Cultural heritage and subsidence: the emblematic case study of Santa Croce in Ravenna (Italy)

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Abstract

The paper deals with subsidence and flooding risks associated to the Archaeological Site of Santa Croce, encompassing a 5th century church together with the remains of a Roman domus and its mosaics, located in the centre of the historic town of Ravenna (Italy). A geotechnical field campaign and the installation of a new piezometer monitoring system were carried out in 2022, under the framework of H2020 SHELTER project, to investigate the critical issues generated by water drainage in the site, requested by the significant natural and anthropic land subsidence phenomenon that has affected the site since its origins. The case study is presented herein, together with a brief description of the ongoing investigation activities and a few preliminary results.

The church and the archeological area of Santa Croce in Ravenna

The ancient city of Ravenna, located in the Northern Italy ~10 km from the Adriatic Sea and ~60 km from the Po River Delta, is worldwide known for its magnificent and well-preserved Byzantine architectures. Over the past centuries, the city has been affected by a phenomenon of intense subsidence, both natural and anthropogenic; at present, the cumulated settlement of most ancient monuments has brought their ground level well below the current water table, causing permanent flooding in the crypt of monumental churches, such as S. Francesco's Basilica, and in the basement of old buildings. The archaeological area of Santa Croce is located in the historic centre of Ravenna, close to San Vitale Basilica and Galla Placidia Mausoleum, in the buffer zone of the UNESCO world heritage site of the Early Christian monuments of Ravenna (see Figure 1A). The peculiarities of the Santa Croce area include an archaeological excavation, carried out during the second half of the 20th century and left open in order to make the unique archaeological stratification permanently visible from the public street (see Figures 1B and 1C). Being the bottom of the excavation over 3 m below the current ground level and more than 2 m below the typical water table, a permanent drainage system was installed at the beginning of the '80. This system is still constantly operating in the area, maintaining it substantially dry, although due to the lack of maintenance it has modified its original functionality, creating local settlements and clear evidences of potential instability (see Figure 2A), especially around the tank area where the submerged pumps are located. Last time only in 2021, the pumping system failed, producing the subsequent flooding of the area and the related damages to the Roman mosaics and the archaeological structures (see Figure 2B). Preliminary studies and investigations were recently carried out within the actions of the European project H2020 SHELTER, with the main aim of understanding and monitoring the effects of the existing drainage system, also identifying the local hydrogeological and geotechnical characteristics. Such pieces of information, analysed in the context

of the land subsidence that has long affected the area, can provide valuable data for its maintenance and preservation.

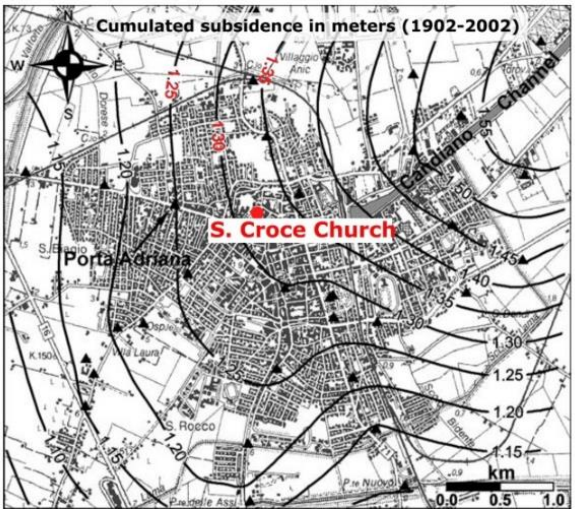
Figure 1A Aerial view of the Archaeological Area of Santa Croce in Ravenna (Italy) and the Monumental zone of S. Vitale and Galla Placidia. B) View of the Santa Croce Church from the street. C) View of the Church and the archaeological remains located at the bottom of the excavated basin around the Church.

Figure 2A Land settlements and instability of the soil slope and of the old brick masonry walls, concentrated around the tank area. B) Drainage operations by Civil Protection of the flooded Archaeological Area of Santa Croce as a consequence of the temporary break down of the pumps (August 2021).

