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Protecting the archaeological heritage from structural risks: some significant cases.

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Abstract

In the present paper the "Three R" Strategy for archaeological consolidation is described, referring to some well-known historical examples and then to some significant cases on UNESCO sites performed by the author. The problem of conserving the constructive info of ancient structures along centuries is summarized, together with a set of recurrent structural problems. Three case studies of sites are explained, two located in Arabic Peninsula (Dhofar district, Sumhuram– Al Balid), one in Jordan (Petra district – Shawbak). The replacement of walls (with or without mortar joints) is performed, together with the strategy to assess a respectful, recognizable and reversible consolidation technique.

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Keywords: Archaeological consolidation; Three R Strategy; UNESCO sites; Masonry structures.

1. Introduction

The issue of preventing deteriorations due to aging, climate actions or external loads is of primary importance on archaeological constructive features. A large number of recent examples in Italian territories show that historical elements, also of huge dimensions like urban walls (Andreini et al 2013, Giresini et al 2018, Puppio et al 2019) are extremely vulnerable from structural point of view. The main observed phenomenon that can cause deterioration up

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to partial or total collapses is the rain penetration, joined with freeze-thaw (Croce et al 2019). Traumatic events like earthquakes or floods can produce failures (Puppio et al 2020), but also anthropic causes, like works in the nearby of the walls (Solarino et al 2018) are able to generate collapses.

In archaeological context those aspects are exacerbated by the vulnerability of the entire constructive system. Indeed the role of the structural engineer is not only to prevent the collapses, but also to conserve carefully the constructive memory “imprisoned” in the walls or the structural features, including construction details also in low technology elements (Sassu et al 2016): their level of accuracy, how materials or elements were chosen, positioned and refinished.

The possibility of testify the current state of the historical constructions and infrastructures is recently increased, thanks to the strong evolution of ICT disciplines: digital photos, movies, 3D surveys with info characterized by high level of definition (Mistretta et al 2019), affordable GIS satellite procedures (Amirebrahimi et al 2016, Pucci et al 2019) and BIM approaches (Fiamma et al 2019) can furnish a virtual re-constructions of the investigated elements. Although the problem of their reliability over time is a crucial issue: how many digital documents, photos, movies drawn up a few decades ago, are today available? An how it can be conserve in a realistic efficient way all those documentations, ensuring procedures that will permit, after further decades or centuries, the integrity of the info on restoration works, in order to avoid confusion or misunderstanding to the future scientists?

Referring to the structural integrity of archaeological walls, one of the more dangerous phenomenon is the out-of-plane rocking. From classic Housner’s approach (Housner, 1964), many contributions have been developed (Giresini et al 2018, Giresini 2019), It can observe that dry stone walls are frequent in the archaeological contexts, so appropriate models (Casapulla et al 2018) should be used to prevent local failures.

Both aspects, to conserve as a “stone archive” the constructive features of a masonry structure in an archaeological element and to ensure a proper safety and integrity level of thee walls along the centuries, are crucial issue for the designer of the restoration procedure.

In the past well-known and appreciated discovering were accompanied by nor reversible reconstructions, we can consider the famous example of Knossos Palace in Creta Island discovered in early ‘900 by A. Evans, in which the reconstructions were supported by extensive reinforced concrete elements (recognizable but not much respectful and not reversible). Or we can evaluate in this sense the reinforcements of the Colosseum in Rome in ‘800, as the spur of Speer: a full clay unit buttress (recognizable but not completely respectful and not reversible); we can compare it with the buttress of arches done by Valadier (recognizable, an interesting respectful interpretation of the use of clay units but anyway not reversible).

Three examples of the so called “Three R strategy” consolidation techniques are here explained (Sassu et al 2017): they can be defined as respectful, recognizable and reversible operating modes.

a) RESPECTFUL consolidation means: if it does not invade the original healthy parts of the building, the reconstructed parts are not dissonant to the original ones and the reconstructed parts do not weaken the original ones.

b) RECOGNIZABLE consolidation means: if the reconstructed part differs from the original one, albeit with technical precautions that "do not visually disturb" the construction.

c) REVERSIBLE consolidation means: whether the rebuilt part can be removed in the future without damaging the original healthy ones

A RESPECTFUL, RECOGNIZABLE AND REVERSIBLE CONSOLIDATION occurs when

The visitor hardly distinguishes the original parts from the reconstructed ones or, if he distinguishes them, the reconstructions are visually RESPECTFUL. The scholar succeeds in distinguishing the original parts from those reconstructed through a series of clearly RECOGNIZABLE technical devices. The owner of the building can make the intervention REVERSIBLE: in the future disassemble it to put in place another better one discovered.

