief, elevation profiles, 3D view); study of geodiversity maps (processes, potential and restrictions of use). Civil Engineering students plan applications of engineering themes in the area, considering the aspects studied. Environmental Management and Analysis students evaluate environmental issues and plan geo-dissemination materials. The results are presented to the class for evaluation. At each experience, new ways of presenting and producing materials are incorporated, taking advantage of digital media. The adoption of these methods (enrichers of remote classes) increasingly involves students, enabling them to learn about the geology of distant places, their occupation, environmental and social problems, enhancing them as future professionals. These practices give students a sense of place.

Keywords: Geoeducation, Teaching, Geotecnology, Sense of place, Site occupation



Example of application of the methodology, based on the Geological Map Bahia de Guanabara, Rio de Janeiro 1:100,000 (Valeriano et al., 2009)

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From LiDAR to Learning: Optimizing 3D Models of the Valkenburg Mines for Educational Virtual Reality Risk Assessment

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Abstract

As part of their Earth related courses, TU Delft Earth, Climate and Technology BSc students conduct post-mining risk management assignments in the historic mines of Valkenburg-aan-de-Geul, The Netherlands. Their focus is on assessing the stability of underground structures, supported by the development of a virtual reality (VR) application within the larger VROCK project. To build this application, 3D models of the mines were created by scanning key features, mainly large, degrading pillars, using two iPhone-based LiDAR scanners and the Scaniverse app. These scans produced highly detailed 3D mesh models with dense polygon counts, which required optimization for VR use. Optimization was performed through quadric error metrics with edge contraction, simplifying meshes while minimizing quality loss. Tests comparing different scan ranges and processing modes revealed that a 5-meter range with "Detail mode" provided the best balance between texture fidelity and polygon efficiency. The optimized models were then integrated into the Unreal Engine 5.3 environment. Performance improvements were achieved through Level of Detail (LOD) management, optimized lighting, and efficient scene design. Although the TU Delft New Media center will eventually create the full application, a small VR demo was developed to test performance and usability. Based on hardware assumptions, a rendering limit of 1,125,000 polygons was expected, but tests showed a maximum of only 465,478 polygons, indicating strong performance even on older systems. A user survey further evaluated the demo, focusing on lighting, motion sickness, and level design. Results were highly positive, with participants preferring three smaller levels over a single large one.

Keywords: post-mining risks, education, virtual reality, LiDar scanning, VR performance optimization



3D scanning of a limestone pillar in the Valkenburg mines. High-powered lamps illuminate the structure to improve LiDAR capture, while an iPhone is used for scanning. Photo by Roderik Lindenbergh, 2025.

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Design-Oriented Role of Engineering Geology in Himalayan Hydropower Projects

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Abstract

Hydropower development in the Himalayan region is governed by complex geological conditions that exert a dominant influence on design feasibility, constructability, and long-term performance of project components. This paper presents a design-oriented synthesis of engineering geological experience gained from Himalayan hydropower projects, emphasizing how Engineering Geological Models (EGMs) inform and guide design decisions for dams, underground caverns, headrace tunnels, pressure shafts, and slope stabilization works. The study highlights typical geological uncertainties encountered during investigation and construction stages, including lithological variability, structural discontinuities, groundwater conditions, and in-situ stress effects, and examines their implications for alignment selection, excavation strategy, tunnel support systems, foundation treatment, and slope stabilization measures. Particular emphasis is placed on geology-driven tunnel support design, adaptive construction-stage feedback, and the emerging role of three-dimensional (3D) geological logging in improving spatial understanding and support optimization. The paper reinforces the role of engineering geology as a central design discipline for achieving safe, economical, and resilient hydropower infrastructure in the Himalayan region, especially in the context of the global energy transition.

Keywords: Engineering geology, Himalayan hydropower, 3D geological logging, Slope stability, Engineering Geological Model (EGM) & Tunnel support systems , Underground caverns

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Is Geology Still a Male-Dominated Science? An Analysis of Gender Parity in Geology and Geological Engineering Programs in Brazil

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Abstract

Despite the expansion of higher education in Brazil and the numerical predominance of women, who account for approximately 59% of enrollments, horizontal gender segregation persists in scientific careers. This article analyzes female participation in Geology and Geological Engineering programs using microdata from the INEP Higher Education Census (2010–2024). The methodology relied on the Gender Parity Index (GPI), comparing geosciences with control fields (Medicine and Social Sciences). The results show that, unlike the compared fields which exhibit a GPI greater than 1 (female majority), Geology maintains a historically male dominated profile, with a GPI fluctuating between 0.6 and 0.8, never reaching equity in the analyzed series. The study discusses government initiatives, such as MCTI programs, but indicates that progress is slow. It is concluded that the general increase in access to higher education has not corrected structural inequalities in geosciences. Institutional policies focused not only on admission but also on retention and the deconstruction of stereotypes associating technical competence and fieldwork with the male gender are required.

Keywords: Geosciences, Gender Parity, Women in Geology, Higher education, Brazil

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Development of Reduced-Scale 3D Printed Physical Models for Geophysics Education in Engineering Geology

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Abstract

The incorporation of additive manufacturing technologies, particularly 3D printing, has expanded significantly within the technical and scientific environment, driven mainly by the development of prototypes with diverse applications. In the field of Geosciences, this trend reflects the continuous search for teaching resources that enhance spatial visualization and enable the simulation of field phenomena at a laboratory scale. The natural variability of the physical properties of rock masses, for example, poses challenges to their study; in this context, the use of reduced-scale physical models fabricated through 3D printing emerges as a robust strategy, ensuring experimental reproducibility through precise control of geometry and material homogeneity. Within this framework, a polylactic acid (PLA) block measuring 20 × 20 × 20 cm and containing an internal tunnel geometry was designed and printed for educational purposes. The model was conceived as a pedagogical tool intended for future laboratory applications involving Ground Penetrating Radar (GPR), Pundit, and Resipod. In this way, the model is intended to enable laboratory simulations of scenarios analogous to geotechnical field investigations in a laboratory setting, fostering understanding of the operating principles of geophysical instruments and the interpretation of data representatives of engineering works such as tunnels and foundations.

Keywords: Education, 3D Printing, Reduced-Scale Physical Models, Brazil,

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Promoting Engineering Geology Through Youth Engagement, Communication, and Professional Advocacy in Nigeria

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Abstract

Engineering geology plays a vital role in infrastructure development, environmental sustainability, and geohazard risk reduction. However, awareness of the discipline and its career opportunities remains limited among many students and early-career geoscientists in Nigeria. As a member of the IAEG Young Engineering Geologists (YEG) and Women in Engineering Geology (WEG) groups, I actively promote the profession through mentorship, science communication, outreach, and professional engagement. A notable opportunity was speaking during the Young Professionals Session at the Nigerian Mining and Geosciences Society (NMGS) Annual International Conference and Exhibition (AICE), where I discussed the roles of engineering geologists, career pathways within the discipline, and the value of participation in professional associations. These interactions revealed both the limited awareness of engineering geology among many young geoscientists and their enthusiasm to learn more. Following the session, several participants expressed interest in joining NAEGE and the IAEG Young Engineering Geologists (YEG) network to further engage with the profession. Beyond professional events, I contribute to outreach initiatives through the women wing of the Nigerian Association of Engineering Geologists and the Environment (NAEGE), particularly the Catch Them Young programme, which introduces high school students to engineering geology and helps guide their future career choices. I also use LinkedIn, WhatsApp, and published articles on Medium to communicate engineering geology concepts to diverse audiences, explaining issues such as erosion, flooding, infrastructure failures, and environmental hazards from an engineering geology perspective. Feedback from university students and secondary school participants suggests that these initiatives have improved awareness of engineering geology, encouraged engagement with professional associations, and inspired some students to consider geoscience as a future field of study. These experiences demonstrate the value of sustained outreach and science communication in strengthening the visibility of engineering geology in a rapidly changing world.

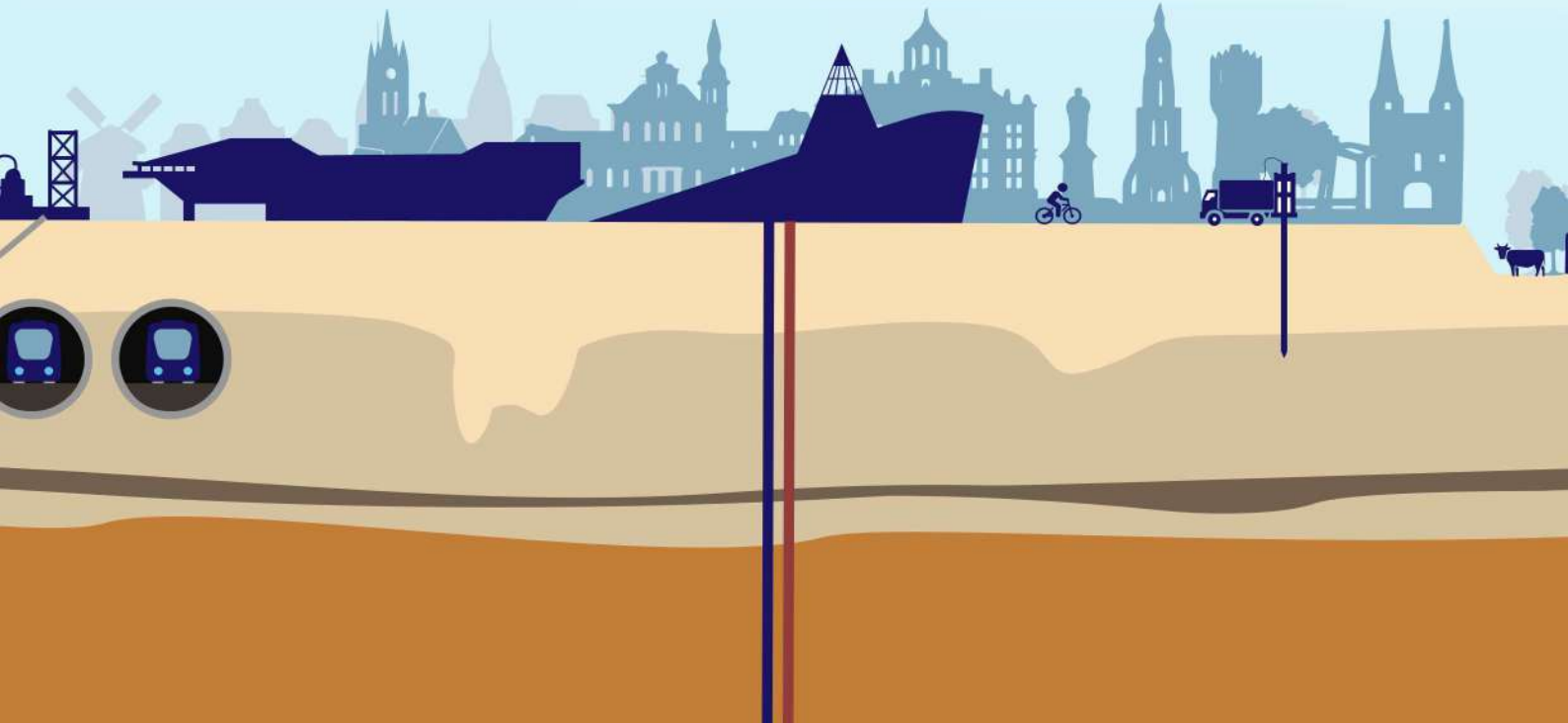
Keywords: Engineering Geology , Youth Engagement , Young Engineering Geologists , Geoscience Education , Professional Advocacy



Enthusiastic senior secondary students at the Catch-Them-Young program held at Ibrahim Badamasi Babangida Staff School Lapai, Niger state, Nigeria, 4th June, 2026

10. Special sessions

Special highlights included sessions on prestigious projects in Europe, China, and beyond, as well as the special community session, Facing the Unthinkable: Science and Responsibility after the Nepal-China Border Cascading Disaster, which brought together participants for solidarity, reflection, and scientific exchange.



