Aga Khan Trust for Culture

Historic Cities Programme

CONSERVATION PROJECT OF THE AQSUNQUR MOSQUE (BLUE MOSQUE)

A project funded by the World Monuments Fund & the Aga Khan Trust for Culture

FINAL REPORT

December 2012 / submitted March 2013

TABLE OF CONTENT:

1. EXECUTIVE SUMMARY

The Aqsunqur Mosque (known as the Blue Mosque) Conservation Project was co-funded by the World Monuments Fund and the Aga Khan Trust for Culture. As part of the Al-Darb al-Ahmar rehabilitation, the project was managed and coordinated by the Aga Khan Cultural Services-Egypt, the local agency of the Aga Khan Trust for Culture in coordination with the Supreme Council of Antiquities.

Located in the southern part of the historic city at the footsteps of the prominent Citadel built by Salah ad-Din at the end of the 12th century, the district of Al-Darb al-Ahmar is an extension of the Fatimid city consequent to the construction of the eastern City wall by Salah ad-Din. This City wall was uncovered recently and is the eastern boundary of the district. Much of the dense urban fabric constituted since the 13th century remains intact and important monuments act as major landmarks for a still lively Community. The opening of the Al-Azhar Park in 2005 has drawn the local and international attention to this specific area of the historical city and is acting as a catalyst for the regeneration of the Al-Darb al-Ahmar district.

The mosque of Aqsunqur, built in 1347 by Amir Aqsunqur, a son-in-law of Sultan al-Nasir Muhammad, integrates the preexisting mausoleum of Kujuk aligned on Bab al-Wazeer Street between the Khayer Bek complex and the Umm al- Sultan Sha‘ban mosque. Later in 1652, the Ottoman Amir Ibrahim Agha Mustafazan initiated a restoration campaign of the mosque that had fallen into decay and redecorated the sanctuary with the Iznik tiles giving the mosque its modern name, the Blue Mosque. Ibrahim Agha Mustafazan is buried in a mausoleum adjacent to the mosque's courtyard. He was the Chief of the Janissaries and built during the period 1632-1657 more than a dozen of construction along the street of Bab al-Wazeer, associating public facilities such as a Sabil and water through, residential units for the middle class and funerary constructions for himself or members of his family. The Aqsunqur Mosque is representative of the courtyard-type mosques but is subject to a well harmonized conglomerate of three different styles marking the presence of three significant patrons, Sultan Kujuk through its mausoleum along Bab al-Wazir, Amir Aqsunqur who developed the courtyard mosque and had its mausoleum built on the South and Ibrahim Agha Mustafazan who decorated the praying space with Iznik tiling and also had his mausoleum built in the same technique.

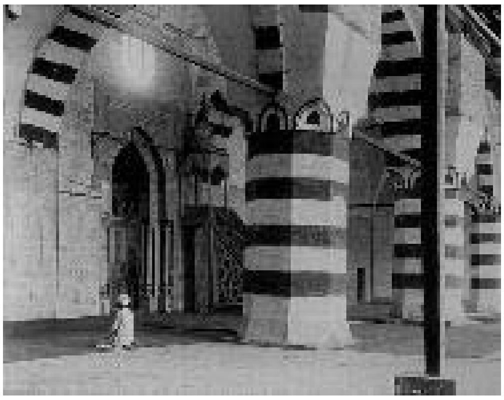
Before intervention started, the building was under a number of threats both natural and human origin. Severely during the 1992 earthquake, the building was closed to prayers and subject to an important shoring and temporary stabilization campaign and no restoration had been underway to address cracking and instability. Man-made threats affecting the building are in the first instance neglect and lack of maintenance, consequence of it being not used as a mosque.

Conservation of the monument was started in June 2009 and completed at the end of 2012 without major delays by a team of 60 to 80 craftsmen and conservators trained earlier in the area. Challenges included the removal of temporary structural supports and the implementation of stabilization measures, the conservation of delicate and rotten marble panels and Iznik ceramic tiles and large scale roofing and façade conservation. An unforeseeable challenge came at early 2011 when unrest in Egypt caused lack of clarity in government procedures and, as a consequence, delay in periodical reviews and approvals of the project

2. HISTORICAL BACKGROUND AND DESCRIPTION OF THE BUILDING

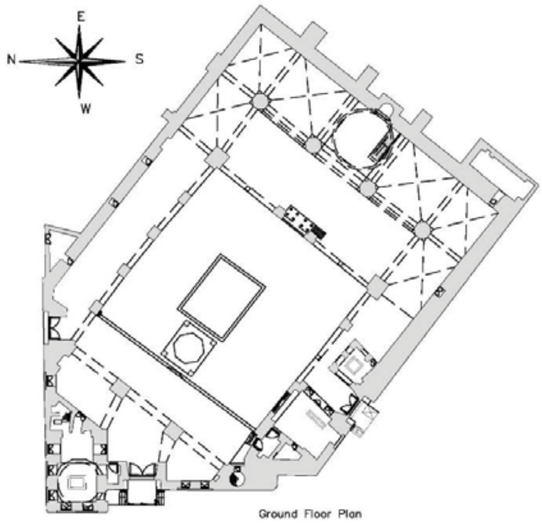
The hypostyle mosque of Amir Aqsunqur was built by the amir, a son-in-law of al-Nasir Muhammad, in 1346-7. Part of the foundation is a mausoleum located on the street side and containing the graves of Sultan 'Ala' al-Din Kuchuk (r. 1341-2), son of al-Nasir Muhammad, and several of his brothers. This mausoleum, which predates the mosque, is one of the very few Cairene mausoleums that follow the street alignment instead of the qibla. As a member of the house of Sultan Qalawun through marriage, Amir Aqsunqur incorporated this mausoleum into the structure of his mosque, which accounts for the irregularity of the ground plan of the complex. He also added another mausoleum in which he and his son were interred.

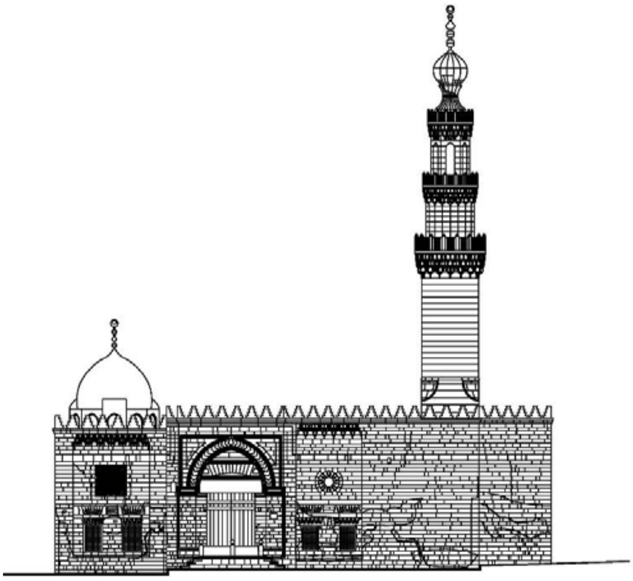
A curious feature of the original scheme of this mosque is its employment of piers sustaining cross-vaults. This is a departure from the standard structural scheme for the interior of hypostyle mosques from the Bahri period, which consists of arcades formed by marble columns carrying arches which support a flat wooden ceiling. However, Aqsunqur, who is reported by al-Maqrizi to have himself been the supervisor on the construction site, had been governor of Tripoli, Syria, the great mosque of which (1294-1314) follows a hypostyle scheme with cross vaults on piers. In addition to these vaults on piers, the mosque has arcades on columns supporting a flat wooden ceiling, probably a later addition.



The brick one-bay dome above the mihrab is carried on four plain squinches built of brick. Similar squinches are also used to carry the brick dome over the mausoleum of Kuchuk, but with a pendentive underneath each squinch. By the time this foundation was built, the use of plain squinches in the transitional zones of domes instead of muqarnas pendentives or squinches was old-fashioned. The blue Iznik tiles on the qibla wall were installed in 1652-64 by Ibrahim Agha, who seized and redecorated the mosque. They were imported either from Istanbul or from Damascus.

Instead of the usual position at the portal, the minaret is strategically located at the southern corner of the facade which projects into Bab al-Wazir Street. This projection cleverly provides the minaret with a complete visual domination of the southern part of the street. The minaret has features that are rare in Cairene minarets. The present minaret of which the upper collapsed portion was reconstructed in 1925, has three stories. The first story, which rises from the short square base, is circular and plain, the second circular and ribbed, and the third is open, octagonal, and carries a bulb. Due to its visual domination of the street, this minaret was the subject of many 19th c. illustrations, which show that it originally had four stories instead of the standard three. The fourth story, which surmounted the present octagonal one, was the standard circular pavilion consisting of eight slender columns supporting a bulb. The original minaret of Aqsunqur and the rectangular minaret of al-Ghuri are the only documented Cairene examples of four-story minarets. The minaret of Aqsunqur is one of the few Cairene minarets which are circular in cross-section from the base to the top, and it also displays the earliest dated example of concave chamfering in the transitional zone between the square base and the circular shaft. Unlike prismatic triangles, undulating moldings, and straight chamfering, this transitional feature was unique to minarets and was never employed on the bases of domes.





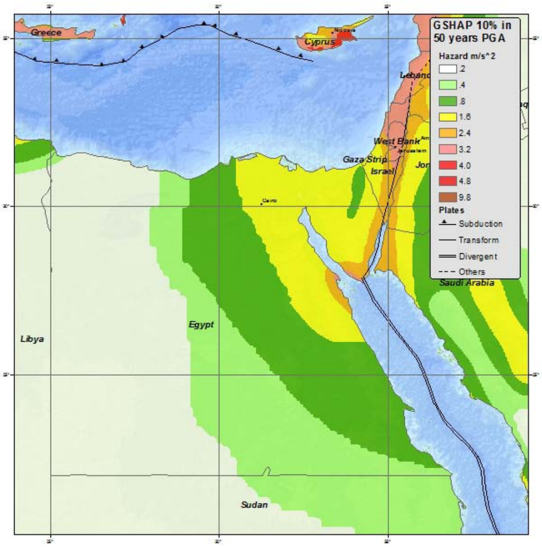
SOURCES:

Behrens-Abouseif, Doris. 1985. The Minarets of Cairo. Cairo: American University in Cairo Press.
Behrens-Abouseif, Doris. 1989. Islamic Architecture in Cairo. Leiden: E. J. Brill.
Meinecke, Michael. 1973. Die Moschee des Amirs Aqsunqur an-Nasiri in Kairo. Mitteilungen des Deutschen Archäologischen Instituts, Abteilung Kairo 29:9-38.
Meinecke, Michael. 1992. Die Mamlukische Architektur in Ägypten und Syrien (648/1250 bis 923/1517). Glückstadt: Verlag J. J. Augustin, I/108, II/198-199.
Meinecke-Berg, Victoria. 1973. Die Osmanische Fliesendekoration der Aqsunqur-Moschee in Kairo. Zur Entwicklung der Iznik-Fliesen des 17 Jahrhunderts. Mitteilungen des Deutschen Archäologischen Instituts, Abteilung Kairo 29:39-62.

3. CONDITION ASSESSMENT PRIOR TO CONSERVATION

3.1. General Seismic Condition

The city of Cairo is subject to high seismic hazards as a result of its location close to diverging plates running North-South in the Red Sea. In 1992, a major earthquake occurred in Cairo and caused significant damage to a large number of historic landmarks. The Aqsunqur Mosque was severely affected, most notably in areas where different load systems connect. In particular, the non buttressed minaret was shaken as a consequence of its isolated location along the Bab al-Wazeer Street. Vertical cracking on 6-8 cm width in the walls connecting the minaret's base and adjacent spaces could be observed.
Monitoring devices were placed to record the movements: inclinometer was placed to monitor the minaret's tilt and gauges were installed along the main cracks to record crack width over time.



Map of Egypt Seismic zones

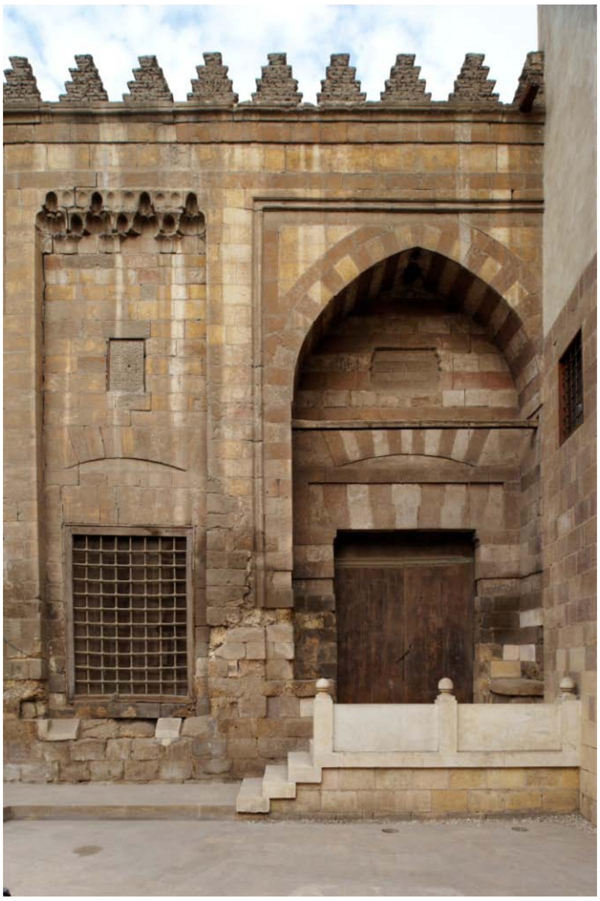
3.2. Architectural and Structural Condition

General view of the building from the North-East, including Kujuk mausoleum in the foreground, the minaret (of which the top fragment was reconstructed in 1924) and in the background the mosque's courtyard and cupola over the covered prayer area.
The building is aligned on darb al-Ahmar Street leading to the Citadel, centre of sultanate power.

(Top) General view of the minaret: the cylindrical base and ribbed second level are exceptional in Cairo: the second platform, the eight columns pavillion and onion shape bulb were reconstructed by the Comité in 1924 not on the base of historical references.
Like many minarets aligned on Darb al-Ahmar Street, the Blue Mosque minaret is lightly tilted to the Street side on the West (1.2°). The minaret's structure was monitored and it proves that the tilt is now stable. It can be explained by the absence of abutment on the West and the limited tensile capacity of the adjacent walls masonry to maintain it in its configuration.
(Bottom) General view of Kujuk mausoleum cupola and of the roofs. The connection between the stone octagonal base of the cupola and the brick semi spherical dome is not perfectly mastered externally. The crenellations are clearly resulting from the Comité intervention. All elevations are covered with the aggregated dust forming a 8-10mm crust that is typical of Cairo's polluted environment.

(Top) General view of the roofs covering the prayer area: roofing system is made by parts and not fully leveled to ensure proper rain water drainage. Decayed materials accumulate in several areas.
(Bottom) View of the roof covering the prayer space and of the dome at its centre: the roofing and insulation systems are not continuous, roofing tiles are decayed leaving the sand visible. The dome masonry has been subject to significant interventions: the joint between the roof and dome does not appear to be water tight, some windows in the drum were blocked by masonry, the brick cupola is cracked, large areas of plaster are missing

(Top) The Mosque's entrance portal and main façade lining Darb al Ahmar Street. The general damage pattern of the Mosque's elevations is marked by a line of salt migration from the ground up to 2-3 m, creating decay to the stone veneer (desquamation) and on the mortar joints (powdering). Cause of this moisture damage appears to be a combination of the Cairene habit of watering the streets, garbage deposits at the foot of the facades and leakage of the underground main potable water pipes.
(Bottom) Elevations of the Kujuk mausoleum. A similar damage pattern is visible, made more significant in the building's edge. The lower portion of walls has lost its pointing mortar and al stones are either covered by thick soluble salt crusts or cracked and desquamated.



(Top Right) The Elevtaion of the Kujuk mausoleum, (Top left) The entrance to the Mosque from the South
Both facades are affected by similar moisture damage dislocating the lower part of the stone masonry up to 3m of height
(Bottom) Detail of the North elevation. Capillary action causes dislocation of stones in the area between 1.5m and 2.5m of height from ground. Pointing mortar loses its consistence in the same zone causing risk of structural collapse.

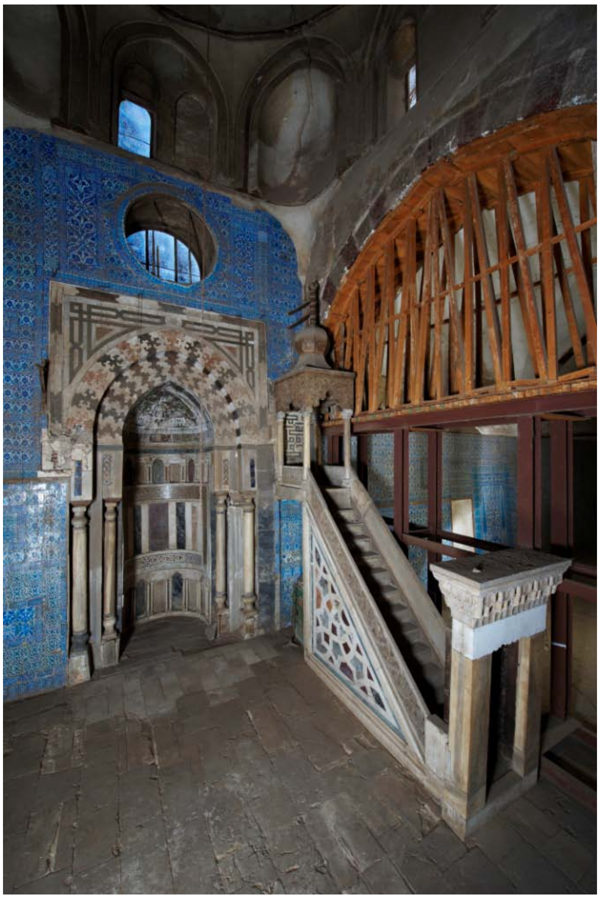
(Top) The Elevation of the Mosque from the East
(Bottom) Detail of the East elevation
This rear elevation, made almost exclusively in brick masonry, was not expected to be visible. It still bear the marks of encased beams, entrance doors, evidences that the prayer space was connected in the past to small buildings, shrines, which used to be abutted and were later demolished. Robust buttresses were constructed to support the quibbla wall. Connection of the façade with the current sport ground tiling causes risks of water ingress into the stone masonry.

