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Structural Rehabilitation of Siad Hashim Historical Mosque in Gaza

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Abstract Historical structures in Palestine are subjected to various types of damages due to natural or manmade causes that result in sudden destruction or progressive deterioration. "*Siad Hashim*" mosque has been subjected to progressive deterioration due to long neglect, abuse, environmental factors, inadequate design and construction, soil settlement, damping, growth of vegetation and other factors that led this structure to a critical condition. This paper describes the nature, cause, assessment and rehabilitation measures corresponding to existing damages. Recent rehabilitation carried out in the structure is also described, emphasizing the criteria and techniques adopted and the underlying studies and analyses. The repair and strengthening carried out to the mosque have not only succeeded in restoring its original conditions but also upgraded its ability to carry applied loads and actions satisfying current code requirements.

Keywords: Cultural heritage, mosque, stone masonry, arches, cracks, tests, structural rehabilitation

Introduction

Palestine is a major cultural and religious center in the World with a large number of historical constructions in the old Palestinian cities of Jerusalem, Bethlehem, Hebron, Jericho, Nablus and Gaza. The 160 years old "Siad Hashim mosque is one of the most important historical buildings in Gaza and lies in its historical center (Masri et al. 2003). The importance of the mosque comes from the fact that "Siad Hashim" who is the grandfather of the Muslim Profit "Mohamed", was buried in the site since about 1500 years ago. In addition, the mosque is the only building in Gaza that was built following the Ottomans architectural style in which a number of domes of different sizes are strategically located in the mosque to produce magnificent view. The mosque has been subjected to serious progressive deterioration that required major rehabilitation work.

By nature, progressive deterioration occurs and increases with time due to adverse influencing factors. Structures are continuously subject to adverse environmental factors, misuse, neglect, and abandon that result in their deterioration if proper maintenance and repair were not carried out regularly. Inadequate design, construction faults and bad construction materials also contribute to progressive deterioration. Deterioration normally requires continuous rehabilitation and reconstruction efforts. Rehabilitation involves a complicated process that include many aspects such as structure type, construction materials, structural system, construction methods and techniques, structural design, building codes, standards, specifications and regulations with level of requirements changes and normally increases with time, existence of structural damage, deterioration and environmental factor, socioeconomic factors, political factors, repair options and decision techniques, management of rehabilitation, etc. (Ziara 2007). In order to assess the safety of the buildings and planning the rehabilitation measures, it is essential to perform complete analysis of historic structures. Rehabilitation of historical structures such as "Siad Hashim" mosque has to be carried out carefully to conform to internationally recognized regulations concerned with architectural heritage.

Mosque Description

General Description The 2400m^2 "Siad Hashim" historical mosque shown in Fig. 1 comprises of a square internal open court surrounded by open halls (rewaqs) at three sides and praying halls at the forth eastern side. The rewaqs lead to a number of rooms of different sizes that have been used for various purposes including study, accommodation, library, etc. The grave of the Muslim Profit

Grandfather "Siad Hashim" lies in one of these rooms at the northern western corner. The rooms, rewaqs and halls of different spans are covered with various types of shell roofs. A 20.4m high minaret is located at the middle of the western side of the prying halls. All halls and rooms are of rectangular cross sections.