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From Rock to Aggregate: Assessing Sustainable Use of Excavated Materials for the Einstein Telescope

Ophélie Faÿ[1], Hannes Claes[1], Alex Müller[2], Julien Denayer[3], Fanny Descamps[4], Adrien Lheureux[5], Rudy Swennen[1], Sara Vandycke[4], Ruben Snellings[1]

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Abstract

The Einstein Telescope (ET) is a flagship European initiative to build the most advanced underground observatory for gravitational waves. The Euregion Meuse-Rhine (EMR) is one of three candidate sites, with a feasibility study expected to conclude by 2026. The project involves constructing a 30-kilometer triangular tunnel network at depths of 200–300 meters. A comprehensive geological mapping and subsurface investigation program is underway to inform tunnel siting, design, and construction. A key component of the ET project is its commitment to sustainability, particularly the valorization of excavated rock as construction material aggregate for infrastructure and local construction markets. This study evaluates the aggregate potential of rocks of Famennian (Upper Devonian), Dinantian and Namurian (lower Carboniferous) age, representing a transition from shallow marine to distal shelf environments. Outcrop analogues were used to sample representative lithologies, including Famennian sandstone/siltstone, Dinantian limestone and dolostone, and Namurian siliciclastics. Geomechanical characterization (uniaxial compressive strength, Brazilian tensile strength, Cerchar abrasivity) was conducted alongside petrographic (thin sections) and mineralogical (XRD) analysis. In parallel, aggregate performance testing (including Los Angeles fragmentation resistance, Micro-Deval abrasion resistance, freeze-thaw resistance) assessed the aggregate mechanical properties in conformity with EN standards for intended use as construction aggregates. The ongoing study reveals that both mineralogy, foliation and microtexture, including grain size distribution, grain contact, and cementation significantly influence the geomechanical and aggregate properties. Establishing these relationships is essential for predicting the performance of excavated materials, supporting both the sustainable material strategy of the ET and the broader geotechnical design of the facility.

Keywords: aggregate, einstein telescope, geomechanical properties, Sustainability, petrography

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3D geological subsurface model as a supporting engineering tool for the Einstein Telescope study area in Sardinia (Italy)

Lorenzo Lipparini[1, 2], Matteo Cagnizi[3], Flavia Ferranti[3], Peppe Junior Valentino D'Aranno[3], Giuseppe Sappa[3], Quintilio Napoleoni[3], Maria Marsella[3]

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Abstract

The Einstein Telescope (ET) research infrastructure is envisioned as Europe's pioneering next-generation underground observatory for gravitational-wave detection.

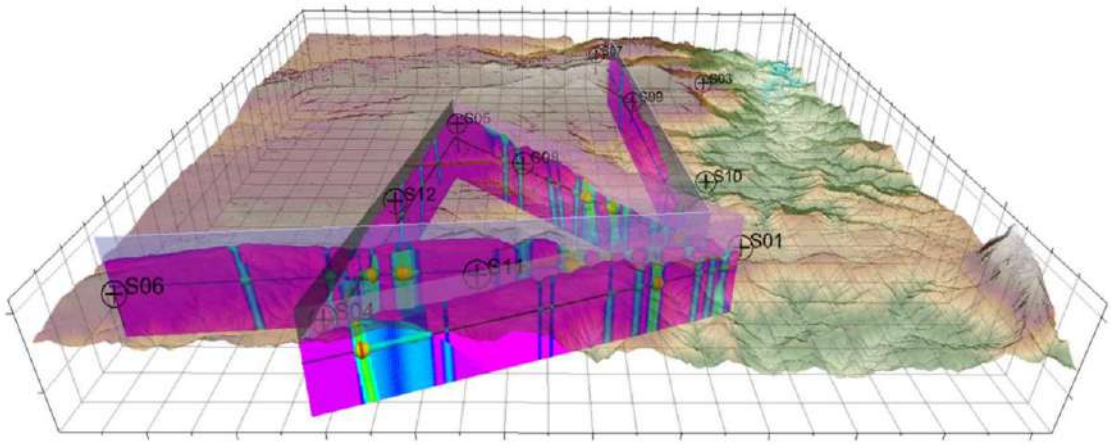
Its engineering design requires a multi-criteria approach capable of identifying and addressing geological, geotechnical, environmental, and landscape challenges. It is essential to consider the site conditions and physical characteristics that may influence the performance of scientific instruments. To navigate these complexities, a collaborative effort from the scientific and engineering community produced an advanced digital multi-scale 3D model for the Sardinia site identified as a potential location.

The model integrates surface and subsurface data at both regional and local scales, consolidating all available geological, geophysical, and geotechnical datasets to support a coherent reconstruction of key subsurface features, including lithotypes, faults, and fracture networks. It incorporates data from surface observations and drilled calibration wells, encompassing geological and petrophysical information, laboratory tests on undisturbed samples, fracture analyses, and geophysical investigations conducted by the ET scientific community. This integrated representation strengthens the linkage between surface and subsurface information.

The obtained model allows for the extraction of geological prognosis in 3D space. This transforms the model from a simple visualization into a predictive engineering instrument.

This advanced modeling approach is intended to support the minimization of geotechnical risks, the optimization of construction strategies and associated costs, and the implementation of scenario-based design analyses.

Keywords: Einstein Telescope (ET), 3D Geological-Geotechnical Model , Subsurface Prognosis, predictive engineering instrument,



3D view of the fracture intensity 3D property of the Einstein Telescope Sardinia candidate site, along the L and T hypothetical layouts.

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Defining a 3D Geological and Geophysical Model for the Einstein Telescope Site at Sos Enattos (Sardinia)

Francesco Maesano[1], Carlo Giunchi[2], Marco Olivieri[3], Antonio Funedda[4], Stefania Da Pelo[4], Valentina Romano[1], Roberta Maffucci[1], Fabio Villani[1]

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Abstract

The site of Sos Enattos in Sardinia (Italy) is a leading candidate to host the Einstein Telescope (ET), the future third-generation underground gravitational wave observatory. The realization of such a sensitive infrastructure requires a robust prediction of the rock mass conditions within the Variscan crystalline basement. This contribution presents the 3D geological and geophysical modeling workflow, grounded in a recently acquired dataset comprising detailed geological field mapping and a campaign of 12 deep boreholes.

The modeling approach aims to integrate surface geological mapping, deep borehole data, and geophysical surveys into a coherent 3D environment. The adopted strategies enable the effective modeling of the structural complexity of the rock mass, addressing both the ductile metamorphic foliation trends and the brittle fracture networks (DFN) which control the hydraulic and mechanical behavior of the rock mass.

This study emphasizes that the utility of the 3D geological model extends beyond the geotechnical design of the underground caverns. The accurate spatial distribution of physical properties represents a fundamental requirement for the future functionality of the observatory. The model is designed to provide the necessary boundary conditions for estimating Newtonian Noise and assessing the site's seismic attenuation capabilities.

Consequently, the proposed framework envisages a multi-purpose 3D model capable of supporting civil engineering decisions while simultaneously characterizing the geological environment's impact on the scientific sensitivity of the gravitational wave experiments.

Keywords: Einstein Telescope, 3D Geological Modeling, Rock Mass Characterization, Geophysical integration, Discrete Fracture Network

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Energy Tunnel Assessment for the Einstein Telescope in the Euregion Meuse-Rhine (EMR-ET)

Davide Agnella[1], Antonio Dematteis[1], Hannes Krietsch[2], Fabrizio Zacco[1]

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Abstract

The Euroregion Meuse-Rhine Einstein Telescope (EMR-ET) project aims to establish a subsurface third-generation observatory for gravitational waves. The EMR-ET will consist of three nested gravitational-wave detectors arranged in an equilateral triangle at a depth of ~300 m. The facility will consist of three 10 km-long TBM-driven tunnels, a set of caverns of different geometries and dimensions around each corner of the triangle, and additional connection tunnels between the caverns. Cylindrical shafts and/or inclined tunnels will connect the surface to the subsurface facility. In this context, an evaluation of the thermal potential of underground structures is considered to assess the feasibility of heating and cooling buildings located near the tunnel entrance, or to help regulate internal temperatures within the EMR-ET. A potential of up to 6-10 MW with a corresponding energy of 15-20 GWh for heating and 30-50 GWh for cooling was assessed, depending on the length of the considered activated underground structures. The energy activation of EMR-ET's underground structures is a safe investment for the plant's lifetime, which can meet local heating and cooling energy needs, allowing for the reduction of greenhouse gas emissions, with clear environmental and social benefits even on a global scale, thus adding value to the project.

Keywords: Einstein Telescope, Energy tunnel, Gravitational waves, Gravitational waves, Heating-cooling

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Geotechnical Framework of Tunnels, Caverns and Shafts of the Einstein Telescope in the Euregion Meuse-Rhine (ET-EMR)

Hannes Krietsch[1], Antonio Dematteis[2], Davide Agnella[2]

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[2] Lombardi Engineering SA,, Bellinzona-Giubiasco, Switzerland

Abstract

The Einstein Telescope project aims to establish a subsurface, third-generation observatory for the detection of gravitational waves, representing a unique undertaking within the Euroregion Meuse–Rhine, should the project be awarded to this region. The facility is designed to comprise gravitational-wave detectors arranged in a triangular configuration at depth of 250-300 m. It will include three tunnels of approximately 10 km length, together with various caverns of different geometry and size located at the triangle corner points. Additional tunnels will link the caverns. Access from the surface will be provided by shafts and/or inclined tunnels. Geological formations consist predominantly of sedimentary sequences of Palaeozoic age. North–south-trending normal faults intersect older north-east–south-west-trending Variscan Front thrust faults in the perimeter. The geological, geomechanical and hydrogeological properties of the ground was up to now investigated in two geotechnical investigation campaigns. A third campaign is ongoing during time of writing. A set of representative ground types has been defined for different lithologies and weakness–fault zones. The in-situ stress field is heterogeneous, with the ratio of $\sigma H,max$ to σV varying between approximately 0.5 and 2.6. The underground excavations are expected to be placed within Famennian sandstone or solid Dinantian formations. For these units, the most likely ground behaviour during excavation is governed by gravity-driven block and wedge instability, with a low to very low potential for stress-induced spalling. The reliability of this geological and geotechnical model was assessed, which helped identify knowledge gaps, guide subsequent investigations, and mitigate the project's geological risks.