2. A set of case studies in UNESCO sites

The first two examples are located in Southern Arabic Peninsula (Dhofar district – Sultanate of Oman): the city of Sumhuram in the UNESCO Khor Rori area built between IV B.C. and VI A.D. and the city of Al Balid in the UNESCO Zafar area, built between IX and XIII A.D. (cited also by Marco Polo in il Milione with the name of Zafar. The first one was a small emporium city over a hill surrounding the lagoon of Khor Rori, the second was a large city with relevant military city walls along the Indian Ocean

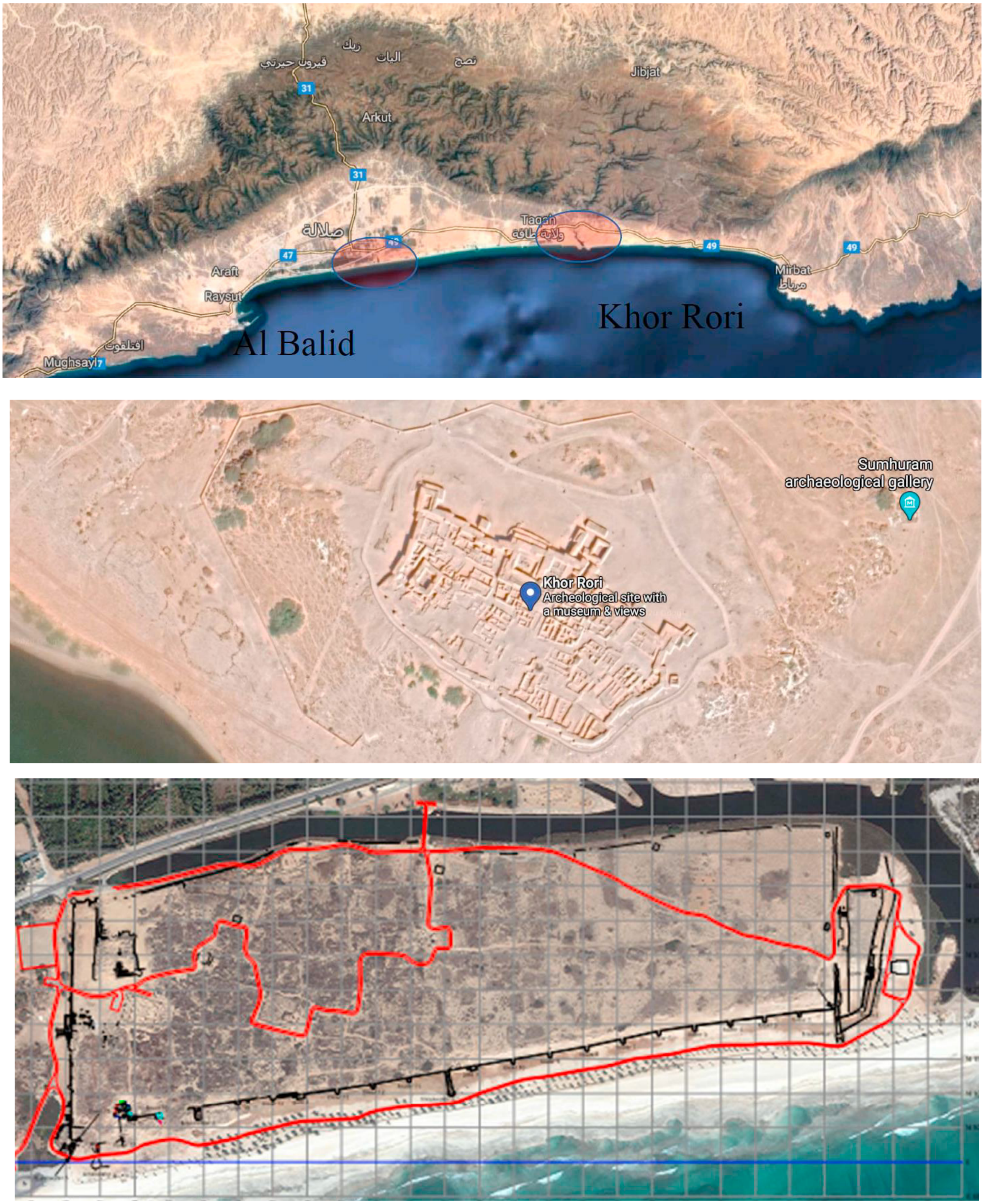

Fig. 1. Maps of Khor Rori and Al Balid.

The main structural vulnerabilities of Sumhuram city walls, observed by the author in 2004, were the following:

- The walls were originally constructed with high percentage of clay as mortar joints, exposed by reduction of its cohesion during Monsoon season, in case of absence of plaster and deck.

