Article

The “Triple R” approach on the restoration of archaeological dry stone city walls: procedures and application to a UNESCO World Heritage site in Southern Arabia.

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Abstract: The “Triple R” approach on the restoration of dry stone walls, using recognizable, reversible and respectful constructive techniques, is here illustrated. A set of restoration procedures are explained and applied to a UNESCO World Heritage site in al-Baleed, (Salalah – Sultanate of Oman), placed in the “Land of Frankincense”. The procedures were adapted in innovative way to take into account the climate features of the Indian Ocean area (Monsoon season). All the restoration procedures aimed at conserving the site’s original architectural features by using only suitable stones and materials found on-site. Specific procedures have been adopted to consolidate walls, gates, foundations and sloping surfaces. Simple on-site mechanical tests and evaluation methods have been developed for a quick assessment of the safety level of the restored walls to ease future archaeological excavations.The application is related to a waterfront side of the ancient city built around ninth century C.E. and added to over the next five centuries. The mentioned restoration procedures allowed to perform further archaeological excavations with new findings here described.

Keywords: masonry; city walls; restoration; archaeological site; UNESCO World Heritage; dry stone walls; rocking collapse; Southern Arabia.

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1. Introduction

The earliest archaeological traces in the seaport of al-Baleed, located on the southern coast of the Arabian Peninsula in the Sultanate of Oman, date back to the Bronze Age (2500-1200 B.C.E.) (Office of the Advisor to H.M. the Sultan for Cultural Affairs, 2015: 17-18, Newton &Zarins, 2017). Its strategic maritime location along the Frankincense Route from India to the Levant and the Mediterranean is due to the presence of a large freshwater lagoon fed by wadis from the Dhofarmountains and its position on the coast ensured near-continuous occupation over the following centuries (Fig. 1). Al-Baleed was one of the main ports for the trade of frankincense (*Bowellia sacra*) and myrrh (*Commiphora sp.*), the former of which grows naturally on the back slope of the Dhofar hills (Miller & Morris, 1988:78-86).

Figure 1 - Aerial views of the archaeological site of al-Baleed (April 2012, Salalah – Sultanate of Oman, from W. Isenberg, Digital Mapping and Graphics)

In the Iron Age through the subsequent medieval Islamic period it was a port of call for boats in the trade with India and China, as well as to the Mediterranean and East Africa (Newton &Zarins 2010, Zarins 2001, Zarins 2009, Vallet, 2010). The province of Dhofar as exemplified by Sumhuram (KhorRori) was a significant participant during the Classical heyday of the South Arabian Kingdoms of Yemen, *Arabia Felix* (400- BCE-350 CE)(Avanzini, 2001, Avanzini, 2008, Ribechini*et al*, 2006). The description of the walled city of Zafar (Al-Baleed) by Ibn Mujawir(Traveler) *Tarikh*(1220

C.E.), Ibn Battuta in his (*Travels) Rihla* (1329 C.E.) and the discussion of the city of Dufar (Zafar) in Marco Polo's(Travels) *ilMilione* (1298 C.E.) testify to the primary role of this site along the incense route (Office of the Advisor to H.M. the Sultan for Cultural Affairs, 2015: 88-90, Newton &Zarins, 2014, Newton &Zarins, 2017).

Since the 1950s the site of al-Baleed has been the subject of excavations organized by Wendell Phillips and F. Albright (1953-1956)(Bowen & Albright, 1958), P. Costa (1977-79)(Costa, 2001), M. Jansen (1999-2001)(Jansen, 2001), J. Zarins (2001-2012) and currently by K. Lewis. Since 2006 a group of engineers directed by M. Sassu consolidated the Citadel and the Great Mosque at the archaeological site ofAl-Baleed(Andreini*et al*, 2008). In 2009 excavations held by J.Zarins& L. Newton revealed a substantial city wall and a series of bastions along the southern perimeter of the site along the Indian Ocean littoral. The wall extends about 1,3 km along the coast, and another part continues along the eastern side another 180 meters. The city wall is punctuated by semi-circular bastions 50-53 meters apart projecting seaward about 7,0-7,5 meters and a width of 6,0-6,5 meters. A total of sixteen bastions were excavated along with three substantial breakwaters and four rather monumental gates.

The wall width averages approximately 1.30 m and is composed of two facings made of dry stone blocks, partly squared with a thickness of about 30 cm; the internal part is filled with a mix of stones and sand. The existing height of the walls is between about 1,0-2,0 meters. Their foundations were partially visible after the excavation and were made by regular stone blocks filled by calcareous plaster still visible in good condition to seal the joints. The visible foundation is about 1,70 m wide and about 1,0 m high in most locations.

