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Endangered historic sites: The case study of Santa Croce in Ravenna (Italy)

Sites historiques en danger: L'étude de cas de Santa Croce à Ravenna (Italie)

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ABSTRACT: The city of Ravenna (Italy) is worldwide famous for the well-preserved late Roman and Byzantine architecture with eight buildings protected by UNESCO as part of the World Heritage Site “Early Christian Monuments of Ravenna”. Climate change effects have increased the site vulnerability to natural hazards, in particular flooding and subsidence, two phenomena often strictly interrelated. The topic has been addressed with reference to the complex of Santa Croce in Ravenna (Italy), an emblematic case of the main hydrogeological and water-related threats affecting the city monuments. A recent geotechnical campaign and a new piezometric monitoring system helped to gain information on the local subsoil and on the drainage system, permanently operating in the area in order to maintain it dry; the 3D geometry of the complex was obtained by integrated geomatic techniques (mainly laser scanning and photogrammetry). The paper aims at presenting the main geotechnical issues affecting the site stability and its long-term preservation.

RÉSUMÉ: La ville de Ravenne (Italie) est mondialement connue pour son architecture de la fin de l'ère romaine et byzantine remarquablement préservée, avec huit bâtiments protégés par l'UNESCO dans le cadre du site du patrimoine mondial "Monuments du christianisme primitif de Ravenne". Les effets du changement climatique ont accru la vulnérabilité du site face aux risques naturels, notamment les inondations et l'affaissement, deux phénomènes souvent étroitement liés. Le sujet a été abordé en référence au complexe de Santa Croce à Ravenne (Italie), un cas emblématique des principales menaces hydrogéologiques et liées à l'eau affectant les monuments de la ville. Une récente campagne géotechnique et un nouveau système de surveillance piézométrique ont permis d'obtenir des informations sur le sous-sol local et sur le système de drainage fonctionnant en permanence dans la région afin de le maintenir sec; la géométrie en 3D du complexe a été obtenue grâce à des techniques géomatiques intégrées (principalement scanner laser couplé à un relevé photogrammétrique). L'article vise à présenter les principaux problèmes géotechniques affectant la stabilité du site et sa préservation à long terme.

Keywords: Historic site; Ravenna; Santa Croce church; land subsidence; drainage system.

1 INTRODUCTION

Ravenna (northern Italy) is renowned for its rich history, cultural heritage and stunning Byzantine mosaics that adorn its churches and monuments. As a UNESCO World Heritage Site, Ravenna boasts eight early Christian monuments that testify its significance during late Roman and Byzantine periods. However, these ancient historic sites face severe natural hazards that threaten their conservation. Being situated in a low-lying area, only few kilometres from the Adriatic Sea shoreline, the city is constantly prone to flooding. High tides, storm surges and heavy rainfalls - whose frequency is rapidly increasing as effect of climate change - can produce potentially significant damages to ancient sites and monuments, which have been historically subjected to relevant phenomena of land subsidence and are therefore located well below the current mean sea level. In order to mitigate such geohazards and preserve Ravenna's cultural treasures, numerous efforts have been made through many conservation and restoration projects, starting from an in-depth study of their current situation and thus devising possible solutions (Santangelo et al., 2022; Bertolini et al., 2023; Marchi et al., 2023a; Franzoni et al., 2023). Any conservation program aiming at safeguarding monuments and mosaics from environmental degradation and the impact of natural hazards should start from a diagnostical analysis trying to connect “root” causes to the effects on the structure (Gottardi et al., 2015; Bertolini et al., 2022; Marchi et al., 2019; Marchi et al., 2022a, Marchi et al. 2022b; Marchi et al., 2023b).