- The top of walls, after diggings, were not protected from rain penetration.
- The archaeological excavations were not conducted following bilateral sequences, inducing transverse forces as a retaining wall.
- Local inhabitants used the archaeological site as a «stone cave».
- Lack on maintenance works after excavations by local autorities.

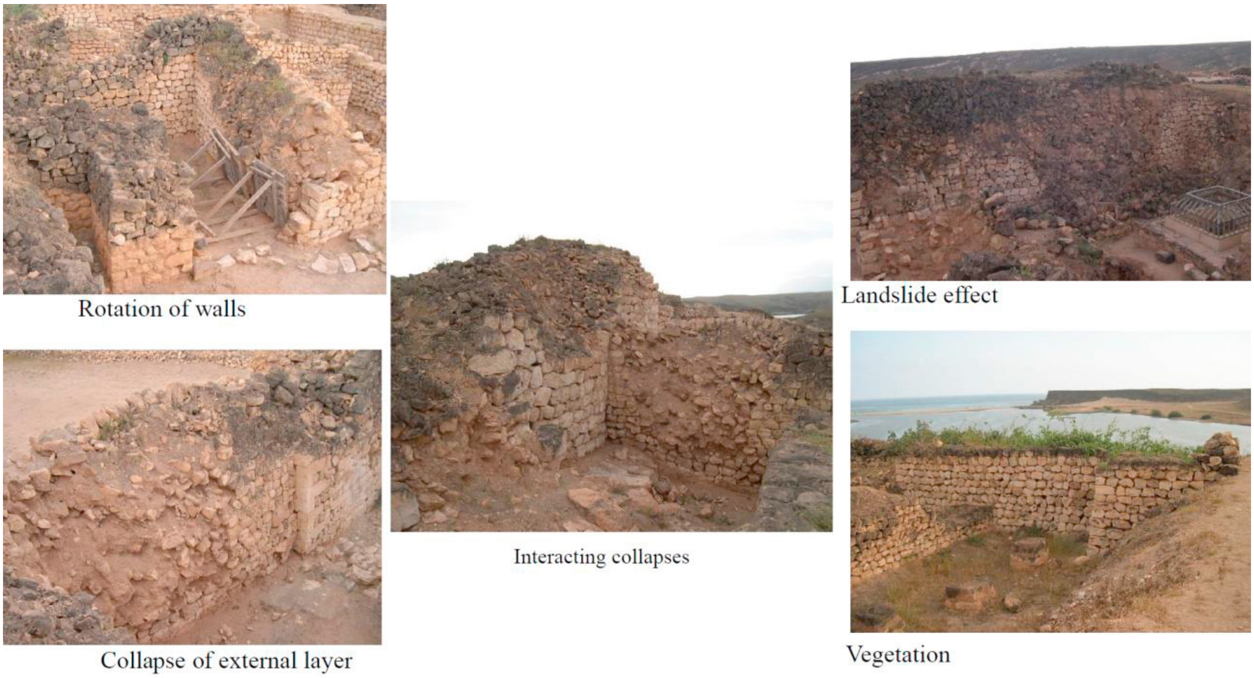

Fig. 2. Structural problems of walls in Sumhuram city.

The procedure of archaeological consolidation in Khor Rori, started in 2004, was prepared by a series of mortar specimen, with the aim to perform the best choice in terms of colors, strength and durability. The colors should be as similar as possible with the clay in the nearby; the strength should strictly sufficient to sustain the blocks but with the possibility to remove it without damages on the blocks; the durability should be sufficient to avoid erosion effects by rain or wind. After this decision, a series of small walls were constructed to test the entire efficiency of the reconstruction phases.

The procedure was then experimented to the easiest archaeological wall (M1), consisting on the isolated masonry panel in front of the main gate. The several phases were the following:

1. Disassembly with care the collapsing zones (conserving the sequences of the blocks);
2. Removal of the clay components from collapsing walls;
3. Application of a geotextile foil to separate existing by reconstructed walls;
4. Reconstructing the walls using new weak mortar (lime - NHL) with same colors of the existing clay mortar;
5. New filling inside the walls using stones, gravel and sand from the nearby;
6. Construction of a «deck» at the top of the walls made by weak mortar (lime - NHL) to avoid rain penetration;
7. Beautification of the top of the walls creating «ruin effect» by stones and gravel with weak mortar (lime - NHL).

The works involved a large number of the walls, permitting a further activity of archaeological diggings in safe conditions and finally the preparation of the path for visitors. A numerical model was then assessed to determine the main mechanical parameters of the masonry, through a back analysis of the observed failures, based on the collapse law of Mohr Coulomb (Sassu et al 2013), in order to assess the level of efficiency of both original and reconstructed masonry elements. The entire textures of block were carefully replaced to maintain their existing features.