The magnificent and monumental configuration of the city wall, its bastions and gates testifies to the importance of the city: the substantial wall suggests that the seaport required defense against enemies coming from the sea. C14 dates from wooden piles found during excavation of the southeastern jetty suggest an early occupation date beginning in the ninth century C.E.This historic city was protected by robust masonry walls that covered about 70 hectares. Due to the large extent of the area, containing a Citadel (*Husn*) and a Great Mosque (*Masjid al Juma*) together with a wide number of buildings partially excavated, it is reasonable to estimate that over 5.000 inhabitants lived in the site during its heyday in the 13th-14th centuries C.E.

Due to internal and external forces, the site lost its importance as a military and commercial power and the population disbursed throughout nearby villages, including Salalah. More recently, the ancient city was partially demolished due to looting of the stones to build new houses and buildings in the center of Salalah. In the 1970's the entire area was fenced in by the government of Oman and preserved as an archaeological site. In 2000 the site was inscribed on the UNESCO World Heritage list as one of four sites selected to be part of the "Land of Frankincense" in Southern Oman. It has since been developed as an archaeological park and is included in the Museum of the Frankincense Land, which is also located on-site.

Collaboration with the conservation and excavation team first focused on the recovery, stabilization and conservation of the Citadel's plan, the Great Mosque and some parts of the walls on the eastern side of the site. Sassu and Zarins carried out the restoration of the perimeter of the Citadel and some original columns on the north-western side of the Great Mosque (Sassu*et al*, 2012, Casapulla*et al*, 2008, Sassu, 2012). After the discovering the city walls on the waterfront, a two-year campaign was planned and executed to consolidate them so that they would be protected from the effects of the summer monsoon and ensure visitor safety. Further technical aspects are included in (Sassu, 2012).

The importance of the archaeological discovery, also with the necessity to preserve it from a constructive point of view—ensuring integrity, durability with respect to the original architectural features—provide the guidelines for this restoration activity, applying also results on recent experiences in Italian monuments and historical walls (Andreini*et al*, 2013, Andreini*et al*, 2014).. From a cultural point of view the excavated city wall, bastions and gates as they are found are monuments that represent a specific history and any constructive operation should be *recognizable* (the reconstruction should be easily distinguishable from the original), and at the same time be *respectful* (the reconstruction as similar as possible to the original), and also *reversible* (consolidated portions should be easily discernible to easily detect original features). Therefore, the example of al-Baleed described here is a practical application of this "Triple R" approach.

2. Consolidation phases of walls, bastions and breakwaters.

Consolidation of collapsed or unstable masonry panels was aimed at rebuilding the walls to resist the seasonal impact of the summer monsoon and primarily preventing damage from the effects of rain and/or continual moisture. Wall consolidation also served to ensure safety for future excavations, as well as visitors to the archaeological park. Consolidation management was influenced by the origin of most of the workers we had at our disposal, which were from Pakistan, India and Bangladesh. These were basic laborers and did not have access to modern engineering tools. Therefore, a more traditional approach was employed, which only added to the authentic, traditional goals desired for this consolidation project(ICOMOS, 2003); moreover the unavailability of modern testing equipment forced to the organization of very simple and repeatable on-site tests, as just experimented in the nearby UNESCO site of Khor Rori (Sassu *et al*, 2006, Sassu, 2006, Sassu, 2008).

The main part of the original walls is composed of regular limestone blocks extracted from adjacent quarries located in Salalah and built without any use of mortar. Occasional traces of plaster were found in some protected corners of walls made by mud and clay or rarely by lime. A systematic calcareous mortar, following the "sarooj" of Arab construction tradition(Al Rawas*et al.*, 2001, Cei&Sassu 2001), was applied on the blocks at sea level. A preliminary cleaning activity of the walls consisted of the manual removal of vegetation, soil, small stones and crumbled blocks from the top and the adjacent lower areas. The blocks were kept in nearby storage areas to be reused for reconstruction phases. The small stones were similarly accumulated on site to be reused as the internal filling of the reconstructed walls. The reconstruction of the collapsed masonry consistently followed the described steps.

a. Manual removal of bricks or stone blocks in collapsed or dangerous conditions (tilt–rotations) on unsafe angled surfaces.