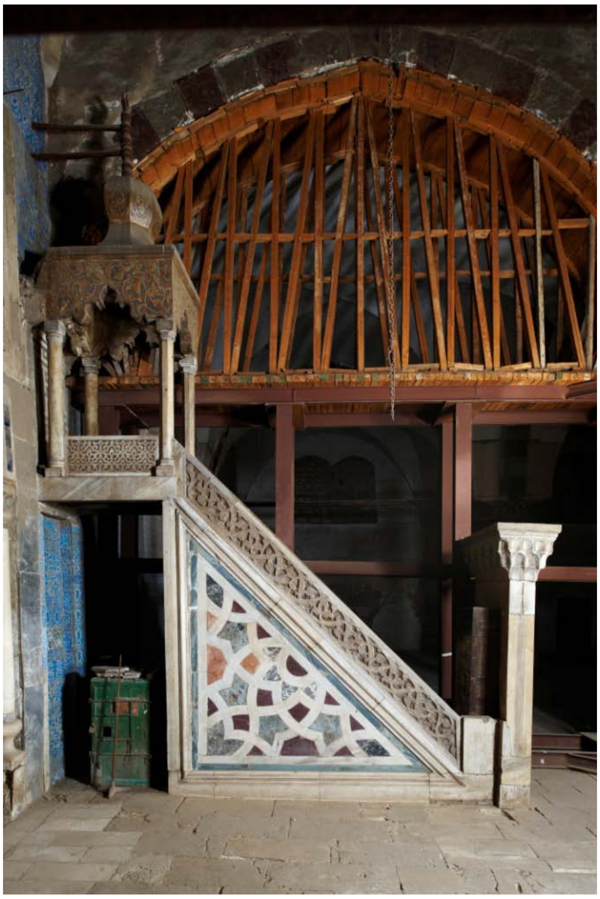
(Top) General view of the courtyard from the West
(Bottom) Courtyard elevation of the portico of the covered prayer hall.
Temporary supports were constructed following the 1992 earthquake to support arches and columns. The shoring technique associates robust welded steel profiles, carrying slim timber beams, expected to reach the extrados of the arches. Unfortunately, since its construction, timber beams shrunk and do not connect t the extrados of the arches, making the shoring structurally ineffective.
Note the good condition of the stone masonry and facing stone in the elevation. The natural color of the stone bands (orange and white) is accentuated by white and red lime wash.

(Top) The geometrical connection between the façade walls aligned on the street and the courtyard pillar marked by an orientation to the qibbla. Despite significant stone repairs by the Comité, stone masonry is not in good condition, in particular in the areas concerned with salt efflorescence.
(Bottom) Detail on typical stone masonry of the Kujuk mausoleum walls. The area is subject to a strong erosion of stones due to salt migration and efflorescence associated with general neglect

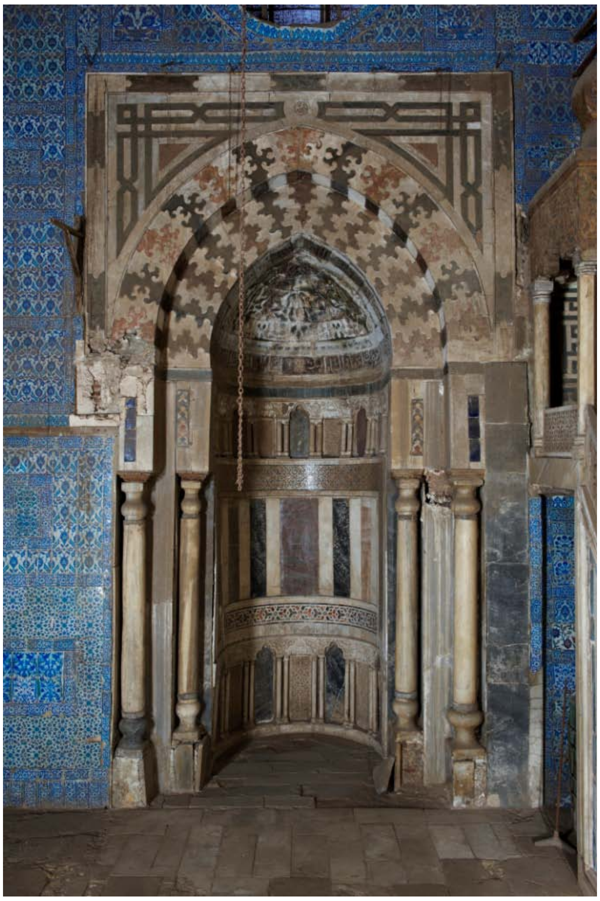
(Top) The covered prayer hall supported by octagonal pillars
(Bottom) Detail of an octagonal pillar and the qibbla wall in the background
The interior prayer area is marked by two different roofing systems: stone masonry cross vault and timber flat roof related to two construction phases.
Insertion of Iznik tiles on the pillars and al along the qibbla wall are the most visible dimensions of the refurbishment by Ibrahim Agha in the 17th century.
Apart dirt and neglect, the area is in a relatively acceptable condition.

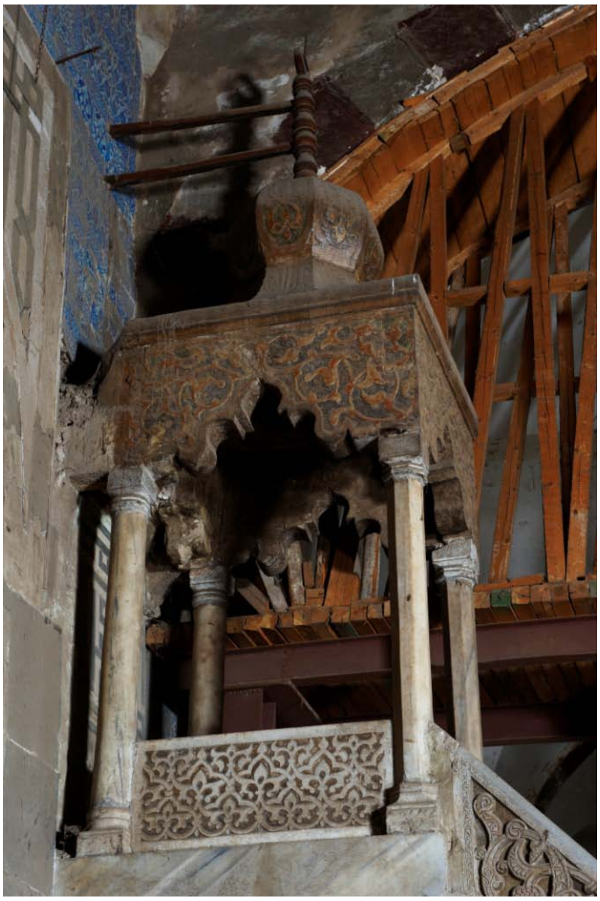
(Top) The central part of the covered prayer hall supported by octagonal pillars, with temporary shoring of the arches carrying the dome
(Bottom) the central dome with spinches over the prayer area.
Cracking of the dome was found critical after the 1992 earthquake to be the reason for the construction of temporary support son its bearing arches.





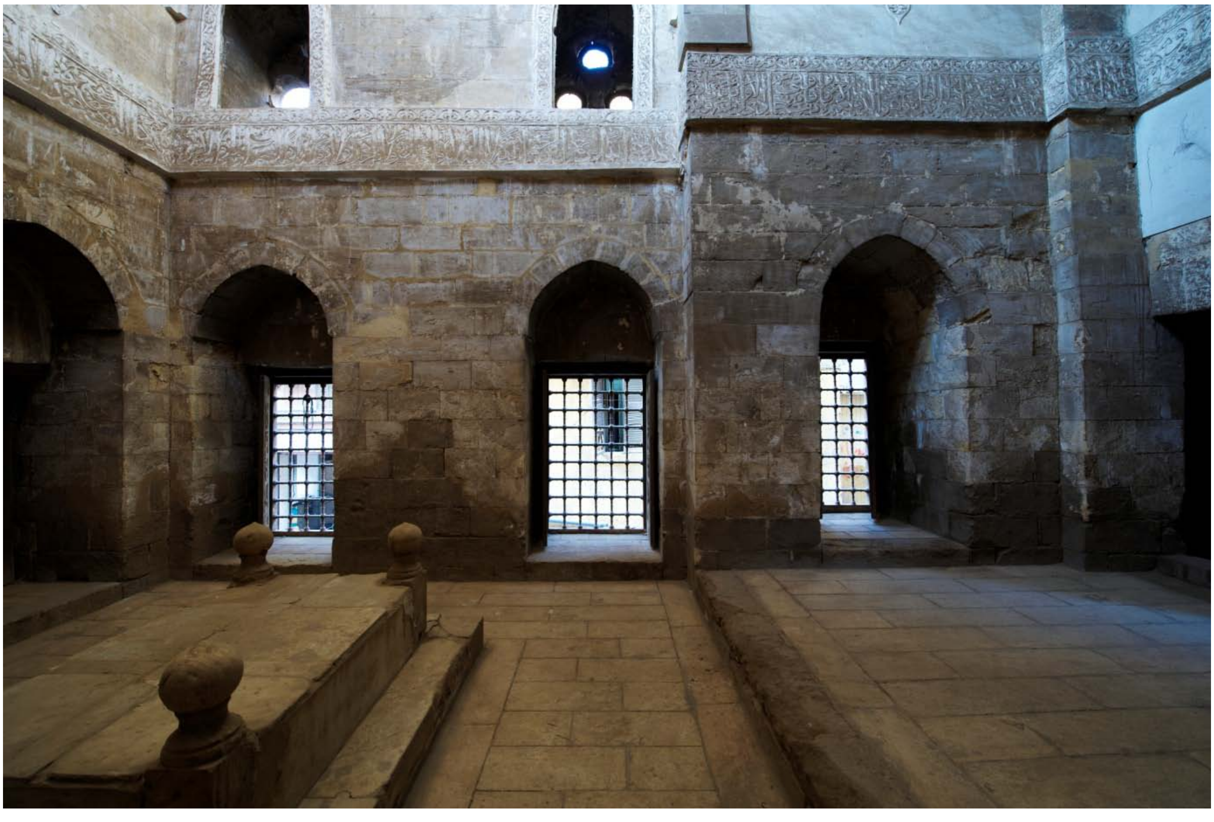
(Top left) The mirhab and mimbar (Top right) the mimbar, made of polychrome marble, porphyry, painted and gilded marble.
(Bottom left) the mirhab, pre existing the Iznik tiling refurbishment. Marble paneling is much deteriorated particularly in the lower zones, where gypsum base is subject to powdering and expansion due to salts migration. (Bottom right) the upper octagonal bulb, adorned with painting and gilding on marble panels

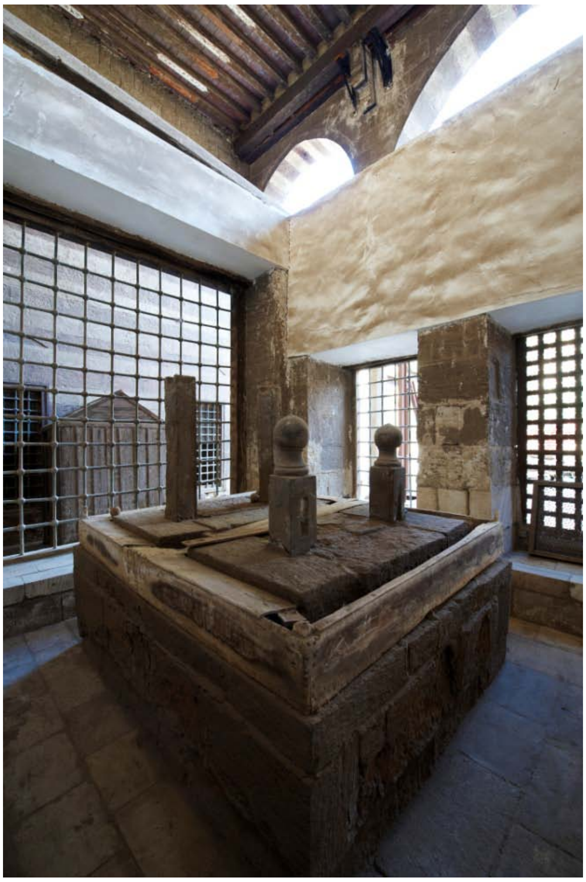




Various motives of Iznik tiling of the qibbla wall: Iznik tiles were in relatively good condition. A large number of them were cracked but stable; some had disappeared due to theft. Neglect and absence of up keeping had caused tiles to be covered by dust and dirt.

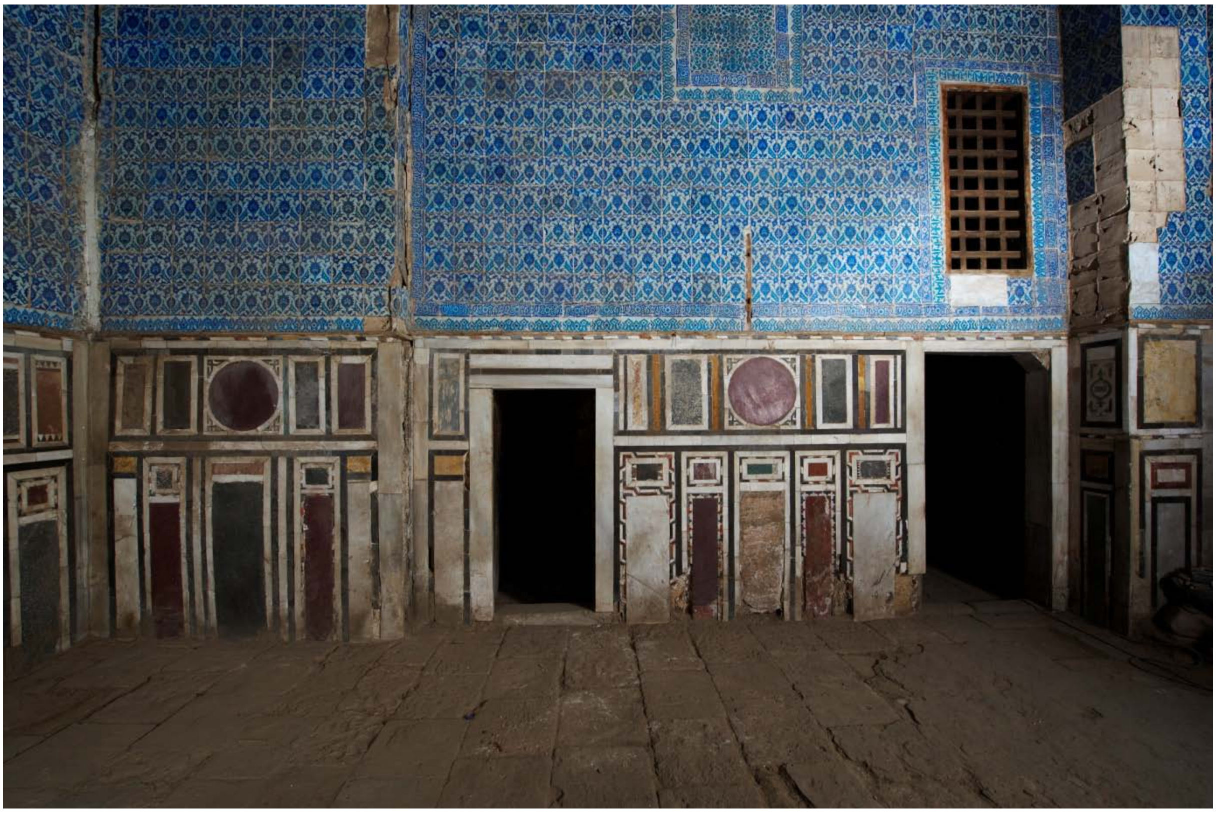
The mausoleum of Kujuk
(Top left) The main dome and drum, (Top right) the stone cenotaph
(Bottom) Side elevation of the mausoleum of Kiûjuk. Gypsum inscription band and high reliefs are still preserved but the decoration that covered the lower part of walls is lost.





Amir Aqsunsur Mausoleum
(Top left) The small edifice accommodating the tomb of Amir Aqsunqur is located on the South portico of the courtyard. (Top right) the cenotaph appears to be constructed during the ottoman period to refer to the Tomb of the Mosque's founder
(Bottom) Despite its modest size and unsophisticated finish, this mausoleum is in derelict condition.

The mausoleum of Ibrahim Agha Mustafazan
(Top) the cenotaph surrounded by walls covered with polychrome marble panels and Iznik tiling
(Bottom) The mausoleum is subject to important decay. Structurally, the wall supporting the minaret base shows detachment and cracking affecting the ornamentation. T he lower level of marble panels is much deteriorated by salt migration causing the building gypsum mortar to burst and powder and the Iznik tiling suffers from significant crack and theft.



4. PROJECT ACHIEVEMENTS

4.1. THE MINARET (JUNE 2009-MAY 2010)

The following activities were implemented to conserve the minaret:

- Cleaning activities and conservation of the minaret have been finalized on both the exterior and interior.
- On the lower balcony, mechanical cleaning of the stalactite was completed and the colour layers beneath the lime crust were revealed. The remaining colours were cleaned and consolidated, and re-touched using red and green natural colour pigments and a diluted type of lime for re-touching the white parts.
- Cleaning of the lower body of the minaret, re-pointing of joints and filling the cracks were completed.

Mechanical cleaning of the lower balcony stalactites

Cleaning of the red stone course in the lower body

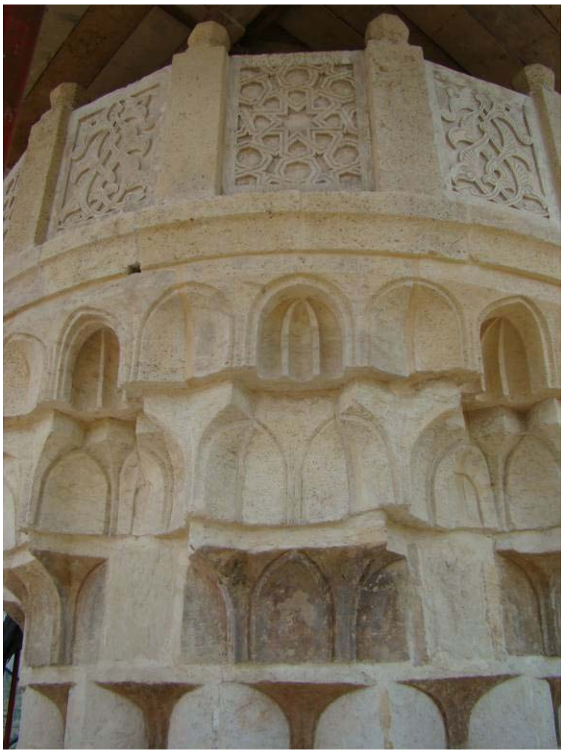
Micro-sand blasting of the lower stone body

Re-pointing of joints and mortar completion of cracked and eroded stone parts

- Similar colours were revealed on the second balcony stalactites. Though the condition of the colour layers was poor, it was decided to fix and consolidate them as these remains are evidence of the different stages of restoration of the minaret.

View of the work progress and the remains of colors on the first row of stone stalactites in the second balcony

View of the middle balcony after cleaning



View of the damaged stone tiles after cleaning

- The upper balcony stone columns have suffered the most corrosion and damage. Four of the upper column parts were broken and detached. After cleaning the detached parts, a carbon fibre rod was placed in the middle of the column in order to give more support to the upper parts. Following, the broken stone parts were assembled and installed in place using epoxy while the joints and cracks were filled with mortar on the surface.

