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STRUCTURAL DEFICIENCY AND INTERVENTION RETROFITTING MEASURES OF RUBBLE FILLED MASONRY WALLS IN ISLAMIC HISTORICAL BUILDINGS IN CAIRO, EGYPT

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ABSTRACT

Multiple leaf- masonry -walls are one of the most important, immediate and characteristic features of Islamic architecture. In Cairo much of masonry monuments have been constructed along different periods on this unique style. Many years ago, where it has been built from two external stone block leaves and another one internal core leaf in a variety of materials and forms.

Damage analysis and assessment of multiple leaf-masonry-walls have to bear in mind the conservation rationale, which is essentially leaving the structure as found, with minimal intervention whenever possible. The intervention should be sympathetic to the original character of the building and carrying out to maintain its structural stability.

A detailed investigation relies on the previous experience of engineering, restoration as well as understanding of the short comings of theoretical calculations and assumed loads versus actual behavior and loading structural monitoring of critical elements to check movements as well as crack growth is important in reaching a final conclusion. Core samples and non- destructive load testing results are also obtained and used to verify analysis and observations.

Predicting the behaviour of multiple-leaf masonry walls is a challenging issue, given the influence of a wide range of factors as the mechanical properties of the two external leaves and internal core materials, their dimensions and the way they are connected to each other. In the present paper, experimental results in specimens are carefully analyzed and reviewed. Simplified calculations for practical assessment of existing walls are also addressed.

Two main case studies in respect of multiple leaf- masonry -walls are studied. The first one as an example for the bearing walls in historical buildings is Wkallah Radwan Bik Al-Fakari. The second one as an example for the retaining wall is Sultan El-Ghouri palace wall remains.

KEYWORDS: *Islamic monuments, multiple leaf-masonry, cracking, deterioration, monitoring, restoration, grouting, structure.*

1. INTRODUCTION

Multiple-leaf walls are frequently found in ancient buildings. They usually consist of two or three leaves made up of different materials such as limestone, brick or rubble masonry. For an appropriate repairing/strengthening of masonry walls with minimum intervention, the bearing capacity of the structure has to be known prior to the intervention. However, this task is especially complex in the case of multiple- leaf walls, because the stress distribution is largely dependent on the mechanical properties of the leaves, on their dimensions and on the way they are connected to each other. In particular, the load transfer between leaves is a key issue when studying compressive damage of heavy pillars in monumental buildings; see [Binda et al, 2003a].

One of the main problems of historical monuments is related to the maintenance and safeguarding of old buildings, often seriously damaged by the ravages of time, most of current damage conditions of historical buildings are mainly due to earthquake, which have occurred on October 1992 approximately 30 km South of Cairo[Giuffre, 1993].

In most cases, the damage is exacerbated by the structural design of the old masonry buildings, the bearing structures of which are inadequate to withstand the seismic loads. Many historical buildings had suffered severe effect, some of them were collapsed (totally or partially) and several damage patterns were observed. Many monuments (historical buildings) has become in need of urgently restoration. Many of restoration projects for several historical buildings had done. The success of structural restoration project depends mainly upon the accuracy of the diagnosis, which is the identification of the causes of damages and deterioration.

References in literature can be found on this topic, see e.g. [Binda et al, 2006., Egermann, 1993., Binda and Fontana, 1994., Tassios, 2004]. Yet, further experimental and numerical insight on the shear and compressive behavior of composite walls is needed. For this purpose, a set of twelve three-leaf stone wallets (regular- rubble-regular) with dimensions of 310 × 510 × 790 mm^3 were built and tested at the Politecnico di Milano, within the frame of a National Research Contract (resp. L. Binda), see [Binda et al, 2003b].

2. RUBBLE FILLED MASONRY WALLS

Rubble filled walls are constructed with two external leaves made of stone or brick with a void of varying thickness between them. The space between the two external leaves is filled with a loose low strength materials made of pieces of stone/brick and mortar.

Figure 1 Construction system of the double faced masonry walls in Islamic monuments in Cairo.

