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Experiences of consolidation on archaeological UNESCO sites in Sultanate of Oman: The Fortress of Al Balid and the Citadel of Sumhuram

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ABSTRACT: Taking the opportunity to collaborate with the archaeological groups a staff of structural engineers has been organized to attend the consolidation works on the UNESCO sites of Khor Rori and Al Balid (Sultanate of Oman).

Starting from early 2005 a series of missions have been managed to restore the ancient city walls of Sumhuram in the site of Khor Rori and other structural elements, establishing the appropriate procedures and co-ordinating the workmen involved during excavations, together with the archaeological Italian Mission To Oman of the University of Pisa. The site is characterized by a cave of limestone, used for the city walls, and a soil with high percentage of clay, used to infill the block joints and the space between the external stone faces. The two faces of walls were not well transversally connected and the internal filling was made by clay soil: during the rain seasons the filling reduced its consistence causing progressive collapse situations. The rebuilding activity of walls has been involved to give safety along the path for visitors, replying the same texture of the stones adding internal transverse stone connections ("orthostati"), accompanied by a proper choice of the mortar (colour, composition and strength) to reply the original joint aspect and filling the walls with a mix with superior permeability. The re-constructed walls has been separated by the original with a geotextile foil. A simplified analytical model has been then prepared to evaluate the increment of safety level due to the consolidations, assigning the shape of the collapse surfaces and adopting a simplified approach of limit analysis.

In the same period members the group have been involved to consolidate the Fortress in UNESCO site of Al Balid in the nearby (Salalah – Sultanate of Oman) erected about 1100 A.D.; the excavations was managed by the Institute of Archaeology of the Missouri University. In this case the absence of mortar did not cause collapses, while the resistance has been ensured by the gravity loads and friction of stones; the collapse has been originated by the loss of permeability of the external wall faces due to the progressive filling of joint by soil. Therefore consolidations consisted to excavate and immediately rebuild the collapsed walls with the same blocks down, after the substitution of the earth behind the external layers remaking a drainage made of mixed gravel and small stones selected on site to ensure an efficient washout during rain seasons. Unoriginal ramps to penetrate inside the Fortress has been removed with accurate excavation, reducing transverse loads due to the unbalanced earth pressure. A simplified model to evaluate the behaviour of walls has been performed to describe failure mechanism and the influence of the main physical and geometrical parameters.

1 AL BALEED FORTRESS: RESTORATION ACTIVITIES

The Fortress of Al Balid, located in Salalah (Oman), is originated around XI century AD and is composed by a texture of dry stone walls partially collapsed or covered by sand and lime. The construction is organized on a rectangular plan of about 70 × 60 meters, with circular towers on the edges and near the gates. The structural consolidation works has been started in early 2007 and has been divided into two main categories:

1. Stone and earth ramps.
2. Local reconstructions of collapsing masonry panels.

1.1 *Stone and earth ramps*

Eight stone and earth ramps has been individuated around the external walls of the fortress, made intentionally during previous works or caused by natural deposit due to environmental effects.

It has been necessary to remove the ramps to show the original walls, avoiding an unbalanced excavation (exterior-interior); moreover some ramp could be precious to remove materials from the inner part of the fortress.

One of them has been completely remove, except a zone of respect in front of the fortress, to prevent rotation collapse of the perimeter walls of the fortress.

Figure 1. A case of Al Balid wall before and after restoration.

On north-eastern edge new ancient structures of masonry walls (maybe pre-Islamic) has been discovered under a round tower.

Another has been partially removed, conserving a path of about two meters to penetrate inside the fortress and maintaining a zone for respect similar to the first one.

Two ramps, artificially erected in the past to take away the stones of the construction, had been strongly reduced in length, to permit the restoration of the adjacent wall zones and to prepare the access along the main gate of the fortress.

1.2 *Local reconstructions of collapsing masonry panels*

It has been individuated and restored typical local collapsing zones on external walls, situated in the southern and in the eastern sides of the fortress. The reconstruction phases has been arranged starting from removing the not structural materials (earth, clays, disaggregated stones etc.) on the top and around the sliding surface.

Bricks in collapsing conditions (tilt – rotations), around the sliding surface, has been removed and placed nearby in order to a further reuse; this dismantling phase last until a masonry course with a proper arrangement has been found.

