

Conservation and Preservation of Historical Earthen Structures

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Abstract: This paper discusses the different techniques that can be adopted for conservation and preservation of historical earthen structures constructed using adobe mud bricks in non-seismic regions. Initially, it reports the different damage patterns and modes of failure that are usually exhibited by these structures due to aging process and poor environmental conditions as recorded from field visits. Then, it explains using structural fundamentals and soil mechanics principles the causes for these defects. Finally, it suggests various measures that can be taken to restore and preserve these endangered structures.

Keywords: Conservation, preservation, historical, earthen, structures

Introduction

In many parts of the old world such as China, India, the Arabian Peninsula, Spain, and North Africa, historical buildings were built from unbaked earth (including adobe, rammed earth, wattle and daub, and so on). These historical earthen structures are primarily a vernacular and a ubiquitous form of construction that is extremely suited to the hot and arid regions, due to their improved thermal performance, inherent relative humidity content, and to low transport costs associated with using soil dug in-situ (local resources). Today, many of these buildings are still surviving, but in relative poor structural conditions that need immediate intervention to restore, preserve or conserve them.

The main aims of this paper are to increase the understanding of the structural behaviour of historical earthen structures, in order to improve the engineering knowledge available to restorers and conservators. Also, to explore in a scientific manner, the different restoration techniques that can be adopted for retrofitting these endangered structures.

In order to develop such understanding many field visits were taken during the period from 2006 to 2007 to the historic site of Al-Dar'iyya which is located 15 km away from Riyadh city (the capital of the Kingdom of Saudi Arabia). This region was the ruling centre of the family of Al-Saud and was initially established in 850AH / 1446 AD. It contains several palaces, administration buildings and other related offices constructed from bearing walls made of mud blocks (adobe) or earth rammed lifts stacked over each other and plastered with several layers of clay supporting roofs made of wooden girders. The site visits were taken as part of a restoration project initiated to restore and conserve this historical site. It followed by experimental and numerical studies to assess the causes of recorded damages and to define the different feasible retrofitting and preservation schemes.

Building Configuration and Construction Techniques

Buildings belonging to this site have a unique architectural configuration. They possess large open courts located in the middle of their premises, surrounded with many rooms leading to these courts as shown on Fig. 1, which shows the ground floor plan for one of the palaces. Around the open court, stone columns were utilized to support the roof as shown on Fig. 2, while bearing walls were used to support the room roofs. Two construction techniques were involved in the construction of these walls. The first technique was utilized for low-cost housing and small administration buildings and involved the use of small sundried mud blocks (adobe) stacked over each other, as shown in Fig. 3, and plastered with several layers of clay. Certain percent of straw was mixed with the clay to work as fibers reinforcing the blocks themselves and the external plaster layers. The second technique was

utilized for construction of palaces and large buildings, where thick-high walls are needed. In this technique walls are constructed in lifts as shown on Fig. 4 and described by Jaquin et al. (2007).

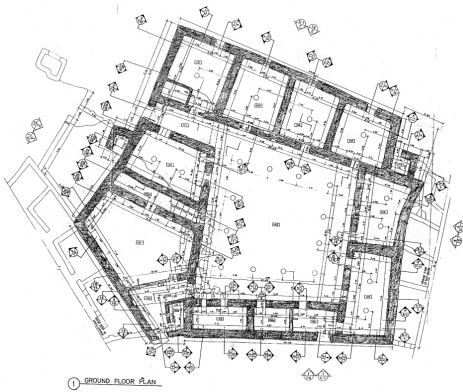


Figure 1: Typical ground floor plan for a Palace



Figure 2: Stone columns around open court



Figure 3: Wall constructed using sundried mud bricks



Figure 4: Wall constructed using lifts

Observed Damage Patterns

Water is considered the main threat to these historical mud structures. As can be observed from examining Fig. 5(a), basal erosion, which is defined as the disintegration and loss of portion of wall at its base, can be caused by surface water runoff during flooding, by water falling from the roof and splashing up against the wall bases, or by accumulation of water beside these walls for relatively long time. Also, damage can be caused by water being drawn up into the walls by capillary action and then diffusing to the wall surface to evaporate. The water in this case may contain soluble salts that crystallize near the surface as the water evaporates. In crystallizing, the salts expand and can fracture the muddy walls. Continuing this process can slowly erode the surface plaster layers and lead to total disintegration of the external plaster leaving the internal wall layer exposed directly to external environment. Furthermore, this erosion can be increased by the abrasive action of the wind, sand and plant growth. In addition, water leaking from around the gargoyles and falling on walls external facade, can cause erosion to external surface of these walls as shown on Fig. 5 (b) and with time, the clay material within this zone can be totally disintegrated. Rain water falls over external walls surfaces can also be a source of damage. With the combination of environmental conditions, continuous drying and wetting of external clayey plaster due to rain fall can cause plaster cracking, disintegration and subsequent fall down exposing the internal walls composition to external atmosphere as shown on Fig. 5(c).