Figure 2 Connection systems and materials of the double faced masonry walls in Islamic monuments in Cairo.

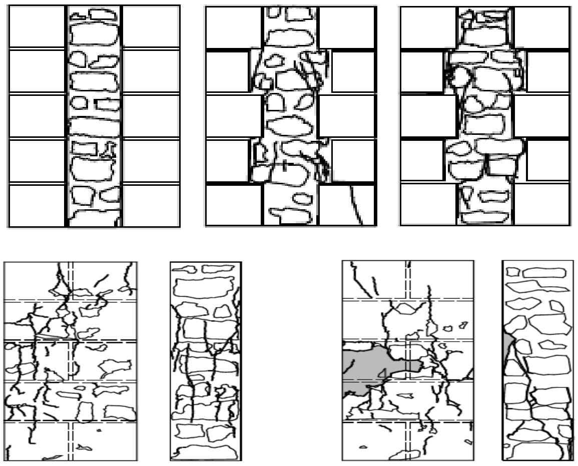


Figure 3 typical failure mode of three- leaf masonry in compression.

This type of masonry is very vulnerable to various actions specially the mechanical actions. In fact as the bond between the external and interior leaves is deteriorated or lost with time, masonry does not behave as a whole, [Hemeda, 2012].

Structural damage: occurs when stresses produced by one or more mechanical actions exceed the strength of the material in significant zones, either as because the actions themselves have increased or because strength has been reduced by other actions.

Vertical loads are the main cause of damage or collapse of structure (cracking, deformations, leaning, crushing, buckling, brittle failure, etc).

Lateral and shear forces and their effects are relevant and more significant in seismic areas.

Also movement of core material may also be a source of new stresses, thus came the faces may became unstable, [Drysdale et al, 1999].

3. CAUSES OF DAMAGE AND DETERIORATION

Almost causes of damage and deterioration appear to be related to the problems that affect the multiple leaf masonry walls, namely:

1) the cracking of the structures was attributed to: Earthquake damages, Permanent deformations or /and, differential settlement of the underlying bearing soil and foundations, Natural wear of construction materials, Deterioration of materials where humidity often plays a prominent role due to insufficient ventilation over along period of time, Construction history.

2) Soil-structure settlements were associated with: Non-uniformly distributed static loadings from the superstructure, Seismic loadings under repeated earthquake activity, Progressive weakening of the immediate foundation material due to intrinsic sensitivity to weathering factors specially the G.w.t., The interventions should be decided only after the results of the investigations and the structural analysis have been considered and these interventions will consist of the minimum possible to ensure the required structural safety levels.

4 EVALUATING METHODOLOGY

The main considerations can be summarized as follows:

1) Problem description and rationale

- Historical and present situation survey of the crack pattern and deformation of structures.
- Rubble Filled Masonry Walls, Construction technique and materials
- Structural damage and material decay, phenomena and causes

2) Geotechnical assessment (Analytical& experimental studies for binders, stones and grouts)

-Soil investigation in order to study the stratigraphy and in particular the variation is ground water table.

-Sonic tests and scopic investigation in order to know the masonry components in the structure.

-Monitoring system is necessary to find out if the movements of structure and soil are stabilize or evolutionary.

3) Analysis of chemical, physical and mechanical characteristics of construction materials.

4) Structural analysis models, taking into account the structural behaviour at the present state in order to evaluate the actual safety levels and the weakest zones.

5) Stabilization engineering measures

- Soil stabilization (grouting) and foundation reinforcement
- Repointing of the existing structures (Double faced walls).

6) Project implementation – Design optimization

This paper addresses the results obtained in the experimental tests and their critical analysis, resorting to simplified calculations and, also, to sophisticated numerical tools.