Fixing and Assembling process of the stone column top

Conservation activities of the upper stalactites and stone columns

- The decorated stone parapets of the balconies were cleaned and deteriorated parts were consolidated. No major parts were missing, so few detached stone parts were completed by mortar in order to minimize further loss or erosion.
- The stone tiles of the all balconies were cleaned and the re-pointing of joints took place. However, the lower balcony tiles were badly cracked and deteriorated and several tiles were replaced following the original pattern.



The upper balcony during the cleaning and the consolidation activities



View of the damaged stone tiles before and during replacement activity of the completely damaged or lost ones

- The led sheets covering the wooden bulb were initially cleaned and they were found in a very bad condition. They were removed to also test the wooden bulb. The wood was cleaned mechanically and detached and cracked parts were restored. Following, an insect disinfectant solution was applied to the middle wooden column in addition to the use of a disinfectant vapour in the bulb interior. Afterwards, a protective layer of linseed-oil was applied to all the wooden surfaces for consolidation.
- The crescent surmounting the wooden central column was dismantled in order to fix the led sheets. The brass crescent was cleaned and will be replaced after fixing the led.
- Currently the installation of the new led sheets is taking place based on the original design.
- The interior staircase of the minaret was cleaned using as a primary method the micro-sand blaster given the condition of the stone. Re-pointing of joints was also completed.

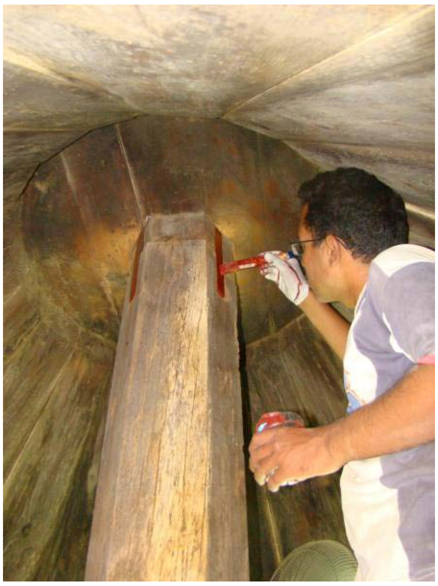
Dismantling and numbering of the brass crescent to enable the replacement of the led sheets

View of the old led sheets

Dismantling of the led sheets

View of the wooden bulb

Application of the linseed oil after cleaning



Cleaning of the interior and insulation of metal

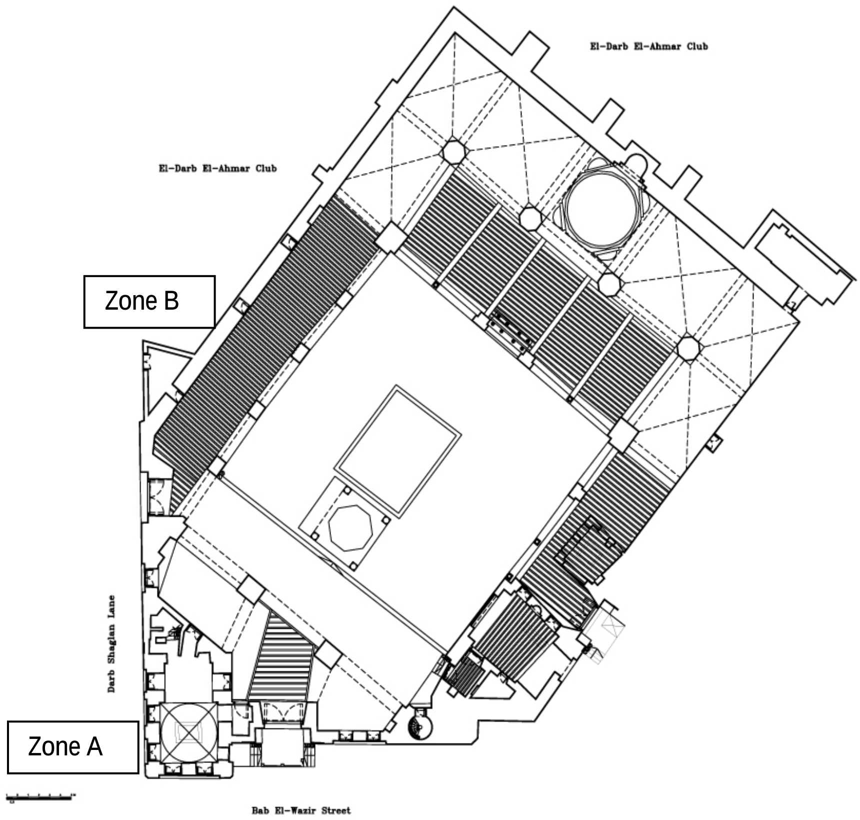
View of the wooden bulb during the led sheets installation

4.2. THE ROOFS

The roofing system results from the succession of construction campaigns of the building:

- 2 domes constructed in brick masonry, covering both the mausoleum of Kujuk and the central prayer area
- Cross vaults in stone masonry on the north eastern part of the prayer area and in the vicinity of the main street entrance
- Flat timber carpentry roofing on 3 sides of the courtyard.

Roofing rehabilitation involved full dismantling of existing conditions up to the structural systems and complete re-instalment of boarding, water insulation and finish coats, as depicted below.



Ground floor Plan showing the variety of roofing systems

Description of achievements (June 2009-December 2012)

Zone A:
The roofing restoration activities in the vaulted spaces adjacent to Kujuk mausoleum and in the area surrounding the dome were carried out as follows:

- Rubble fill was removed and the crack were repaired
- A light weight mortar layer was added before water insulation membrane was laid
- A final mortar layer was applied to protect the roof.

The space above the main entrance had no proper roof to protect the vault underneath. Roofing activities took place as follows:

- Wooden cushions were inserted on the side of the walls to support the new wooden beams.
- New shingles were placed over the wooden beams, followed by placing the electric conduits and cables required for lighting
- Two layers of plastic sheets were placed above the shingles followed by a layer of mortar to be used as a base for the bitumen sheets layer.
- The water insulation was tested before the final mortar layer was applied.

Roofing work in progress


View of the space above the main entrance showing the existing condition


View of the space during carpentry work


Application of plastic membrane above shingles and torch applied bitumen sheets for water insulation


General view showing the existing condition

Removing the rubble layer


Crack repair in the drum of the dome

COURTYARD NE


Application of insulation sheets

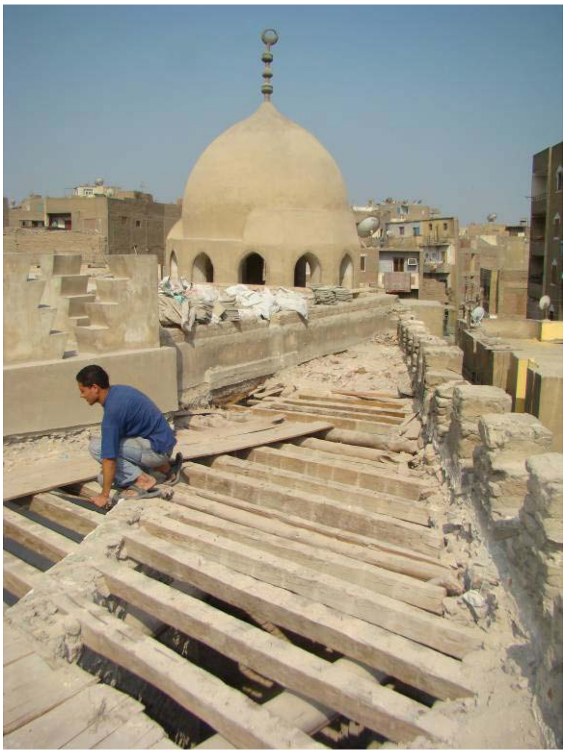
Final mortar application on top of water insulation

ROOFS

The roofing restoration activities in Norh-East area of the courtyard were carried out as follows:

- All carpentry beams were checked and dismantled for stability reasons; those which were in a good condition were selected and consolidated, painted. The beams which were completely cracked and could not be re-used, were replaced by pitch pine larger sections given the wide span of the roof. The damaged existing shingles were also replaced.

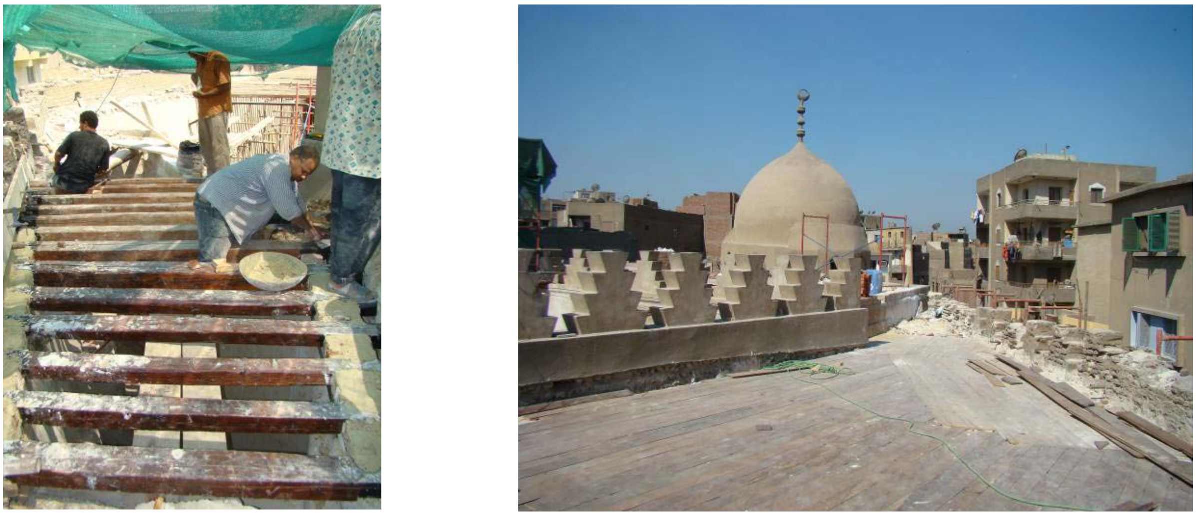
- The space above the north eastern arched entrance was covered in rubble; after cleaning, the surrounding walls showed several of brick cracks which were repaired and plastered.
- Wooden cushions were placed all along both sides on the walls of the north east bay.


North Eastern Roof during removal of shingles


restored brick space above the arched entrance


Installation of wooden cushions along the side walls


View of the roof


Brick repair activities and replacement of wooden beams and shingle proceeding in parallel

SOUTH EASTERN ROOFS (THE BAYS PARALLEL TO THE QIBLA);

The roofing restoration activities in South-East area, in the cross vaults parallel to the qibbla wall, were carried out as follows:

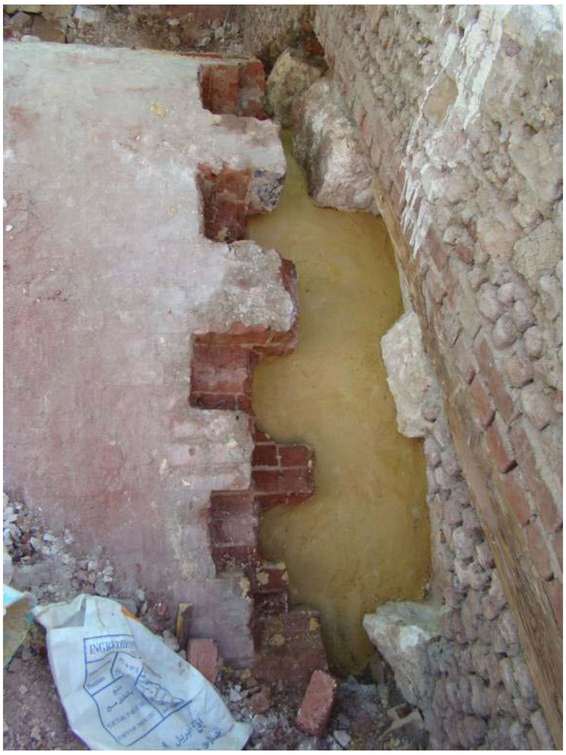
- Removal of the cement tiles and of rubble fill
- Dismantling of the shingles and wooden beams
- An intermediate masonry support had been constructed to reduce the span of wooden beams. The parapet was resting directly on one of the cross vaults and therefore, transmission of loads was detrimental to the vaults.
- The brick cross-vault was revealed and cleaned; several cracks had appeared; they were thwe consequence of the detaching of the south-eastern wall due to obvious missing structural ties or support. The bricks surrounding the cracks were removed carefully. A fine mortar mixture was injected to fill any remaining voids or fissures. Brick stitching then took place reusing the same brick sizes of the cross vault. Two wooden ties were also imbedded within the stitching for tying the cross vault structure with the wall parapet. This process was repeated in other location of the cross vault where the wooden tie beams were replaced by steel rods in order to ensure the best results for the stitching of the brick vault.
- An open crack had appeared in the north western side of this section of the roof due to lack of connection between the brick vault and the stone arch. The cross vault was stiffened, bricks were removed carefully and brick stitching activity were finalized.
- After completing brick stitching activities on this section of the roof, new wooden beams were installed to form a uniform roofing system.


View of the roof removal of shingles and wooden beams

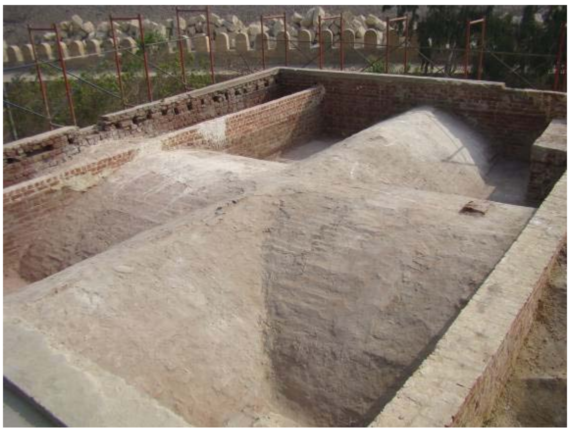


Brick repair activities





Brick repair activities

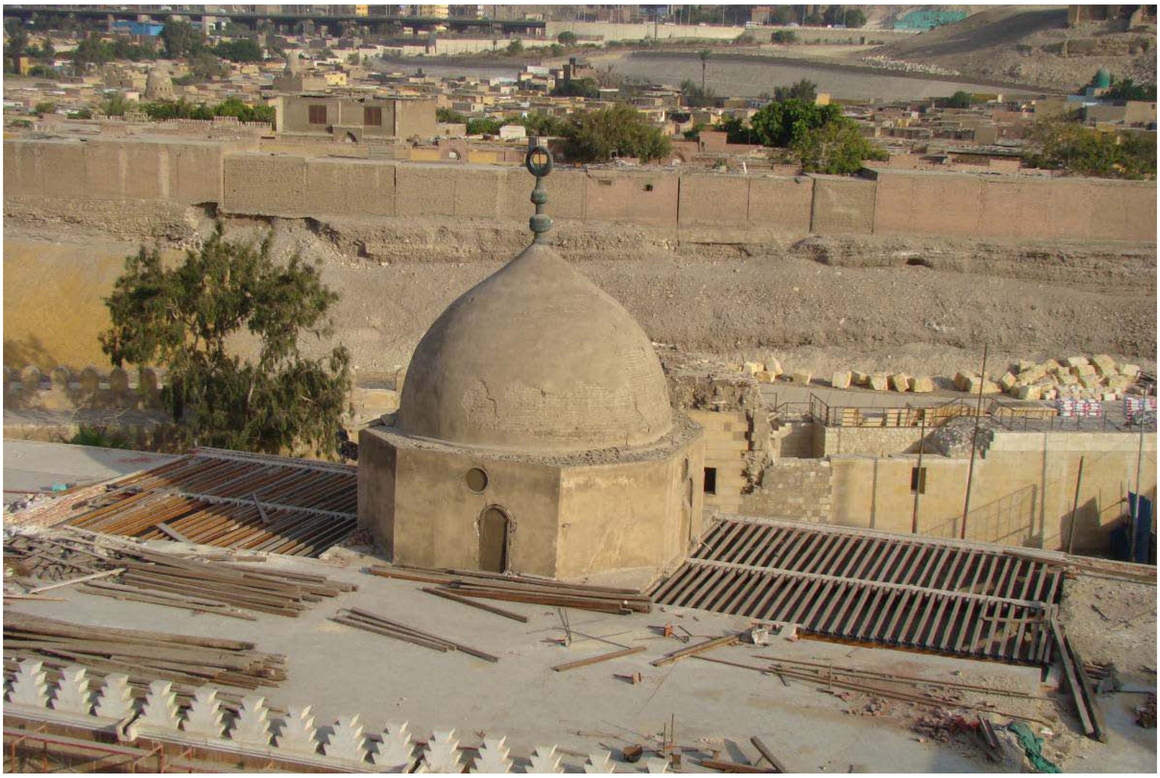



View of Section after brick repairs

Following activities in South-Eastern roof:

In the sections North and South of the main dome, the following was carried out:

- The existing roof was being carried on posts supported by the cross vault, which caused severe cracking in the cross vault. This system was replaced with a different loading system, using steel I-beams in order to transfer the loads of the roof on the two stone arches at either side of the cross vault.
- The I-beam was placed, followed by the wooden beams, shingles and water insulation



General view of SE roof after placing the steel I-beam and completing the carpentry activity

Application of the bitumen sheets for water insulation


The final mortar layer application

View of south eastern section after completing the work

2.4. THE MOSQUE INTERIOR

Conservation of the interior spaces of the mosque involved not only activities of architectural conservation but of ornamental conservation.