Keywords: Einstein Telescope, Geotechnical Characteristics, Ground Type, Behaviour Class

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Reflection Seismic and Ambient Noise Measurements as Well as Seismic Modelling in Support of the Einstein Telescope

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Abstract

The new second generation of gravitational wave detectors is designed to measure gravitational waves also in the low frequency range of ~2-10Hz. It is predicted that for this frequency range the sensitivity of these detectors is going to be limited by the so-called Newtonian noise, that for example gets induced by seismic ambient noise that includes this frequency band. To understand the impact of the seismic ambient noise on the operational window of the Einstein Telescope the current ambient noise has been and still is recorded using seismic broadband sensors installed at estimated target depth of the Einstein Telescope and at surfaces. In addition, ~400 3C 5Hz geophones were used to measure the seismic noise at the potential site of the Einstein Telescope in the Meuse-Rhine region. Next to measuring ambient noise it is equally important that the seismic noise and its influence on the Newtonian noise can be modelled. For this a 3D subsurface model was constructed based on the available geological and borehole information as well as reflection seismic data, which were acquired early 2025. This will allow us to predict for example whether the construction of a new wind turbine park in the Meuse-Rhine region might have a negative impact on the sensitivity of the Einstein Telescope and if so, it could help to identify mitigating approaches that might reduce their impact.

Keywords: Einstein Telescope, Near surface imaging, Reflection seismic, Ambient seismic noise, Seismic modelling

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Geological Subsurface Studies for Einstein Telescope

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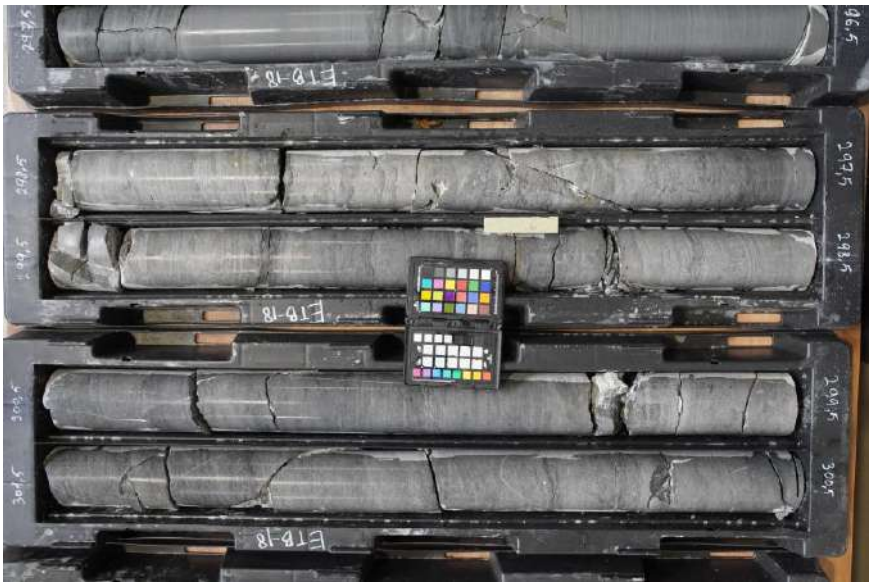
Abstract

In the search for the optimal location for the construction of Einstein Telescope in the Euregion Meuse-Rhine (EMR) over 20 exploratory boreholes were drilled in recent years retrieving over 4000 m of rock core from the Upper Devonian to Carboniferous succession. The target depth of the feasibility study for this large subsurface infrastructure lies between 0 and -100 m with respect to average sea level, and while the land surface is quite undulating the boreholes are drilled down to 250 to 400 m depth to reach that target depth. After coring, all boreholes were logged geophysically and packer tests were performed to investigate the physical and hydrogeological properties of the rock column. Additionally, in boreholes that represent potential vertex locations, in-situ stress tests provide information about the local magnitude and orientation of the horizontal stresses. After completion of the investigation programme, boreholes are transformed into either permanent piezometer locations using filters and electronic sensors or into permanent noise monitoring stations by installing a metal-free casing equipped with Distributed Acoustic Sensing (DAS) cables and seismometers. The rock cores from the boreholes are described for geological and geotechnical properties. While the analyses of measurements, observations and samples are ongoing, the initial results demonstrate that competent Famennian (Upper Devonian) sandstone is present at suitable depths in the region. A progress update from the project will be shared in this presentation.

Keywords: Einstein Telescope, rock core, international, subsurface, excavation



Famennian sandstone in core of borehole Henri Chapelle-1 (ETB-18)

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Seismic Interpretation in Support of 3D Modelling in the Euregion Meuse-Rhine for Einstein Telescope

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Abstract

Early 2025, a series of new 2D reflection seismic lines were acquired in the Euregion Meuse-Rhine for the site investigation for Einstein Telescope. Along and nearby these lines, data of several boreholes recently drilled for the project became available. The sonic logs in these boreholes allow for tying the lithostratigraphic interpretations of the boreholes with the seismic lines. In addition, legacy borehole and outcrop data in the area were converted into time-domain to support the seismic interpretation. The seismic interpretation of horizons and faults is key input for the 3D geological model of the study area. The most important lithological transitions have been consistently interpreted. These are the base upper Frasnian, top Famennian, top Dinantian and base Cretaceous. Most of these horizons represent (local) unconformities. In the central part of the study area, the quality of seismic sections is best as the top Dinantian and underlying horizons are not affected by major thrust faulting. To the north , faulting associated with the Asse Thrust Fault provides a very complex image of forethrusts in the north and backthrusts in the south. Here, Famennian sandstones were thrust over Namurian shales. To the south, a series of major thrust faults caused stratigraphic repetition of the Famennian sandstones, Dinantian limestones/dolostones and Namurian shales. The major thrust faults seem to be rooted here in the lower section of the Famennian interval, which explains why no strata older than Famennian are outcropping here.

Keywords: Seismic interpretation, Euregion Meuse-Rhine, Einstein Telescope, upper Paleozoic, thrust faults

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Einstein Telescope - 3D Engineering Geological Model

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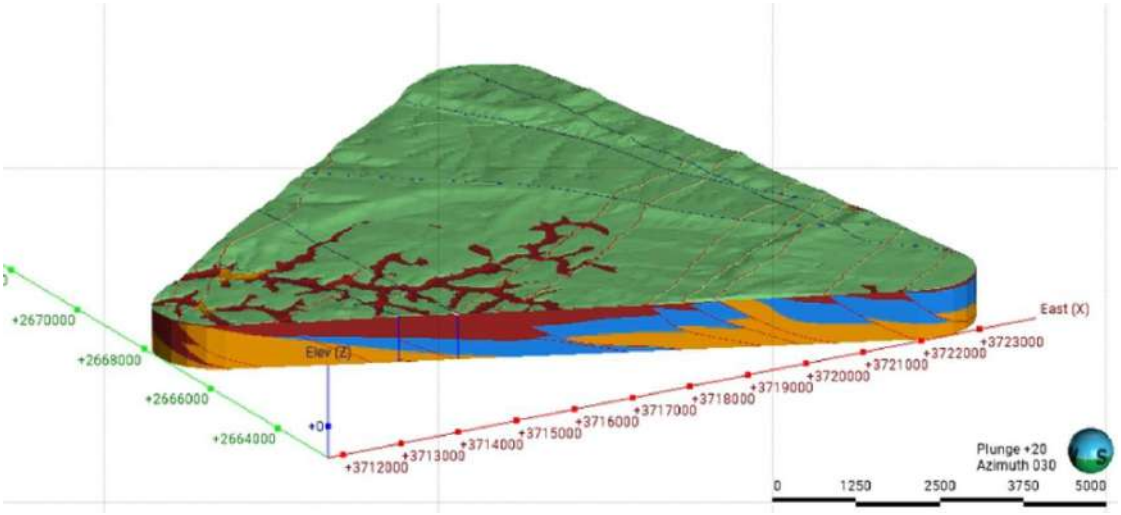
Abstract

As support of the Engineering Geological Model (EGM) a digital 3D geological model of the underground was developed, in which tunnels and caverns for the Einstein Telescope Euregion Meuse-Rhine are to be designed. The geological input comes from geological maps, boreholes, outcrops, cross sections and geophysical investigations, deriving from preexisting data sources or specifically produced for the project itself. Significant effort went into the compilation and analysis of this information leading to a conceptual geological model, which was then translated into the digital geological model. The main task of developing the digital geological model was performed in the implicit geological modeling software packages SKUA GOCAD and Seequent Leapfrog. The lithological and most relevant fault interfaces were built from borehole and particularly from extent reflexion seismics, they were modelled in GOCAD, and later assembled into a volumetric model in Leapfrog, to build a geological model around a specific detector setup with a kilometre-wide buffer. In the 3D geological model the planned ET tunnels and caverns are inserted together with the available geological information to find their optimized placement, given by the critical design aspects, which are geological-geotechnical design, hydrogeology and noise propagation. In an iterative optimization process tunnels and caverns are moved to find their best positions. Thanks to the implicit modelling approach, changes in geological, hydrogeological or noise-related input or project alignment is automatically updated in the model. The softwares were also used to create cross sections along the project alignment and to perform other exports which are used for further design purposes in the various disciplines.

Keywords: Einstein Telescope, 3D geological modelling



3D geomodel of an ET detector setup with a 1 km buffer. Inside this model, the geological and structural setting of the area can be analysed together with the tunnels and caverns of the ET project.

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Hydrogeological Characterization and Modelling as Part of the Feasibility Study of the Einstein Telescope in the EMR Region

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Abstract

The Einstein Telescope (ET) is an advanced third generation gravitational wave observatory currently in the planning stage in Europe. The ET project involves the construction of a triangular shaped underground facility with 10 kilometres long arms. At the corner points of the three arms, large caverns host the infrastructure needed for the spectrometers. The border region between the Netherlands, Belgium and Germany is considered a potential location and is now investigated in a feasibility study. Hydrogeological properties/conditions are one of the key elements for the design of the ET infrastructures but are also of primary importance to assess the potential impact of ET on the surrounding environment. Field data including groundwater pressure, hydraulic conductivities, groundwater quality at the depth of the future infrastructures are required. A monitoring network based on the new deep boreholes and existing wells has been designed to measure groundwater pressure. This network includes also multi-levels pressure probes to identify interactions between aquifers. In each new deep borehole, hydraulic tests including injection tests/pulse tests between packers have been carried out. Classical pumping tests are also foreseen in some of these boreholes. A 3D regional groundwater flow model has been developed to assess the regional impact of the ET infrastructures on groundwater levels and surface water baseflow. A locally refined model around the ET tunnel including a detailed representation of the cavern design, refined geology and expanded stream network has also been developed. Potential measures to mitigate the impacts of the infrastructure are also modeled.