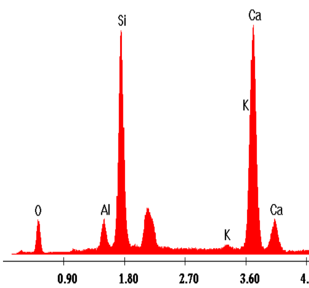
5 MICROSTRUCTURE AND MECHANICAL STRENGTH OF CORE BINDERS AND STRUCTURAL MORTARS

Microstructure of old mortars

Numerous pieces of information have been gathered from the examination of core binders or mortars by microscope. Apart from the main constituents the minor ones usually found are: stone rubbles, Local concentrations of unslaked lime or calcite, Grain of carbon (Qosrmil), Sand, Aggregate natural or pieces of brick or tile of different max size, Crushed brick (homra), Marble grain, Wood fibers,

It is remarkable that crushed brick aggregates exhibit better adhesion to paste than the natural aggregates of great size. There are cracks on the borders of aggregates. Salts are concentrated in pores or cracks. It seems that they filled them and have not created cracking.

Thin section analysis indicates a great variety of silicate aggregates and the excellent bond between aggregates and paste in well compacted mortars of very good quality, figure (4).



Elements	Wt %	At %
O	20.26	35.26
Al	3.66	3.78
Si	27.24	27.00
K	1.17	0.84
Ca	47.67	33.12
Total	100.00	100.00

Figure 4 Stereoscopic, polarizing and SEM with EDX microstructures examinations and analysis of the deteriorated core of rubble infill masonry walls under investigation.

Gradation of old mortars

Graduation was determined by hand grinding and sieving an amount from 300 to 500gr of mortar samples. Structural mortars usually contain coarse aggregate in different sizes while coating mortars mainly consist of sand up to 4mm. exceptions are observed in rendering mortars of some monuments which contain coarse aggregates. The ratio of fine to coarse is higher in renders and lower in structural mortars. For example the ratio is 2,5:1 for structural and about 6:1 for renders.

This ratio seems also to characterize the technique of this period. In good quality mortars this ration is between 2:1 or 3:1. This implies the role of aggregates in strength.

During sieving analysis the curves of each mortar were compared with the curves given by the regulations of modern technology. A part from sand of rendering mortars, which are outside the limits, (much finer) the relevant curves of structural mortars, especially those of high strength, usually lie between limits.

Why were coarse aggregates used?

For economy

To limit shrinkage cracks of paste

Comparing coarse aggregate content with strength and type of binder it seems that when coarse aggregates is added to air-hardening lime mortars they contribute much more than in the case of hydraulic mortars with lime and Grain of carbon (Qosrmil).

Chemical and XRD analysis

For each mortar sample the composition in oxides and the composition in soluble oxides in 0,1 NHCL as well as the content in water soluble salts was determined.

In the table (1) following, the estimated composition for some monuments is given.

Comparing the composition of mortar provides data useful for identification of historical phases. We can also see at which proportions the binders were usually used. The grade of disintegration usually goes with the salt content. Although the research was not oriented to estimate the grade of deterioration, it was found that pollutants from car traffic, attack mortars as well as chlorines from the ground water, lower parts covered for long time with ground also present high percentage in NO- and SO4.

Mechanical strength

In the table (1) the range of strength with the type of mortars is depicted. Since many of the mortar samples were from disintegrated areas there is a great variation in values determined by a crushing test. In spite of this we could end with some conclusions which could be used as a guide for designing new mortars, in particular for manufacturing some mixtures of ready mortars.

Porosity

Most mortars have apparent .specific gravity 1.60-1.75. The natural absorption depends on leveler cracking the sample but for sound mortars of good quality the range is 15-20%. For lime mortars porosity reaches 30%. It is very difficult to find a definite relationship between porosity and strength in old mortars. This due to different: Grade of deterioration, cracking, Content of fines, which also depend on position of sampling.

Overall, It could be said that coarse aggregates greater than 6mm are found usually in structural mortars. They can be natural or crushed bricks. For the latter the adhesion to paste is better. We could use the modern gradation limits in order to decide about the graduation of new repair mortars. The gradation of aggregates seems to particularly influence lime mortar strength.