Fig. 3. Reconstruction phases in Sumhuram city.

The second example was in Al Balid. In that case the texture of the urban walls consisted of dry-stone masonry structures. The were made by double facing with regular blocks and clogging small stone fragments. A magnificent military waterfront of about 1,3 km, built around XI A.D., was discovered by the archeologist J. Zarins in 2007. It was restored in 2010-2012 to ensure conditions of historical integrity and safe conditions for archaeologists and visitors (Sassu et al 2017). It was possible to identify a series of masonry components: a) walls; b) bastions; c) towers; d) columns; e) piers-breakwater; f) gates; g) stairs and slopes. For each component a proper procedure was performed to follow the cited Three R strategy. The constructive sequences for consolidation were: I) survey; II) cleaning; III) preparation; IV) re-construction; V) finishing activities. After geometrical survey of wall, bastions, towers and piers, the cleaning activity was the removal of the top soil and each unsafe stone by hand. The preparation consisted of the laying geotextile foils to recognize the original parts from the repositioned ones, followed by choice of stones from the storage area, based on similar nature, color and size.

Fig. 4. Aerial view of the waterfront city walls of Al Balid (Zafar in "Il Milione" of Marco Polo).

Fig. 5. Cleaning, preparation and re-construction phases in Al Balid city walls.

Great attention was devoted to replace the same texture during re-construction phasis, due to the fact that it testify the technological level of the original manufacturers. In this sense, it occurred a hand-made processing of the stones on site with a “dry” reconstruction of the missing masonry parts. The finishing phases consisted of filling the interlock zones with small “dry” stones (without soil), to ensure permeability in case of rain, followed by the application of a double layer of silt and sand, wet and beaten, to create a "surface crust" on the top of the walls. For this last aspect it was used the same lime available in the nearby.

The re-construction of the main gate, made by large regular blocks, involved an activity similar to the composition of a puzzle. Each stone was surveyed and virtually replaced to simulate the best location, in view to a proper replace.

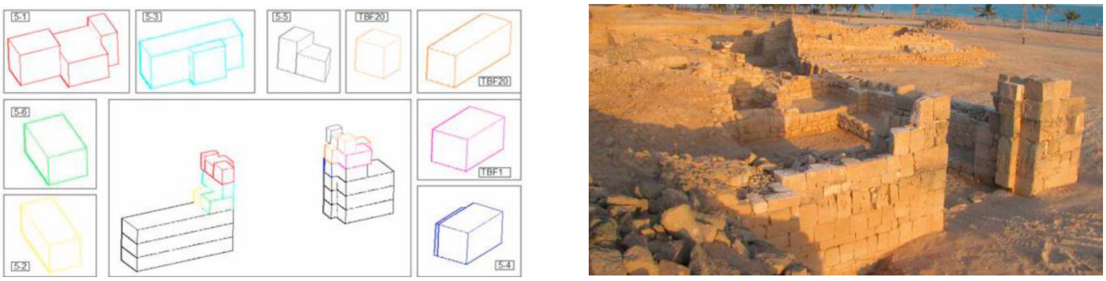

Fig. 6. Re-construction of the main gate in Al Balid city walls.

The replacement of the columns in the Great Mosque held in 2008 followed the principle of limiting the re-construction by only the stones available in the nearby, respect to the approach used in 2001 (Fig.7)

Fig. 7. Replacement of columns: (left) the approach in 2001, (right) the approach in 2008 (Great Mosque in Al Balid).

The last example is located in Shawbak Castle, in the UNESCO Petra site (Jordan). The archaeological consolidation design is devoted to conserve the original features of the several types of walls. Each typology reflects the culture of the communities that lived in the Castle. Starting from Roman period (II A.D.) in which large regular walls showed a military organization, the further periods were characterized by poor technology, like the Christian Crusades (XII A.D.), and more rich occupations, as the Ayyubid, Mamluk and Ottman communities.

Fig. 8. The Shawbak Castle in the great Petra area (Jordan).

The necessity to preserve the features of walls, arches and vaults is accompanied to ensure a safe archaeological diggings and path for visitors, to admire the monuments inside the Castle, as the Ayyubid Palace or St Mary Church. To this aim the re-construction of huge sites like this should start programming proper storage areas for blocks and materials and ensuring separated entrances with specific ramps for work activities. The role of structural engineers is of primary importance in archaeological context to help the scientists in a safe and conscious re-constructions.

Fig. 9. The Ayyubid Palace (left) and St Mary Church (right) in Shawbak Castle.

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