Earth embankment behind the wall had been excavated for a depth of about 1 m, in order to get a proper space for placing small stones as drainage, to avoid penetration of clay particles between brick joints with the consequential drop of friction, together with the decrease of water pressure against the wall in case of rain.

Reconstruction of wall face and retro-filling with small stones proceed in same time, step by step. After two or tree layers of masonry, according to height of blocks, small stones has been placed until the last course was reached.

In order to detect the new masonry and remark the restored part, a film of geotextile had been placed at the basement of the reconstructing zone.

The lacking part of each zone has been rebuilt, as over described, using blocks without mortar, with the caution to pose the inferior side with a small opposite inclination respect to possible sliding movements and with a set of small stones forced into the joints to give proper equilibrium and pre-compression to each block. Bricks that have been used for reconstruction had been chosen in order to obtain a masonry texture similar to the adjacent.

2 SIMPLIFIED NUMERICAL MODEL OF THE WALLS OF AL BALID FORTESS

2.1 *Generality*

The restoration work changes the collapsing behaviour of the wall. The removal of the clay from the joints of the bricks allow to reach again a friction resistance and the placing of a drain, behind the wall, allow to remove the water pressure and to avoid small clay particles to come again between blocks. This let us to consider the dry wall as a vertical set of rigid elements, overlapped with staggered joints and unilateral frictional constrains; the whole structure is standing against the pushing of the earth embankment behind itself.

The aim of this study is to describe the geometry of the collapsing portion of masonry with a limit state analysis; a simplified model permits to find the highness $\times$ of the wall involved in the collapse and how it change according to physical and geometrical parameters.

2.2 *Description of the simplified model*

The supposed cinematic model, close to the actual behaviour of some already collapsed walls in the site, is characterized by the bulging of two symmetric triangular portions from the wall surface, as proposed by Casapulla [1999–2007].

Each triangle is free to bend around two plastic hinges, as shown by following figures, while the other part of the wall is stable. A generic horizontal plane cut the collapsing faces in a set of arch-beams with various span and three hinges: in the centre and in the springer.

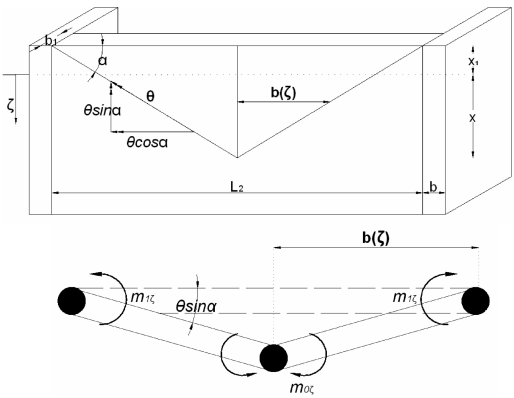

Figure 2. The failure mechanism.

Once decided the characteristic displacements of the failure models, the angles ψ and Θ, respectively of the foot and of the lateral out-of-plane sides of the masonry, are known. Moreover, even if the distance from the top of the wall changes, the rotation around the oblique hinge remains constant on every horizontal plane.

This rotation can be divided into one, around an horizontal axis ($\Theta\ \cos\alpha$), and one around a vertical axis ($\Theta\ \sin\alpha$); only the last one is responsible of the working of internal and external forces.

Frictional resistance is activated out of the main plane of the wall face; it consists on pure torsion, on the interface of the blocks of the middle axes' hinge, and in a combining action of shear and torsion, on lateral hinges.

On the frictional surface between two blocks, ($l*b_1$), calling ζ the distance from the top of the wall, pure share and pure torsion resistance are given by:

$$T_{0\zeta} = \tau_\zeta b_1 l \tag{1}$$

where $\tau_\zeta = \gamma\zeta \tan\phi$ and γ and Φ respectively unitary weight and frictional angle, while

$$M_{0\zeta} = T_{0\zeta} d_0 \tag{2}$$

where it has been taken, according to Casapulla:

$$d_0 = \frac{1}{12 b_1 l}[l^3 \ln\frac{b_1 + \sqrt{l^2+b^2}}{l} + 2b_1 l\sqrt{l^2+b^2} + \\ + b_1^3 \ln\frac{l+\sqrt{l^2+b^2}}{b_1}] \tag{3}$$