It is obvious that the addition of ash of furnace and brick dust improves the strength level considerably. But in all cases the proportion of ash of furnace is the same or half of that of lime (1:1 or 1:0,5). Based on tests done at our lab, an indicative table of mortar strength acquired at 28 days is given.

Mortars for restoration work

The main result is that we have to focus on some types of mortars to standardize them facilitating and upgrading restoration work. This is very important for second stages of restoration activities.

While interventions to address problems of both extensive cracking decay are often carried out by the appropriate fluid lime mortar to consolidate the structure (grouting).

The experimental study referred that the mix of lime+ sand+ brick dust+ greater proportion of white cement 3:1:1:0,5 respectively gave the best results under the mechanical testing. The hydraulic lime based grouts (due to their improved bond properties with the in-situ materials) become more important due to the durability ensured by the use of materials that are compatible with the existing ones from the physical-chemical point of view, (see Fig. 7).

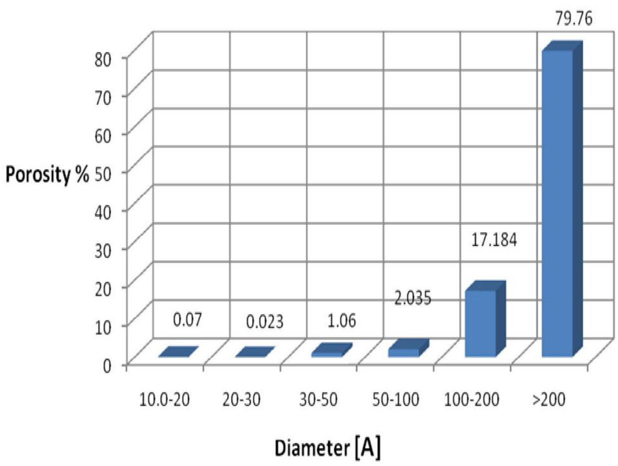


Figure 5 Pore size distribution of the deteriorated core mortar samples of rubble infill masonry walls under investigation.

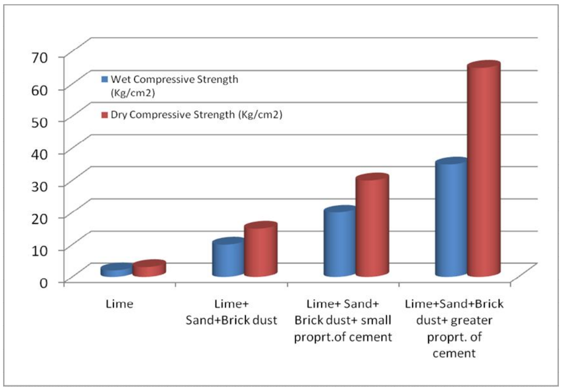
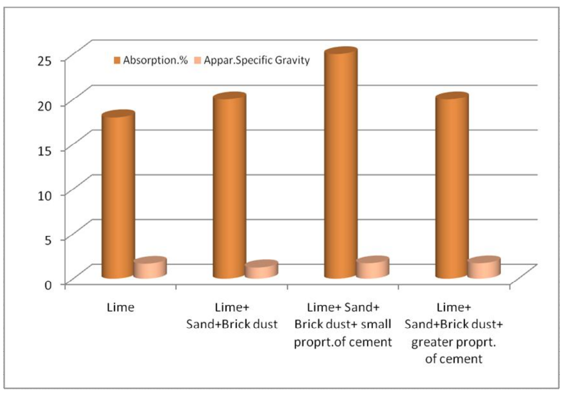


Figure 6 Physical and mechanical properties of the new hydraulic based lime mortars for restoration and injection of the deteriorated core of rubble infill masonry walls.

Table 1 Main features of structural core binders, structural mortars and aggregates of the double faced walls in Islamic monuments in Mamluki and Ottoman periods in Cairo.