Another observed damage pattern, was the walls out-of-plumb that results from faults in vertical alignment during construction of walls, settlement to the soil supporting the wall, distortion to wall after getting wet (wall slumping), and unbalanced erosion on walls both sides. This issue can be further aggravated by the loss of any strong connection between this wall and the rest of the buildings.

Fig. 6 shows an example of tilted walls at site. In addition, some walls were noted to be unstable due to absence of any firm tying connection with surrounding walls or due to high slenderness of these walls ($h/t > 8$), where h is the wall height and t is the wall thickness. Fig. 7 shows one of these slender walls were, the height to thickness ratio for the wall exceeded 8. In response to such instability, the authority had to safe guard these walls against collapse by safeguarding and propping them.

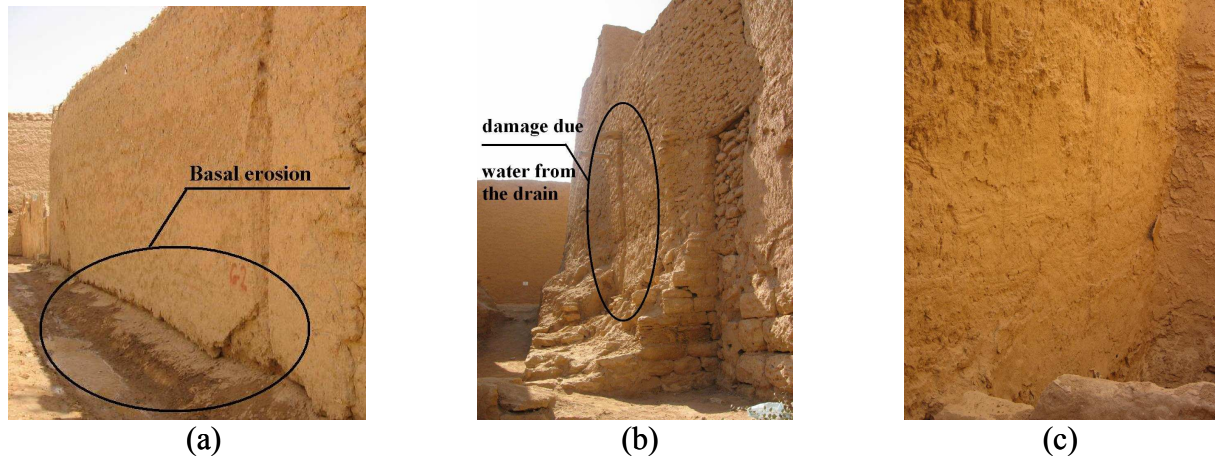


Figure 5: Damage patterns due to water action



Figure 6: Tilted wall at site



Figure 7: Unstable slender wall



Figure 8: Cracks within walls bodies



Figure 9: Separation at walls intersection

Deep through cracks within the walls and between perpendicular and adjacent walls at their intersection were noted to be another major defect. The initiation of cracks within the walls bodies was attributed mainly to; 1) cycles of wetting and drying accompanied by small movements resulting from possible settlement; 2) weakness at certain planes within the walls due to disintegration of bonding materials; or 3) high local stresses due to the existence of openings. Fig. 8 shows an example of such failure pattern. With regard to cracks at walls intersections, it was attributed to loss of physical connection between these walls and presence of high flexural and tensile stresses at wall connections. Fig. 9 shows an example to these deep cracks. In general these existing cracks are affecting the stability of these walls, since they tend to make the behavior of them independent from each other, rather than making them to behave as one unit.



Figure 10: Collapse at door opening due to loss of the wooden lintels



Figure 11: Cracks at door opening due to inadequate due embedment length of the wooden lintel within the walls

At many locations around openings, damage was recorded in the form of cracking or collapse to the blocks above the opening lintel. Such failures were attributed either to disintegration and/or deflection of the doors wooden lintels, or to the inadequate embedment length of the wooden lintels inside walls along the two sides of the opening. Fig. 10 and Fig. 11 show examples for such failures for the two indicated patterns, respectively.



Figure 12: Decay to foundation rocks



Figure 13: Tunnel done by animals

Another damage pattern was disintegration and decay of the rocks forming the foundation layer for the walls as shown on Fig. 12. Such damage can lead to wall total collapse. Burrowing tunnels within walls bodies by reptiles as shown on Fig. 13 is another damage pattern that was recorded during these site visits. These tunnels can reduce tremendously the walls thickness leading to their collapse.

In addition to walls observed damage, wooden roofs and stone columns supporting them were also exhibited some degree of damage. Wooden roofs at many locations were totally disintegrated, while at other locations were severely deflected. Also, stone columns experienced tilting, and collapse to their heads at many locations.