On lateral hinges the shear T_ζ over stand the external action on that height. The used relation between

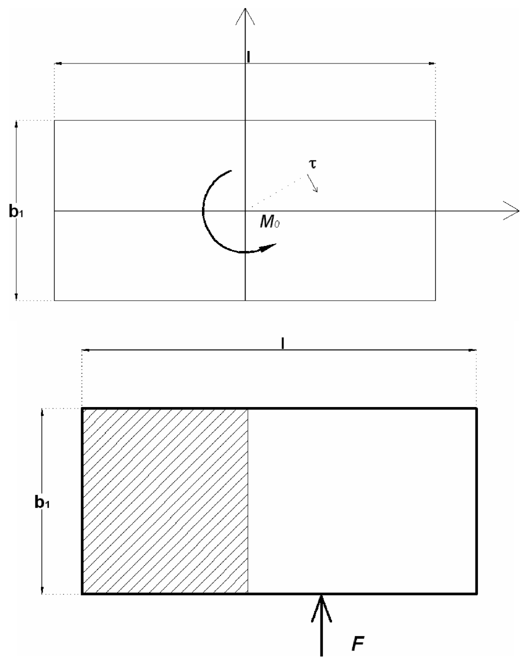

Figure 3. Block with pure moment and Block with moment and shear: resistance surface of the block.

torsion moments and shear action, regarding to safety conditions, is:

$$M_{1\zeta} = M_{0\zeta}(1 - \frac{T_\zeta}{T_{0\zeta}}) \tag{4}$$

2.3 *Elaboration of the model for the specific case study*

External loads acting on the wall are the weight P and the pressure of the earth embankment ST, while the internal working forces are torsion moments generated by the frictional contact surfaces between the bricks.

Calling h, highness of each course, unitary moments are:

$$m_{0\zeta} = \frac{M_{0\zeta}}{h} \quad \text{and} \quad m_{1\zeta} = \frac{M_{1\zeta}}{h}.$$

The work of the internal actions, on the generic x length, is given as follow:

$$L_{INT} = \int_0^x 2(m_{0\zeta} + m_{1\zeta})(\theta \sin\alpha)d\zeta = \\ = \int_0^x 2\frac{T_{0\zeta} d_0}{h}(2 - \frac{T_\zeta}{T_{0\zeta}})(\theta \sin\alpha)d\zeta \tag{5}$$

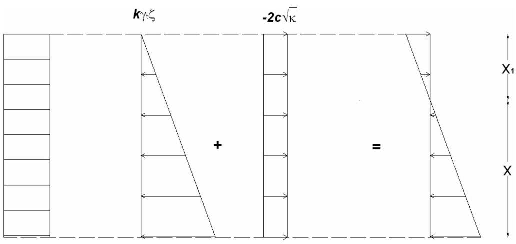

Figure 4. Diagram of pressures on the wall.

The rate of the shear acting on the single block, at ζ dept, can be evaluated as follow from Rankine's equation for a cohesive ground:

$$\sigma_{T\zeta} = K_a \gamma_T \zeta - 2c\sqrt{K_a} \tag{6}$$

The first part of the ground, until x_1 is characterized by shrinkage caused by tractions. For taking account of this, the push σ has been considered starting from x_1, as follow, where depth x_1 is also the zero of the ζ axis, given by:

$$x_1 = \frac{2c}{\gamma_t \sqrt{K_a}}$$

Along the generic course, which length is b(ζ), involved in the failure mechanism, we have:

$$dS_{T\zeta} = \sigma_{T\zeta} b(\zeta) d\zeta = K_a \gamma_T \zeta b(\zeta) d\zeta \tag{7}$$

with

$$b(\zeta) = \frac{L_2}{2(x + x_1)}(x - \zeta).$$

Then:

$$T_\zeta = \int_{\zeta-h}^{\zeta} dS_{T\zeta} = \int_{\zeta-h}^{\zeta} K_a \gamma_T z \frac{x - z}{x + x_1}\frac{L_2}{2} dz \tag{8}$$