Monument	Binder	Proportion	Lime con %	Appar. Spec Gravity	UCS K/cm 2
Raaba and Sabil& Kutab Al-Qazzlar	Lime+ stone rubbles+ pieces of brick + Sand+ Brick dust (homra)	1:0.3:0.3:0.3 : 0.2	40	1.65- 1.7	15-35
Mosque and Sabil& Kutab Gonbolat	Lime+ stone rubbles+ pieces brick + Sand+ Brick dust (homra)+ Qosrmil	1:0.3:0.4:0.2 :0.3:0.2	35	1.55	30-35
Wakala Radwan bik Al-Fakari	Lime+ stone rubbles+ pieces of brick + Sand+ Brick dust (homra) + Qosrmil	1: 0.7: 0.4:0.5 0.4:0.3	25:30	1.6-1.7	20-25
Al-Ghorri palace Wall ruins	Lime+ stone rubbles+ pieces of brick + Sand+ Brick dust (homra)+ Qosrmil	1:0.6: 0.6:0.5 0.6: 0.5	40:30	1.65-1.7	20-30

*remarks: stronger mortars are used in key areas of arches
The 17th cent. Structural Mortars are characterized from high quality aggregates: fines/coarse 2:1 up to 3:1



The important observation insinuates that the key property governing the mechanical properties of grouted masonry is not the compressive strength of the grout. the key parameter for the improvement of the mechanical properties of three-leaf masonry is the bond properties of the interfaces between grout and in-situ materials, as improved bonding properties along the external leaves to filing material interfaces contribute to delayed opening of transverse cracks that lead to failure of masonry. It proves that ternary and hydraulic lime based grouts, that are expected to satisfy durability requirements, may also enhance the mechanical properties of three-leaf masonry to a level that complies with the bearing capacity requirements set for historic structures. grouting with cement based mixes leads to ore brittle behavior of masonry, whereas ternary and hydraulic lime based grouts allow masonry to sustain larger compressive strains before its maximum resistance is reached. This is another sign in favour of the use of low to medium strength grouts. it is evident that grouting leads to substantial strength enhancement, in this case as well, it may be observed that the strength increase of the stress at failure obtained with medium to low strength grouts suggests that, in this case too, the decisive parameter is the bond between grout and in-situ materials.

The compressive strength of the external leaves can be measured in-situ, applying the flat jacks techniques. The compressive strength of the filling materials can be measured in the laboratory, on cores taken in-situ. The use of cement-containing mortars should be avoided in the restoration of historic buildings. In walls built with gypsum-containing mortars, the reaction between gypsum and cement –minerals results in the formation of salts that sooner or later will lead to destruction. In other cases there may be a problem of leaching of soluble salts from the mortar resulting in efflorescence on the surface of brickwork, (particularly dangerous when there are historic plasters or frescoes) or there may be changes in the path of moisture through the wall.

Fiber reinforced polymers (FRPs) are being more and more used for external strengthening of masonry structures. Therefore, characterization of the short and long-term behavior of bond between FRP composites and masonry substrates in a service environment is crucial for design purposes. A full body of experimental and theoretical investigations is required for durability assessment of FRP strengthened structures. However, most of the research in this area has been devoted to FRP-concrete specimens, and the available data for FRP-strengthened masonry components is still lacking.

This paper presents recent experimental results of a large experimental campaign under development. The aim is to characterize the short and long-term behavior of bond in FRP-strengthened masonry elements. Debonding tests have been performed on masonry strengthened with different FRP materials for investigating the short-term aspects of the bond behavior. Accelerated ageing tests have been performed on FRP-strengthened masonry elements and the degradation of the bond due to environmental conditions is investigated. The environmental conditions consist of the coupling effect of temperature cycles and relative humidity. The degradation of bond has been measured by performing conventional single-lap shear bond tests.

6 WEKALLAH RADWAN BIK AL-FAKARI

6.1 *Architectural Style*

The Wkallah Radwan Bik Al-Fakari is an ancient historical Islamic monument, and is built 400 years ago, 1635AD. The complex of Wkallah Radwan Bik Al-Fakari is situated in the El-Darb El-Ahmar of old Cairo in Qassabit Radwan Street, on the east side of the street there is the wkallah and wakf of Radwan Bik Al-Fakari.

