Systematic assessment of damage to buildings due to groundwater lowering-induced subsidence: methodology for large scale application in the Netherlands – update with results from the Dutch nationwide model

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Abstract

Subsidence of peat and clay soils due to (artificial) lowering of the groundwater table and loading of soft soils is commonplace in the Netherlands, causing extensive damage to exposed and vulnerable assets. In Costa et al (2020) a methodology is presented for the systematic regional or countrywide assessment of two subsidence-related damage mechanisms to buildings: differential settlement of buildings on a shallow foundation, and timber pile degradation due to low groundwater levels. The methodology is set up in a modular, systematic way – initially based on expert judgement and validation with available local detailed information - which allows for future improvements. In this update we present results of the model that can be a valuable input for public or private decision making, e.g. in awareness raising and evaluating interventions.

Introduction

In the Netherlands, subsidence of peat and clay soils due to (artificial) lowering of the groundwater table and loading of soft soils is commonplace, causing extensive damage to exposed and vulnerable assets. Improved risk assessment of subsidence-related damage to buildings would inform public and private actors from national to local scale on current and future risks and stimulate them to address this issue. In Costa et al. (2020) the authors proposed a methodology for systematic regional or countrywide assessment of two subsidence-related damage mechanisms to buildings: timber pile degradation due to low groundwater levels and differential settlement of buildings on shallow foundations. In this update the results of the corresponding model are presented.

Methodology recap and additional detail

The risk assessment is constructed in a modular, systematic way that allows for continuous improvement. Modules are built based upon the conceptual framework of Hazard (H) – Exposure (E) – Vulnerability (V) according to the definitions by the UNISDR (2016). Figure 1 and Figure 2 illustrate the methodology for the calculation of damages due to the two damage mechanisms. Details of the modules are given in Costa et al. (2020).

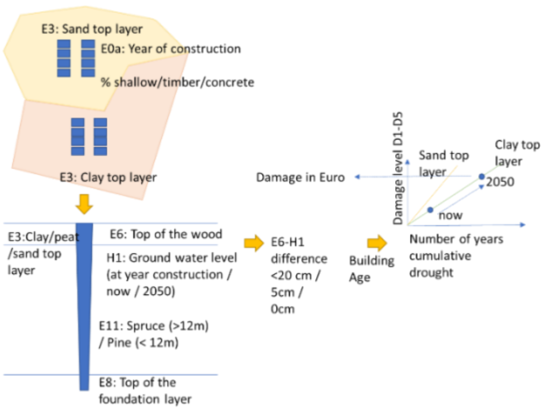

Figure 1 Schematic for the calculation of damages due to timber pile degradation induced by low groundwater levels.

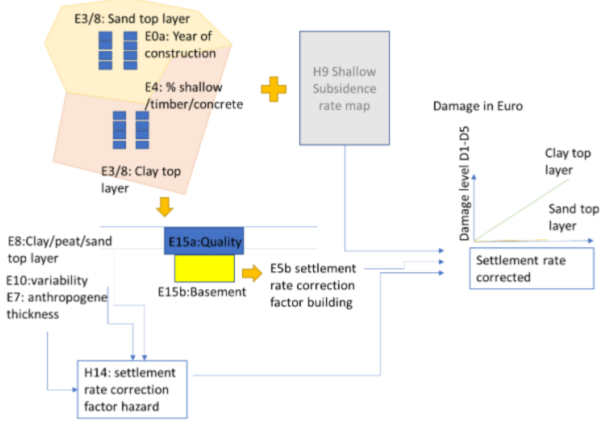

Figure 2 Schematic for the calculation of damages due to differential settlement of buildings on shallow foundations.

The exposure characterizes the buildings that are at risk. Key indicators for the exposure are the foundation types, characteristics and location, see Figure 3. Regional areas of typically similar foundations based on historical practice each have a foundation type probability per building, per year, per area and per soil type based on the expert sessions and local inventories made in some locations. For both damage mechanisms, the damage level is expressed in classes ranging from 1-5, (Burland and Wroth 1974). Damage classes for shallow foundations are assigned based on the rate of settlement with correction for factors of local hazard, shown in Table 1.