Keywords: Einstein Telescope, Groundwater, Monitoring network, Modelling

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https://doi.org/10.59490/6ad298d24b8d546528fc6196.

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Chemical And Mineralogical Evaluation of Potential Use of Excavated Materials for the Einstein Telescope Candidate Site of the EMR

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Abstract

Euregion Meuse-Rhine (EMR) is a candidate for hosting the Einstein Telescope (ET). The sedimentary nature of EMR offers an exquisite opportunity to use excavated material for construction of the infrastructure itself. With sustainability at ET's core, careful evaluation of potential uses of excavated material is part of the current feasibility phase, where chemical and mineralogical composition is crucial.

68 samples were collected from 12 boreholes and outcrops representative of the regional stratigraphy. Total concentrations of 24 elements and LOI were measured, complementary to X-ray diffraction analysis and petrography, and evaluated against material standards and thresholds.

For shales, high S content (>1%) may compromise use of those stratigraphic intervals as aggregates, or as raw materials for ceramic bricks or cement clinker. Slightly elevated concentrations of Potentially Toxic Elements (PTEs) correlate to sulfide presence. Depending on intended use, however, PTE concentrations remain well below threshold values and do not jeopardize the most likely use of shales for landscaping or backfilling. One sample did show increased Cr concentrations (>900 mg/kg) and requires detailed evaluation. Bound construction material applications require further environmental compatibility testing by leaching tests.

For limestones, chemical analyses confirm their pure composition and high potential as aggregates, in cements and even chemical industry. A dolostone sample, however, shows elevated Pb, Zn and S related to sulfides, known to occur along veins. While current measured values are below industrial soil thresholds, further study is recommended.

Composition of sandstones-siltstones, the main targets for hosting ET, supports their highest potential use as rock aggregates.

Keywords: Einstein Telescope, Use of excavated material, Sustainability, Chemistry

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Subsurface Geological Insights from Deep Boreholes in the Framework of the Einstein Telescope Feasibility Study (Belgium–Netherlands–Germany Border)

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Abstract

The Einstein Telescope feasibility study requires extensive subsurface investigations near the EMR region. Thirteen deep boreholes—each approximately 400 meters deep—were drilled to characterize the local geological and geotechnical conditions. Issues related to drilling, core and box handling, and transportation have affected the factual data collection process and, hence, the consistency of the database.

To improve the completeness and reliability of the database, a dedicated QA/QC methodology has been developed. This method consists of a detailed comparison of BHTV and rock cores, which allows for core depth correction. For each borehole, dedicated 'strip logs' were produced, which helped—to a large extent—to differentiate anthropic factors (such as induced fractures) from geological ones. This method has therefore partially compensated for the absence of factual drilling data.

Geological core logging, as well as structural and rock mechanics analyses, revealed a complex subsurface primarily composed of Famennian and Namurian sedimentary rocks, affected by thrust and back-thrust fault zones.

These new geological and geotechnical findings from the boreholes not only support the assessment of the site's suitability for the Einstein Telescope infrastructure, but also provide valuable constraints on the tectonic evolution of the area and, in particular, enhance the understanding of the regional Variscan suture geometry.

Keywords: Einstein Telescope, deep boreholes , engineering geology, Variscan tectonics, geological-geotechnical logging

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Assessment of the Lusatian Granodiorite for the Construction of the Einstein Telescope

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Abstract

The Einstein Telescope (ET) is a next-generation underground gravitational wave observatory designed to operate at depths of 200–300 m, where seismic, thermal, and Newtonian noise are significantly reduced. The facility requires a geologically stable, well-characterized host rock over a large area of 100–225 km². The Lusatia (Lausitz) region in eastern Germany is one of three candidate sites under evaluation alongside Sardinia and the Euregio Meuse-Rhine. This contribution presents results from the exploration and construction assessment of the Lusatian Granodiorite as a potential host rock.

The subsurface comprises Quaternary and Tertiary cover sediments, kaolin horizons, and weathered zones overlying a crystalline basement of primarily granodiorite. A key challenge is characterizing the spatial distribution of weathering, hydrothermal alteration, and kaolinization, which critically affect rock mass quality, hydraulic behavior and the final functionality of ET.

The investigation includes a core drilling campaign of seven boreholes to 250 m depth each, enabling identification of five principal geotechnical units representing the granodiorite's variability and structural inventory. Laboratory and in-situ measurements provide mechanical and hydraulic properties as well as rock mass quality assessments. A 3D bedrock model was derived by interpolating data from several thousand documented drill holes correlated with newly drilled cores. Regional characterization is further supported by geophysical methods—seismics, gravimetry, and geomagnetics—as well as geochemical analyses, enabling spatial extrapolation of subsurface structures.

Groundwater modelling integrates observed hydrogeological conditions into regional and detailed site-scale models, focusing on alteration zones within the granodiorite as potential hydraulic pathways. Scenario models assessed groundwater inflow to caverns representing the ET infrastructure and the influence of these caverns on groundwater conditions in the overlying sedimentary layers.

The comprehensive multi-disciplinary dataset provides a critical basis for assessing the suitability of the Lusatian Granodiorite as an ET host rock and for guiding further site investigation activities.

Keywords: Einstein Telescope, Lusatia, Characterization, Granodiorite

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Challenges and Climate Related Issues from Geo-Hazards Threatening Sustainable Development of Bangladesh - Some Geological Engineering Solutions

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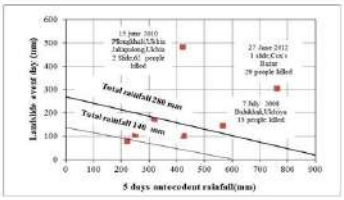
Abstract

Abstract

Bangladesh is a South Asian Tropical Monsoonal Country and is facing many climate-related hazards and disasters every year which is a big challenge for the current sustainable development of Bangladesh. Every year casualties due to hazards and disasters are increasing and affecting the food security, livelihood, health, and economic growth of the country. In very recent years Geological Engineering is playing a vital role in managing climate-related issues, challenges, and hazards to become a developed nation by 2041. With the great initiatives of the GoB (Govt. of Bangladesh), several measures were taken at the policy level to construct climate resilient housing, build a sustainable community and society to become the world leader in managing hazards & disasters. Some climate-related hazards, modeling results, hidden ground-related problems, and mitigation measures are also discussed in this paper to achieve the UN (United Nations) SDG's goals. To manage pore water pressure, piezometers were installed and drainage were allowed along the hilly area, river bank, landslide prone sites to control river erosion, rainfall induced landslide hazards to reduce risk. Several ground improvement techniques such as compaction grouting, dynamic compaction and deep soil mixing (DSM) methods were used to improve the soft ground conditions and to reduce liquefaction risks in many mega projects of Bangladesh. Geological Engineering is playing a vital role in the societal and sustainable development of Bangladesh. Recommendations have also been made to improve the Geo-engineering curricula in the Universities by introducing geotechnical instrumentations and early warning monitoring system (EWS) to manage hazards and disasters and to build a smart resilient society and smart Bangladesh to meet the new challenges of the 21st century under the current context of global climate change.

Keywords: Climate Change , Geohazards, Challenges , Sustainable Development, Engineering Geology



Rainfall Threshold Line The SE Fold part of Bangladesh (Hossain et al., 2023)

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Drowning Deltas: Land Subsidence, Elevation Change and Relative Sea-Level Rise in Sinking Coastal-Deltaic Areas

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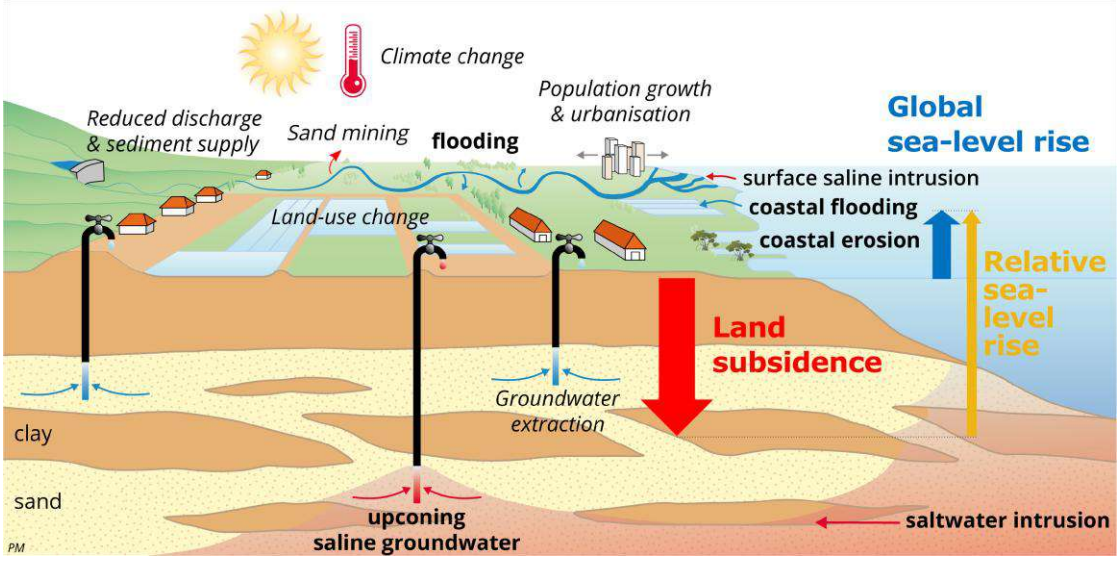
Abstract

Coastal land subsidence worldwide is drastically increasing due to anthropogenic activities, resulting in unprecedented high rates of relative sea-level rise. Land subsidence processes are a main driver of coastal elevation loss, rendering sinking coastal-deltaic areas increasingly exposed to coastal flooding from high tides, extreme wave events and other cyclone-related hazard, and ultimately permanent drowning. This contribution provides an overview of ongoing research towards coastal-deltaic land subsidence and elevation change dynamics for study areas around Asia, a.o. the Mekong (Vietnam), Chao Phraya (Thailand), Ganges-Brahmaputra-Meghna (Bangladesh) and Ayeyarwady (Myanmar) deltas and the north Manila Bay area (Philippines). Our cross-disciplinary, integrated approach unravels the drivers of deltaic subsidence, links subsurface characteristics (i.e. geology, hydrogeology, geomechanics, collected with Large Language Model AI tools) and subsurface processes (groundwater flow, aquifer-system deformation) in numerical models and enables process-based, science-informed quantifications and projections of land subsidence rates. In combination with best-available elevation data, these quantifications are used to assess ongoing and future elevation dynamics and project future relative sea-level rise and coastal hazard exposure. Our results reveal the importance of subsurface dynamics to create accurate projections of future delta elevation evolution and assess increased coastal hazard exposure following relative sea-level rise. Our collective, interdisciplinary research efforts, integrating processes of land subsidence, elevation change and relative sea-level rise, provide the fundamental basis to achieve a holistic understanding of sinking coastal lowlands and drowning deltas. This thorough understanding, quantifications and projections of interacting physical and human mechanisms will support risk-informed decision-making and effective adaptation and mitigation strategies development.