The paper addresses the steps taken to analyse, from a geotechnical point of view, the “state of health” of the archaeological site of the Santa Croce Church in Ravenna, encompassing the visual analysis of its decay due to the effects of natural and anthropic land subsidence with the preliminary results of a recent

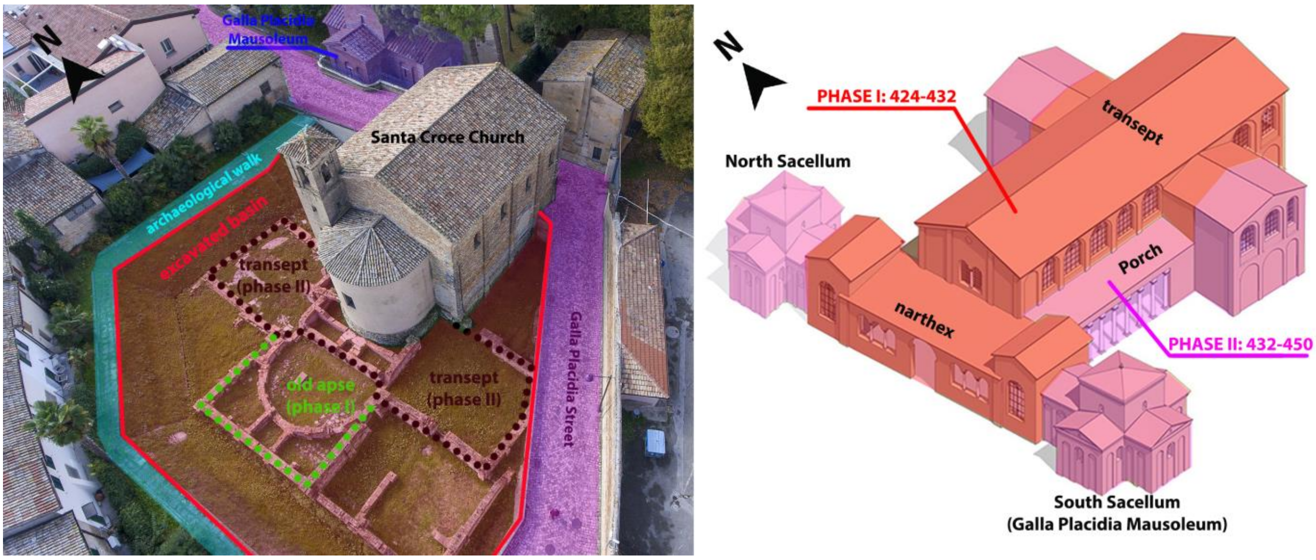

Figure 1. On the left, a bird's eye view of the area under study, with the excavated basin containing the archaeological remains and the Church. On the right, reconstruction of the geometry of the church at the end of the placidian era (modified from Cassanelli et al. (2013)).

geotechnical campaign investigating the local stratigraphy and the piezometric regime acting in the shallow aquifers as induced by a previously installed drainage system.

2 THE ARCHAEOLOGICAL SITE OF THE SANTA CROCE CHURCH

The archaeological site of Santa Croce is located in a buffer zone of the UNESCO early Christian monuments of Ravenna, adjacent to the world-famous San Vitale Basilica and Galla Placidia Mausoleum. While the two latter monuments are in good conservation conditions and are open to the public, the Santa Croce site appears in a partially abandoned state and is currently not accessible to visitors. The Church of Santa Croce, in ancient times, was a three-nave building preceded by a long portico (narthex) at the ends of which probably opened two symmetrical chapels (*sacellum*). The only surviving chapel is the south one, the so-called Mausoleum of Galla Placidia. The church was likely built in two phases on the structures of a roman *domus,* of which beautiful floor mosaics are preserved on site. The first church configuration dates back to the period between 424 and 432 A.D., constructed by the will of the roman empress Galla Placidia, and was followed by an enlargement between 432 and 450, precisely with the addition of two chapels and small adjacent porches next to the aisles, configured for funerary purposes (Figure 1, right). The early Christian church had a rich mosaic and stucco decorations, almost entirely lost today, similar in splendor to that still observable in the south *sacellum*. The old placidian church has been almost entirely reconstructed in time. In particular, at the beginning of the 17th century, the church front was set back and separated from the south chapel to make space for the Galla Placidia road today bordering two sides of the site. Concurrently, the apse has been demolished and reconstructed, in smaller dimensions, in correspondence of the old transept, considerably reducing the length of the church nave (Figure 1, left). In the 18th century, a bell tower, still observable today, has been added at the side of the apse.