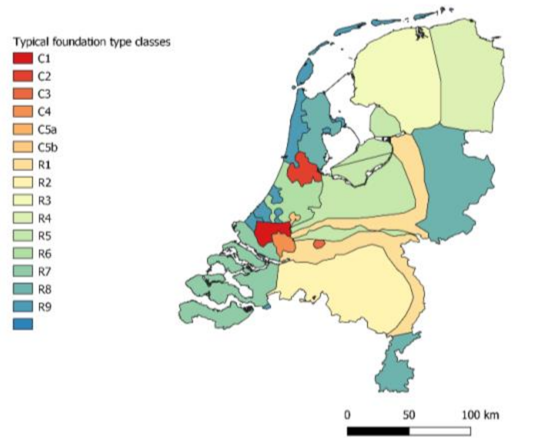

Figure 3 Map with regional areas of typical foundation types.

Table 1 Relationship between settlement rate and damage class.

Corrected settlement rate [mm/year]	Damage class
< 0.1	D0
0.1-1	D1
1-2	D2
2-3	D3
3-4	D4
>4	D5

Sensitivity analysis of model

A sensitivity analysis was executed on the impact of underlying assumptions on the hazard correction factors (e.g. the impact of a sand, clay or peat soil type at the foundation layer on the susceptibility of a building to differential settlement) as described in Costa et al (2020): Figure 4 shows the impact of alternative underlying assumptions on the resulting corrected subsidence rate in mm/year (which affects the expected damage level) against the number of buildings in the database. Similar analyses were done on several of the hazard and exposure parameters for the shallow foundation model, and the vulnerability function for the timber pile model. The shallow foundation model is most sensitive to assumptions regarding impact of heterogeneity in the subsurface and the type of soil at the foundation level. The timber pile model is quite sensitive to the assumed shape of the vulnerability function. These parameters will be focus of further study to reduce uncertainty in the model.

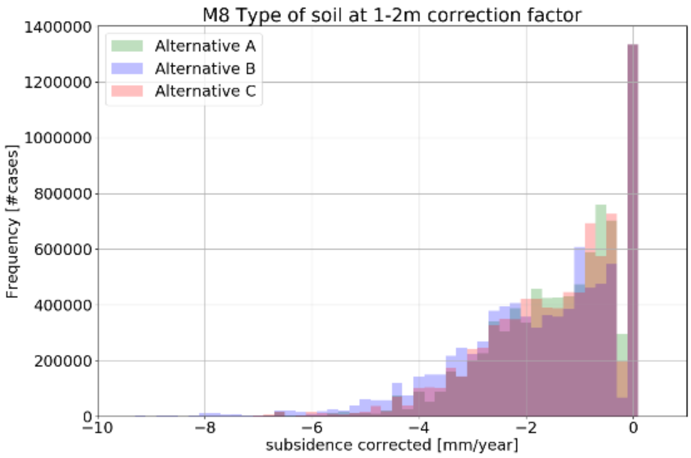

Figure 4 Number of buildings and their resulting subsidence rate including correcting factors as described in Costa et al (2020) for three different soil types (A, B, C).

Results of the model

To arrive at a national level estimate of expected damage in 2050, all information and indicators are collected at the building level in the model, with aggregated results presented in Figures 5 and 6.

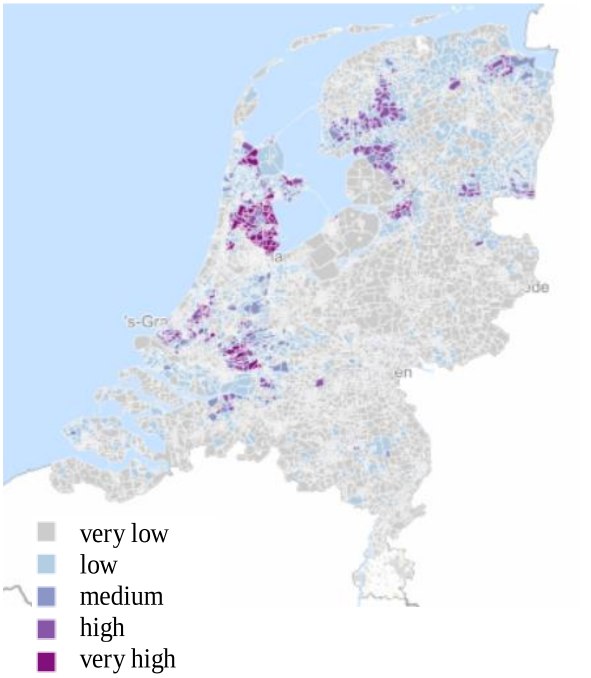

Figure 5 Shallow foundation risk per area; 2050 scenario with high climate change effects (very low: risk score <1; low: <5; medium: <10; high: <25; very high: <100)