Keywords: Land subsidence, Deltas, Relative sea-level rise, coastal elevation, dynamic elevation change



Drivers and impacts in sinking coastal-deltaic areas, where relative sea-level rise is often dominated by land subsidence (modified after Minderhoud, 2019)

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Prediction of Brittle Rock Failure Severity of Underground Powerhouse of Shuangjiangkou Hydropower Station Based on Rock Mass Failure Process

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Abstract

Based on field surveys of brittle failure occurred in the underground powerhouse of Shuangjiangkou hydropower station from Qinghai-Tibet Plateau, four types of brittle rock failure with different failure mechanisms are classified as: Type I, Stress-induced spalling; Type II, Stress-induced buckling; Type III, Stress-induced shear, and Type IV, Stress-structure coordinated failure. The brittle rock failure severity can be classified into four grades: minor, moderate, major, and severe. If there is no discontinuity being developed in the rock mass, spalling is of minor brittle failure, followed by buckling of moderate brittle failure. The V typed pit with shear failure is major or severe brittle failure. The severity of each type of brittle rock failure is classified by the ratio of failure depth to tunnel radius, and the boundary value will be upgraded by one level if there are discontinuities developed in rock mass. When minor or moderate brittle failure damage severity occurs, the stress in the surrounding rock mass should surpass the crack initiation stress σci of rock mass. However, shearing failure leads to major and severe brittle rock failure, i.e., rockburst. At these stages, the crack damage stress of the rock mass, denoted as σcd, is surpassed. Additionally, the assessment of brittle rock failure severity necessitates careful consideration of the integrity of the rock mass under study. By applying the criteria proposed, various areas with different prediction levels of damage severity have been identified, and it has been observed that all brittle rock failures occurred within the predicted area.

Keywords: rock burst, brittle failure, Progressive failure, High geostress, Underground excavation

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Lithological Weakness Meets Geomorphic Activation: Terrain Controls on Red-bed Landslide Clustering in Southeastern Tibet

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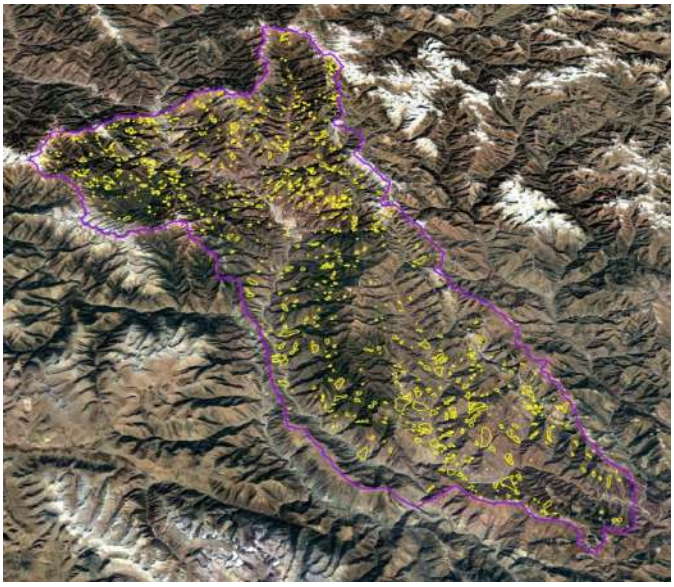
Abstract

Red beds, composed of clay-rich mudstone, siltstone and sandstone, are recognized as weak and water-sensitive strata prone to weathering, disintegration and strength loss. In southeastern Tibet, tectonic deformation, faulting and river incision have created valley systems in which red-bed slopes are exposed. Along the Chamdo–Chaya reach of the Lancang River, remote-sensing interpretation and field checks identified 1082 landslides in this red-bed valley system. The inventory reveals an uneven pattern: failed slope sectors occur adjacent to stable ones within the same red-bed stratigraphic belt. This contrast shows that lithology alone cannot explain where failures concentrate. This study aims to identify the terrain conditions under which weak red beds become landslide-prone in a plateau valley. We examined 13 topographic, lithological, structural, hydrological and surface-environmental factors, and compared four machine-learning models to test the robustness of the observed pattern. The landslide inventory defines a discrete terrain envelope, with failures clustering at elevations of 3400–4200 m, slope angles of 15–34°, relative relief of 800–1400 m, distances of less than 5 km from faults and 3 km from rivers, and intermediate wetness conditions marked by TWI values of 4–8. We interpret this pattern as the co-location of material weakness and geomorphic activation: red beds provide degradable materials, river incision supplies relief and basal unloading, faults increase rock-mass damage, and hillslope water accelerates weathering and strength loss. This terrain-envelope framework offers transferable rules for identifying hazardous red-bed slope belts along hydropower, reservoir-bank and railway corridors in southeastern Tibet and similar active mountain belts.

Keywords: Red-bed landslides, Landslide clustering, Geomorphic activation



Remote-sensing interpretation and field validation identified 1082 red-bed landslides clustered along the Lancang River and its major tributaries in the Chamdo–Chaya valley system, southeastern Tibet.

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Overview and Typical Cases of Deep Engineering in China

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Abstract

Advancing into the Deep Earth has become a crucial direction for China's future scientific and technological research and engineering practice. This paper introduces the depth range and connotation of deep engineering, as well as the current status of China's deep engineering development and its international standing. It presents the typical deep engineering cases in China: China's first 10000-meter scientific exploration well (named Shenditake 1, 10910m), the deepest and largest ultra-deep underground lab (China Jinping Underground Laboratory, with a rock cover of 2400m), deep resource development projects (6000m deep oil field mining, 1500m deep coal mining), deep-earth space utilization (million tons CCUS projects), and so on. This study analyzes the characteristics of the disaster-prone environmental conditions in deep engineering projects, which are characterized by "three highs and one disturbance": high geo-stress, high ground temperature, high seepage pressure, and strong tectonic fracture zones. It provides an overview of six types of deep engineering geological hazards: rock/coal-rock outburst, mining bump/earthquake, water/mud inrush, large deformation of soft rock, gas outburst, and roof collapse. This paper focuses on a case study of an extremely large-scale water inrush in a structurally fractured zone during deep coal mining. It analyzes the process of "seepage transformation" and water inrush mechanism in fault and collapse column structural fracture zones under high permeability pressure, as well as post-disaster rescue and advance disaster prevention and control technologies.

Keywords: Deep engineering, Tthree "highs" and one "disturbance", Deep engineering geological hazards, Deep engineering cases, Deep mining water inrush

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Urban Metro Construction in China: General Overview and Typical Cases of Geohazard Challenges

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Abstract

As a vital underground transportation artery of modern cities, metro systems play a pivotal role in optimizing urban spatial layouts, balancing regional resource allocation, and mitigating urban traffic congestion. After nearly six decades of rapid development, 43 cities in China have established urban metro networks with a total operating mileage exceeding 10,000 kilometers, ranking China first globally in terms of urban metro track length. However, metro construction in China is generally threatened by complex geological hazards, including land subsidence, ground fissures, active faults, karst landforms, collapsible loess, and soft soil strata. This keynote first reviews the evolution and current status of urban metro construction in China. Taking Xi'an, the time-honored ancient capital of thirteen dynasties, as a typical case, it systematically introduces core disaster prevention and mitigation technologies for metro-induced land subsidence and ground fissures developed by the research team of Chang'an University. Long-term InSAR and surface deformation monitoring clarifies the distribution and evolutionary trends of subsidence and fissures in Xi'an. A series of large-scale model tests reveal the catastrophic mechanical mechanisms of linings for mined and shield tunnels under such geo-hazard conditions, establishing a key technical system for tackling land subsidence and ground fissure in metro tunnels. This presentation concludes outstanding critical engineering geological bottlenecks and outlines frontier research areas: intelligent perception of long-term operational catastrophes, multi-driving-force coupled disaster mechanisms, and reinforcement-based hazard mitigation. The research provides a solid theoretical foundation and technical reference for metro construction and safe operation & maintenance under extreme climates and complex geological conditions.

Keywords: Metro tunnel, Land subsidence, Ground fissure, Catastrophic mechanical mechanisms, Countermeasures



Urban Metro Construction and Typical Cases of Geohazard Challenges in China

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Engineering Geological Challenges and Representative Practices in China's Mountain Tunnels and Underground Caverns

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Abstract

China's mountainous terrain, shaped by tectonic activity along the Tethyan–Himalayan orogenic belt and the uplift of the Tibetan Plateau, presents some of the world's most challenging conditions for underground construction. Over the past three decades, China has developed the largest tunnel and underground cavern system globally, encompassing over 35,000 km of highway tunnels, 23,000 km of railway tunnels, and underground hydropower installations with a total capacity of over 200 GW. These projects have been constructed under extreme geological conditions, significantly advancing engineering geology in practice and research. Key challenges include high geo-stress and rockburst, which were observed in deep tunnels like the Bayu Tunnel (buried >2,000 m) and the Jinping II Hydropower Station headrace tunnels (stress: ~70 MPa). These sites contributed extensive field data to better understand rockburst mechanisms and microseismic precursors. Large deformation in squeezing ground has also been prevalent, with the Wushaoling Tunnel and numerous Sichuan–Tibet Railway tunnels prompting innovations in adaptive support design and large-deformation control. Water and mud inrush, particularly in karst and fault-controlled aquifers, remain persistent risks. The Ningnan Tunnel experienced severe water inrush and became a model for grouting-based pre-treatment. Geothermal hazards, such as those in the Sangzhuling Tunnel (rock temperature: 89.9°C) and Gaoligongshan Tunnel, have driven improvements in tunnel thermal risk management. Gas hazards in non-coal strata were addressed through real-time monitoring and sealed-ventilation systems in the Meilingguan Tunnel. Underground hydropower caverns, such as those in the Jinping I power stations (maximum stresses: ~35.7 MPa) and the Shuangjiangkou Hydropower Station (37.8 MPa), have further advanced the understanding of stress-path-dependent support design and progressive failure mechanisms in high-stress environments. Collectively, these projects have enhanced practical and scientific approaches to underground engineering in extreme geological conditions. The experience and innovations provide essential guidance for infrastructure development in tectonically active mountainous regions worldwide.