b. Placement of a geotextile layer on the base of the reconstruction zone. This separated the reconstructed part from the original wall (Fig. 2).

c. Selection of useful piece-by-piece blocks, in terms of color and shape, from the existing blocks to use for various reconstruction activities (Fig. 3).

d. Rebuilding the missing part of masonry walls with blocks without mortar; the selected set of blocks should have a small opposite inclination with respect to possible sliding movements preventing and correcting for a washout caused by rain in any adjacent part of the walls.

e. Stabilization of the rebuilt blocks with small stones by hammering them into the joints. This ensured equilibrium and mutual lateral pressure between blocks and regained the integrity and texture of the original walls, replicating also the existing texture.

f. When rebuilt walls were high, a series of internal transverse small walls were inserted to connect both external masonry faces. This protected them from potential collapse due to future excavations.

g. Fill in the empty zones between external masonry faces with chosen small stones to prevent a washout of potential rains penetrating through the walls and thereby avoiding any dangerous hydraulic transverse pressure.

Figure 2- Cleaning (left) and laying geotextile (right).

Figure 3. Piece-by-piece reconstruction phases: (upper) works in progress, (lower) wall textures with indication of the geotextile (original-under the line, reconstructed-over the line).

Each phase of wall reconstruction is thus entirely recognizable, reversible and respectful, in harmony with the original traditional building techniques: they are simply the replication of the ancient techniques, with small adaptation to increase safety to the archaeological elements, permitting the opening of the site to researchers and visitors. Finally, the use of geotextile is almost invisible to the visitor respecting the overall image of the site, but provides a clear signal to the researcher to distinguish and recognize reconstructions from the original wall.

3. Finishing phases of the walls and bastions.

After achieving a sufficient height of the walls from an aesthetic point of view, it was deemed necessary to cover the top of the rebuilt walls using a reversible and recognizable technique. The soil excavated around the walls is characterized by a mix design of clay, lime and sand: when water is added, it reaches an acceptable cohesion to sustain wind erosion. It was then decided to use the adjacent soil to arrange a cover on top of the walls. The constructive phases were as follows (Fig. 4):

a. uniform manual application of a layer of the soil matrix;
b. compaction of the layer by spraying water with low pressure;
c. cleaning of any ground spills by manually brushing the stone surfaces.

The final treatment on the top of the reconstructed walls (beautification) in the Northern and Western sides without bastions or characterized by internal buttresses was done by internal filling. It was completed with irregular stones along with, creating a series of irregular steps along the longitudinal profile to obtain a pleasing "ruin effect". Note also that in this case the entire procedure of reconstruction is reversible (due to the use of dry stone technique), recognizable (due to the presence of separating geotextile) and respectful (due to the use of similar blocks and the same constructive technique employed in the past).

Figure 4 - Bastion before (upper) and after (lower) completion.

4. Consolidation phases of special elements.

Further restoration activities were performed on special elements, which required implementing appropriate procedures to ensure their correct conservation. For example, the following procedures were employed when required:

- localizing sub-foundation or gravity walls for foundation consolidation
- slope reinforcement for paths near gates or breakwaters.

4.1. Localized Sub Foundation or buttresses.

Some walls did not have sufficient foundations, which would likely lead to problems with stability. When these situations were discovered, the following work in several phases was then performed:

1. localized excavation under the wall;
2. selection of regular blocks to fill in holes under the wall;
3. closure of holes by applying additional blocks/building stones.

For example, in one case, behind the city wall was a stone-built construction that should be excavated, but its foundations are higher than the elevation of the city wall ruins at this locale. In addition, the soil is characterized by compressed layers of lime and sand, which is vulnerable to degradation due to decreased flow when it rains. Therefore, it was crucial to construct new stone block buttresses to prevent the collapse of the building due to rotation or slip of the base (Fig.5).This section may be divided by subheadings. Authors should discuss the results and how they can be interpreted in perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted. These activities were carried out in the following phases.