Considering the equation (5) the internal work is:

$$L_{INT1} = [\int_0^x 2\frac{T_{0\zeta} d_0}{h}(2 - \frac{\int_{\zeta-h}^{\zeta} K_a \gamma_T z \frac{x - z}{x + x_1}\frac{L_2}{2} dz}{T_{0\zeta}}) d\zeta]\theta sin\alpha$$

where, in this specific case,

$$T_{0\zeta} = \gamma(\zeta + x_1) b_1 l * tan\phi$$

From the top of the wall until the depth x_1, blocks are not submitted to any shear force, due to the fact that the work of σ tractions is spent in the opening of small cracks in the ground. All the hinges are characterized by pure moments $m_{0\zeta}$; under these hypothesis internal work from top to x_1 can be written as follow:

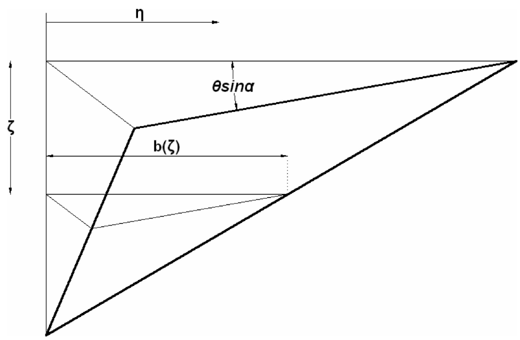

Figure 5. View of rotation of wall triangle.

$$L_{INT2} = \int_0^{x_1} 4(m_{0\zeta}\theta sin\alpha) d\zeta = \int_0^{x_1} 4\frac{T_{0\zeta} d_0}{h}(\theta sin\alpha) d\zeta$$

Solving the integrals above is possible to obtain total internal work:

$$L_{INT} = (\frac{1}{6}d_0 x \frac{12\gamma b_1 lfx^2 - \gamma_t K_a L_2 h x^2 + 36\gamma b_1 lfx_1 x}{(x + x_1)h} + \frac{1}{6}d_0 x \frac{24\gamma b_1 lfx_1^2 + 2L_2 K_a \gamma_t h^3}{(x + x_1)h} + 2\gamma b_1 lf\frac{d_0}{h}x_1^2)\theta sin\alpha \tag{9}$$

The work done by the external actions can be divided into a contribute given by the pressure of the embankment and one given by the self weight.

This last contribute is:

$$L_P = -\frac{\gamma b_1^2 L_2^2}{8}\theta sin\alpha$$

Referring to figure 5 the elementary work of the push of the ground at the generic depth, is:

$$dL_{ST} = \sigma_t \eta \theta sin\alpha d\zeta d\eta$$

and, so:

$$L_{ST} = \iint \sigma_t \eta \theta sin\alpha d\zeta d\eta$$

which must be evaluated first in dη, between 0 and b(ζ), then in dζ on the whole depth x. After this:

$$L_{ST} = 2\int_0^x \frac{\gamma_t K_a \zeta}{2}(\frac{L_2}{2}\frac{x - \zeta}{x + x_1})^2 = \frac{1}{48}K_a \gamma_t L_2^2 \frac{x^4}{(x + x_1)^2}\theta sin\alpha$$

Finally, the total work of the external actions is given by:

$$L_{EST} = [\frac{1}{48}K_a\gamma_t L_2^{\ 2}\frac{x^4}{(x+x_1)^2} - \frac{\gamma b_1^{\ 2}L_2^{\ 2}}{8}]\theta\, sin\,\alpha \quad (10)$$

The height of the portion of wall involved in failure mechanism can be found equalling the work of the internal forces with the work of the external action, as follow:

$$[\frac{1}{48}K_a\gamma_t L_2^{\ 2}\frac{x^4}{(x+x_1)^2} - \frac{\gamma b_1^{\ 2}L_2^{\ 2}}{8}]\theta\, sin\,\alpha =$$

$$[\int_0^x 2\frac{T_{0\zeta}d_0}{h}(2-\frac{\int_{\zeta-h}^{\zeta} K_a\gamma_T z\frac{x-z}{x+x_1}\frac{L_2}{2}dz}{T_{0\zeta}})d\zeta + \int_0^{x_1} 4\frac{T_{0\zeta}d_0}{h}d\zeta]\theta\, sin\,\alpha \quad (11)$$