Keywords: Mountain tunnels, Underground caverns, Extreme geological environment, Engineering geohazards, Risk control

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Overview of Marine Engineering Geology in China and Typical Cases

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Abstract

China is a leading nation in marine engineering. To date, China has completed world-class cross-sea cluster projects such as the Hong Kong–Zhuhai–Macao Bridge and the Shenzhen–Zhongshan Link. Meanwhile, significant breakthroughs have been achieved in natural gas hydrate production tests in the South China Sea, and exploration and pilot mining of deep-sea polymetallic nodules are progressing steadily, reflecting an overall acceleration in marine resource development and engineering utilization. However, the complex and variable geological conditions of the seabed pose severe challenges to the design, construction, operation, and maintenance of engineering structures. This report systematically reviews the major advances and representative case studies in the field of marine engineering geology in China, with a focus on a series of China developed in-situ monitoring and testing technologies and their applications. For shallow waters (0–5 m depth), an in-situ monitoring system for three-dimensional seabed deformation and movement was developed, enabling real-time investigation of seabed deformation and sliding. For deep waters, the world's first in-situ long-term monitoring system for complex deep-sea engineering geological environments was developed, which continuously acquired 12 months of engineering geological parameter data at a water depth of 1500 m in the South China Sea hydrate production test area. For deep-sea mining environments, an in-situ monitoring device for plume effects from polymetallic nodule mining was developed and has been deployed for four consecutive years at a water depth of 5000 m in the Pacific nodule belt, achieving simultaneous in-situ observation of plume concentration and redeposition thickness. In addition, a full-ocean-depth in-situ testing device for soil mechanical properties was developed, with a maximum operating water depth of 11,000 m, capable of accurately determining the mechanical properties of deep-sea soft clay.

Keywords: Marine engineering geology, In-situ monitoring, Submarine disaster, Ocean engineering, Marine resource exploitation

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Overview and Typical Cases of Rockfall Prevention Engineering in China

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Abstract

Rockfall disasters pose severe threats to infrastructure and public safety across China, where steep topography, active tectonic fault zones, fractured rock masses, and intense hydrometeorological conditions converge to create highly susceptible environments. This paper provides a comprehensive overview of rockfall prevention engineering in China, tracing the evolution of mitigation paradigms from rigid barrier systems reliant on heavy structural resistance through flexible energy-absorbing protection systems characterized by lightweight, adaptable, and high energy-dissipation capacity, to the current smart resilience-based management framework integrating Internet of Things, artificial intelligence, and big data analytics for proactive hazard perception and intelligent response. Three representative case studies illustrate the diversity and adaptability of contemporary prevention approaches. The Tibet Central Power Grid Project demonstrates the deployment of satellite InSAR, UAV-borne LiDAR, and oblique photogrammetry for wide-area hazard identification along high-altitude transmission corridors, complemented by reinforcement and interception measures including novel multi-stage buffered rockfall barriers. The Liangshan ecological–geotechnical collaborative protection system integrates vegetation restoration with structural engineering to construct a three-dimensional "upper interception, middle stabilization, lower energy dissipation" mitigation framework within mountainous small catchments. The Three Gorges Reservoir Area case addresses rock mass degradation driven by periodic reservoir water-level fluctuations, establishing a lifecycle risk management system that combines point-specific engineering remediation with grid-based smart monitoring and early warning. The synthesis underscores a strategic transition from passive response to proactive, intelligent, and resilient disaster management, underpinned by precise hazard identification, multi-level structural protection, and dynamic risk assessment.

Keywords: rockfall prevention, flexible protection system, ecological–geotechnical collaboration, engineering geology

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Movement Mechanisms and Impact Range Assessment of High-Elevation Long-Runout Landslides in Southeastern Tibet

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Abstract

High-elevation long-runout landslides represent one of the most consequential hazard types in southeastern Tibet, posing significantly threats to transportation corridors, settlements, river channels and major engineering projects. The behavior of these landslides is controlled by coupled triggering factors including ancient landslide reactivation, structural preparation, hydroclimatic weakening, and involves complex physical mechanisms that influence their impact range, such as basal erosion, pore-pressure generation, and entrainment. This paper collects recent findings from several representative landslide cases, integrating fields investigations, physical experiments and AI-based prediction methods to examine the movement mechanisms and assess potential impact ranges. The case studies show that high-elevation long-runout landslides may evolve through different pathways, ranging from localized creep of ancient landslide deposits to structurally prepared slope failure and rapid impact-entrainment cascades. Flume impact experiments reveal transient compression, high-frequency particle collisions, basal erosion and entrainment, while ring shear tests indicate two major mechanical pathways: drained residual sliding in slow-moving ancient landslides and undrained impact-induced weakening in rapid long-runout failures. Based on these findings, a mechanism-informed assessment framework is proposed by linking landslide detection, activity diagnosis, mechanism interpretation and rapid runout prediction. An AI-based landslide detector based on segment anything model (LSDSAM) supports regional landslide identification from remote-sensing imagery, while a physics-informed runout emulator enables fast prediction of potential impact ranges. This integrated pathway provides practical support for hazard assessment of high-elevation long-runout landslides in southeastern Tibet.

Keywords: high-elevation long-runout landslide, Southeastern Tibet, ring shear test, artificial intelligence

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Remote sensing for landslide investigations: A progress report from China

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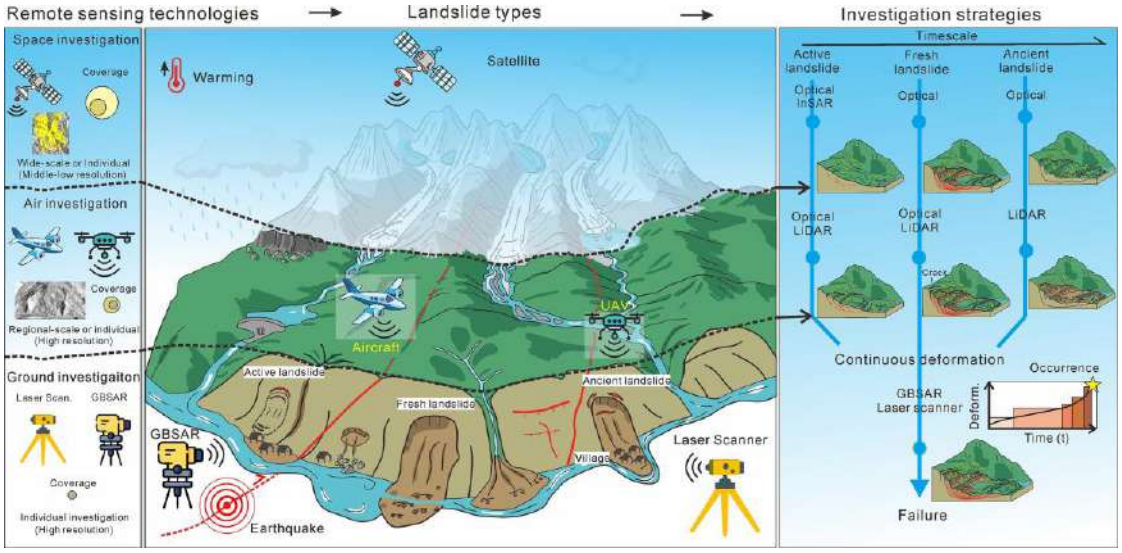
Abstract

China has a substantial land area situated in regions prone to landslides, where remote sensing technologies are increasingly becoming the preferred tools for landslide investigation and monitoring. Although significant advances have been made in both the development and application of these technologies within China, a systematic review summarizing their use is still lacking. To address this gap, we provide a comprehensive overview of the current applications of Synthetic Aperture Radar (SAR), optical remote sensing, and laser-based technologies in China, covering their deployment across space-borne, air-borne, and ground-based platforms.

Multi-temporal optical imagery and time-series SAR data are commonly employed to detect active landslides over interannual to monthly timescales. In contrast, the latest optical images and SAR intensity data are primarily used for mapping fresh landslide events, particularly those triggered by earthquakes. LiDAR technology has seen widespread adoption in the identification of ancient landslides. By evaluating the strengths and limitations of each technique, we propose an integrated space-air-ground collaborative investigation strategy aimed at enhancing the early identification and early warning of landslide hazards.

Furthermore, we suggest that future developments are likely to move toward a comprehensive investigation framework that combines remote sensing with multidisciplinary approaches, including geology and geophysical exploration. Since remote sensing can only provide surface-level information, a complete understanding of landslide mechanisms ultimately requires additional data on geotechnical parameters, subsurface geological features, and in situ field conditions.

Keywords: Landslide investigation, Remote sensing technologies, Investigation strategies, China



An integrated space-air-ground investigation strategy for landslide early identification, monitoring, and early warning.

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Engineering Geological Challenges and Solutions in Permafrost and Seasonally Frozen Ground Engineering in China

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Abstract

China has nearly 70% of its territory classified as cold regions, including 2.15 million km² of permafrost and extensive seasonally frozen ground. Engineering construction in these areas faces severe geological hazards, including ice-rich permafrost, frost heave, thaw settlement, thermokarst, and freeze-thaw induced slope instability. This paper reviews the major engineering geological problems and mitigation strategies developed over decades of practice. For permafrost regions, the Qinghai-Tibet Railway (QTR)—with 550 km built on warm, ice-rich permafrost—exemplifies the paradigm shift from passive insulation to the "active cooling" approach. Engineered measures such as crushed-rock embankments, ventilation ducts, thermosyphons, and sun-shading boards utilize natural cold energy to lower ground temperatures and maintain permafrost thermal stability. Eleven years of monitoring confirm that properly designed cooling structures can reduce ground temperatures by 1–3°C and effectively control thaw-related settlement. For seasonally frozen ground, represented by the Harbin-Dalian High-Speed Railway, key countermeasures include non-frost-susceptible fill materials (with fines content <5%), insulation layers, waterproofing geomembranes, and drainage systems to control moisture migration. Ongoing challenges include accelerating permafrost degradation driven by climate warming (0.3–0.4°C/decade on the Qinghai-Tibet Plateau), increasing thermokarst hazards, and the need for adaptive maintenance strategies. Future research must address long-term performance under warming scenarios, develop enhanced cooling techniques for expressways, and revise frost susceptibility criteria for high-speed railways. This experience provides valuable references for cold-region engineering worldwide under a rapidly changing climate.