1 – Regularization of the trench behind the wall and use of geotextile.
2 – Filling the trench with small stones up to the level of the newly rebuilt and constructed wall foundations.
3 – Construction of support walls in front of any areas with higher soil levels.
4 – Construction of barriers to support old walls,

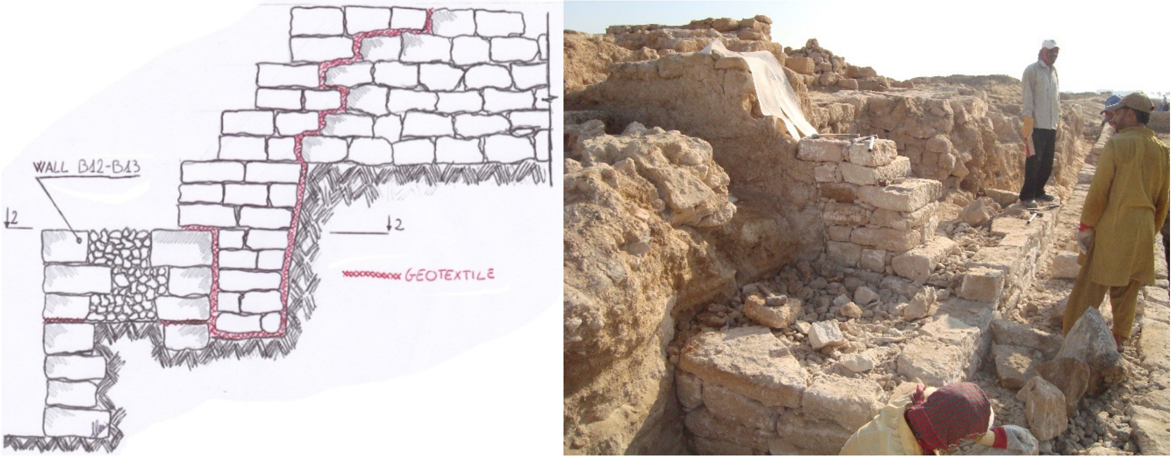

Figure 5 - New buttresses to sustain the building behind city walls

4.2. Slope reinforcement for paths on or near gates or breakwaters.

We undertook consolidation activities for slope reinforcement aimed at improving the stability of the embankment supporting the floor for access at gate n°3. The floor was at one point in time exposed to water damage due to insufficient transverse slope containment. Lateral containment was achieved by engineering the proper slope that stabilized the support for the floor. This approach was also employed because it did not require any modification of the archeological features. Thus, we accomplished these goals by the following steps.

1 – excavation of a trench at the base of embankment and laying geotextile
2 – placing large stones in the trench
3 – removing the first layer of sand
4 – constructing the proper slope with layers of compacted stones
5 – applying a layer of compacted sand with high silt content
6 – finishing by applying a layer of beach sand for a natural appearance.

In front of the eastern breakwater the excavations brought to light large rectangular stone blocks, each pierced with couple of holes, likely supported wooden posts for a deck. Accordingly, it was decided to use only stone and sand available at the site; the consolidation steps were (Fig.6):

1. construction of the semicircular base layer with large stone blocks (height about 40 cm)
2. cleaning of the slope by removing loose small stones by hand
3. positioning medium size and flat stones over the ground compacted with dark sand and water leveling of the slope manually
4. superficial covering of the stone blocks with white sand to reach the desired aesthetic result.

Figure 6 - Construction of the protective slope.

5. Procedures employed to reconstruct the gates.

The reconstruction of the gates required a careful evaluation of the original position of each block. The doorposts were indicated by a series of large limestone blocks of about 400-600 kg each. Utilizing a CAD program, a sort of virtual puzzle was created which revealed several possible solutions for the reconstruction (Fig.7). The procedure was addressed to ensure a clear identification of each block, measuring all the dimensions of every side and modeling the assembling phases in a virtual environment to correctly determine all the working phases. The step were the following:

Figure 7 - Sketch of the "stone puzzle" and the main gate after restoration

Figure 8 -The Main Gate with stones incorrectly placed before (upper) and after restoration (lower).

a) each block, identified by two numbers (gate – piece), was measured and described by means of photos and drawings
b) each block was protected with plastic sacks and/or with polyester belts, raised up by a mechanical loader and moved near the gate
c) each block was wrapped up in several belts and hung on the mechanical loader near the final position and applying a geotextile strip to separate original elements from the repositioned ones
d) the horizontal level of each support was verified; moving the block to locate it in the final position and removing the belts.

Particular interest was dedicated to gate n.5. It probably represents the Main Gate to the city (Fig.7). It is located on the south-western side and connects the waterfront to a street that runs directly to the Citadel and the Great Mosque. The analysis of shape and dimensions of the stones of the entire gate revealed some errors in previous restoration attempts (Fig.8). Once rectified, these incorrectly placed stone blocks were then put in their proper position.