View of the courtyard facades with site installations and scaffolding

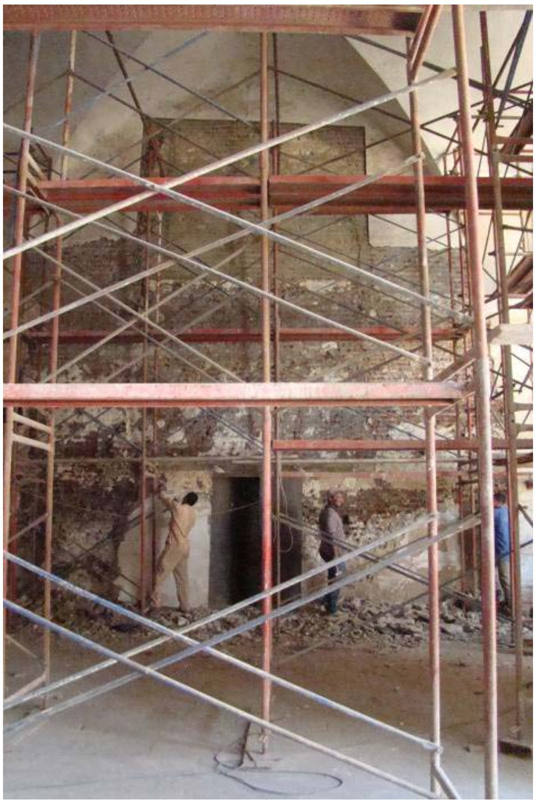
STONE REPLACEMENT IN WALLS AND PILLARS:

In areas such as the bottom of walls where the soluble salts migration has caused irreversible lack of consistence for structural stones, they had to be replaced with natural stones originating from similar quarries. The pictures below depict phases of work:

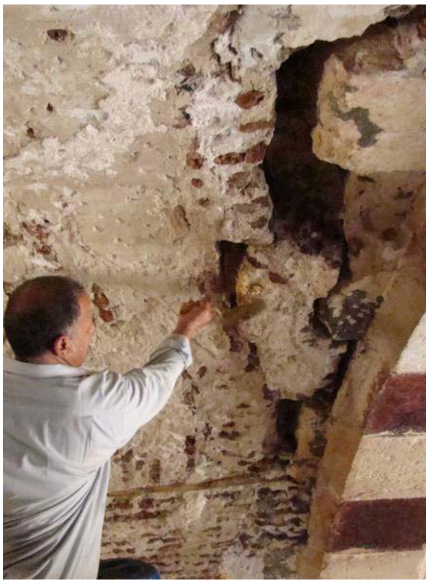
Stone replacement activities in the South Western Facade

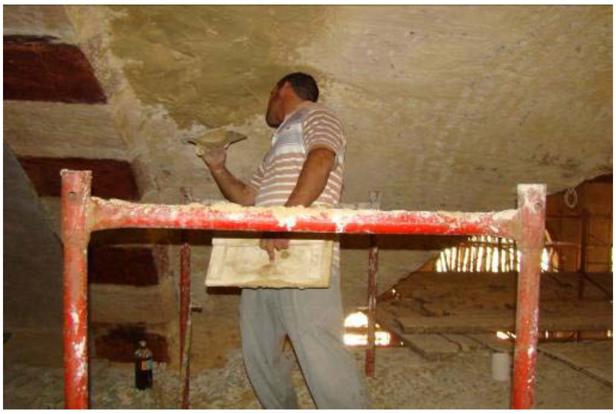
BRICK MASONRY REPAIRS AND PLASTERING:

Large parts of the buildings are constructed in brick masonry in walls and vaults. Because modern black cement plaster was found on some walls and cross vaults and cement is not compatible with porous building materials (bricks, limestone), this layer had to be removed. In other areas, brick walls were cracked and stitching had to be carried out. Finally, rarely, completely deteriorated bricks had to be replaced where necessary.



Brick repairs activity





Plastering activity

REMOVAL OF TEMPORARY SHORING

As per the structural engineers' analysis and recommendations, the shoring placed by the SCA in 1992 below the arcades of the façade of the *qibla riwaq* and the arches around the dome, could be removed, using precautions as to the phasing and procedures of work.

The arches were in a good condition and it was difficult to understand the motivations of such an extensive shoring. As an insurance policy, monitoring devices were installed to verify that no further movement would take place.

Shoring dismantling phases (from top left to bottom right). To be noted was the absence of contact between the timber poles and planks with the stone arches, due to timber shrinkage. The shoring in place was not playing any structural support function

STRUCTURAL STRENGTHENING OF THE *QIBLA* DOME:

View of the *qibla* dome before starting the restoration & conservation

View of the *qibla* dome after erecting the scaffolding

Flaking the plaster

Blowing the dust

View of the lower part after removing the plaster

Opening the vertical cracks

Filling the vertical cracks

Installing the galvanized steel mesh

Applying a plaster layer of a material suitable for historic buildings to level the surface before installing the FRP

Phases of work for installation of the FRP wrap using epoxy resin for confinement of the dome

FINE CONSERVATION:

CEILINGS CLEANING AND CONSERVATION

Conservation activity the timber ceiling was minimal: dust was removed using soft brushes; decorated beams were cleaned using a mix of water and alcohol. This will be followed by minor re-touching activities where necessary.

Cleaning and conservation activities using soft brushes, water & alcohol

Painting the non-decorative beams

Re-touching the decorative pattern

Timber ceilings before conservation (Top) and after conservation (Bottom)

STONE CLEANING AND CONSERVATION:

Stone cleaning and conservation of plain walls and pillars were implemented using the following sequences:

- The dust and recently applied lime wash layers were being removed from the stone surfaces using soft brushes and hand tools;
- The white limestone courses were cleaned using poultices and the red-painted stone courses were cleaned using water and alcohol;
- Final repointing using lime based mortar was applied.

Removing the lime wash layer

Stone conservation in the qibla *riwaq*

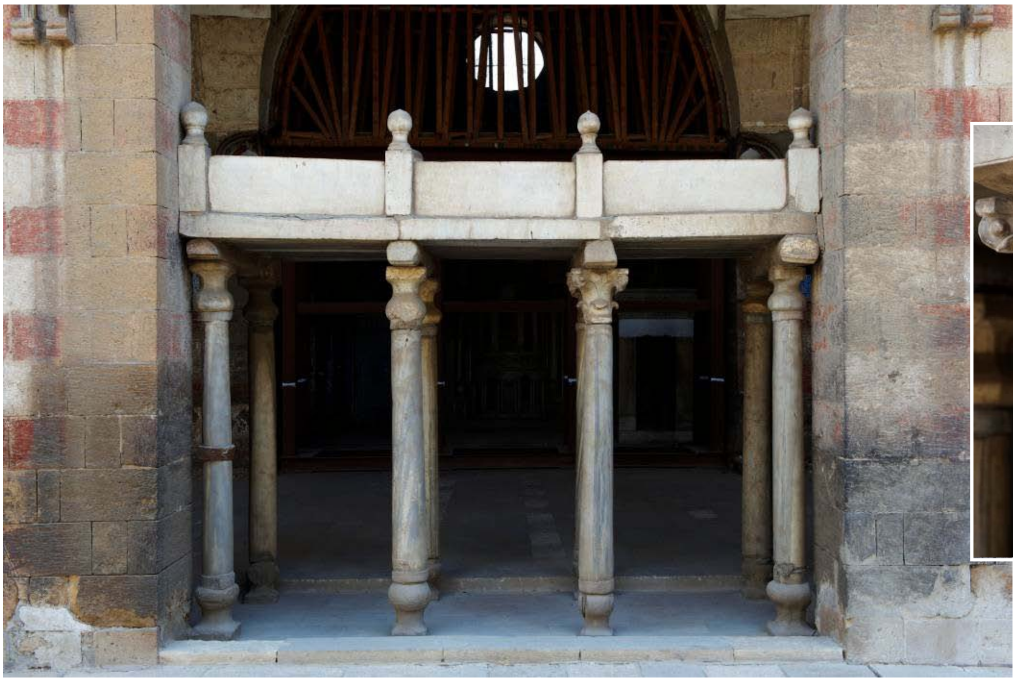
Cleaning activity using poultices

The cleaning activities and re-pointing in the stone pillars and arches

MARBLE CLEANING AND CONSERVATION

The conservation of *dikkat al-mobaligh* is being used as a reference to depict procedures and phasing of decorated marble conservation.

- The carved and plain marble elements were cleaned using poultices. Few areas had a strong crust layer and hence required cleaning using the micro-sand blasting technique.
- This was followed by the re-pointing activity.
- The joints between the column capital, the body of the column and its base were in lead. The existing lead was cleaned. The missing / broken parts were completed using new lead sheets.
- The bases of the columns had some broken elements. These were completed with a marble-powder mortar mixed with epoxy.



Detail on marble column

View of *dikkat al-mobaligh* before intervention

Conservation activities of the *dikkat al-mobaligh*

Poulticing and re-pointing activities

Cleaning the lead joints and completion of the broken marble parts of the columns

View of *dikkat al-mobaligh* after conservation

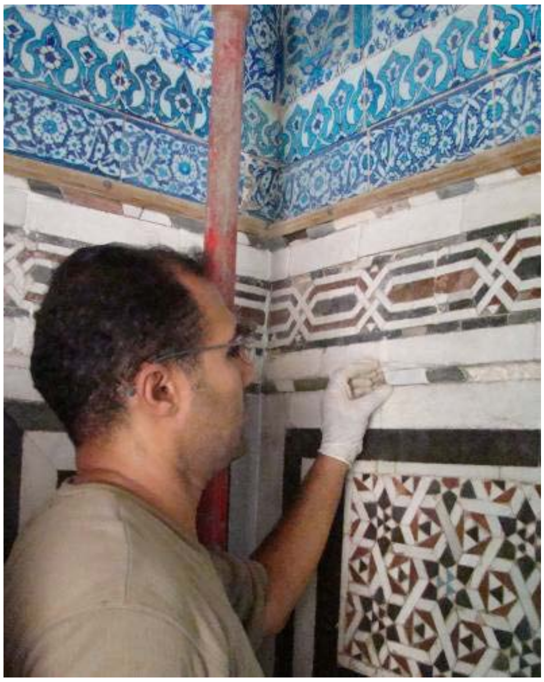
IZNIK TILING PANELS CLEANING AND CONSERVATION: THE QIBBLA WALL

Iznik tiling cleaning and retouches: water based manual cleaning was performed, local repointing and retouches to integrate damaged areas.

IZNIK TILING AND MARBLE PANELS CLEANING AND CONSERVATION: THE IBRAHIM AGHA MAUSOLEUM

Fine conservation in the Ibrahim Agha Mausoleum includes a large panel of activities due to the various materials this building component is made with. The entire panels of Iznik ceramic tiles were cleaned using water based solvents. Detached and broken tiles were assembled and reinstalled. Four samples of retouching were presented to the SCA and discussed; the option taken is a sample based on drawing the pattern retouching with similar colors as the original. In this way, the decoration looks integrated when seen from the ground, while one can clearly differentiate between the old and the new material from close. The lower white marble panels were cleaned using the poulticing technique while the totally missing marble pieces were being replaced. Colored marble and stone were cleaned with a mix of poultice and mechanical techniques. The cleaning activity was finalized in the decorative wooden ceiling; the flaking painting was fixed and protected, then the dust was removed and where necessary minor re-touching activities took place in order to show the continuity of the decoration.
The cleaning of the wooden shutters of the mausoleum are taking place; where modern paint exist, it is being removed. The door shutters were treated against insects and repainted using traditional gum painting where necessary.

Cleaning and re-pointing activities of the blue tiles



The conservation and re-touching activities of the mausoleum's entrance

The conservation and cleaning activities of the *mihrab* using the poulticing technique

Reassembling of broken elements

Painted ceiling conservation and retouches

The marble replacement activity of the lower part

Cleaning the wooden shutters of the mausoleum and removal of the modern paint on the back

GYPSUM STAINED GLASS RESTORATION AND NEW MANUFACTURE

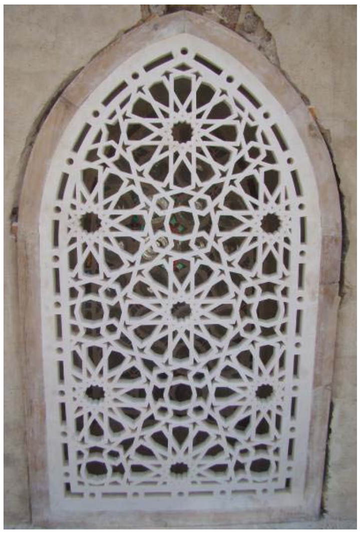
Arched windows were filled-in by steel mesh (type of chicken wire mesh), installed by the *Comité de Conservation des Monuments de l'Art Arabe* during the 20th century.
In coordination with the SCA, the steel mesh was dismantled to be able to clean stones of the openings. After cautious analysis of gypsum remains in the openings and similar buildings, it was decided to proceed to the installation of new gypsum windows.

Dismantling the mesh windows

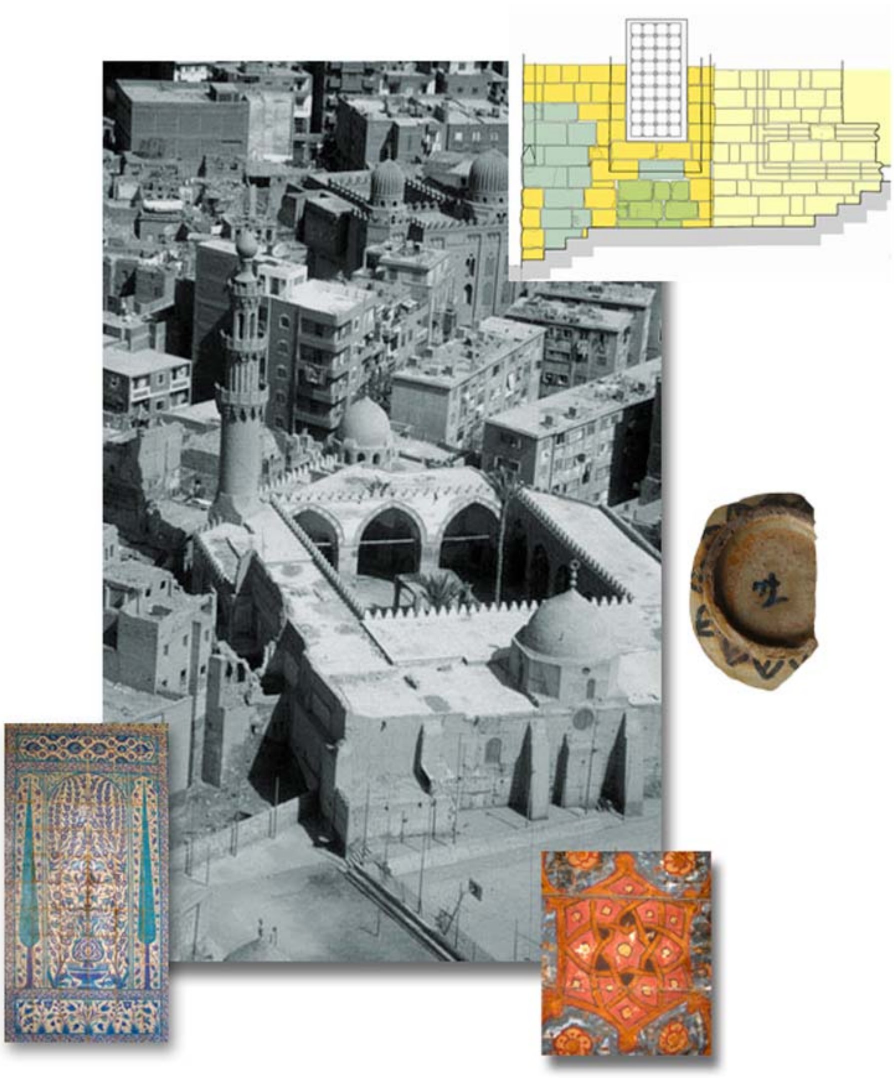
Conservation and cleaning activities of the stone openings

Producing and erecting the gypsum grills: gypsum is being cast inside a timber frame. Once solid enough, but still humid, the carver replicates the design by facsimile onto the gypsum and starts to carve the voids. After carving is complete, the panel is left to dry, before being erected in the opening.

(Above) General view of the façade after conservation and installation of the gypsum windows. (Below) phases of work and installation of gypsum windows on Kujuk mausoleum