The Wkallah is composed of central hall and surrounded by large number of hwanits or small shops with different areas.The main façade is the south west façade with 31,4 m length, in the middle is small entrance with pointed arch 1m in width and 1.8 height and 11,7 length from which we can reach the central hall of the wekallah, this façade composed of 9 hwanits 5 in right side and 4 in left side whose floors are higher than the central area.The east south façade is 12,6 m, overlooks the Qasabit Radwan street and composed of 5 hwanits. The east north Fcadae is 14,8 m, overlooks Taht El-Rabaa street and composed of 5 hwanits. The hwanits overlooks the central hall through a pointed arch. The complex is roofed by a wooden ceiling of girders supported on a frieze.

6.2 Statical System of Wkallah Radwan

General, The Wkallah is designed on the pattern of suspended monuments; it consists of ground with 29 hwanits and 2 multi floors.

Walls: Bearing walls type for structural skeleton of the building. Pointed arched walls for the internal walls of the central hall and rooms. Walls are double leaves type with different thickness. Limestone and sandstone are used for the construction of walls.

Roofs: Wooden ceilings are consisting of girders, joists and blanks. Masonry tunnel vaults for roofs of ground floor are carrying the floor of the Wkallah for the first floor. Masonry cross vaults for the roofs of some shops are located in ground level.

6.3 Description of the Damage to the Wkallah

An inspection of the Wkallah reveals some very severe long-standing problems observed before and after October 92 earthquake. The floor of the Wkallah undulates dramatically evidence of very significant foundation problems of the masonry vaults supporting the floor. Attempts have been made in the past to support the sleeper walls supporting the vaults. These attempts have failed. Most of the walls of the wkallah exhibit very severe fractures, as shown in (fig.8). Rising contaminated ground water table caused many problems for the foundations of walls, leading to uneven settlements of the foundations and structure. Further problems in the external walls have been caused by the activities of the shop keepers trying to enlarge the space available for selling their wares. Sections of masonry have been demolished at ground floor level to create this additional space. Many cracks in the walls, as shown in (Fig.8). Vertical and shear cracking patterns intersected the structures as shown in (Fig. 8b). Many problems in arched and vaults, vertical cracks, fractured masonry and fallen key stones. Generally, the damage appears to be most severe on the east south elevation, the west elevation, particularly the North West corner and the four sides of the central courtyard. The north elevation and the east elevation appear to be little damaged (fig. 8a).

6.4 Cause of damage to Wkallah's Structure

The causes of the major damages occurred to the wkallah can be summarized as follows:

General : Age of the building, it had survived for nearly 500 years time-stresses effect on construction materials. Lack of maintenance. Loss of mechanical characteristics of the walls at foundation level due to moderate aggressive environment (ground water and soil). The activities of the shop keepers attempting to increase the size of their selling area.Deterioration of stone walls in some areas.

Structural: Very high walls are laterally unrestrained and very vulnerable; therefore to lateral forces such as may be produced by seismic loads. Walls are generally built of two facing skins of limestone infilled with a weakly cemented conglomerate probably confined on the near side by crushed limestone.Weakness and there is no enough connection between roofs structure and the perimeter walls.

The large arched openings are particular points of weakness in the structure. There is no longitudinal ties in each of the stone facings of walls above the arch to resist the thrusts naturally produced by the arch as well as serving to assist the walls to resist lateral forces. There is no transverse ties bonding the two skins of walls decreases the resistance of the walls.

6.5 Site Investigations

Site and analytical investigations were made for structural restoration; the main points can be summarized as follows: Analysis of chemical, physical and mechanical characteristics of the building materials such as stones and binders. Soil investigations in order to discover the stratigraphy and in particular the variation of ground water table. Survey of the crack pattern and deformation of structure. Monitoring system is necessary to find out if the movements of structure and soil are stabilized or evolutionary. Mathematical models taking into account the characteristics of the structure at the present state in order to evaluate the actual safety levels and he weakest zones.