Finally it deduces an equation in the form:

$$Ax^4 + Bx^3 + Cx^2 + Dx + E = 0 \quad (11')$$

where:

$$A = 2\frac{d_0}{h}\gamma b_1 lf - \frac{1}{6}d_0\gamma_t K_a L_2 - \frac{1}{48}\gamma_t K_a L_2^{\ 2}$$

$$B = 8\frac{d_0}{h}\gamma b_1 lfx_1 - \frac{1}{6}d_0 K_a\gamma_t L_2 x_1$$

$$C = 12\frac{d_0}{h}\gamma b_1 lfx_1^{\ 2} - \frac{1}{3}d_0\gamma_t K_a L_2 h^2 + \frac{1}{8}\gamma b_1^{\ 2}L_2^{\ 2}$$

$$D = 8\frac{d_0}{h}\gamma b_1 lfx_1^{\ 3} + \frac{1}{3}d_0\gamma_t K_a L_2 h^2 x_1 - \frac{1}{4}\gamma b_1^{\ 2}L_2^{\ 2}x_1$$

$$E = 2\frac{d_0}{h}\gamma b_1 lfx_1^{\ 4} - \frac{1}{8}\gamma b_1^{\ 2}L_2^{\ 2}x_1^{\ 2}$$

2.4 *Analysis and discussion of results trough a numerical application on the intervention on site*

The (11') represent an equation where the solution x represents how the maximum allowable height of the wall changes in relation with mechanical and physical parameters.

The solution of the equation has been reproduced on several graphs with the aid of the Mathcad code, taking account time by time, the most significative uncertainties. Under this point of view is important to consider the non homogeneity of the blocks and the uneasy determination of the characteristics of the retrofitting earth.

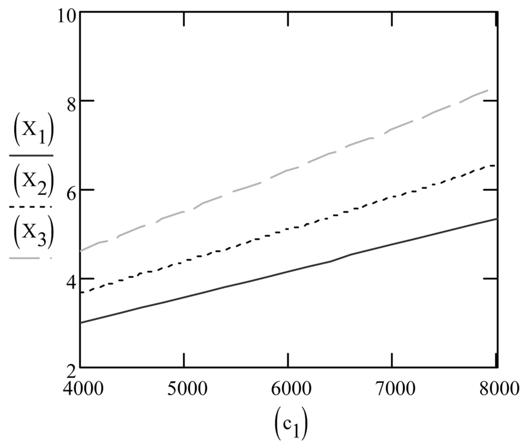

Figure 6. Variation of x with cohesion ([x] = m, [c_1] = N/m^2 $X_1 \rightarrow b_1 = 25$ cm; $X_2 \rightarrow b_1 = 30$ cm; $X_3 \rightarrow b_1 = 35$ cm).

To get round the first problem, and obtain a kind of regularity of geometrical parameters, we may refer, case by case, to average values of characteristic dimensions of a specific wall.

In this numerical example, unitary weight (γ_t) and friction coefficient (f) has been taken as 2000 daN/m^{3}and 0.4, while the average longitudinal dimension of the blocks (l) is 40 cm. Highness of singular courses (h) is 25 cm and doesn't show particular variation across the wall.

In the following graph is represented the variation of x with the cohesion c [c_1 in the graph axis], in this specific case the width of the wall was about 30 cm, but it had been set as a parameter to check its influence on the highness of the wall.

In the graph below is possible to notice the variation with the length of the wall L_2; width $b_1$and cohesion c, had been set up as parameters.

As it can be notice from these two figures, the height of the wall x, representing the maximum dept for the archaeological excavation to reduce with a proper safety coefficient, is related to the cohesion of the retro filling earth.

The evaluation of this parameter may be difficult and its values show deep changes in relation with environmental and weather conditions. During the year, the site can be in two opposite climatic situations: a rainy season, with high rate of humidity, from June–July until September, and a very dry and hot climate in other months. Therefore further studies and measurements of the cohesion values might be interesting in order to obtain the gap of its variability and the applicability of the model.