AQSUNQUR MOSQUE
"THE BLUE MOSQUE"
Ad-darb al-Ahmar, Cairo



Archaeological survey report
04th-30th January 2009

Nicolas **LACOSTE**
Archaeological consultant

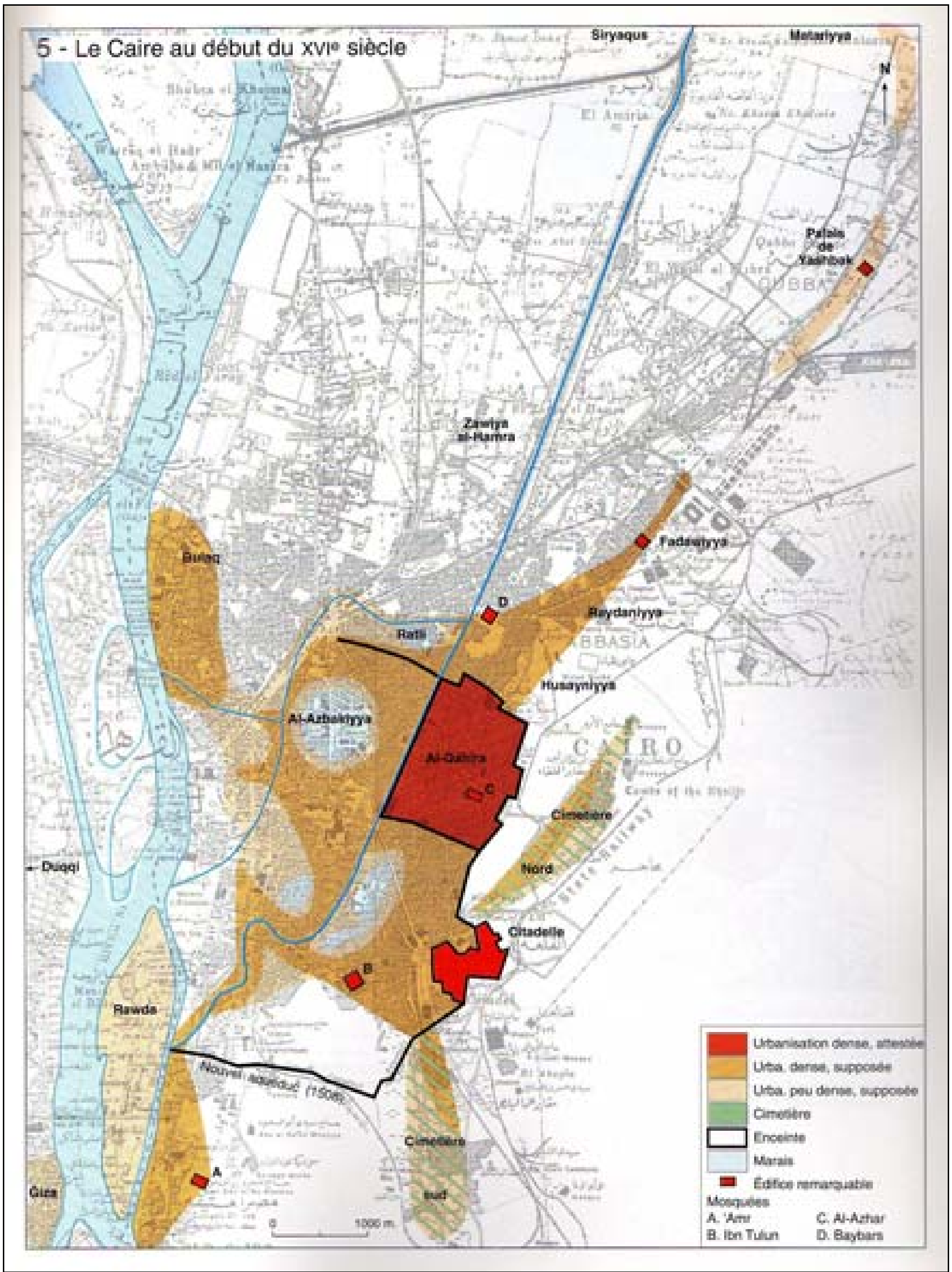
INTRODUCTION

BIBLIOGRAPHY & Internet Resources

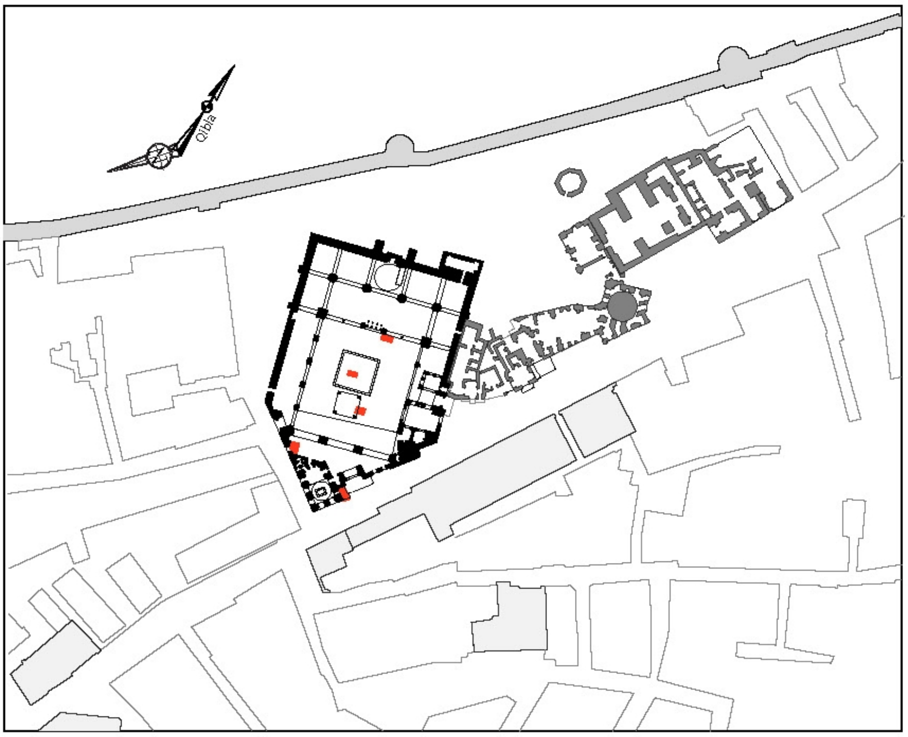
APPENDED

Introduction

The Bab el-Wazeer street is an incredibly rich and complex area in regards of Cairo's urbanistic history. It is one of the main ostentatious path between the Citadel and Bab Zuweila since the very beginning of this area, the mamluks (especially the **Sultan al-Nasir Muhammad**) really put great means in the constructions they founded there.



doc. 1 : map of 16th century Cairo (J.-C. Garcin, 2004).



doc. 2 : Blue Mosque - 2009 Archaeological test-pits.

In the studied area, the chronology of the main remaining buildings can be detailed as follows (the registration numbers corresponds to the **Index of Monuments**) :

Name of the building	Type of building	Date of construction	Registration N°
Ayyubid wall	Military	1171-76	307
Palace of Alnaq al-Nasiri (formely known as Alin Aq' Palace)	Civil	1329-30	249
Aqsunqur Mosque (also known as Ibrahim Agha Mosque or Blue Mosque)	Religious	1341-47	248
Zawiya & Tomb of Sheikh 'Abdallah al-Baz	Funerary / Religious	end 16th - 17th century	U 58
Ottoman House of Ibrahim Agha Mustafahfizan (known as House n° 27)	Civil	1652	619
Hawd of Ibrahim Agha Mustafahfizan	Civil	1659	593

During this four weeks mission, we had to work over two monuments restored by Aga Khan Trust for Culture : **Alin Aq' Palace** & **Aqsunqur Mosque**. The time schedule was therefore quite short and we've chosen to divide the time in two, spending two weeks on each projects. This was quite a short time but we could reach some valuable results in terms of knowledge of this very interesting area.

doc. 3 : general view of Alin Aq Palace and of the Blue Mosque.

Regarding the Blue Mosque, the objectives were multiple (as seen in **doc. 2** & **doc. 4**), each one of them being treated through a punctual test-pit (TP). Along with this five test-pits realized here, we spent quite some time to observe the elevations, the walls, the stone courses, the buildings itself. It is what we call in France *Arquéologie du bâti* (*archeologia dell'architettura* in Italy) that could be translated by *architectural archaeology*. Any building is showing the marks of its own evolution and history. Any addition, destruction, restoration will mark it and let some traces. So, combining the stratigraphical analyse with the observation of those traces is the best way to understand the different phases of construction of a building.

We were two archaeologists to follow the work and to teach archaeological techniques to the workers. Alexy DUVAUT & I drawn the structures and described every layers found. All these drawings were made at 1:20 scale on tracing paper that was afterwards scanned and retraced using **Illustrator CS2**. Pictures were taken all along the excavation process to archive as much data about the place as possible. Pictures in this report are just samples chosen to illustrate various aspects of the excavation.

As for the phasing methodology itself, we used two ways. There is the *Absolute chronology* and the *Relative chronology*. The first one is using is the exact dating of a layer through chemical dating (Carbone C14, thermoluminescence, dendrochronology…), by object's dating (typology of the coins, ceramics or glass..). This method is unfortunately not always usable, by lack of data or by lack of money to rule them. This is why we use more often the *Relative chronology* method. It's the analyse of the logical and physical relations between the layers, the structures and the objects found in a studied area. It means that if we know that a layer is *the* circulation level of the mosque (1347), then the layer recovering has appeared after this period (it may seem obvious but it's sometimes important to point things out). Of course, *relative chronology* has to be confronted to *absolute chronology* and to the text (such as *Waqf*, charts of foundation, Comité's reports…) even though we have to be very careful about this historical documentation. It's not always as accurate as we'd like or even can be false[1] (forging history through texts is existing since the invention of writing itself !).

Let's point out that this two weeks mission is only a first overview of this Mosque and is certainly not a full archaeological study of the Blue Mosque. It would require quite more time to study fully this complex building.

[1] - To know more about the fascinating world of archaeology, you should have a look at this Wikipedia page describing in a more detailed way those methods : http://en.wikipedia.org/wiki/Dating_methodology_(archaeology).

Historical Context

It's well known that the urbanistic development of Cairo is rythmed by the construction of mosques[2]. For instance, in the 14th century, more than 600 ha were conceded by the Sultans as *hikr* (territorial concessions made to the mamluk emirs) pushing the Emirs to build a certain amount of monuments (mosques, *sabils, kuttab, maristans…*). After al-Nasir Muhammad's reign, the area of *Birkat al-Nâsiriyya* (including sharia Bab el-Wazeer) was particularly built.

The foundation of the Blue Mosque is a perfect illustration of this movement. In the 14th century, there is an increasing number of *khutbas* built by emirs in Tabbanah Quarter :

1329 Ylmâs Mosque
1329 Qûsûn Mosque
1337 Bachtâk Mosque
1339 Altunbughâ al-Mâridânî Mosque
1344 Aslam al-Silâhdâr Mosque
1347 AQSUNQUR MOSQUE
1349 Chaykhû Mosque
1356 Sarghatmich Mosque
1356-62 Sultan Hassan Mosque
1368-69 Mosque of Umm al-Sultan Sha'ban

According to *D. Behrens-ABouseif & S. Denoix*[3] this shows a great need of legitimation of the rulers, expressed through monumental foundations along the main streets of Cairo. At medieval time, there were no global urbanistic approach nor a specific governmental decision about the whole city organisation. Eventhough the Sultan and his mamluks were supposed to provide the main infrastructures to the inhabitants of the cities (such as markets, *birkat*, streets..) and to supervise the constructions in term of safety (people mostly lived in the *rab'* and problem were legions), we know that the government didn't really followed up the anarchistic expansion of Cairo.

In this report we will refer to this mosque both as Blue Mosque and Aqsunqur Mosque. This monument had several names (let's add *Ibrahim Agha Mosque*) so it's hard to have to choose one.

In 1347 (747 H) the mosque is officially founded. Historically speaking, **Aqsunqur "the white falcon"** (also called *Ak-Sounkour el-Naseeri*) is the original founder of this Mosque. He was the son in law of the great **Sultan al-Nasir Muhammad** (he even married his wife after the Sultan's death).According to **Maqrizi**, **Aqsunqur** was so passionated by architecture that he followed personally the work (he's even supposed to have given a hand to the masons). He possessed a house in the very street of Bab el-Wazeer and became the governor of Tripoli. This could explain the Syrian stylistic influences over the monument. For the construction and maintenance of the Mosque, he gave annually 150,000 silver drachmas from the revenues of a small village near Aleppo. Unfortunately, after a revolution in Damascus, the money didn't came anymore and the Mosque started to crumble apart.

In 1412 (815 H) the **Emir Tughan ad-Dawadar** built an ablution fountain in the centre of the mosque and probably made some punctual restoration retouches over the Mosque, without touching its structure or architectural style. We know that the Blue Mosque was at that time only used on Fridays. Being a *khutba's* Mosque was more by lack of financial means to do something else than by symbolic necessity.

[2] - A. Raymond, 1993.
[3] - Doris Behrens-Abouseif et alii, in J.-C. Garcin, 2000, pp. 177-203.

In 1652 (1062 H), **Ibrahim Agha Mustafahzan**, one of the most energetic builder of Tabbanah neighbourhood, decided to acquire this Mosque and the monuments all around. This include Alin Aq' Palace, Khayr Bek Mosque and the destruction of a bahrite mamluk palace in front of *Umm al Sultan Sha'ban*[4]. This is probably the biggest reorganization of the place. We'll see later on that the infrastructural work had been quite huge, including the reconstruction of the whole courtyard hypostyle pillars, the replacement of the roof, the addition of his huge mausoleum near the minaret and of course the installation of the blue tiles that are making this mosque famous now.

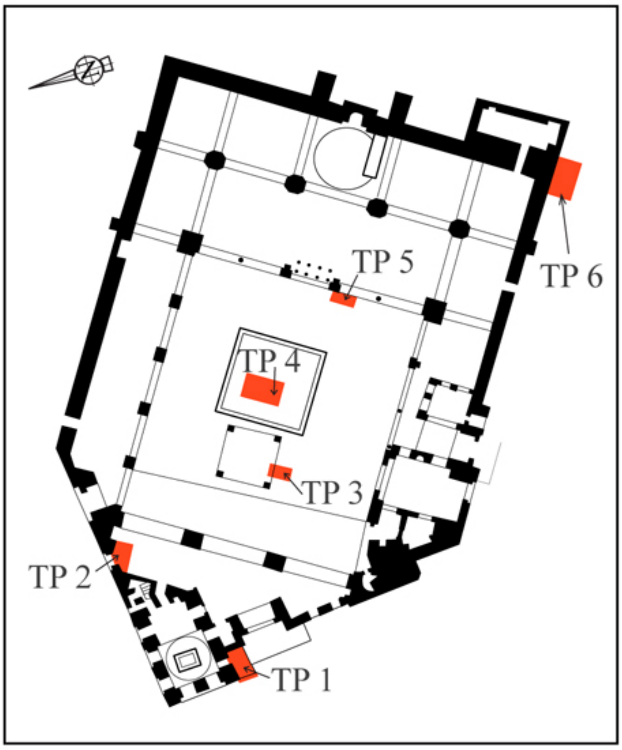
The offences of time were strong over this Mosque. And when the **Comité de Conservation des Monuments Arabes** decided to restore this Mosque in 1888, they never suspected that it would take them 36 years to finish the job (1924). There again, the scale of the work done was quite huge and including a lot of demolitions of shops and houses outside and even *inside* the Mosque. They also rebuilt the minaret, 'forgetting' to put back the 4 floors that were originally there.

1992 saw a major earthquake striking Cairo. A lot of monuments were badly injured and the Blue Mosque didn't escaped to this destructions. The **Supreme Council of Antiquities** decided to reinforce the collapsing arches and to restore some parts of the Mosque.

We could resume the main historical phases of the Mosque like this :

1341	Mausoleum of **Sultan al-Kujuk**
1347	**Emir Aqsunqur al-Naseery** built his Mosque against the mausoleum
1412	**Emir Tughan ad-Dawadar** built a fountain in the *sahn* of the Mosque
1652	**Ibrahim Agha Mustafahzan** reuse the Mosque and implemented his mausoleum
1888 / 1924	Restoration of the Mosque by the **Comité**
1992	Earthquake and punctual structural consolidations and reconstructions.
2009	**Aga Khan** starts to restore the Blue Mosque

[4]- Space used to build his own little mausoleum, before he even started to think to invest into the Blue Mosque.



doc. 4 : Blue Mosque - 2009 : Implantation of the archaeological Test-Pits.

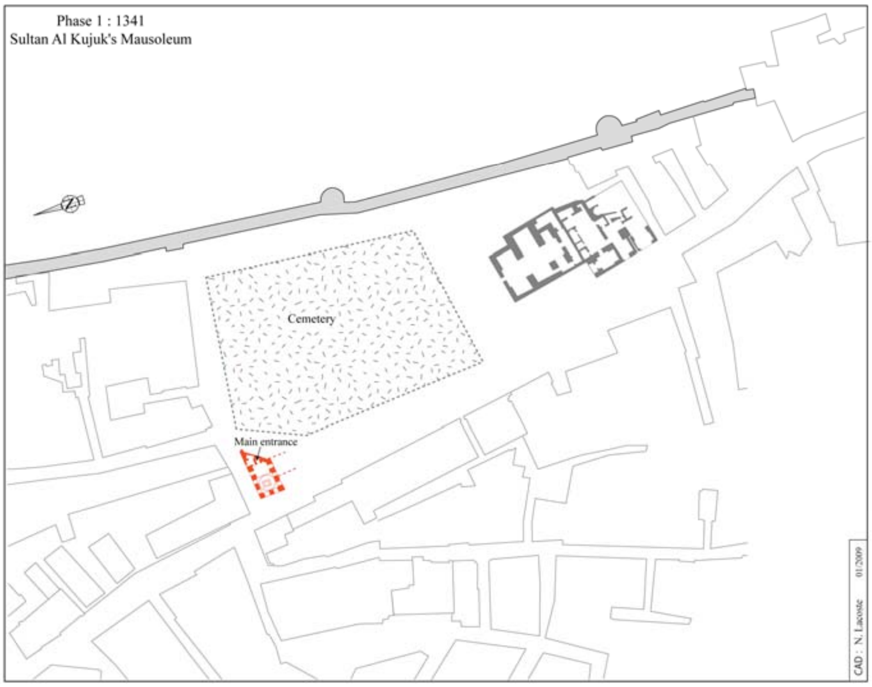
Now, to be more specific let's present the different problematics concerning the Blue Mosque that we'll try to answer to in this report :

- The physico-chronological relations between the Mausoleum of al-Kujuk and the Aqsunqur Mosque (**TP1** & **TP2**)
- The modification of the *sahn* by including a fountain (**TP3** & **TP4**)
- The re-use of the Mosque and its complete restructuration at Ottoman period (**TP2** & **TP5**)
- The extent of the Comité's restoration (**TP1**, **TP2**, **TP3**, **TP4** & **TP6**)
- Let's add that test-pit **TP6** also answer to some questions regarding Alin Aq' palace circulation levels

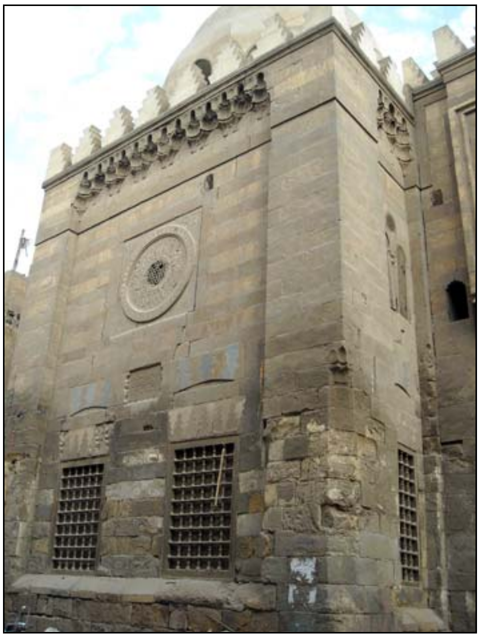
Of course, all those main events are more or less described by historical sources but we'll see that there is much more to seek and to understand than those main phases. All these intermediate states are as important in the global understanding of the building as its foundation date, simply because when comes the choice of the kind of restoration to apply to a particular area, it's necessary to know precisely the origins and chronology of each stone.

We'll see how archaeology can underline those phases of construction and add some valuable informations about those transitions.

1- The Mausoleum of al-Kujuk - 1341



If you observe the general plan of the Mosque, there is a peculiar thing about its north-western corner. Peculiar and unusual for mamluk architecture which really adore the architectural symmetry (to the point of having to play with the external lines to 'adapt' a monument to its religious obligation (distorted mirhab, distortion of the façade in comparison with the inner structure...). The *waqfs*[5] are mentioning a pre-existing monument, supposedly built over the old ayyubid city cemeteries.

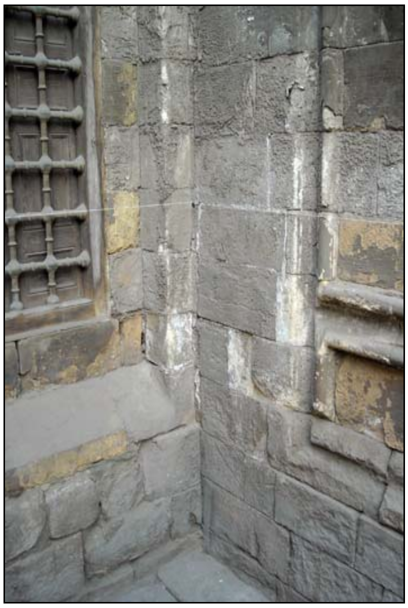


The Mausoleum external façades are in quite bad state of conservation, especially the lower parts. Inside, the Mausoleum is in much better state of conservation and, even with the strong restoration from the Comité, it's still possible to check the original patterns.

[5]- translated by Creswell (Keppel A.C.), *BIFAO* n° 16, 1919, p. 39-164.

So, this first structure had a funeral vocation. It's a rather small mausoleum situated in what must had been a corner junction between three streets (cf. **doc. 5**). Those streets are heavily symbolic but nevertheless, both size and pattern of this tomb are rather strange. If you consider that it's the tomb of several childs of **al-Nasir Muhammad**, one of the most powerful mamluk sultan. Let's add that on of them was child-sultan **Sultan 'Ala' al-Din Kuchuk** aka **Sultan al-Malik al-Ashraf Kujuk** (strangled in **746H** after being in charge only for a year) this raises questions about its scale.