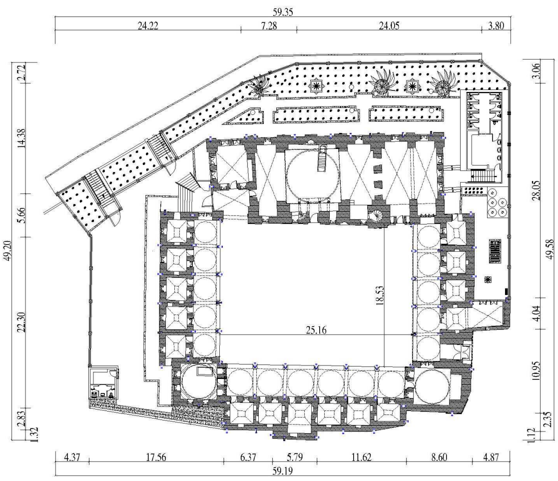


Figure 1: Mosque plan

Structural System and Construction Materials The structural system consists of shell roofs supported by walls or arches that in turn are supported by either columns or 1m thick bearing walls of 6m height. The walls extend down 40 cm to 80 cm underground where its cross section is widened by 15 cm each side to act as wall footing. The total underground extension of the walls including their footings is about 2.2 m. The supporting soil is poorly graded silt sand with low plasticity. The construction materials used were mainly hollow pottery, sand and lime stones that were bonded together using a mixture of lime, crushed pottery, egg shells, fly ash, crushed sea shells and other compounds. The roofs were later covered by 10 cm reinforced concrete layer for protection from adverse environmental factors. The types of shell roofs include spherical dooms of 2.9 m to 7 m diameter and thicknesses range from 62 cm to 73 cm. The cross section was made of either lime stone or hollow pottery for small or large diameter domes, respectively. The domes are supported on octagon walls that are in turn supported by either columns or walls. Interconnecting vault roofs were also used to cover 5 m by 10 m rectangular halls. Each vault is supported on two main diagonal stone arches that are in turn supported by 1 m thick walls. The minaret is made of lime stones and has a square cross section of 2.9 m at its lower part. The cross section of its upper parts is of hexagonal shape of dimension decreasing from 2.2 m to 1.4 at its highest point.

Diagnosis

The rehabilitation works carried out to the mosque have addressed many aspects in addition to structural rehabilitation such as site layout, landscaping, water networks, sanitary installation, drainage, fire fighting system, electromechanical works, architectural works, floors, windows, doors, furniture, etc. However, this paper is concerned with structural rehabilitation only. In structural rehabilitation, symptoms or observations of a deficiency must be differentiated from the actual cause of the deficiency, and it is imperative that causes and not symptoms be addressed in repairs. Since many deficiencies are caused by more than one mechanism, a basic understanding of causes of deterioration is needed to determine the actual damage-causing mechanism for a particular structure. Before rehabilitation of "Siad Hashim" mosque a number of activities have been carried out in the site, laboratory and office in order to document existing conditions and assess the damages to reach conclusions regarding: Existing conditions, deterioration types and causes, impact of damage on present and future structural behavior, especially load carrying capacity, repair options, impact of repair on extending the lifespan of the structure, repair cost and ultimately deciding on future actions to be taken.

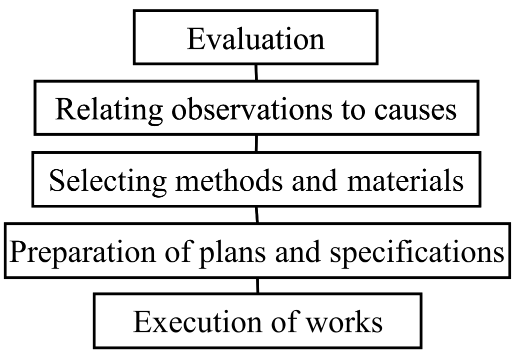


Figure 2: Rehabilitation Procedure

The general procedure shown in Fig. 2 was followed for evaluating the conditions and correcting the deficiencies in the structure. The first two steps, i.e. evaluation and relating observations to causes, are assessment steps while the remaining steps are concerned with the rehabilitation works. The evaluation step has included a review of structural instrumentation data, a visual examination, nondestructive testing, and laboratory analysis of stone and bonding materials as well as soil exploration and investigation. Once the evaluation had been completed, the damage observations and other supporting data were related to the mechanisms that caused the damage. Subsequently, appropriate repair materials and rehabilitation methods have been selected. The next step in rehabilitation process has been the preparation of project plans and specifications. Rehabilitation projects require much greater attention to good practice, detail and highly specialized construction techniques than those which may be necessary for new constructions. Therefore, in the final step in the procedure of the rehabilitation the designer responsible for the investigation of the distress and selection of repair materials and methods has been intimately involved in the execution of the rehabilitation work of the mosque.

Analysis and Evaluation

The structural analysis included the determination of strength, stiffness and stability for all types of the structural elements under gravity and lateral forces including earthquake and wind loads. Subsequently, the adequacy of the structural elements was assessed based on the mechanical, chemical and physical properties of the construction materials and soil that were obtained from laboratory tests. The tests also included measurements of crack widths for long periods using demec gauge and button techniques. The following loads were used in the structural analysis.

Loads **-** Stone unit weight = 24.5 kN/m^3 (for walls and stone arches).
- Roof unit weight = 18 kN/m^3 (for roofs made of pottery and filling materials).
- Live load = 0.5 kN/m^2 (for shell roofs).
- Live load = 1 kN/m^2 (for inaccessible flat roofs).
- Wind load = 0.8 to 1.0 kN/m^2 (increases with height- wind velocity 120 km/hr.).
- Seismic loads were determined based on (UBC 1997) with seismic zone factor (Z) = 0.15.