As it can be notice from the graph below the field of existence, and of related results, may be very deep: within the decrease of cohesion, during the rain season

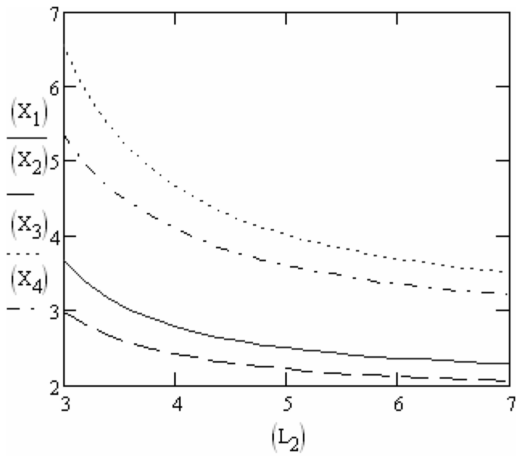

Figure 7. Variation of x with L_2 ([x, L_2] = m, $X_1 \rightarrow$ c = 400 daN/m^2, b_1 = 25 cm; $X_2 \rightarrow$ c = 400 daN/m^2, b_1 = 30 cm; $X_3 \rightarrow$ c = 800 daN/m^2, b_1 = 25 cm; $X_4 \rightarrow$ c = 800 daN/m^2, b_1 = 30 cm).

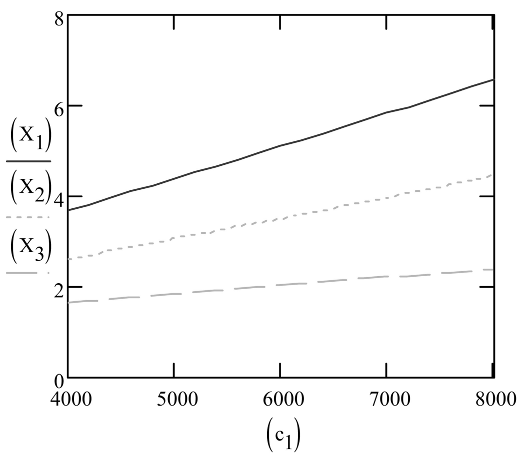

Figure 8. Variation with cohesion c_1, in both cases of dry and wet conditions. ([x] = m, [c_1] = N/m^2 $X_1 \rightarrow \gamma_t$ = 1600 daN/cm^3; $X_2 \rightarrow \gamma_t$ = 2000 daN/cm^3; $X_3 \rightarrow \gamma_t$ = 2000 daN/cm^3;f = 0).

it also occurs an increase of the unitary weight of the ground due to reduced permeability of the soil behind the walls.

In above figure it can be pointed out how x decrease when clay particles enter between block surfaces, removing the contribute given by friction.

When the ground became full of water, the cohesion decrease, so it could be interesting find a relation between this decrease and the moist content, and then with γ_t, in order to have the two extreme ranges of the validity of the theory in opposite climatic conditions.

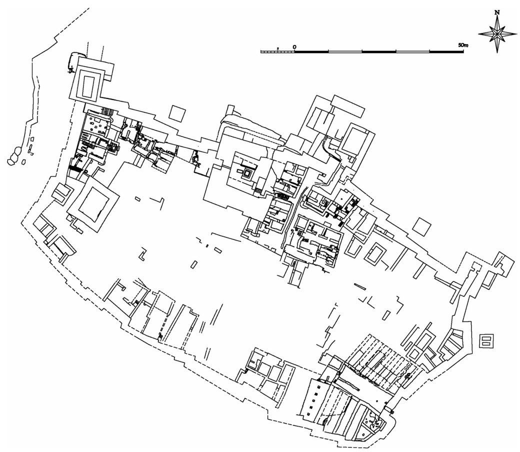

Figure 9. Plan of the masonry walls in the Khor Rori site.

Anyhow it can be remark that max x value after consolidation work should be to refer to the lower limit for safety reasons.

3 ARCHAEOLOGICAL AND STRUCTURAL PROBLEMS OF WALLS OF KHOR RORI

3.1 *Description of the site*

The archaeological site of Khor Rori is situated along the southern coast of the Arabian Peninsula, about 35 km east of Salalah, the main city of the Dhofar region and the second largest in the Sultanate of Oman. A natural harbour on the Indian Ocean, the site is crossed by a large stream (the Khor) fed by the rainfalls that periodically flow from the Wadi Darbat. The runoff is caused by a particular meteorological phenomenon known as 'Kahreef', stemming from the effects of the westernmost edge of the Indian monsoon, which brings continuous light rains during each summer, as well as the well-known moderate temperatures much appreciated by the Arabians. Here, the desert climate is strongly mitigated by the effects of Kahreef.