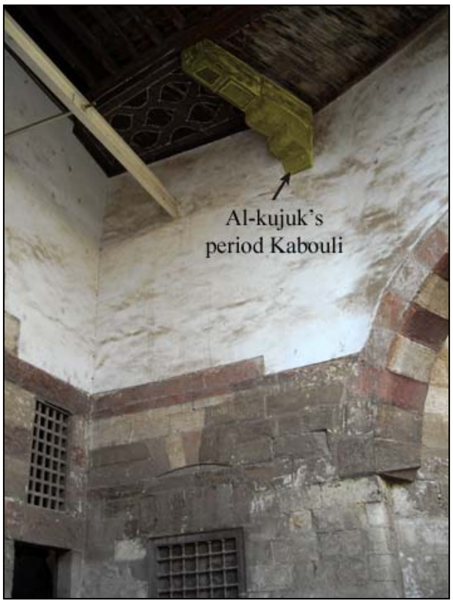
To check the relations between the Mausoleum and the Mosque we performed two Test-Pits. The first one (**TP1**) was in the street and also checked the main staircase entrance of the Mosque. We started by cleaning the façade and getting rid of the modern tar of the street (**doc. 4** & **10**). Unfortunately we reached really quickly (15 cm) a street lamp electric wire that prevented us from continuing deeper. It's obvious that the staircase is continuing under the actual street. If you take as an example the close mosque of Sultan Sha'ban (excavated in 2004 by Aga Khan[6]), the stairs reached a meter and half below the actual street.



doc. 5a : Cleaning the façade of the mausoleum / 5b : after cleaning / 5c : Junction between the two ensembles.

The first striking thing here is the very composite way this façade had come to us. The multiple restorations had certainly respected the general pattern of this mausoleum but we can see on **doc 5b** and on **doc 39** the diversity of the stone used. The Mausoleum as preserved nowadays is measuring 14,24m in its NW-NE section and over 7m in its N-S section. As we said earlier, it's a rather small module for a sultanian Mausoleum. But, the Test Pit has revealed that the Mausoleum was continuing toward south, where stands now the Mosque entrance. It's rather strange to see that here the Qibla is absolutely not respected, nore there is a mirhab inside the Mausoleum. The only other famous example of this lack of Mirhab is inside the small mausoleum of Umm al-Sultan Sha'ban. It demonstrates a peculiar approach of construction and the predominance of the external constrains over the religious one.

[6]- Lacoste (N.), 2004.



doc. 7 : al-Kujuk's Corbel, inside the mosque

doc. 6 : Close-up view of the junction

We can see on **doc 6** the junction between the Mausoleum and the Mosque. It clearly shows that the Mosque took the place of a continuing wall when **Emir Aqsunqur** decided to show his belonging to the sultanian family of **al-Nasir Muhammad** by including the sutanian tomb to his own funeral Mosque. Indeed it's a very deep symbolic act to try reaching sultanian level by construction, short after marrying al-Nasir's widow. Another clue also shows that this mausoleum had a different plan in 1341. Next to the actual entrance of the Mausoleum there is a *Kabouli* (corbel, cf **doc. 7**) following the precise orientation of the NE façade of the Mausoleum.

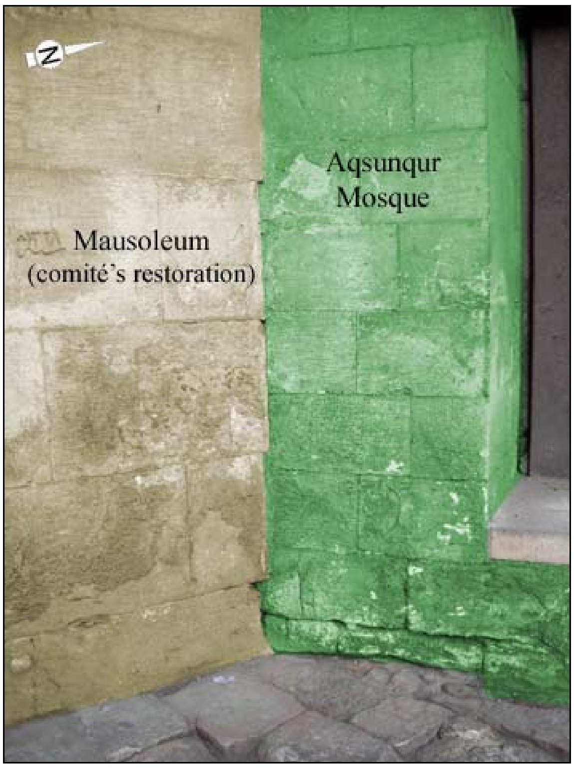
As we said, **TP1** revealed the marchs of the mamluk staircase (even if the upper part has been redone by the Comité, they reused the same stones so we'll refer here as a mamluk stairs access). On the following documents Each march is 16-18cm high, done in big squared sandstones. The staircase presents the typical two side entrances of the 14^{th} mamluk style, with little decorations and the stones being set against the façade and not linked to it.

doc. 8a : excavating in front of the stairs / 8b : TP1 after excavation (electric wires on the side).

This test-pit **TP1** has mainly provided us a global vision of the phases, showing that the Mausoleum clearly pre-dates the Mosque and that it was continuing toward south. We can wonder what kind of construction was in such a narrow space between two streets and a cemetery. Further excavations on the northern façade of the Mausoleum could enlight us a great deal about the former streets and the shape of the building in 1341.

doc. 9 : Test-Pit TP1 from above after excavation.

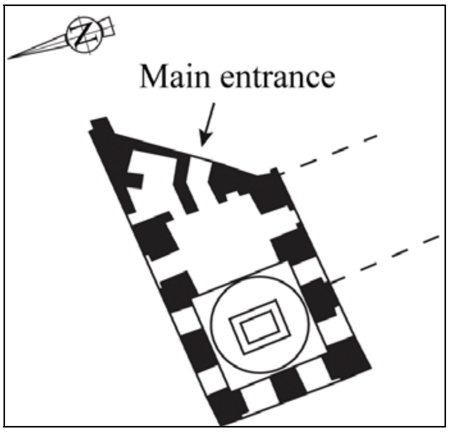
In test-pit **TP2**, we can clearly see the abutment of the Mosque against the Mausoleum (cf. **doc. 10a** & **10b**). We can also see the beginning of an arch in **doc 10a**, showing that this upper part of the Mausoleum has been retouched by the Amir Aqsunqur to install his vaulted roof (we'll see that has been rebuilt later on at Ottoman time). Eventhough this inner façade has been strongly restored by Comité, we still can see on doc 10b the way the stone courses are not respected between the two ensembles and the way the Mosque's wall abut the Mausoleum's one.



doc. 10a : General view of the junction between the Mausoleum and the Mosque / 10b : closer view.

It’s even clearer when you look at the foundations on **doc 11**. We can clearly see that the foundations of the Mosque **L TP2-6** are coming against the Mausoleum’s one. Eventhough the upper part of those foundations **L TP2-4** are Comité, the lower part are well dated from the mamluk period (cf ceramic page on **doc 43**).

To conclude this first overview of al-Kujuk’s Mausoleum, we can say that it’s small scale isn’t really significant. Indeed we might think that this funeral structure was somehow continuing to the south. Let’s point out also the position of this Mausoleum, right on the most important street for the mamluk ceremonial.

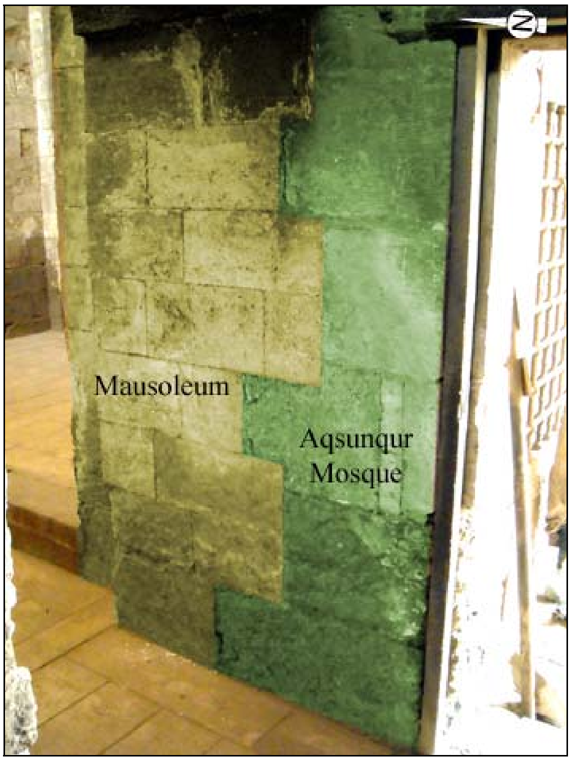


doc. 13 : First phase of the Mausoleum - 1341

Another thing should be pointed out. It seems that the actual entrance of the Mausoleum have been changed by Aqsunqur. Indeed on **doc 12** we can see the difference of stone courses between the inner part of the Mausoleum and the entrance itself, illustrating the opening of the window into a door. The plan **doc 13** illustrates where this former entrance must had been. The area of the former main entrance rises questions. Indeed, the angle it forms is really not in adequateness with the symmetrical necessity of such a place. Should we imagine that this whole triangle is a later addition from Aqsunqur or the entrance was due to be seen in this very angle (like a former street) ?

Anyhow, this is quite a small but remarkable mausoleum standing in sharia Bab el-Wazeer, the most important street leading to the Citadel. We can tell that this mausoleum has suffered a great deal from time and was therefore really strongly restored by the Comité. Though the shape still remain almost untouched. It would be interesting to know how many people are buried there and if the body of the child-Sultan has been differentiated from the rest of its dead brothers.


doc. 11 : TP2 - Foundations of the Mausoleum and of the Mosque.



doc. 12 : Adjustment of the Mausoleum SE window into a door

2- The Aqsunqur's Mosque - 1347 (747-48H)

It's now well known that Blue Mosque has been done by the same architect that did **Mosque Amir Altinbugha al-Maridani**[7]. The Emir Aqsunqur (or Ak-Sounkour el-Naseeri) was really found of architecture and, as we said in the historical context, is supposed to have supervised himself the construction. The Mosque's construction started on 16 Ramadan 747 (**31st December 1346**), and worship was first celebrated there on Friday 3 Rabi I 748 (**13th June 1347**)[8]. Since the beginning, Aqsunqur had decided that himself and his wife were to be buried there.

It presents the traditional hypostyle plan of the 14th century's cairene Mosques. I quote D. Behrens-Abouseif when she writes "*the interior presents a rather incoherent layout, as part of the arcades are carried by piers supporting cross-vaulted bays while others are carried on columns supporting a flat wooden ceiling.* […] *The piers supporting the cross-vaults remain unique in Egyptian medieval architecture, with no later imitations. The prayer niche is enhanced by a one-bay dome on plain squinches, an archaic feature in 1347, though the combination is also found in brick in the same mosque in Kujuk's mausoleum. The stone version is seen at the mausoleum domes of Umm al-Sultan Sha'ban and the two domes of Tankizbugha (1359 and 1362).*"[9]

So, we are confronted here to a Mosque that presents unique, strange and somehow old-fashioned ways of construction for the time. Could the Syrian background of Aqsunqur explain it all ? As this mosque has been quite well studied in term of architectural point of view (Behrens-Abouseif, 1989, included as an appended at the end) we won't paraphrase her by describing the general stylistic approach and focuse more on the few conclusions gathered archaeologically.

---

[7] - Behrens-Abouseif, 1989, p. 115.
[8]- BCCMA, 1884, p.9.
[9] - Behrens-Abouseif, *op. cit*.

Test-pit **TP2** really bring a great deal of data. On **doc 14** we can see the bad state of conservation of the Comité's pavement **L TP2.3** where we decided to implemznt the Test-Pit TP2. This particular place had the mix interest of being situated at the junction between the Mausoleum with the Mosque. It's also showing us the pavement itself. Made of squared eroded limestone blocks, the pavement is clearly a Comité's reconstruction. On **doc 16** we can see at the bottom the red compact homogeneous layer quite typical of the Comité's work.

Pictures **doc 16** and **doc 17** illustrates the stratigraphy inside the Mosque. It shows a 45 cm high brownish looth sediment recovered by 52cm of sandy compact layer.

doc. 17 : TP2 : Eastern stratigraphical section

TP2 was the richest test-pit in term of ceramic found. We gathered the object The only mamluk ceramics founds inside the Mosque were found in this brownish layer **L TP2.6**. It consists mostly in simple forms, glazed and nicely done bowls (cf **doc 18**). There is no inclusion of late manufactured ceramics in TP2.6, which proves that this lower part of the corner really is from the 14th century.

doc. 18 : Blue Mosque - TP2 : ceramic found in Layer TP2.6

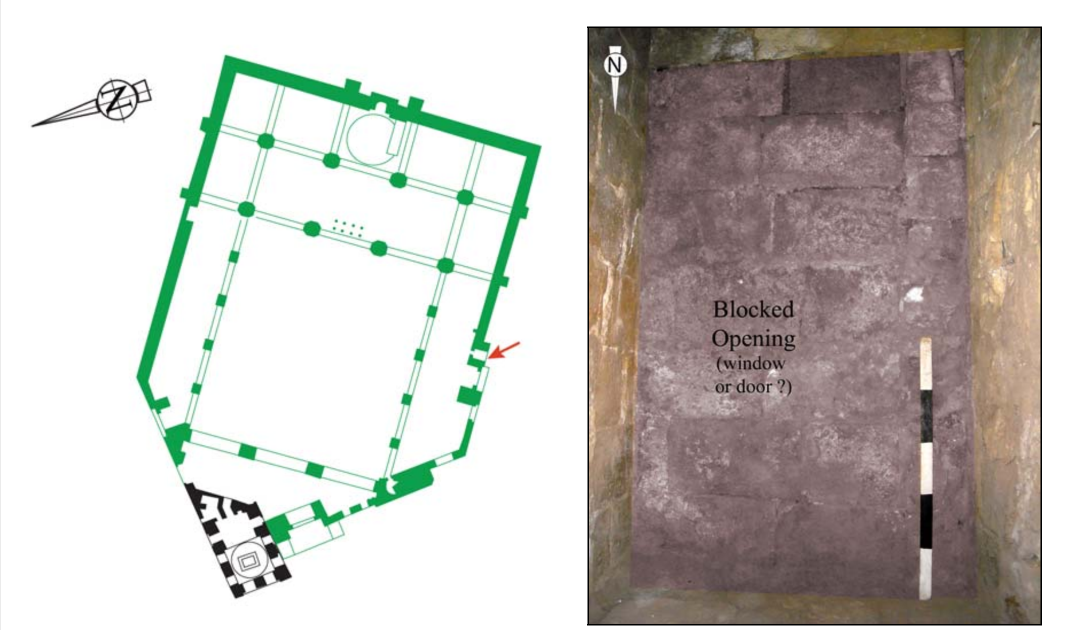
There is some interesting aspects of the mamluk period that should be underline. Let's start with a blocked entrance, just behind the so-called Aqsunqur Mausoleum (we'll see later that it's more an Ottoman mausoleum).

doc. 14 : TP2 : Pavement after its cleaning

doc. 15 : TP2 : Dismantling the pavement

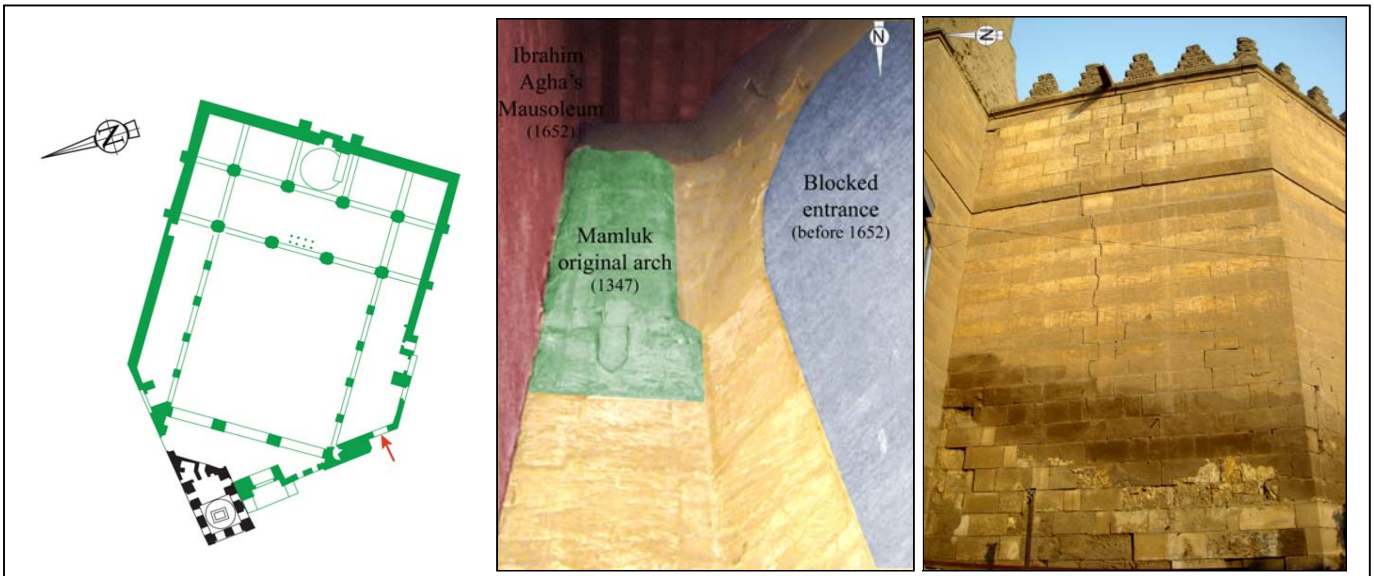
doc. 16 : TP2 : southern stratigraphy

On **doc 19** one can see the difference of stone courses in this small room at south-east of the southern entrance. The blockage is rather well done and correspond quite clearly to the addition of the adjacent Ottoman **houses 25** and **27**. Still the place itself could really correspond to the sabil that has been included to the 1347's project and that we have lost since. But, considering the lintel itself, it could also be a simple window next to the entrance.



doc. 19 : Blue Mosque : blocked opening near the southern entrance

Another really interesting aspect is this huge arched door, blocked between 1347 and 1652. On doc 20 we can clearly see the different phases of this structure. The arch is quite monumental, though not really decored from inside. The relative chronology indicates that the blockage has been done before the addition of Ibrahim Agha's Mausoleum. From outside the façade's restoration have destroyed any possible remaining traces of this opening. This, by the way, illustrates perfectly the type of construction at mamluk period : two facing walls filled with rumble stone and mortar, allowing to adjust structurally the inner and outer constrains. Should we see here a fourth unknown entrance or something else ? The size and quality of the opening could indicate an entrance toward the street but this should be verified.



doc. 20 : Blue Mosque : Blocked entrance, views from inside and outside

Until now, we knew that the wooden roofs are Ottoman. With test-pit **TP5** we can add something to the understanding of the mamluk mosque. We were trying to find here the eventual traces of a former mamluk pillar (cf. **doc 21**). Indeed, if we observe carefully the pillars of the courtyard we can see that some of them aren't aligned with the four big corners ones. There is clearly a difference of position. Let's add that the four corner's pillars have traces of the former mamluk arches and that the other don't even show the stone hatching of destruction (cf. **doc 23**).

doc. 21 : Test-pit TP5 : Former pillar foundations

Considering the size of the foundations on **doc 21** and **42**, we can tell that the pillar there were much bigger than the actual ones. They were also slightly to the south, aligned with the qibla ones. The ceramic found in **TP5** is clearly Ottoman, which corresponds with the general understanding we had of the place. To summarize, this particular test-pit shows that the pillars were bigger and aligned both with the corner and with the mirhab ones. Probably not shaped like a palm-tree but squared, decorated in *ablak* and massive.