Land subsidence in Ravenna

The archaeologic site of Santa Croce was first seat of a Roman domus; later, in the V century, the original church started to be built and subsequently enlarged and substantially modified over the subsequent centuries. Archaeologists have estimated a difference between the current configuration and the ancient Roman floor of more than 3 m, mostly due to the natural subsidence of local highly stratified alluvial sediments (Cassanelli et al, 2013). In more recent times, the land settlement in the Ravenna city centre has passed from few millimetres per year (~5.5 mm/year in the period 1900-1957) to 80 mm/year between 1972-73 (Bertoni et al, 2005), primarily due to groundwater pumping for industrial and civil purposes and, to a lesser extent, to gas extractions from onshore and offshore

reservoirs. Therefore, the archaeological area of Santa Croce experienced ~1.3 m of land subsidence in the period 1897-2002 (Teatini, 2015) (see Figure 3 left). The corrective actions taken by the Italian government starting in the ’60 eventually mitigated the problem. As a consequence, the settlement decreased to a rate of ~1.3 mm/y in the period 1998-2002 (see Figure 3 right), a value close to the natural subsidence rate (Bertoni et al, 2005). Although these data suggest that land subsidence evolution in the Ravenna city center do not currently represent a decisive factor (Bitelli et al, 2020), the cumulated anthropogenic settlement has seriously aggravated the environmental conditions of the investigated site and of the other contemporary monuments.



Average subsidence rate (mm/year)	
Time interval	Historic Centre of Ravenna City
1900-1957	5.5
1949-1972	2.5
1972-1973	80
1972-1977	60
1977-1982	13
1982-1986	5
1986-1992	5
1992-1998	4.5
1998-2002	1.3

Figure 3 Left: Cumulated land subsidence in the historic centre of Ravenna between 1902-2002 (image modified from Teatini et al, 2005). Right: Average subsidence rates in mm/year registered in the historic centre of Ravenna in the different time intervals, from Bertoni et al (2005).

The Area of S. Croce and the operating drainage system

In 1979 a permanent drainage system was built at the foot of the slope that surrounds the archaeological excavations of the Santa Croce site. The system still runs along two sides of the excavated perimeter. The reconstruction of the original system, as deduced from the documents collected in the Archives and field observations, is shown in Figure 4. The water that enters in the perforated pipe of the horizontal drainage starts from P1 and gets to a main well (C1 in Figure 4), where two submerged pumps lift the water into the public sewer. In 1984 a large concrete tank was built, to enhance the storage of the drained water. After more than 40 years from its installation, the drainage system, in particular the perforated drainage pipe, results completely obstructed and, as a consequence, water runs by gravity in the trench above it and it is only partially collected into the final concrete tank.

2022 Geotechnical investigations in the S. Croce area

In 2022 the subsoil underneath the archaeological site of Santa Croce and the Monumental area of S. Vitale and Galla Placidia have been investigated by means of two continuous coring boreholes, two cone penetration tests CPTu, one seismic CPTu, one dilatometer test, several SPT, dissipation and LeFranc permeability tests. The collected data, integrated with the results of previous investigations described in Ricceri (1992), enabled to define an accurate stratigraphic model of the site up to a depth of 35 m from the ground level. The subsoil is constituted by: an anthropic unit, ~5 m thick, rich in archaeological remains; a sandy layer, down to a depth of ~22 m (the shallowest Aquifer 1); a silty-clay layer, interposed between such first and the second aquifer, which ends at a depth of 33 m from the ground level. Below this unit, and up to the maximum investigated depth, a second fine grained

material can be observed. During the same geotechnical campaign, 5 new standpipe piezometers were installed in the area for the continuous monitoring of the pore water pressure (pwp) distribution in the two aquifers, with the aim of quantifying the incidence of the drainage system and of local precipitations on the local hydrogeology. The recorded data from the two piezometers installed in the shallowest aquifer (Aquifer 1) close to the pumps show a marked drawdown, which reduces with the increasing distance from the pumps, as expected. At the same time, the analysis of additional preliminary data suggests that the drainage influence on the second aquifer is rather limited. The set of collected data and information will enable a well-calibrated design of a new drainage system or a renewal of the existing one. Both field investigations and subsequent possible interventions must guarantee the least disturbance of the archaeological site and of the surrounding monumental area, preserving its historic characteristics and integrity. The new challenge for the preservation of the site will be related not only to the installation and maintenance of the new drainage system but also to its required features for guiding the operation of pumping devices and for informing a related alert system. Together with the remotely-controlled drainage system, an emergency plan will be therefore defined to manage possibly arising critical situations.