Remedial Measures

To avoid the occurrence of damage associated with water, it is recommended to cover the base of all walls with stone skirts up to a height of about 50 cm in order to prevent wall erosion resulting from running water or splashing effect. Also, the land outside the premises of the building should be sloped away from the walls to divert the rainwater away from the walls as shown on Fig. 14. Furthermore, accumulation of water adjacent to walls should be prevented.

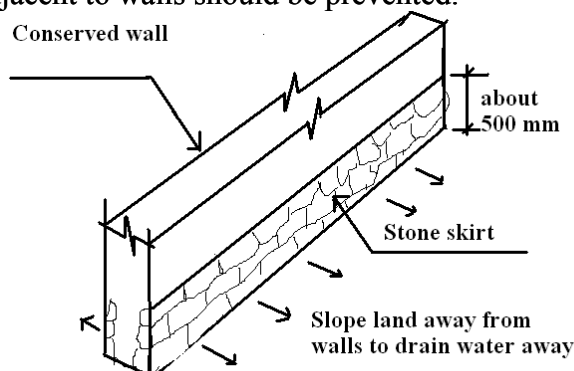


Figure 14: Illustration showing measures to avoid damage due to water

For damaged walls, loose parts should be removed. Then, the remaining walls treated with suitable chemical (with Silbond-40 or equivalent) to soak into porous adobe, where it sets up and hardens so that the adobe is no longer turned into mud when in contact with water. At the same time replace the lost parts of the wall thickness by the erosion process. Then, new plaster layers are provided to walls surface. This layer should be associated with water repellent suitable for adobe protection. All roof drainage gargoyles should be replaced with sufficiently long ones to drain water far away from wall surfaces and their connections with the buildings should be treated adequately to prevent leakage.

For slender walls having height to width ratio more than 6, buttresses should be provided to avoid any possible overturning. Buttressing can be done by firmly tying this wall to other perpendicular walls or by installing a tapered buttress. Fig. 15 illustrates the rules followed for laterally restraining the walls using cross-walls or buttresses. Tie-rods made from non-corroded material and environmentally friendly such as stainless steel or titanium can be used to connect wall to buttress.

For cracks within walls, wood/stainless wedges/bars can be used to connect both sides of the walls along the cracks. Also, perpendicular walls can be connected using wooden ties to provide the required stiffness to building and stitch any existing cracks along the corner.

To rectify the damage due to decay of wooden lintels, new lintels with sufficient embedment length into the adjacent walls should replace the old ones. Also, props should be done through the walls to identify the existence of cavities. Normally, four holes drilled per square meter. In case any tunnels are discovered, the thin external clay layers should be carefully removed and the tunnel filled again. These holes can be also, used for injecting anti termites materials. Fig. 16 shows views to different suggested remedial measures, as reconstruction of parts of damaged walls to enhance walls stability, rejoining perpendicular walls and stitching cracked walls. On the other hands, Fig.17 shows the mathematical model utilized to examine the stress within the body of parts of the building to assess the need for remedial measures.

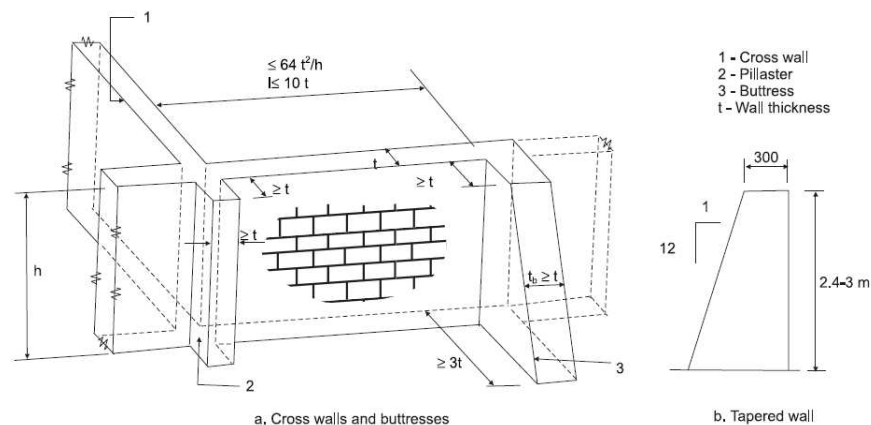


Figure 15: Rules followed for laterally restraining walls



Figure 16: Photos to different suggested remedial measures



Figure 17: The finite element model for part of the building

Conclusions

The paper discussed the different damage patterns and modes of failure exhibited by earth structures in non-seismic regions due to aging process and poor environmental conditions. Emphasis was placed on explaining the reasons behind these observed damages. Various remedial measures that should be taken to restore and preserve these endangered structures were explained.

References

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