Figure 7 Present state of Wkallah Radwan Al-Fakari, before restoration processes.

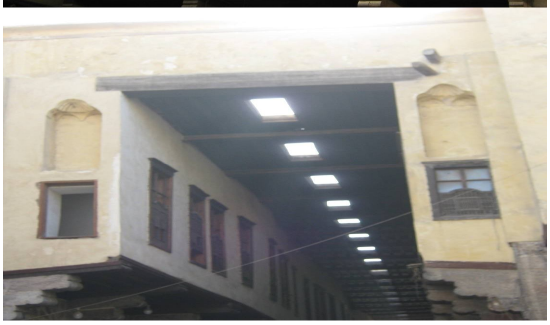


Figure 8 Wkallah Radwan Al-Fakari. After restoration processes.

Figure 9 Wkallah Radwan Al-Fakari. During and after restoration processes.

6.6 *Main Structural Interventions*

Description of the restoring works for the existing shallow foundations of the ancient historical wkallah Radwan Al-Fakari: Improving the bearing capacity of foundations under the structures of the masonry by jet grouting techniques led to: The capacity of the supporting elements and materials (jet grouting columns) would be able to take care of the whole weight of the monument. The supporting elements would widely spread under the superstructures avoiding concentrated loads.The supporting elements would connect each other and to the superstructures by R.C beams/ slabs to redistribute loads and to give confinement. The existing shallow foundations would improved by low pressure injections of cement grout. It is necessary to be introduced stitching system to tie the elements of the superstructure together. Double faced walls should be gravity grouted to ensure that any voids which exist are filled with lime grout. Intervention on deteriorated stones and external surfaces. Restoration of cracks in walls. Restoration of connections between walls. Interventions on floor and roof structures. Interventions for waterproofing.Intervention for facades. Intervention for internal arches.

7. SULTAN El-GHOURI PALACE WALL REMAINS

7.1 *Architectural Style*

Sultan El-Ghouri palace wall remains is a part of the walls of the modern thinking school at El- Saliba Street in old Cairo. This part of walls lies in El-Saliba Street at the opposite of Ibn Toulon mosque (Fig. 11). The wall is bearing and retaining wall types. The wall was built of lime stone masonry double leave, with average thickness 0.8m to 1.2 m. The length of wall is 60m and the height of wall is about 12m from the ground level. The statical system of the walls is cantilever type. The wall has ashlar courses on the exterior facing of the rubble-core walls. There are some old buildings adjacent for the wall.

7.2 *Description of Damage to the Wall*

The observations of the damage of the wall as following: Tilting and settling of wall. Separation and open cracks at the connection of wall with stable areas. This major crack is much wider at the top than at the base. Settlement and movements of wall blocks at the 2 sides of the cracks. Vertical crack at the 1/3 of wall, starts from the top in joints blocks one crack while become two cracks on the bottom and it have outer displacement about 1.5 cm. Horizontal cracks on the platform level behind the outer wall and parallel to it. Deterioration of lime stone masonry of wall as in (Figure 11 and12).

7.3 Site Investigation

The site investigations were done for structural restoration, the main points can be summarized as follows: Analysis of chemical, physical and mechanical characteristics of main wall material (Stones, mortars and binders), old and new which for restoration had been done. Survey of crack pattern and deformation of the wall and the tower. Soil investigations in order to find out the soil layers and ground water table.

7. 4 *Causes of Damage to the Wall's Structure*

Sultan El-Ghouri palace wall is an ancient historical monument, affected by heavy stability problems.

The main evidences of the stability problem, still in evolution, are: Tilting and settling of wall which causes open cracks at the connection with stable areas not involved by the phenomenon; the major crack is much wider at the top than at the base. Cracks on the ground behind the wall and parallel to it that indicate the presence of tensions in the backfilling material at the rear of the wall; this affects the structural integrity of constructions built nearby the massive retaining wall.