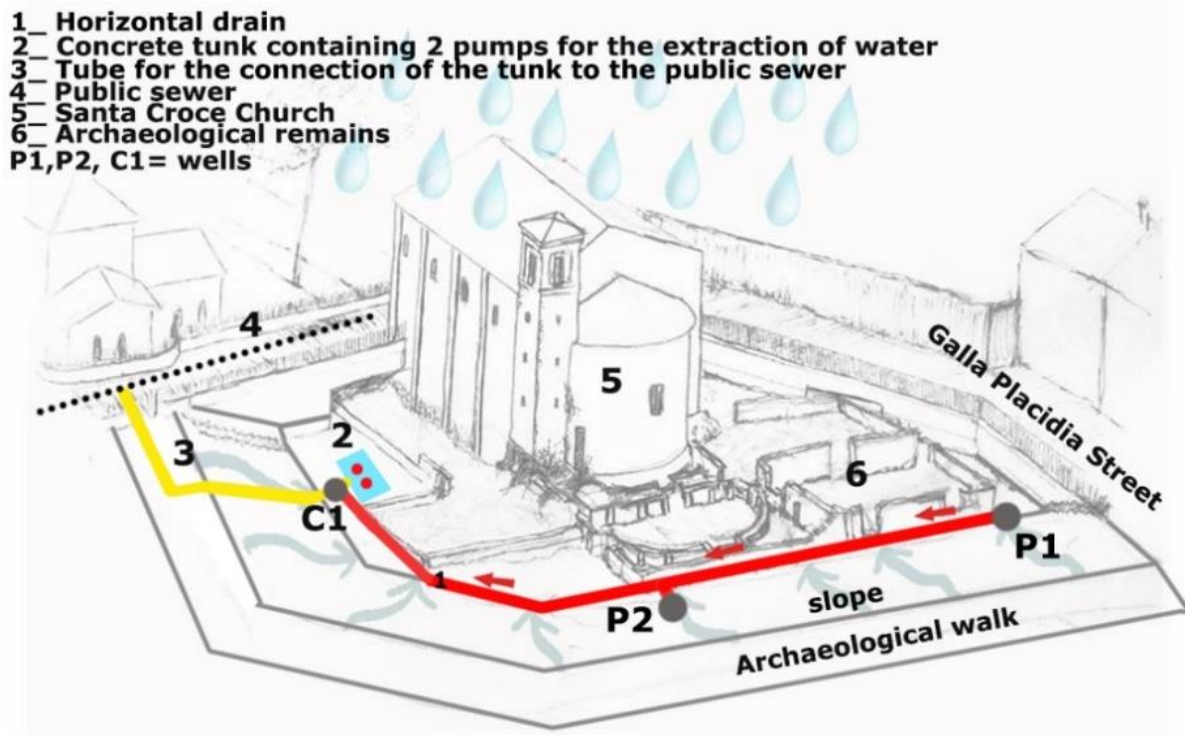


Figure 4 Schematic representation of the drainage system operating in the investigated area to keep dry the archaeological excavations around the church.

Conclusion

In the framework of H2020 SHELTER research project, the delicate situation and the numerous criticalities associated with the Archaeological Area of Santa Croce have been highlighted in relation to their effects on the historic heritage. Land subsidence and flooding are deeply interconnected natural hazards that threaten this unique area and require special care and attention in order to mitigate the related risks, making possible the preservation and future fruition of the entire complex. The performed geotechnical campaign together with the preliminary results of the on-site monitoring are a valuable source of information to understand the present context and design proper management strategies.

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References

Bertoni, W., Elmi, C. & Marabini, F. (2005). The subsidence of Ravenna. *Giornale di Geologia Applicata* 1, 23-32.

Bitelli, G., Bonsignore, F., Del Conte, S., Franci, F., Lambertini, A. et al (2020). Updating the subsidence map of Emilia Romagna regioni (Italy) by Integration of SAR interferometry and GNSS time series: the 2011-2016 period. *Proceedings of IAHS,* 32, 39-44.

Cassanelli, R., Cirelli, E., Crociati, E., Civiletti, J.P. et al (2013). *La Basilica di Santa Croce: nuovi contributi per Ravenna tardo-antica*. Curated by David M. Edizioni del Girasole.

Ricceri, G. (1992*). Studi e ricerche nell'area di S.Vitale Galla Placidia e Santa Croce in Ravenna. SGEditoriali*, Padova (Italia).

Teatini, P., Ferronato, M., Gambolati, G., Bertoni, W., Gonella, M. (2005). A century of land subsidence in Ravenna, Italy. *Environmental Geology*, 47,831-846.