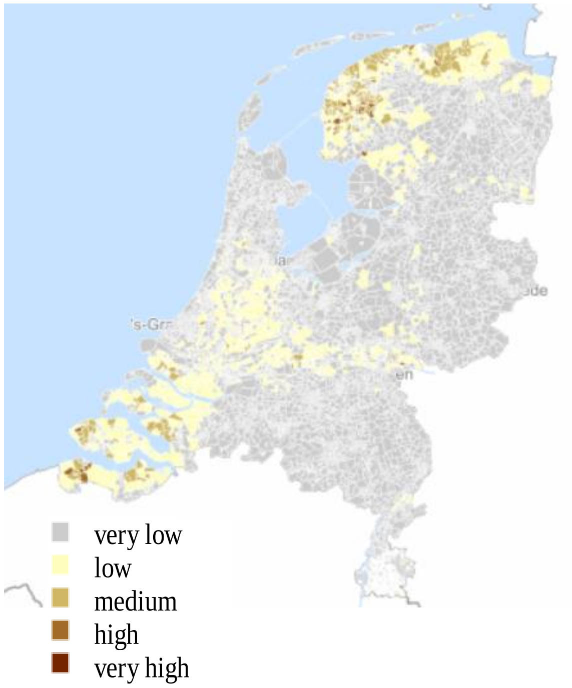

Figure 6 Timber pile foundation risk per area; 2050 scenario with high climate change effects (very low: risk score <1; low: <3; medium: <6; high: <15; very high: <41; medium: <10; high: <25; very high: <100)

Aside from this visual application of the model, the model was also run to derive an estimate of total risk (in number of buildings/ damage class and nominal € restoration cost) in the Netherlands until

2050 (see Figure 7, Table 2). As opposed to the previous version of the model of which results were used in the Klimaatschadeschatter (2019), this run was based on updates in vulnerability functions for both timber pile and shallow foundations, updated baseline subsidence map and updated shallow soil type map to better reflect sensitivity to shrink-swell behavior of clays, and new low groundwater level maps. Results show that total damages will be in the order of €9 to €40 billion until 2050. Most of the damage is to be expected in buildings with shallow foundations: in particular the small selection that is expected to reach damage level 5 and require full restoration. It should be noted that uncertainty in the model outcomes is still very high.

Conclusions and future work

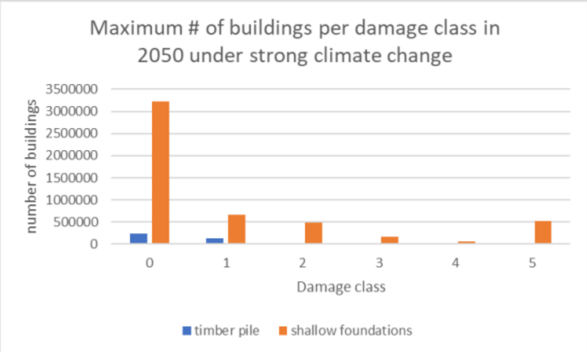

Figure 7 Maximum amount of buildings in each damage class by 2050 under strong climate change.

Table 2 Total restoration costs until 2050 for strong climate change scenario.

	Total restoration costs until 2050 per damage class in € *mln under strong CC			
	timber pile		shallow foundations	
Damage class	min	max	min	max
1	135	241	0	0
2	56	1038	115	1147
3	36	658	164	819
4	55	562	220	1323
5	11	310	8573	34291
	293	**2809**	**9072**	**37579**

This paper shows results and sensitivity of the damage assessment due to subsidence and drought to shallow foundation and foundations with timber piles. The approach relies heavily on the quality of the data. At this moment the model is being converted to a fully probabilistic model as to enable better propagation and assessment of uncertainties. The probabilistic model will be used to assess the sensitivity of the parameters in more detail. Also, ongoing research in the NWA-Loss project (nwa-loss.nl) on fragility functions for building damage will be implemented (see Prosperi, 2023 in this conference).

References

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