Keywords: Permafrost engineering, seasonally frozen ground, active cooling, Qinghai-Tibet Railway, frost heave

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Rock Friction Reshaped by Extreme Environments

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Abstract

Extreme environments, particularly high temperatures and pressures, substantially modify the frictional stability and energy release of rock fractures, yet how thermal damage controls fault-slip recurrence and rupture energy remains poorly understood. Here, the frictional slip of granite fractures were investigated, subjected to temperatures of 25–600 °C, covering conditions relevant to deep geothermal systems and the quartz α–β transition. Stepped-velocity friction tests were conducted to characterize rate- and state-dependent friction, followed by stepped-unloading tests on fractures treated at 300 and 600 °C under comparable stiffness ratios. Thermogravimetric analysis, scanning electron microscopy, and high-temperature hardness measurements were used to characterize thermal degradation and its effects on real contact area. An energy-budget analysis quantified the energy required for contact recovery and the radiated energy released during slip. Increasing temperature enhances velocity-weakening behaviour and increases the characteristic slip distance, while thermal microcracking and mineralogical changes substantially weaken asperity contacts. Despite comparable stiffness ratios, the 600 °C fracture exhibits larger stress drops, longer and more irregular recurrence intervals, and an earlier transition from periodic to complex slip. Thermal damage increases the elastic energy required to reconstruct the fragmented contact network while reducing radiated energy per unit contact breakage, creating an energy imbalance that promotes sequential and aperiodic slip. Comparison with repeating earthquakes further reveals a consistent association between elevated temperature, prolonged recurrence, and greater energy accumulation. These findings identify temperature-dependent asperity contact evolution as a fundamental control on fault reactivation, slip recurrence, and energy release in high-temperature fractured rocks.

Keywords: Extreme environments, Friction slip, Rock fracture, Energy release , Thermal degradation

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Grounded in Resilience: Harnessing Engineering Geology and Emerging Technologies for Disaster Risk Reduction

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Abstract

Engineering geology lies at the heart of effective disaster risk reduction, linking the observation of natural processes with the development of resilient infrastructure and communities. This keynote explores how engineering geological knowledge can transform emerging technologies into reliable, practical and decision-oriented solutions without bypassing or oversimplifying what lies beneath the ground. This process rests on three fundamental questions.

First: What is the ground made of, and how is it structured? Understanding geological genesis and evolution allows us to define the ground profile and develop an engineering geological model that captures the complexity, variability and uncertainty of subsurface conditions.

Second: How will the ground behave? Identifying potential failure mechanisms and the geological "keys" controlling them enables more reliable interpretation of present conditions and prediction of future hazards.

Third: Which parameters are critical for design? Representative values must translate geological reality into meaningful analytical and numerical models. Weaknesses in the geological model inevitably propagate into behavioural assessments, parameter selection and risk-reduction decisions.

Remote sensing using UAVs, terrestrial LiDAR and satellite imagery, together with advanced site investigation, geostatistics, machine learning and automated classification, provides unprecedented volumes of high-resolution data. However, without understanding subsurface structures, potential failure surfaces and the mechanisms governing their evolution, even sophisticated datasets may be misinterpreted.

Emerging technologies and artificial intelligence cannot replace geological reasoning and informed professional judgement. Their full value is realised when combined with field observation, site investigation and robust geological modelling. Through this integration, engineering geology can lead the development of realistic and resilient solutions that genuinely reduce disaster risk.

Keywords: Disaster risk reduction, Emerging technologies, Engineering geological modelling, Ground behaviour, Engineering geology

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Disaster Effects of Climate Change in High Mountain Asia

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Abstract

High Mountain Asia (HMA) exhibits significant warming, variable precipitation trends, and intensified meteorological extremes. Rapid cryosphere thawing is altering the frequency and magnitude of natural hazards. This review examines the impact of climate change on HMA hazards, including phenomena, mechanisms, and consequences: 1. Extreme meteorological hazards are exhibiting increased frequency, while accelerated cryospheric melting has amplified the occurrence and magnitude of snowmelt-induced flooding. 2. Mass movements are intensifying due to triggers like glacier debuttressing and shifting thermal-hydrological regimes. 3. Increased active-layer detachment and retrogressive thaw slumps, thaw settlement, and thermokarst lakes are damaging infrastructure in permafrost zones. 4. Cascading hazards, like glacial lake outburst floods (GLOFs) and avalanche-induced mass flow, amplify the destructive potential relative to the primary hazard event. 5. Accelerated slope destabilization and amplified sediment yield in highland regions may cause far-reaching catastrophic impacts on downstream lowlands. Addressing escalating hazards in HMA requires overcoming critical challenges, including understanding the evolution and mechanisms of hazard-prone systems, coupling thermo-hydro-mechanical processes in multiphase flow models, predicting catastrophes induced by extreme climate events, and understanding cross-altitude hazard propagation mechanisms under climate change.

Keywords: High-mountain Asia, Climate change, Cryosphere degradation, Nature hazards, Disaster risk

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The Long-Term Evolution of Paleo-Landslides: Insights From the Petacciato Landslide Basin

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Abstract

Many slow-moving and deep-seated landslides across the Italian peninsula were first triggered centuries to millennia ago under geomorphological conditions different from those prevailing today. These paleo-landslides continue to evolve through recurrent reactivations, often accompanied by progressive failure. Their evolution is governed by the interaction between pre-existing shear bands inherited from past failures and evolving hydrogeological and geomorphological boundary conditions. The Petacciato landslide basin, one of the largest along the Adriatic coast, comprises landslides nested within a large deep-seated roto-translation paleo-landslide, originally triggered by marine erosion during the Quaternary. Since then, recurrent reactivations with sudden accelerations have repeatedly damaged the strategic transport infrastructure linking southern and northern Italy. Since the early twentieth century, reactivation has been confined to the inland sector of the paleo-landslide, leading to the development of a new shear band extending to the present-day coastline. Current instability is controlled by pre-existing deep shear bands and high piezometric heads at large depth. The recurrence of reactivations between late winter and early spring suggests that cumulative seasonal rainfall is a key trigger of slope instability. The Petacciato case demonstrates that the evolution of paleo-landslides is not limited to repeated movement along inherited slip surfaces, but involves the progressive reorganisation of the landslide system in response to evolving geo-hydro-mechanical conditions driven by climate and erosion. More broadly, it highlights how the long-term evolution of paleo-landslides results from the interaction between inherited mechanical weaknesses and changing environmental forcing.

Keywords: paleo-landslide, slow-moving, clay succession, coastal erosion

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Risk-Based Geotechnical Design in the Oosterweel Link (Belgium): Impact of Excavation Methodology on Geomechanical Behaviour of undrained Boom Clay

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Abstract

The Oosterweel Link in Antwerp, Belgium, is aiming to complete the Antwerp Ring Road through a network of tunnels in a densely urbanised environment. The major excavation works go down to 26m below ground surface at two different locations : along the Albert canal (KZT) and crossing the Albert canal (FORK). Both structures are excavated in the similar Antwerp subsurface, characterised by alternating Quaternary deposits, tertiairy sands and the tertiairy Boom clay formation. Despite being developed within the same project and geological settings, risk-based geotechnical design leads to different engineering solutions. The risk-profiles are dominated by the deformation management in proximity to sensitive constructions, limitations in available buildingspace, maintaining the operational functionality of the Albert Canal, restricting construction logistics and economical risks. Along the Albert canal, the tunnel is realised using a conventional bottom-up methodology. The excavation is realised under the support of diaphragm walls and three levels of struts. Upon reaching the foundation level, the tunnel is progressively constructed from the bottom up. The crossing of the Albertcanal is realised using a top-down methodology. Following the installation of diaphragm walls, the roof slab is constructed and the ground surface reinstated. Excavation subsequently progressed underneath the completed roof in stages, allowing intermediate slabs and finally the base slab to be constructed as the excavation advanced. The different construction methodologies induce different geotechnical stress paths in the underlying Boom clay. The bottom-up construction reestablishes the vertical loading conditions. The top-down methodology maintains a reduced stress level in the undrained Boom clay for a significantly longer period. These different construction methodologies provide the opportunity to evaluate the influence of stress path on the geomechanical behaviour of heavily overconsolidated clay within the same geological setting.

Keywords: deep excavations, risk-based design, Oosterweel-Link, urban infrastructure, geotechnical risk management

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Hans Cloos Lecture 2026 - From Rock to Resource: Engineering Geology for a Sustainable and Resilient Built Environment

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Abstract

Geological materials underpin the built environment, yet their extraction and use must increasingly be evaluated through the combined lenses of resource efficiency, environmental responsibility, resilience and circularity. This Hans Cloos Lecture presents a rock-to-resource framework demonstrating how engineering geology can connect geological understanding with material performance, resource confidence, extraction efficiency and sustainable resource use. Dimension stone and aggregate deposits are inherently variable. Their value and behaviour are controlled by lithology, mineralogy, texture, discontinuities, alteration, weathering, hydrogeological conditions and durability. An engineering geological model integrating these factors with laboratory and field data is therefore essential for predicting material quality, managing geological uncertainty, guiding selective extraction and quarry design, and assessing recoverable resources. The same framework supports slope stability, environmental protection and early identification of hazardous or deleterious constituents. These principles are directly relevant to international mineral-resource reporting, including CRIRSCO work on dimension stone and aggregates. For these commodities, resource confidence must reflect not only geological volume or tonnage, but also material quality, extractability, processing behaviour, block recoverability and end-use requirements. Resource efficiency further requires reconsidering quarry and processing residues. Materials regarded as waste may often be redirected to aggregates, road construction, fill or secondary raw materials. A near-zero-waste quarry therefore treats the deposit as a source of multiple material streams rather than a single product. By integrating geological characterisation, engineering performance, risk, durability, circularity and resource reporting, engineering geology can provide the scientific basis for more responsible resource development and a sustainable, climate-resilient built environment throughout the full material life cycle.

Keywords: engineering geology models, resource characterization, aggregates and stone production , near-zero-waste quarry , circular economy

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Engineering-Geological Challenges in the Construction of the Brenner Base Tunnel

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Abstract

With a length of 55 km—and 64 km including its connection in the Inn Valley—the Brenner Base Tunnel is the longest railway tunnel in the Alps. The tunnel passes through the most important tectonic units of the Alps: the Eastern Alps, the Penninic, and the Southern Alps. Both the route selection and the preliminary geological and geotechnical investigations posed unique challenges for the project. It is practically impossible to even begin to adequately present this large-scale project in a single lecture. Following a brief overview of the technical framework, the presentation will address the most important engineering-geological challenges in the form of key problems and hazard scenarios on which the preliminary investigations focused. Despite the extensive preliminary exploration, the scope and severity of many problems could not be fully anticipated. Some of these problem areas will therefore be briefly presented, and potential solutions will be outlined.