To finish this overview of the 1347's Blue Mosque, let's focus on the *qibla* space. The **doc 22** shows the former mamluk pillars, the unusual palm tree shape of the eastern ones, the cross-vaulted arches in the foreground and the Ottoman wooden roof in the first plan. It shows a rather sober mosque, the acme being put only when reaching the qibla itself. Compared with a lot of other mamluk mosques, Aqsunqur inner mosque must had looked almost 'humble'.

doc. 23 : Traces of the original mamluk arches

Of course the accent was more on the outside, by its position in the city (you had to see it going to the citadel) and by its four levels minaret. But on the inside, eventhough it has been really destroyed since 1347, we can still feel the sobriety in which the Amir has build his mosque. We could also point out the lack of money that had made him choose poor quality stones and prevented him to maintain correctly this place. The loss of the Syrian *hikr* participated to the deterioration of the Blue Mosque.

3- The Sahn of the Mosque - 1412 (815H)

In 1412, the **Emir Tughan ad-Dawadar** started the construction of a fountain in the centre of the mosque. It was surrounded by marble columns supporting a small roof. The columns are supposed to come from **El-Khandak Mosque**, so did the water[10]. Test-pit **TP4** was performed to check this integration and also to verify if any trace of the former mamluk pavement could be found.


doc. 24 : View of the actual courtyard

[10] - Creswell, 1919, p.102-104.

We know from the Comité that the interior was later on reorganised as a madrasa (**Madrasseh-el-Aksounkourieh**). “The interior has been rebuilt with numerous squared rooms allocated to the Gamalieh school. The inner pavement level is increased over a meter[11].” Level that the Comité has later on lowered from a meter, which explains the fact that we found Comité’s red layer under the pavement. Test-pit **TP3** was performed at the south of the stone octagonal basin. We removed the 1992 pavement over 35cm to reach the Comité’s one (cf **doc 25**). Next to the basin we have found some small bricks (4 / 8-10 cm) surrounding an hole. The actual octagonal fountain is preserved over two stones courses, one of them being clearly recent (1992). All this together might indicate either a wish of the Comité to restore a fountain has they imagine it should be or real traces of an old fountain. Only a complete excavation of the basin would clarify the situation but we can still indicate that it’s rather odd to find such a fountain in the middle of the Sahn and that the original ablutions area probably stood outside the boundary of the mosque itself.

doc. 25 : Test-pit TP3, 1992 & Comité’s pavement

doc. 26 : Test-pit TP4, marble basin

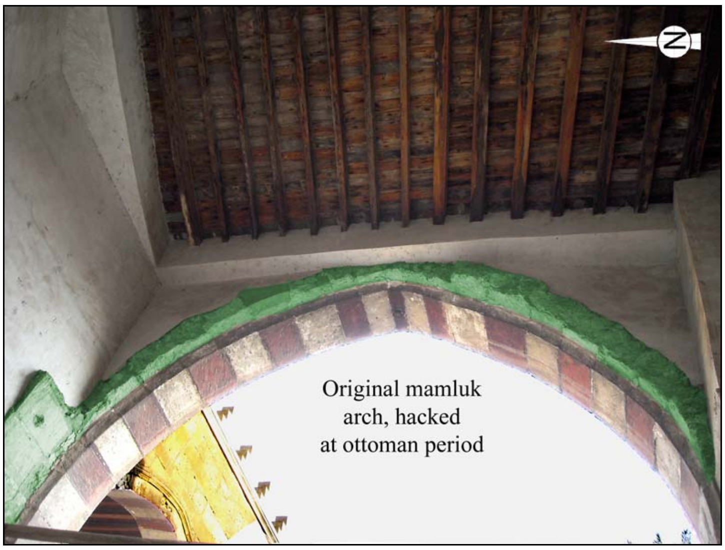
The other attempt to understand the inner organisation of the sahn was done in **TP 4** around a grey marble basin, situated to the east of the octagonal fountain. We thought that this basin could be on a genuine mamluk soil. In fact, has shown in **doc 41**, we found out that this basin is laying in the middle of a recent 94cm high looth layer (**L TP4.3**). No connections were found with any organised layer or even circulation/utilisation layer. We are convinced that this basin has been put there by the Comité, as a symbolic act may be. The only interesting part of this test-pit was Layer **L TP4.4**, a compact red-yellow heterogeneous layer situated at the bottom of the test-pit, 112cm below the actual level. Some fragments of ceramic were appearing and this is surely the remaining soil of the mamluk occupation. Unfortunatly, the test-pit was too narrow to allow going down more than this.

[11] - BCCMA, 1891, p. 43.

4- Ibrahim Agha's re-use of the Mosque - 1652 (1062H)

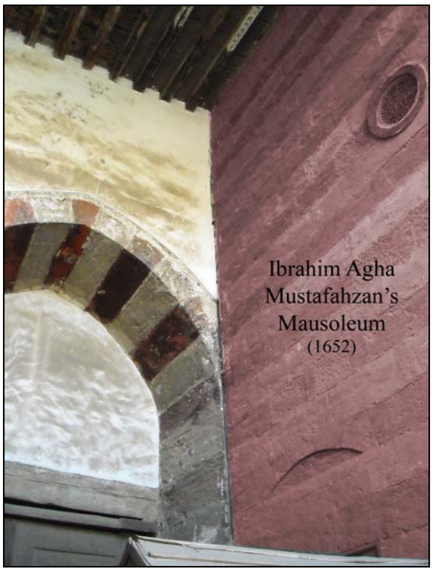
As we said earlier, the Emir Ibrahim Agha was a really rich an important actor of the urbanisation of this neighbourhood (on the previous phase plan you can see in red the major constructions in made in the area). In a strange way, Ibrahim Agha had deeply restored this mosque but with a lot of respect for the pre-existing pattern and style. At the Ottoman period many sponsors of religious foundations restored old mosques that had fallen into decay or built upon their foundations and walls, rather than building new ones. Such mosques then acquired the name of the restorer, and this mosque, after restoration, was sometimes called the mosque of Ibrahim Agha. He already had built a place for its mausoleum, in front of **Umm al Sultan Sha'ban Mosque**.

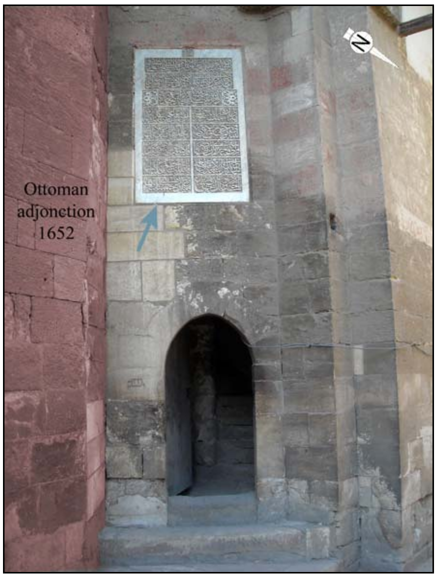
A thing has always intrigued the observators of the Blue Mosque. The fact that some roofing are stones cross-vaulted bays and that some other are made of wood. In 1652 **Amir Ibrahim Agha Mustahfizan** made important structural restorations to the arcades and to the roof. We can see both on **doc 23** and **27** the traces of stone cutting that have preceded the installation of the wooden roof.



doc. 27 : Hacked mamluk stone arch and Ottoman wooden roof

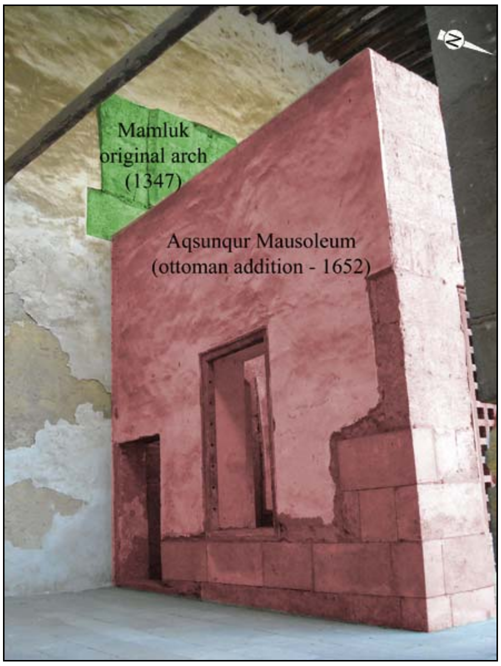
To be honest, it’s more than likely that the poor quality of the job done by the Aqsunqur maçons must had lead directly to the very destructed state of the roofs, reason for which Ibrahim Agha had redone only a part of arcade roof and tried to keep as much of the old system as he could. Ibrahim Agha also built for himself and his wife a mausoleum in the southern arcade of the mosque. It’s covered with marble in Mamluk and present also in its lower part the blue tiles decoration. Here again, there is something quite strange about the prayer niche. It’s really looking like a typical Bahri Mamluk marble one and we still wonder why Amir Ibrahim Agha pushed that far the symbiosis with the mamluk style and still added this blue tiles. One thing is certain : with relative chronology, we are able to tell that his mausoleum has been built way after the rest of the mosque. The two pictures of **doc 28** show this late addition, also visible in the general shape of the mosque.





doc. 28a : Ibrahim’s mausoleum against the mosque eastern part / 28b : western part, against the minaret entrance

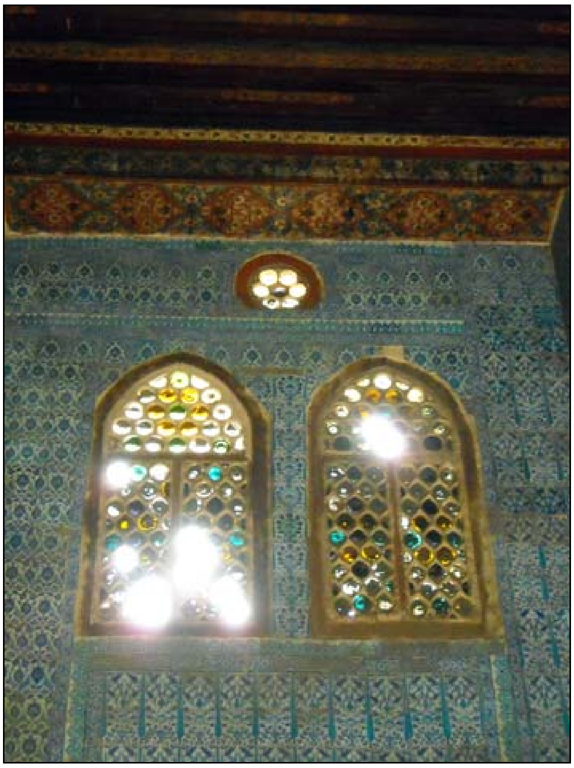
Next to the southern entrance, under the arcade, we can see what is referred as Aqsunqur Mausoleum. We can clearly establish that this is more an Ottoman cenotaph referring symbolically to the Amir Aqsunqur than the real tomb. First of all, on **doc 29a** we can see the persistence of the beginning of the mamluk arch, just under the so-called mamluk mausoleum. More over, the stone courses aren’t linked and don’t even correspond. Let’s add that the very poor quality of the structure really plead for a later construction. Aqsunqur would never had built such a poor thing for his final place.



doc. 29a : Aqsunqur’s mausoleum against the mosque / 29b : Closer view of the relation between the mosque & the mausoleum

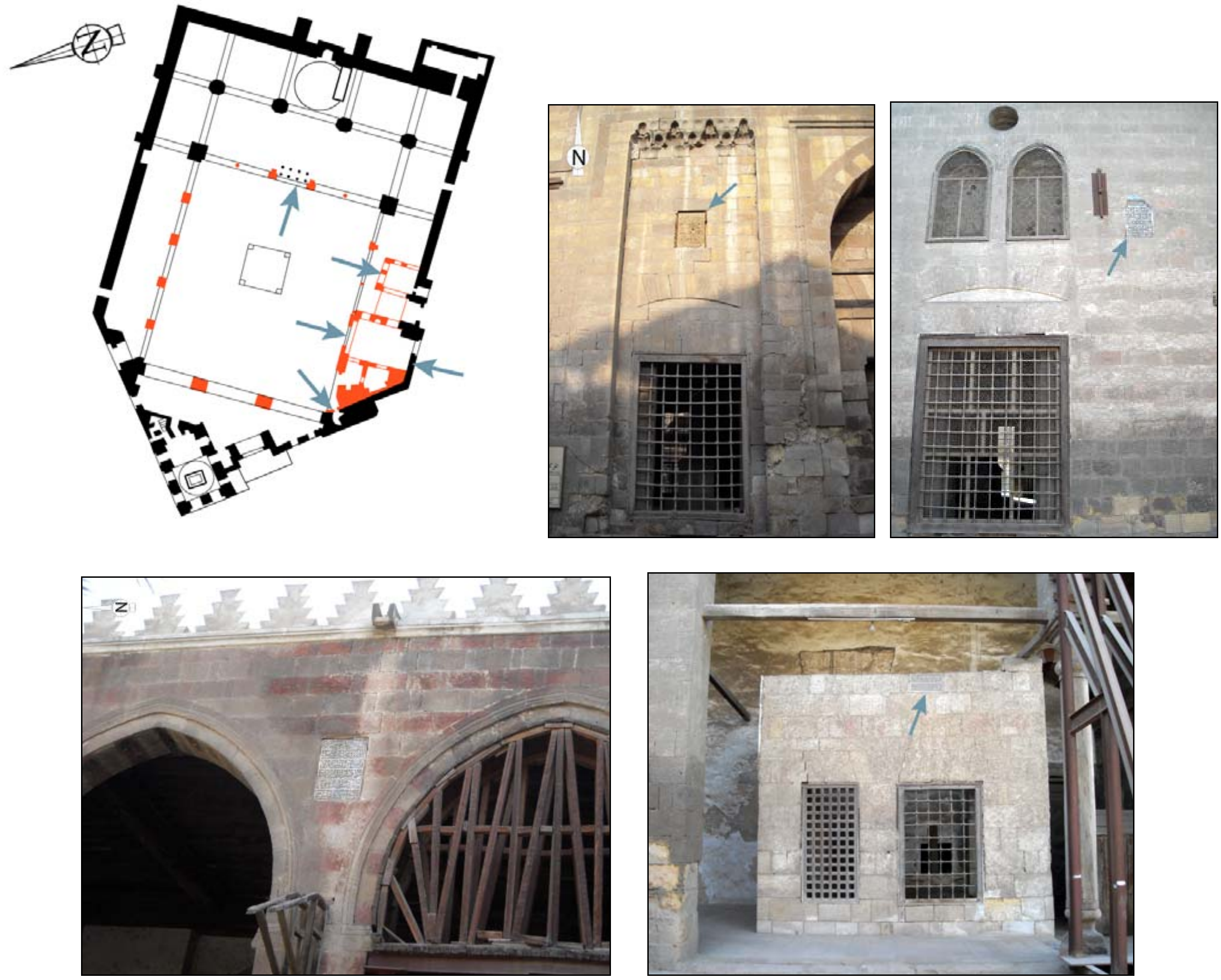
Of course, the Blue Mosque received its name after the blue tiles covering the qibla and Ibrahim Agha's mausoleum. The tiles are supposed to be seventeenth-century Turkish Iznik style, coming from his home own village. A deeper study should clarify both the provenance and the phases. One thing is sure : Cairo craftsmen were not quite familiar with the art of tile panelling and the tiles are not really well applied to the walls. On **doc 30** we can see that the blue tiles have recovered a discharging arch on the qibla wall but still let blank a small shelter under the windows. Always this desire of not overchanging the place. Inside the mosque, only the qibla wall is covered, in its lower part. The richest place in term of tiles is of course the mausoleum itself (cf **doc 31**) showing great windows, tiles up to a nicely polychromic wooden roof.

doc. 30 : Qibla wall, blue tiles near the mirhab



doc. 31 : Ibrahim Agha's mausoleum, blue tiles and decored roof

Another detail shows the attribution of the mosque by this rich Ottoman Emir. He installed some plaster inscriptions panels on several highly symbolic and important spots. There style is similar in any point (even when on the one over the so-called Aqsunqur mausoleum) and illustrates which places meant more to Ibrahim Agha. Strangely, most of the inscriptions can be found on the inside and follow the restoration of the arcade. You can see them over Agha's mausoleum, over minaret entrance and even one at the middle of the arcade's façade (cf **doc 32**). In my opinion this shows the part restored or built by the new owner of the Blue Mosque. He respected the place and its old style but had let enough clues for everyone to understand fully who is the new beneficient of the place.



doc. 32 : Ottoman period : examples of Ibrahim Agha's inscriptions (the blue arrows indicate the positions)

5- Comité's restoration - 1888/1924

As always, the Comité has done a huge work over the Blue Mosque, both in documentation and in restoration. Reading the *Bulletin du Comité de Conservation des Monuments Arabes*, journal in which they were expressing their goals and achievements, two things strike us. First of all, the extent of the job done. They really took this monument in its globality, thinking both in structural and stylistical terms, restoring it from head to toe (I should say from minaret to the surrounding street). It took them 40 years to pass from a destroyed shell used as a school and housing project to the idea of what must had been the Blue Mosque few centuries ago. The second striking aspect is the very bad condition the mosque was and therefore the extent of the stone replacement done by the Comité. If the general pattern is preserved, few original stones are still in place.