In about the 4th century BC the ancient city of Sumhuram was founded on the main hill adjacent to Khor Rori. It was to remain a centre of frankincense trade up to the early Islamic period (6th century AD), and grew to become the major port on the Arabian Peninsula for shipping trade from India, along the renowned "incense route". The archaeological site first investigated in the 1950's by an American expedition has been declared a UNESCO world heritage site and since 1997 has been under the management of the I.M.T.O. (Italian Mission to Oman), conducting a series of archaeological campaigns directed by A. Avanzini of the University of Pisa.

Figure 10a. Example of collapsing walls (type a).

Figure 10b. Example of collapsing walls (type b).

3.2 *The structural problems*

The ruins of the ancient city are bounded by walls of considerable thickness (up to 4 m). The walls' masonry as well as their infrastructures (towers, gates, entrances, etc.) and the dwellings within them are all made up of two poorly worked limestone or sandstone external layers without mortar joints. In their centres is a disorganized mixture of unselected ground materials, mostly sand and clay. The grain composition of such a random mixture ensures a certain degree of internal cohesion and shear strength during the monsoon rain season.

It is very likely that when the walls were built they were coated with plaster and some kind of topside protection against the rains. Such measures would have afforded cohesion to the walls, which are mainly of an "opus incertum" type, and prevent the filling material between the two outer facings from losing cohesion and being washed out.

There are now large sections of the walls that show marked signs of subsidence attributable to the poor quality of the inner plaster mixture, exposing them to transverse earthquake collapses and the effect of the monsoon seasons, and the lack of topside protection from the rain.

Two types of collapse have been encountered:

a) expulsion of the outer facings caused by the transverse pressure exerted by the random inner clay-sand mixture, due to loss of cohesion and meteoric washout. These extrusions are visible as vertical bulges as well as rigid rotation of single bricks or groups of bricks starting at the top;
b) expulsion of the outer brick layers and the internal mixture of the thicker walls. These appear as surfaces collapsed into the spoon shape typical of the landslide mechanics of soil subsidence in presence of transverse loads, as earthquakes, joined with repeated monsoon seasons.

Both phenomena, which began after archaeological excavations were initiated and worsened with each monsoon season, have reached macroscopic proportions and manifest such a rapid and irreversible development that large sectors of the existing walls are now so damaged that there is a real risk of their collapsing within few years.

The situation is compounded by further issues, amongst which the critical state of stability of the wall base should be noted. In fact, the bases in many sections manifest progressive thinning or thickening as a result of the lateral thrust of the ground materials within the brick masonry layers.

3.3 *Guidelines for consolidation*

Given the structural damage to a number of the walls in question and the impossibility of onsite reinforcement without significantly altering their constructional and aesthetic features, the only course of action is to carefully dismantled and rebuild them. One critical consideration is that the extreme precariousness of some of the walls constitutes a very real risk for visiting tourists and scientists alike. In order for reconstruction to be carried out properly, that is, by replicating the original techniques, particular attention must be focused on the nearly perfectly preserved residues of mortar in the joints between some stone blocks. As far as possible, rebuilding should adopt the same mixture, design and chromatic effects as the originals. These were presumably prepared in underground ovens to produce quicklime (CaO), which was then slaked by soaking to produce $Ca(OH)_2$ (also known as lime putty), which when mixed and left to hydrate yields limestone ($Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$). There is much evidence supporting the utilisation of this procedure, in many ways similar to age-old building techniques used elsewhere, including Europe.