2.1 Past and present hazards affecting the site

After the World War II, the economic recovery increased the need for fluid withdrawal from the subsurface. The exploitation of the Quaternary multiaquifer system underneath the Ravenna city centre and of new on-shore and off-shore gas reservoirs, increased the subsidence rate of the area from few millimetres/year (natural land subsidence rate before 1950) up to a peak value of ~80 mm/year recorded in the period 1972-73 (Carbognin et al., 1984). The cumulated subsidence in proximity of the Santa Croce site has been estimated ~1.3 m between 1897-2002, as a result of the superposition of natural and anthropic subsidence effects (Teatini et al., 2005), leaving evident signs of a marked decline in the urban and natural environment.

In the period between 1970 and 1980 the Santa Croce site was subjected to an important archaeological campaign aiming at bringing to light the archaeological stratification in the area. A basin was therefore excavated on three of the four sides of

Figure 2. On the left, scheme of the drainage system operating in the area. On the right, a picture taken during the drying procedures required following the basin's flooding caused by the malfunction of the two submersible pumps in 2021.

Figure 3. Pictures highlighting the different types of deterioration to the masonry structures and to the earthen slope of the basin, caused in time by the operating drainage system.

the church up to a depth of ~3.7m from the current street level (at ~1.5 m a.m.s.l) (Figure 1, left). The phreatic water level in the area is consistently located at ~1.5 m below the actual ground level; thus, to perform the excavation and maintain the archaeological remains in dry conditions a drainage system had to be set in place. A scheme of the drainage system, still in operation, is shown in Figure 2 (left). A perforated horizontal PVC tube (red line in Figure) bordering two sides of the excavated basin channels the water from well P1 through P2 and C1 to a buried concrete tank (indicated with a blue dot in Figure 2, left) containing two submersible pumps. The pumps lift the drained water to the street level and release them in the public sewer (light blue line in Figure 2). The subsequent piezometric lowering in the shallow aquifer initially produced new settlements in the overall site containing the church structure, the archaeological remains in the excavated basin and the private buildings standing at the site borders. Moreover, the lack of maintenance to the drainage system caused over the past years the progressive obstruction of the drainage pipes by soil particles. From a recent site inspection, the water still drained by the pumps flows along the soil surface, on a shallow trench self-created above the pipes (blue arrows in Figure 3, left), producing continuous shallow erosion and local instabilities. Despite the underpinning works operated in 1985 to the masonry remains in proximity of the tank, the negative effects of the continuous water withdrawal appears to have never stopped. In fact, the area in proximity of the concrete tank is clearly the most affected by settlements, as visible in all the close by masonry archaeological structures in the south side of the church and in the deformation of the slope (Figure 3, right and left, respectively). Furthermore, occasional malfunctioning of the pumps in the past caused multiple flooding of the area with subsequent damages to the archaeological remains and to the roman mosaics (Figure 2, right).

2.2 The 2022 geotechnical investigation campaign and site monitoring

Funded under the European research program Horizon 2020, SHELTER (Sustainable Historic Environments holistic reconstruction through Technological Enhancement and community-based Resilience) project aims to increase the resilience of cultural heritage and reduce its vulnerability to natural and anthropic hazards through the elaboration of disaster risk management plans and protocols of intervention. The archaeological area of Santa Croce was selected as emblematic case study because it incorporates all the preservation issues characteristic of coastal, low-land, historic cities.

In 2022, among many other investigations, a geotechnical campaign was carried out, aiming at investigating the local soil stratigraphy and characteristics, together with the piezometric conditions in the area, as induced by the drainage system. Two piezocone penetration tests (CPTu), one seismic cone penetration test (SCPTu), one dilatometer test and three corings (two continuous and one destructive drillings) were executed in the area. Under a 5.5 m thick anthropic fill (unit R), rich in archaeological remains, the deposit turned out to be a succession of highly permeable aquifers (units U1 and U3) and low-permeable aquitards (units U2 and U4), up to the maximum investigated depth (~ 45 m) (Figure 4).