6. Collapse testing and the evaluated safety level of dry stone walls.

On-site tests on a movable leaning sloping surface were performed to evaluate an experimental procedure to determine geometrical conditions of failure for reconstructed walls together with their main mechanical parameters (the internal friction angle in different collapse steps). The progressive inclination of the base simulates transverse forces on retaining walls or when out-of-plane loads occur. The measurements of collapse inclination provide the maximum safe height of the adjoining excavation near the walls, which ensures safety to laborers, visitors and the wall itself.

Five dry masonry specimens were prepared on the hydraulic lift bed of a small truck to measure the angle of failure due to the sliding self-weight. The specimens replied the transverse section of the reconstructed walls; their dimensions were: 1.30m (the typical width of the southern city wall) x 2.00m (the width of the utilized hydraulic bed of the truck) x 0.40-0,90 (from the top of the truck bed edge) as illustrated in Fig.9.

Out-of-plane rocking and sliding mechanisms were then observed and the maximum angles, corresponding to each step of the failure, were recorded. Two different collapse mechanisms were observed: the first is the rocking of irregular stones, mainly in the center of the testing procedure blocks, corresponding to the internal filling of the city walls. This mechanism was activated at an angle of about 12° with a truck load composed of irregular stones (spec.W1) and 22°-23° in case of medium regular stones (spec.W2-W3-W4-W5).

The second mechanism is the sliding movement of regular stones, mainly on the external layers of walls. It is related to the friction coefficient of the surface of walls, with collapse angles of about 28°-38°, depending on the presence of transverse connections (spec.W3-W4) and the height of the wall (W2). This section may be divided by subheadings. Authors should discuss the results and how they can be interpreted in perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

Using a design value of 22° for the friction angle, a Mohr Coulomb friction coefficient of φ = tg 22° = 0,40 can be deduced, corresponding to the standard value adopted for masonry structures. Considering the diagrams reported in fig.21 (Sassu*et al,* 2012), a maximum free height for dry stone walls of about 2,8-3,1 meters is the maximum range for a safe one-side excavation. This limit value has been adopted by archaeologists to determine the maximum differential height of the slope/embankment during excavations near the walls. It permitted a convenient safety level for workers and researchers involved in the nearby archaeological excavations.

Start of test (a)

Tilt failure (b)

Specimen	Dim [cm]	Rocking angle [°]	Sliding angle [°]
W1	90 x 130	12°	12°
W2	60 x 130	23°	27°
W3	40 x130	22°	38°
W4	60 x 130	22°	29°
W5	60 x 130	22°	31°

Sliding failure (c)

Table of specimen results

Figure 9 -On site mechanical tests.

7. South Wall Investigations 2011-2013

New archaeological investigations between 2011 and 2013 along the south seawall have presented additional challenges in the restoration and conservation activities described above. In the first case study presented here a unique building was uncovered lying outside the southern city wall not reported previously either from al-Baleed or elsewhere in South Arabia (Fig. 10).This section may be divided by subheadings. Authors should discuss the results and how they can be interpreted in perspective of previous studies and of the working hypotheses. The findings and their implications should be discussed in the broadest context possible. Future research directions may also be highlighted.

This trapezoidal-shaped structure, constructed from local limestone blocks, dates to the 13th century or later by virtue of its location outside and above the 10th-12th century CE city wall. This building ultimately proved to consist of a series of outer rectangular storerooms, some plastered, which surrounded an inner central square structure. This central square had two ascending staircases leading to upper large formal plastered basins(Fig. 10A) (Newton &Zarins, 2014:258-261; and Figs.2-3). The layout is completely different from any building yet excavated at al-Baleed and suggests a religious purpose unconnected to local Islamic practices. The interpretation of a ritualistic building function (Zarins, 2007)was reinforced by discovering inside the debris a large number of local limestone carved heads, small stone basins, and carved offertory bowls (Newton &Zarins, 2014:261-263; and Fig. 5). They may have been originally incorporated into the walls and rooms of the trapezoidal structure. The discovery of these carved artifacts and more specifically the carved heads (The Indian deity Hanuman?) and nearby diorite stone lingams suggests religious beliefs associated with Indian practices perhaps Hinduism.