In order to rebuilt the structurally damaged walls in accordance with UNESCO guidelines, taking into

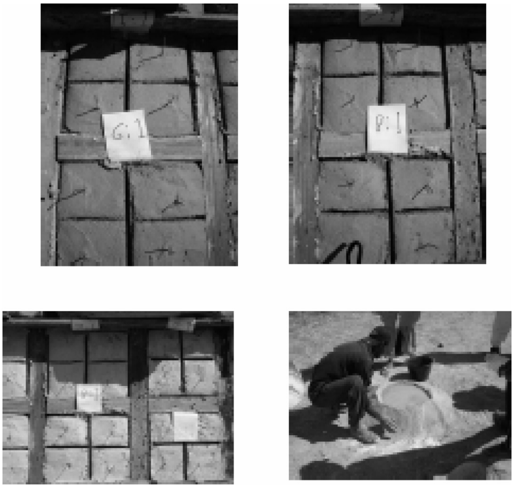

Figure 11. Specimens of mortar mix design.

account the geometrical and historical features, intervention should proceed as follows:

a) Reducing the internal transverse loads, by way of partial calcification of the inner random mixture in order to afford it permanent cohesion. This can be achieved by adding a low percentage of lime mortar, similar in composition and colour to the residues examined, together with random stone filler to reduce the percentage of clay and increase the internal friction properties of the inner mixture. This will lessen the horizontal load on the external brick layers. Furthermore, wherever possible, more stone slabs should be placed crosswise, as "orthostati" to connect the external layers and prevent bulging.
b) Preventing rain seepage from the top, by protecting the upper part of the walls through addition of a layer of "poor lime mortar" to form a suitable deck laid with a slight camber (a slope of $1 \div 2\%$) on both sides to allow rainwater runoff. This layer can be finished with a mixture of stones and sand designed to yield the same colours as the walls (beautification).
c) Preventing lateral washout of the internal mixture, by sealing the interstices between the non-squared stone blocks with the same lime mortar used for beautification. The mortar should, as far as possible, be applied under the cut (back from the wall surface) to reduce its visual impact.

3.4 *Mechanical model for sliding surface*

From the observations on site, some collapsed masonry structure portions are similar to a spherical sector which has endured a rigid rotation in the orthogonal plane to vertical facings. The parameters for relative volumes and possible sliding surfaces

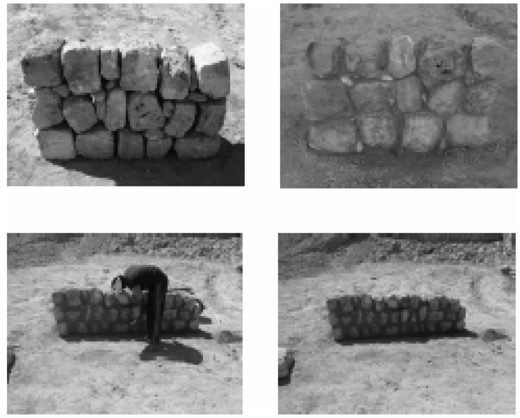

Figure 12. Small test walls for rebuilding procedure.

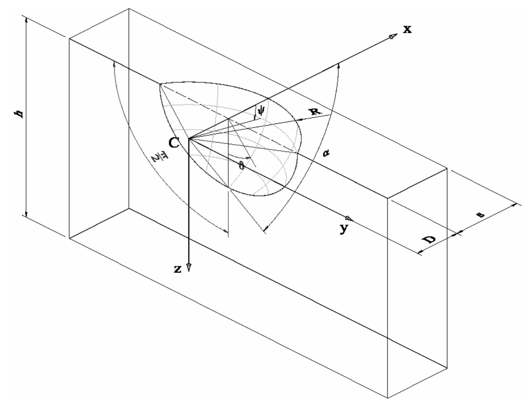

Figure 13. Geometrical parameters for volumes and sliding surfaces definition.

determination are the radius R and the angle α (Fig. 5), where the angles ϑ e ψ define volume and surface infinitesimal elements used in this analysis.

The material responds to the Coulomb strength criterion, defined by the values of the cohesion c and the angle of friction ϕ as explained in Sassu et al. [2006].

4 CONCLUSIONS

In the present paper two different kind of restoration activities have been shown; both works have been done using natural materials according to UNESCO issues and permitted to reach satisfying results under aesthetical and safety aspects.

In the same time related simplified models of the structural behaviour of the failure mechanism have been developed.

Due to non standard collapse surfaces and to the uncertain of the parameters further studies may be necessary in order to get limit boundaries of the applicability of these model together with considerations on seasons and consequential variability of weather conditions. Anyhow, is important notice that the proposed application allow to describe into a numerical way the different influence of main parameters on the whole mechanism and how it find correspondence in the real observations on site.

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