Allowable Compressive Strength The allowable compressive strengths obtained from core tests were equal to 4 MPa and 0.6 MPa for the lime and sand stones respectively. It should be mentioned that the factor of safety was assumed to be equal to 4.

Allowable Tensile Strength The allowable tensile strengths were assumed to equal 1/10 of their corresponding compressive strengths.

Allowable Bearing Capacity The soil investigation which included exploration pits and deep boring tests showed a soil profile consisting of three layers as follows:

- The first layer of 2 m depth is silt with some gravel.
- The second layer of 12 m depth is medium brown poorly graded silty sand.
- The third layer extending down to unknown depth is fine sand.

According to the soil investigation the allowable bearing capacities of the supporting soil considering both shear strength and settlement limitations were equal to 200 kN/m^2 and 140 kN/m^2 underneath the walls and minaret, respectively. It should be mentioned that groundwater table was not encountered and the factor of safety used was equal to 3.

Results of Structural Analysis The results of structural analysis showed the adequacy of the cross sections to resist safely the imposed loads for the main structural members as follows:

- The 6.7 m diameter dome: Factor of safety = 30 and 3.8 for meridian and ring stresses, respectively.
- The 7 m clear span arch: Factor of safety = 1.9.
- Cross vault covering 6.7 m × 3.7 m rectangular hall: Factor of safety = 8.7.
- Minaret: Factor of safety = 5 (considering imposed vertical loads as well as existing tilting).
  = 2.5 (considering seismic loads).
- Walls and Footings: Factor of safety = 11.

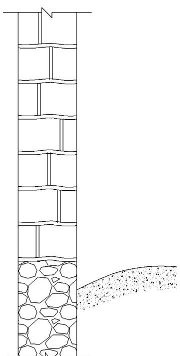
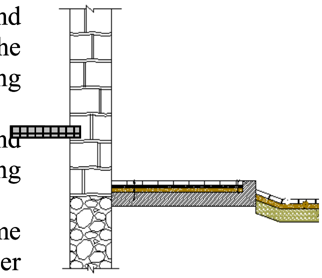
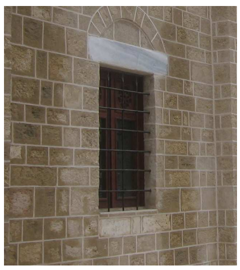
Concluded Remark The results of structural analysis showed that all structural elements are safe under imposed loads. However cracks, deterioration and other forms of damages do exist in most of these members. The causes of the damages are related mainly to environmental factors and ground subsidence as normally found in similar historical stone buildings (Meli et al. 2007).

Damages and Structural Rehabilitation

Figure 3:Photo of the mosque after rehabilitation

The structural rehabilitation needs for the mosque were determined based on the results of the structural analysis and the assessment of existing damages. The structural damages in the mosque included wrong interventions, stone deterioration and crushing, cracking of wide thickness in all types of the structural elements, minaret tilting and vertical misalignment, separation between different construction members, e.g. between walls, walls and slabs, etc., vegetation growth in the stones, splitting of column capitals, damp infiltration to the stones and corrosion of steel plates used to connect the minaret stones. A summary of damages, wrong interventions and carried out repair works in the mosque are presented in table 1 to table 3. Each table is concerned with one element type of the mosque; i.e. external walls including foundation, internal walls and roofs and minaret, respectively. The photo in Fig. 3 shows the mosque after rehabilitation.

Table 1: Rehabilitation of external walls and foundations

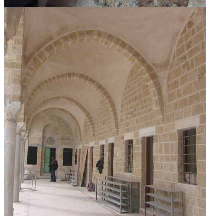
No.	*Damage*	*Description and Evaluation*	*Repair*
1.	Stone surface cracks	Surface cracks in a number of external walls due to environmental factors and thus did not represent structural risk.	1. Cleaning of cracks. 2. Crack widening. 3. After washing injection with lime mortar*.
2.	Cracking of walls	Cracks in walls due to soil settlement, overstressing and growth of vegetation roots inside walls. The cracks were inactive according to demec gauge measurements thus caused no immediate structural risk.	1. Removal of vegetation roots using proper chemicals. 2. Removal of broken stones. 3. Cleaning of adjacent stones. 4. Replacement of stones. 5. Injection between stones with lime mortar.
3.	Erosion of footing and damp infiltration	Erosion of foundation soil in some locations and damp infiltration into the wall stones causing deterioration of stones and bonding mortar layer. 	1. Leveling the ground at -60cm below the inside finishing level. 2. Cleaning and removal of damping effect. 3. Injection with lime mortar after washing. 4. Casting of a 2 m width reinforced concrete apron covered with stone floor. 
4.	Wall damping	Damp infiltration from roof and improper connections between walls casing deterioration of stones and growth of algae and vegetation. 	1. Fixing of roof drainage and other seepages. 2. Cleaning of stones and removal of algae and vegetations using proper chemical compounds. 
5.	Stone deterioration	Deterioration and braking of stones due to environmental factors and wrong intervention.	Mainly similar to above.
6.	Deterioration of mortar bonding layer.	Deterioration and spalling of the mortar that bond stones together due to environmental factors causing water and dirt penetration inside walls and vegetation growth.	1. Cleaning of dirt. 2. Washing. 3. Injection between stones with lime mortar.