A piezometric monitoring system was thus installed in the site with the aim of recording in situ pore water pressure (pwp) data in the shallowest aquifers at different distances from the buried tank. As expected, the greatest dropdown in piezometric head is registered in PZ3, installed in the first aquifer and located in proximity of the pumps (Figure 5). The effects of the drainage system seem to reduce with distance in fact, PZ1, 50 m far from PZ3, has a higher piezometric head (with a difference of ~ 0.2 m). The deeper aquifer (monitored by PZ2) is only marginally influenced by the drainage conditions and tends to the undisturbed water level, located ~1.4 m below the street level (as measured locally at pumps shut down).

Various geomatics techniques were also integrated to create a highly detailed 3D model of the Santa Croce site (Bitelli et al., 2021). These geometrical data will support the creation of a seepage Finite Element (FE) model able to accurately reproduce the pwp distribution in the 3D system of aquifers as a consequence of the drainage currently in operation and to reproduce the effect of possible, more effective, solutions. Piezometric observed data will be used for a suitable calibration of the FE model parameters.

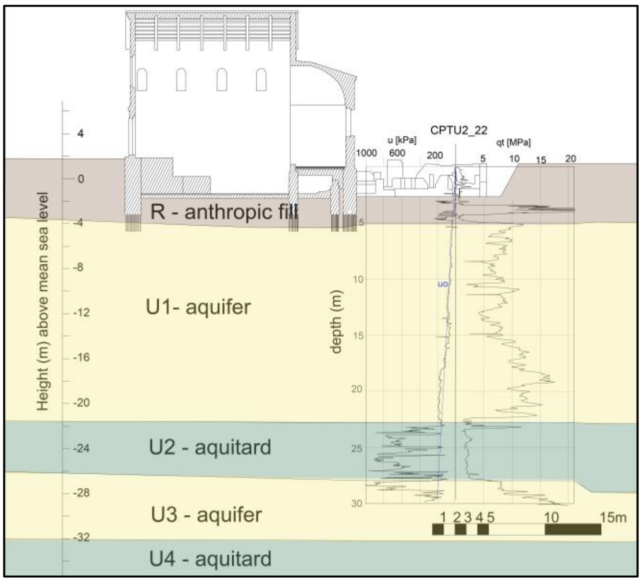

Figure 4. Soil stratigraphy in the investigated area with superimposition of the q_t and u profiles from a CPTU.

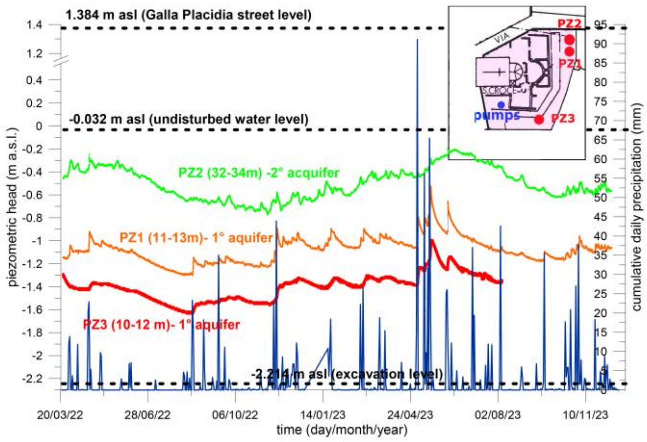

Figure 5. Piezometric head trends with time measured in PZ1 (1st aquifer), PZ2 (2nd aquifer) and PZ3 (1st aquifer).

3 CONCLUSIONS

The paper focuses on the precarious conditions and the number of hazards affecting the archaeological area of Santa Croce. This scrutiny has brought to light their significant implications to the preservation of such invaluable historic site. Diligent care and increased vigilance are required in order to effectively mitigate the associated risks, thereby enabling the safeguarding and future accessibility of the entire complex. The extensive field campaign conducted, coupled with the initial findings from on-site monitoring, represents a valuable analysis of the current geotechnical situation. These findings not only shed light on the existing context but also pave the way for the formulation of well-informed management strategies essential for the preservation and sustainable use of the site. In this perspective, multiple solutions can be proposed to ensure an optimal control of the groundwater conditions in the area. Among them, a re-efficiency of the old drainage system in use or the design and implementation of a new dewatering system (e.g., well-points), able to guarantee spatial uniformity of pore pressure distribution and lower hydraulic gradients in the area.

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