To the north of the trapezoidal building, approached by a formal northern gate over the old city wall, a large rectangular basin well bonded in lime plaster represents a large water feature (Fig. 10B). With basins, walls, and drains, it may also be similar to Hindu temple water features found in temple complexes in India (Newton & Zarins, 2014:263; and Fig.2). To the west of the trapezoidal building a series of large amphorae were found perhaps associated with a nearby drain system attached to a local mosque (Fig. 10C). These large amphorae were probably part of maritime shipping and found principally on ocean-going ships. Many are hole mouth vessels with or without handles. Primarily red in color, they are paddle stamped, some with graffiti and markings on the shoulder(Newton & Zarins, 2014:263; and Fig.6). Similar amphorae have been found throughout the Northern Indian Ocean in an early 2nd millennium CE context. Inside one of the amphorae was found a bone/ivory pachesi gaming piece most likely of Indian origin – one of the earliest known (13-14thcentury?).

Figure 10. The Southwest Corner Complex of al-Baleed (insert) and the Specific Areas. (W. Isenberger, Digital Mapping and Graphics).

To the west of the amphora area a unique cemetery was located and defined by the interment of single bodies in slab lined graves (Fig. 10E) (Newton &Zarins, 2014:265-266; and Figs.8-9). They had been placed in the area after the abandonment of the southwest gate, sometime in the 12-13th century CE(see above).

Finally, a new stone jetty was uncovered in 2012 (Fig. 10F). It projected east from the earlier city wall contrary to all other jetties and piers described above. It appears to have been associated with an earlier city phase in which the jetty and city wall served as a small offloading pool in which goods were taken to the storehouses(Fig. 10G) and the Sultan's residence (*husn*) via the formal south main gate (Newton &Zarins, 2014:257-258; and Fig.2). This jetty was cut into by the later cist grave cemetery which in total numbered perhaps over 50 burials (Newton &Zarins, 2014:265-266; and Figs. 8-9). Ongoing analysis through diet studies with Strontium isotopes etc. suggests the interments are not those of locals – reinforcing the Indian connections described above (for the summary of some of the most important connections with India, see [11] p. 267-271).These new developments as well as the ongoing work in the large formal southwest warehouse by K. Lewis suggest new and ongoing emphases and challenges for the consolidation and restoration of the newly uncovered as well as existing major features of al-Baleed.

8. Discussion.

The need to implement a strong co-operation between archaeologists and structural engineers in archaeological activities is crucial to ensure safety during and after diggings. This co-operation regards the consolidation of buildings and infrastructures, as testified in the same area by previous restoration activities (D'Errico, 1983). It is also relevant to achieve a satisfactory safety level for the excavated and restored masonry elements considering not only the in-plane mechanisms but also those out-of-plane(Lourenço*et al*, 2005, Claxton *et al*, 2005).Specific attention should be addressedto one-side excavations that can cause the out-of-plane rocking of the masonry walls. This issue is of primary importance in case of archaeological sites located in seismic areas. More in detail, rocking mechanismsare generally analyzed with conventional techniques, based on equivalent static approaches. This approach could overestimate the collapse transverse force, limiting in a not proper way the depth of one side excavation or causing an over-designed structural consolidation (Giresini*et al*, 2015). The over estimation of the seismic forces could also limit the use of roofs (Giresini*et al*, 2016) to protect the excavation findings from climate events. For this reason, a pure dynamic approach based on the Housner's formulation should be considered in addition to conventional techniques (Giresini*et al*, 2015, Giresini&Sassu, 2016). In addition, similar issues can be faced by evaluating other structural responses, such as energy dissipation (Giresini, 2015). Further "triple R" restoration procedures can be then developed to cover this aspect, not considered in the present paper, to extend the proposed procedures to archaeological sites in seismic areas. Finally, further simple experimental procedures have to be performed to permit assessment of mechanical properties for dry stone masonry (Villemus*et al.* 2016), also when technological devices are not available on site.

9. Conclusions.

The "Triple R" approach for the restoration of historical constructive features has been explained by way to an extensive network of defensive city walls, recently discovered at al-Baleed, a UNESCO World Heritage site in southern Oman.

Specific procedures for the reconstruction and protection of walls, foundations, slopes and gates have been illustrated, referring to actual recovered and excavated examples uncovered by archaeologists.

Simple mechanical tests and evaluation methods have been presented, which furnish a practical procedure to assess the maximum one side excavation level near dry stone walls, while offering safe conditions for future archaeological excavation. Finally, achieved a sufficient safety level for excavations, relevant discovering in the South-Western side of the city have been presented.

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Author Contributions: Mauro Sassu conceived and designed the restoration procedures on walls, Linda Giresini conceived and designed the restoration procedures of the gates and the slopes, Juris Zarins and Lynne Newton developed the historical aspects, described the archaeological excavations and the related findings.

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