7.	Efflorescence formation.	Efflorescence is deposited salts leached out of stones crystallized on subsequent evaporation of water or interaction with carbon dioxide in the atmosphere. In the mosque the source of water is the roof leakage into the wall.		1. Apply waterproofing to the roof. 2. Cleaning of efflorescence. 3. Temporary apply a water-clay layer to absorb slats. *4.* Removal of the water-clay layer.	

* Mortar made of lime, sand, ground pottery, fly ash and clay (1:1:0.5:0.25:0.25)

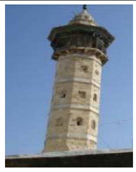
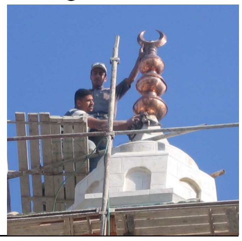
Internal walls of the mosque have been subjected to various types of damages including damages that are similar to those encountered for external walls. Therefore, table 2 will show only damages and repair works that are different from those already discussed for the external walls.

Table 2: Rehabilitation of Internal walls and roofs

No.	*Damage*	*Description and Evaluation*		*Repair*	
1.	Wrong intervention by covering stones with cement plaster.	Cracking and spalling of plaster. Formation of efflorescence. Removal of plaster revealed cracking and serious damping inside the walls and roofs.	 	1. Apply waterproofing to the roof. 2. Removal of cement plaster. 3. Cleaning of efflorescence. 4. Temporary apply a water-clay. 5. Repair stones or apply lime plaster#.	 
2.	Wrong intervention by covering the walls with ceramic tiles.	Entrapping damping inside the wall causing deterioration of wall stones.		Mainly similar to above.	
3.	Cracks in the roofs.	Inactive wide cracks in the roofs due to soil settlement and deterioration of bonding layer.		1. Cleaning and widening of cracks. 2. Injection of cracks with lime mortar. 3. Using galvanized wire mesh that extends 60cm around the crack and mechanically fixed to the roof. 4. Apply lime plaster.	

Plaster made of sand, lime, white cement and ground pottery (4:1:0.5:1).

Table 3: Rehabilitation of Minaret

No.	*Damage*	*Description and Evaluation*	*Repair*
1.	Tilting of minaret	The tilting ranged from 0.2% to 3.5%. Structural analysis showed the minaret is safe under its eccentric own weight combined with either wind or seismic forces.	No remedial measures are needed. However, the tilting should be observed with time. 
2.	Stone braking	Minaret stones are interconnected to each other by means of ∩ steel bars that have been badly rusted and caused splitting of the stones. 	1. Removal of broken stones. 2. Exposing of steel bars and removal of rust. 3. Coating bars with a primer to provide protection against corrosion. 4. Replacement of broken stones. 5. Applying of protective top coating. 
3.		Cracking and disintigration of the upper part of the minaret due to inveronmental factors and long neglect. 	Rebuilt this part using same stones. 

Conclusions

Full scale rehabilitation work has been applied to the historical "*Siad Hashim*" mosque in Gaza, Palestine. The rehabilitation work has been based on full understanding of causes of damages.

The main cause of damage was wrong interventions and damping to footing and lower parts of walls from soil and to upper parts of walls and roofs due to improper waterproofing of the roof.

The structural analysis carried out to all main elements showed that they are structurally safe. However, they have been subjected to many types of damages and deterioration due to environmental factors and soil settlement. The cracks were found inactive.

Repair works have utilized repair materials that are similar to original construction materials.

It is believed that the rehabilitation methodology and techniques that have been successfully used in "*Siad Hashim*" mosque can be followed in similar buildings made of sand and lime stones.

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