Keywords: engineering-geological Challenges, Brenner Base Tunnel, preliminary investigations , key problems, hazard scenarios

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FedIGS Lecture 2026 - Kimberly-Clark Distinguished Lecture Award 2026 - Carbon Dioxide Injection into Deep Aquifers: a Geomechanical Perspective

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Abstract

Carbon capture and storage (CCS) in deep geological formations is a key strategy for reducing atmospheric CO_2 emissions and mitigating climate change. However, the successful and safe implementation of CO_2 injection into deep aquifers requires a comprehensive understanding of the geomechanical and multiphase flow responses of the subsurface. This lecture will explore the pore-scale to reservoir-scale challenges and opportunities associated with CO_2 sequestration, focusing on reservoir integrity, caprock stability, and reactive transport processes. By integrating experimental studies, numerical modeling, and field data, we will examine the complex interactions between fluid injection, pore pressure evolution, two-phase flow, and rock deformation within heterogeneous porous media. The discussion will highlight recent advances in understanding and predicting thermo-hydro-mechanical (THM) processes triggered by CO_2 injection. Additionally, we will explore the role of permeability evolution and wettability effects in storage security. The development and evaluation of analytical and computational modeling approaches will be presented as essential tools for reliable risk assessment and process optimization. By providing a multiscale perspective, from microstructural effects to large-scale reservoir behavior, this presentation aims to foster cross-disciplinary discussions and contribute to the development of robust and sustainable CCS solutions, aligning with key challenges in porous media research, geomechanics, and subsurface engineering.

Keywords: Carbon capture and storage, thermo-hydro-mechanical (THM) processes, multi-scale modeling, porous media engineering,

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The Geology of the Netherlands or the Geology of the Dutch?

Michiel van der Meulen[1]

[1] TNO, Geological Survey of the Netherlands, Utrecht, Netherlands

Abstract

When the Romans made the lower Rhine the northwestern boundary of their empire, they considered the Dutch lowlands barely habitable. It took many centuries before the Dutch managed to build a thriving society of their own in this environment. Developing land and resources first required them to gain control over water, gradually—and largely inadvertently—becoming a dominant geological factor. The Dutch have largely suspended fluvial and coastal morphodynamics, rendered floodplains sediment-starved, while at the same time moving and channeling more sediment than natural processes and producing more subsidence and earthquakes than tectonic activity. We are only beginning to grasp the responsibilities and implications this brings in the face of global change.

Keywords: anthropogenic geology, Rhine Delta evolution, sediment dynamics, land subsidence, global change impact

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Earthquake and Climate Change Induced Cascading Hazards: Mechanisms and Prediction

Xuanmei Fan[1]

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Abstract

Strong earthquakes in steep orogens can induce cascading chains of surface processes that have short- to long-term impacts on landscape. The chain initiates from the coseismic landslides that can generate enormous quantities of debris over vast areas, by eroding soil and regolith as well as bedrock. The occurrence of coseismic landsides is controlled by the coupling effects of geomorphological, geological, hydrological and seismotectonic factors. Post-earthquake rainstorms often trigger a large number of debris flows and secondary landslides that gradually transport sediments to rivers. Climate change, aside from earthquakes, is recognized as another primary driver of slope failures, particularly evident in cold, high-altitude regions like the Himalaya and Tibetan Plateau regions. Glacier retreat and the consequent expansion of glacier lakes are key factors contributing to the increase of large rock/ice avalanches and GLOFs, which threaten the livelihoods of people and can result in severe damage to infrastructure. This keynote presentation focuses on the mechanism and prediction of cascading hazards induced by earthquakes and climate change.

Keywords: cascading geohazards, earthquake-induced landslides, debris flows and sediment dynamics, climate change impacts, glacier lake outburst floods (GLOFs)

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Can Engineering Geology Save the World?

Chris Jackson[1]

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Abstract

Keywords: sustainable geosciences, energy transition, subsurface characterization, geological carbon storage, geoscience for society

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Engineering Geology Challenges and Risk Mitigation in Major Infrastructure Projects

Harry Saroglou[1]

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Abstract

Keywords:

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Building the Future from the Classroom: Innovative School–Geoscience Initiatives for Engineering Geology in Nigeria

Attah Fakeye[1]

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Abstract

This keynote highlights innovative initiatives that connect Nigerian schools with the geosciences, fostering early awareness, curiosity, and practical engagement with Engineering Geology. It explores how school-based programmes, mentorship, competitions, and partnerships can inspire young people, strengthen STEM education, and create sustainable career pathways for the next generation of engineering geoscientists.

Keywords: engineering geology, geoscience outreach, STEM education, mentorship programmes, Nigeria

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Glossop Award Lecture - Geohazard assessment of legacy mine workings using borehole images and wireline logging

Rowshi Hussain[1]

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Abstract

Keywords:

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Dewatering: Where Science and Art Meet

Ann Williams[1]

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Abstract

Dewatering, the removal of water from soil or rock, is a practice that has been applied for centuries - a strategic intervention (often a necessity) that enables safe, stable, and efficient construction below the water table. But that doesn't mean we fully understand what is taking place, or even that we have got it right, as we see both expected and unexpected effects from lowering groundwater level. Dewatering will have an increasingly important role as we experience the impacts of climate change. This lecture explores the multifaceted world of dewatering, where technical know-how (science) meets creative problem-solving (art). A range of case studies, from different parts and in differing ground conditions of New Zealand are shared, to examine the diverse purposes and sometimes inventive applications of dewatering: dewatering to facilitate construction, but also for ground source heating, creating capacity in an aquifer for storage of rainfall, landslide stabilisation, seismically induced dewatering and the reduction of liquefaction risk. Dewatering can cause ground settlement, contaminant migration, disrupt ecosystems, alter hydrological balances, and pose construction and regulatory challenges. The case studies demonstrate how dewatering influences our environment and that its success depends on a dynamic interplay of design and engineering geological intuition.

Keywords: dewatering, construction dewatering, geohazard mitigation, climate change adaptation, engineering geology case studies

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Mitigating (Relative) Land Subsidence in Venice through Deep Seawater Injections and Shallow Soil Disposal

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Abstract

Keywords: land subsidence mitigation, Deep seawater injection, Soil deposition, Venice (Italy),

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Engineering Geological Analysis of the Rock Slope Failure and Resulting Hazard Cascade that Destroyed the Village of Blatten, Valais, Switzerland

Jordan Aaron[1]

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Abstract

On May 28, 2025, the Kleines Nesthorn rock slope failed, initiating a hazard cascade that destroyed the Swiss mountain village of Blatten, causing one fatality. In this event, a large volume, limited runout rockslope failure loaded an adjacent glacier, ultimately resulting in a catastrophic ice-rock avalanche. This talk provides an engineering geological analysis of the kinematics and dynamics of this failure, and discuses the implications for managing future rock slope failures.

Keywords: rock slope failure, ice -rock avalanche, cascading hazard, Blatten, Valais (Switzerland)

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The 2026 Niscemi Landslide: from Catastrophic Failure to Integrated Risk Management

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[1] University of Florence, Florence, Italy

Abstract

The 2026 Niscemi landslide in Sicily represents a paradigmatic case of large-scale slope instability affecting an urban area with deep historical and geological vulnerability. This keynote will present how geomorphology, remote sensing, geophysics, numerical modelling, and emergency management were integrated to understand the failure mechanism, support rapid decision-making, and design long-term mitigation strategies for resilient urban slopes.

Keywords: urban landslide, remote sensing and geophysics, integrated geohazard assessment, mitigation strategy, Niscemi, Sicily (Italy)

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The 2026 Rasuwa Disaster: A Transboundary Rock–Ice Avalanche, Himalayan Tsunami, and Cascading Hazards

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Abstract

The Himalaya is increasingly affected by high-mountain disasters driven by the interactions among cryospheric change since 1990, slope instability, thawing of glacial deposits and rock-mass permafrost, avalanches, and river systems. The 2026 Rasuwa disaster in the Nepal Himalaya highlights the destructive potential of these cascading processes, in which a massive rock–ice avalanche transformed into a devastating downstream flood and sediment-laden flow. This event is referred to as a "Himalayan tsunami" because the rapidly propagating flood and debris-flow wave resembled the destructive waves of an oceanic tsunami. Similar, although comparatively smaller, disasters have occurred across the Himalaya, including the Seti River disaster in Pokhara, Nepal, on 5 May 2012; the Bhotekoshi disaster in Sindhupalchowk, Nepal, in July 2016; the Chamoli disaster in India on 7 February 2021; the Melamchi disaster in Nepal on 15 June 2021; and the Sikkim disaster in India on 3 October 2023. Together, these events demonstrate how high-altitude mass movements and hydrological processes can propagate through mountain river systems, threatening downstream settlements and critical infrastructure. Based on satellite imagery, available field observations, photographs, and geomorphological interpretation, this study examines the source characteristics, cascading processes, and environmental implications of the Rasuwa disaster. Rapid fragmentation and movement, combined with river interaction and the entrainment of sediment and water, provide a reasonable mechanism for the destructive downstream flood and debris-flow wave. The event underscores the limitations of isolated, single-hazard assessments and downstream-focused monitoring. Effective risk reduction requires integrated source-to-sink (S2S) investigations, high-altitude slope materials and glacier monitoring, real-time river observation, transboundary data sharing, impact-based early-warning systems, and risk-sensitive infrastructure and land use planning. The Rasuwa Disaster reinforces the need for coordinated scientific investigation and cross-border management of cascading Himalayan hazards.

Keywords: 2026 Rasuwa disaster, cascading hazards, rock-ice avalanche, Himalayan tsunami, cross-border disaster risk management

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Bridging Geophysics and Geotechnical Engineering: Integrated Characterization of Rock Masses, Buried Structures and Earth Dams

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Abstract

Geophysics offers tools to improve understanding of geological and geotechnical conditions when its results are integrated with other sources of information. Drawing on research experiences combining laboratory testing, physical models and field investigations, this lecture will discuss applications to the characterization of rock masses, buried structures and earth dams. For rock materials, the contributions of destructive and non-destructive testing and of direct and indirect methods to the assessment of geotechnical properties will be explored. The discussion will include relationships between laboratory and field information, considering geophysical logging and ultrasonic wave propagation, as well as the influence of measurement conditions on interpretation. Physical modelling will be presented as a means of investigating geophysical responses under controlled conditions. Examples involving ground penetrating radar (GPR) will support discussion of how material properties and moisture affect the identification of buried structures, with potential applications to tunnel investigations. Applications to earth dams will be addressed through a study combining electrical resistivity, self-potential and GPR with geotechnical information, illustrating the contribution of integrated interpretation to assessing the condition of the dam and its foundation. The lecture will bring together findings and ongoing studies associated with the Applied Geophysics Laboratory (LGA) at the Federal University of Viçosa, Brazil, to discuss opportunities, limitations and challenges observed in these applications, including the organization and integration of geophysical data into geotechnical workflows.

Keywords: rock mass characterization, integrated geophysics, physical modelling, earth dam, buried structures

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