The causes of the major damages occurred to the wall structure and the kinematics of the instability phenomenon can be summarized as follow: Age of the massive wall, time-stresses effect on construction materials. Lack of maintenance and loss of mechanical characteristics of the wall at foundation level due to moderate aggressive environment into the soil are all factors that have contributed to the actual bad condition of the structure. Direct effects comes from the earthquake happened in Cairo on October 1992 which probably have triggered the tilting phenomenon. The massive retaining wall, made by an outer wall of blocks of limestone, backfilled by a weakly cemented conglomerate probably confined on the rear side by a subvertical bedrock of limestone, which the backfill material disengaged by the confining walls act as a wedge behind he outer wall increasing the tilting movement after its triggering.

7.5 *Main Structural Intervention*

On restoration of walls it is useful to follow the observational method which consists of organizing the work on a step by-step basis, having initially carried out the most urgently-needed repairs, then monitoring the situation.

The restoring works involved the entire massive wall, affected by the stability problem, to reinstate the original static scheme foreseen for such structure by the systematical destruction and reconstruction of the entire wall.

1. The destruction processes started from top to bottom of the wall with attention to save and reuse of the original rubbles and blocks of limestone after cleaning, sat removal and consolidation.

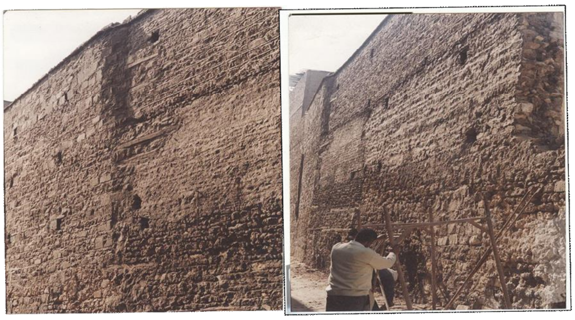


Figure 10 Present state of Sultan El-Ghouri palace wall remains, before restoration processes.

Figure 11 Present state of Sultan El-Ghouri palace wall remains, during restoration processes.

Figure 12 Present state of Sultan El-Ghouri palace wall remains, after restoration processes.

2. The reconstruction processes started by improving the stability of the massive retaining wall by low pressure injections for filling strata of soil up to 10 m below ground level and making new steel reinforced concrete strip foundation forming a wide and deep foundation base under the high bearing capacity to stop tilting phenomenon and give adequate factor of safety against further seismic events;

3. Rebuilding of the superstructures of the wall from base meter by meter using the original construction materials and the new hydraulic based lime mortars and binders. By this way we restored of cracks in walls, vertical separation and open crack at the connection of wall with stable areas. Restored the horizontal separation crack on the platform level with adjacent old building. Interventions on floor of platform.

8 CONCLUSIONS

The following conclusions have been drawn from the present study:

In the study of the existing buildings, the results make the calculus, by itself, not always adequate to make a final judgment on the safety levels. So, it is very important to augment the study with historical research and direct survey analysis of the construction.

The connections or corners are often weak areas, often partially or totally disconnected from the main structure. It is important to ensure proper structural connections between all walls.

When shear or tension stresses become relevant, as in walls with insufficient overlapping elements, a positive connection between the stone blocks may be required; this can be done using dowels, cramps, bars, etc.; special tie-bars or other structural connections.

Gravity injection can be used to enhance the homogeneity and strength of weak and porous mortars of roundly-caused masonry with irregularly shaped stones and of sack (in filled) masonry, especially if the external faces are badly tied to the internal core.

The radial arrangement of wedge shaped stones in arches is a result of skilful choice reducing the shear and tensile forces to a minimum.

The skillful use of wood, not only for roofs and floors but also for chains or ties to balance the thrust of vaults and to improve continuity and the connections between walls.

The use of transverse ties of length equal to the thickness of the wall is effective to increase the strength of the wall.

The use of longitudinal stitches is effective to tying the structure to the perimeter walls and creates a diaphragm action.

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