Let's start by a chronological approach of the Comité's restoration. 1891 was a really dense year in term of work done over the Blue Mosque. We saw that the pavement is Comité, which is confirmed by the fact that they destroyed the inner partitions of the madrasa and lowered the courtyard level over a meter. They also reopened a door, either to the south or on the street. Like I said, 1891 was a great starting point for the Blue Mosque as the Comité started to plan the reconstruction of the minaret, then in really bad condition. Unfortunately, instead of re-do it with its full four storeys, which is an almost unique characteristic in mamluk Cairo, they did it on a common plan of three stories and a general bulb. "*The tall circular minaret* […] *was frequently illustrated by nineteenth-century artists and photographers. In three of this illustrations, we see a remarkable feature that characterized this minaret before it was restored – it originally had four, not three stories.* "[12].

doc. 33 : 19th century picture of Sharia Darb el-Ahmar, wooden roof in front of the Blue Mosque

On the previous picture **doc 33** we can see in the foreground the wooden roof covering the street, in front of the Blue Mosque. It's also in 1891 that they planed to dismantle it for being 'modern'. Finally, this same year the Comité started to empty completely the earth in the arcades and the mausoleums. According to them, in some places, the earth was almost reaching the top of the walls (at the bottom of the Dome for instance). This 1891 Bulletin of BCCMA gives us a last interesting clue. It's written that they re-opened the abandoned room south to the Dome.

[12] - Behrens-Abouseif, 1989, *op. cit.*

On **doc 34** we can see that this room as been built after the mamluk period, the hacking of the stones and the differences of stones courses make no doubt about it. Then it raises the question of the construction date for this room. We might think of an Ottoman addition but it still has to be proven.

doc. 34 : South-east room next to the qibla wall, later addition to the mosque

At the beginning of the 20th century the work was going on quite quickly, mainly on structural bases. In 1901 they finished the restoration of the minbar and the mirhab (**doc 35**). In 1904 it's the whole south-west angle that is redone, which corresponds to the space of the blocked entrance in **doc 20**. They also destroyed all the houses and shops that were built against the mosque and were slowly destroying it, mostly against al-Kujuk's mausoleum. All this lead to 1907, when all the façades restorations were finished and, I quote "*The pavement was almost entirely finished and the unattractive construction of the well has been removed*". This explains the strange organisation of the soil in test-pit **TP4**. Let's add that the mausoleum has been consolidated (eventhough they don't precise which mausoleum, we can think of al-Kujuk's one, for structural reasons the weakest).

doc. 35 : end 20th century picture of the qibla wall


doc. 36 : Test-pit TP2 : eastern wall of al-Kujuk's mausoleum

In 1908 the Comité ordered the resealing of some tiles inside Ibrahim Agha's mausoleum. They also replastered the mamluk roofs, al-Kujuk's mausoleum and the arcades. They have most of the eastern wall of this child sultan's tomb (**doc 36**). In the 1920's they built buttresses in the middle of the outer part of the qibla and cleaned the picturesque cemetery heading north of the mosque, buttresses you can see on this Creswell old picture of the Blue Mosque taken at the end of Comité's work (**doc 37**).


doc. 37 : middle of 20th century picture of the Blue Mosque after Comité's restoration (cl. Creswell)

6- Test-Pit TP6 : north-east corner of the Blue Mosque

To fully evaluate the archaeological potential of Alin Aq' courtyard, we performed a small test-pit along the south-eastern blue mosque's corner. This 2m/5m test-pit was rich in findings. After only 1m of modern fulfilments appeared two different structures built against the foundations of the the Blue Mosque (**doc 38**).

doc. 38: Alin Aq' courtyard - Test-pit TP6 against the Blue Mosque.

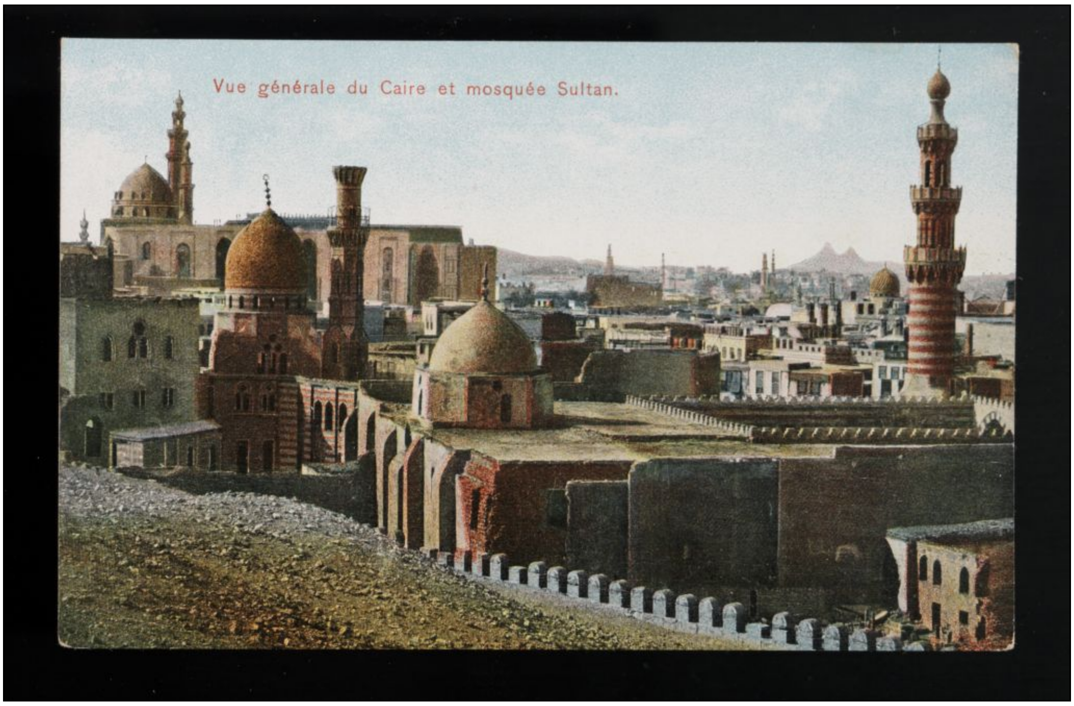
Even though this 'archaeological window' was quite narrow, this test-pit had brought us to some quite interesting conclusions. First of all, we can notice the peculiar form of the structures found there and their level of apparition. Those two structures are clearly built against the **Blue Mosque** and therefore are built later. All the material found in this test-pit is really modern (including plastic bags) that can't really inform us on the date of construction of those structures.

- The first structure is forming a square 90° angle with the mosque. It's made of an outer part built with 26 cm high limestone squared blocks, quite thin (18 cm) and not really well assembled. The inner blockage is made of rubble stones and earth (the less expansive way of building a platform). It's real use is still unknown.
- The second structure is stranger. It's forming a 30° angle with the mosque's façade and is built in the same 'cheap' way than the other one. The stone courses are also 26cm high but they don't really correspond with the one of mosque or even with the other structure, which could indicate a difference of construction's period. The specificity of this structure is to have some pavement still preserved, indicating the upper level of circulation. There again, we can't specify the use of this construction but the way it's built really reminds us of all the other mausoleums found in the area. Moreover, it does not correspond at all with the level of circulation of **Khayr Bek** but completely fit the 19^{th} century levels of the other mausoleums in **Zone 2** of Alin Aq courtyard (in front of the **Zaouia**).

All this would drive us to date those structure from the 19^{th} century, before the restoration of the **Blue Mosque** by the Comité (1904) that has destroyed the upper levels of the constructions (we can see two preserved stone courses of the mamluk mosque at the bottom of the wall and then the complete reconstruction of the small SE room on its upper levels).

Conclusion

1347. We're facing one of the last buildings established before the huge breakdown of 1348. Indeed, the big Plague of 1348 will durably strike deeply Egypt and Europe. It will start the decline of Cairo for a century or so. The neighbourhood of birkat is highly symbolic and linked to the power. According to Maqrīzī, in the 14th century the number and localisation of the *Khutbas*[13] show a great dispersion of the housing settlement. But we can tell with this Mosque that a pre-existing street of great importance constrained the construction of an emiral Mosque. Therefore, we are hereby touching the principles of the urbanisation of mamluk Cairo. This urbanistic fossil that is the Blue Mosque shows that each actor of its history, rich and powerful enough to change it, on contrary always kept in mind the necessity to preserve its general pattern. This is a moving testimony of a revolved past that is now under restoration for another layer of fine integration to its environment. We are confronted to the remains of a monument that has always mixed evolution and preserving the general pattern of the place.



There is a lot of aspects that make this mosque quite unique. The place itself, as we already pointed out, makes it special. The proximity of the Citadel, the fact that Aqsunqur was a son-in-law of al-Nasir, that he choose to integrate a former sultanian mausoleum to his mosque, all this express the political approach of this construction. The second interesting aspect is that there is a lot of unusual esthetical characteristics for a 14th century cairene mosque. The first one being the irregularity of the ground plan, due to the presence of al-Kujuk's mausoleum on the street side. Let's add that this mausoleum is not Mecca-Oriented, which is also unusual. It has been built to follow the street alignment, as a symbol of the victory of external symbolic constrains over the religious necessities. We could also add the palm-tree style of the arcade pillars, quite old-fashioned when they were built. Or the four stories minaret, one of the two known examples in Cairo. The presence of three different mausoleums, belonging to the three most important actors of this building also add to its oddness. For me, on of the most interesting part is the way all thos characteristic and different periods of existence mix together and respect the general plan founded in the middle of the 14th century. This mosque would require a much longer archaeological study to be fully understood, we only are giving here the first observations to guide the ongoing restoration.

[13] - in his *Kitab al-mawaiz wa l-i tibar fi dhikr al-khitat wa-l-athar* he counted 129 *gami'* built during this period.

Bibliography

- Antonious (J.), *Historical Cairo*, Cairo : American University in Cairo Press, 1988.
- Ayalon (D.), *Le phénomène mamelouk dans l'Orient islamique*, Paris : PUF, 1996, 168 p.
- Behrens-Abouseif (D.), *Islamic architecture in Cairo*, New York : E.J. Brill edition, 1992.
- Behrens-Abouseif (D.), Dunoix (S.), Garcin (J.-C.) dir., « Le Caire », pp. 177-203, in Garcin J.-C. (dir.), *Grandes villes méditerranéennes du Monde musulman médiéval*, Rome : Ecole Française de Rome, n° 269, 2000, 323 p.
- Brown (J.), *Glossary of Islamic art and architectural terms*, American University in Cairo Press, 1990.
- Creswell (Keppel A.C.), « A brief chronology of the Muhammadan monuments of Egypt to A.D. 1517 », *BIFAO* n° 16, 1919, p.102-104.
- Garcin (J.-C.) et alii, *Palais et Maisons du Caire, T. 1 : Epoque Mamelouke*, Paris : ed. du CNRS, 1982, pp. 49-177.
- Garcin (J.-C.) et alii, *Grandes villes méditerranéennes du Monde musulman médiéval*, Rome : Ecole Française de Rome, n° 269, 2000, 323 p.
- Lacoste (N.), *Alin Aq' Palace, archaeological survey report*, Aga Khan Egypt report, 2008, 46 p.
- Lacoste (N.), *Madrasa of Umm al Sultan Sha'ban,* Archaeological survey report, Aga Khan, Cairo, 2004.
- Lézine (A.), 1972, « Les salles nobles des palais mamelouks », Le Caire : *Annales Islamologiques*, T. X, pp. 63-149.
- *L'Art Mamelouk, splendeur et magie des Sultans*, Aix en Provence : Edisud, p. 123, 2001.
- Massignon (L.), « La Cité des morts au Caire (Qarāfa - Darb al-Ahmar) », *BIFAO* n° 57, 1958, p. 25-79.
- Organization of islamic capitals and cities Center, *Principles of architectural design and urban planning during different islamic eras*, 1992, 667 p.
- Raymond (A.), *Le Caire*, Fayard, 1993, 428 p.
- Revault (J.), 1979, « Habitations citadines du Caire et de Tunis », Le Caire : *Annales Islamologiques*, T. XV, pp. 293-312.
- Shalaby (N.), *Khayer Bek excavations report: Alin Aq Palace*, August 2005, Aga Khan, 8 p.
- Warner (N.), *The Monuments of Historic Cairo, a map and descriptive catalogue*, Cairo : AUC, 2005, 251 p.

Internet Resources

- **Ancient Medieval Cairo**: http://touregypt.net/cairoislamic.htm
- Australian National University : **Photo database of islamic monuments in Cairo** http://rubens.anu.edu.au/cairo/
- Boston M.I.T. **ARCHNET Database on islamic architecture** http://archnet.org/library/
- **Center for conservation & preservation of Islamic architectural heritage** http://www.ciah.biz/
- Chicago University **Mamluk On line Bibliography** http://mamluk.uchicago.edu/
- Chicago University **Mamluk Studies Review** http://www.lib.uchicago.edu/e/su/mideast/MSR.html
- **Dictionary of French architecture from the 11th-16th century by Eugène Viollet-le-Duc** (one of the greatest source in regard to historical architecture) : http://en.wikisource.org/wiki/Dictionary_of_French_Architecture_from_the_11th_to_16th_Century
- Toledo University Department of Geology : **Survey of ornamental stones in mosques and other islamic buildings of the pre-Ottoman period in Cairo, Egypt** http://www.eeescience.utoledo.edu/Faculty/Harrell/Egypt/Mosques/Survey_Intro.htm

Appended

Creswell, 1919, p.102-104.

747-748 1346-1347 MOSQUE OF THE EMÎR AQSUNQUR, also known as the Blue Mosque and the Mosque of Ibrahîm Aghâ (No. 123 on Plan). — According to two inscriptions, one above the north-eastern, and the other above the south-western entrance, this mosque was commenced 16 Ramaḍân 747 (31st December 1346), and worship was first celebrated there on Friday 3 Rabî' I 748 (13th June 1347). In 815 H. (1412-1413) the Emîr Ṭughân ad-Dawâdâr constructed, in the middle of the mosque, a basin surrounded by marble columns supporting a roof. These columns were taken from the Mosque of al-Khandaq. The mosque was restored, and largely rebuilt as far as the interior was concerned, by Ibrahîm Aghâ in 1062 H. (1652), and the fact is recorded by three inscriptions, one above a window to the west of the south-western entrance, one above the outer central arch of the east lîwân, and a third to the left of the miḥrâb just above the dado of blue tiles. The tomb of Ibrahim Aghâ is dated 1062 H. also, by an inscription on a small slab of marble on the wall facing the *ṣaḥn*. From an examination of the building I would divide it into two periods. The whole exterior I believe to be original, with the exception of the east end of the north side, which I attribute to the Turkish period, especially the doorway, and I think the slab with inscription dated 747 H. over the door must merely have been rescued during a restoration and embedded in its present position. The architecture of the door is distinctly inferior, and it is not surrounded with a moulded frame like the other two. The interior appears to have consisted originally of arcades, two deep on the east side and one deep elsewhere, composed, as the inner arcade of the sanctuary still is, of thick squat piers carrying transverse arches and intersecting vaults. The original north and south arcades and the outer arcades of the sanctuary have fallen, but the remains of the springing of intersecting vaults are still visible on the north and south walls, and at the north end of the west arcade also. From these remains it is clear that the sides of the *ṣaḥn* were originally bounded by arches as follows : east side, 3; west, 3; north, 4; south, 4. Ibrahîm Aghâ, instead of rebuilding the fallen portions in their original form, replaced them by lighter arcades carrying a flat timber roof, resting on piers on the north side, and on columns and piers on the east and south. He did not even follow the original spacing, the present number of arches being as follows : east, 5; north, 5; south, 3. These latter only occupy half the south side, the remaining space being occupied by his mausoleum, which has a flat timber roof level with the rest of the building. There are three bays on the west side which remain nearly in their original state, except that the centre and north bays now have a flat timber roof; remains, however, of the springing of an intersecting vault may still be seen in each of the four corners of the north bay. The dome over the space in front of the miḥrâb presents novel features, resting as it does on a high octagonal drum composed internally of simple squinches alternating with double lights. This I attribute to the original building also, as a similar arrangement is found in the Mosque-Mausoleum of the Emîr Tankizbughâ, 764 H. (1362), and in the two mausoleums of Sultan Sha'bân's Madrassa, 770 H. (1368-1369). At the north-west corner of this mosque is the tomb of Sultan al-Malik al-Ashraf Kujuk, who was strangled in 746 H. There is an inscription on the west façade which contains this date, but as he is referred to in terms which show that he was no longer living, it follows that this mausoleum was constructed after his death, and there is little doubt that it was built at the same time as the mosque under discussion, of which it forms an integral part.

See *C. I. A.*, pp. 197-198 and 200-206; and *C. R.*, 1884, p. 9.

blue and white faience mosaics The ablution fountain in the courtyard is not part of the original mosque

On the northern wall of the sanctuary is an inscription panel of white marble carved and inlaid with green gypsum-like paste

Bibliography

ʿAbd al-Wahhāb *Masājid*, pp 147 ff

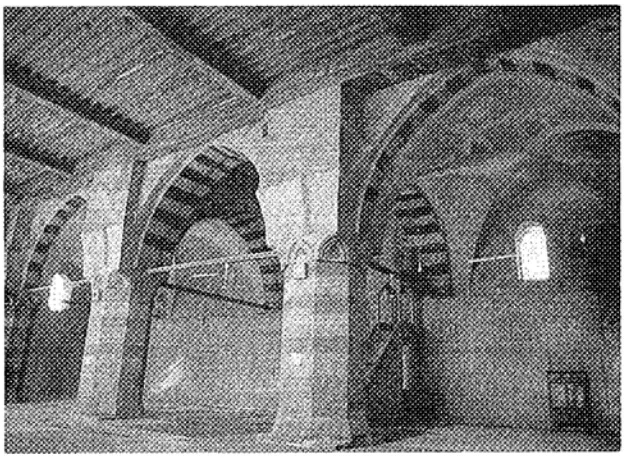
Maqrīzī *Khiṭaṭ*, II, p 308

THE MOSQUE OF AMIR AQSUNQUR (1347)

The mosque built by Amir Aqsunqur, a son-in-law of Sultan al-Nāṣir Muhammad, and the husband of his widow, stands in the Tabbāna quarter between Bāb Zuwayla and the Citadel It has a hypostyle plan like the mosque of Amir Alṭinbughā al-Māridānī, though it differs in many other respects.

Because it is situated on a thoroughfare, the mosque has a ground plan that is not quite regular It has three entrances, the main one opening onto the western arcade opposite the sanctuary, and two side entrances, one into the southern arcade and the other at the corner between the northern and western arcades

The primary irregularity of the ground plan is the presence of a mausoleum dome on the street side that predates the foundation of the mosque and which was incorporated into its masonry The mausoleum is not Mecca-oriented, which is unusual in Cairo mausoleums; instead it follows the street alignment



Pl 82 The sanctuary of the mosque of Amir Aqsunkur.

When integrated with the mosque, the western arcade acquired a triangular shape to cope on one side with the street alignment and to be parallel on the other side to the Mecca-oriented sanctuary Thus, the entrance bay is set askew to the rest of the mosque, as it is at al-Aqmar

The Exterior

The tall circular minaret at the southwestern corner of the mosque is visible to the passerby coming down from the Citadel long before he reaches the door of the mosque This minaret, because of its location in relation to the winding street and other buildings, was frequently illustrated by nineteenth-century artists and photographers In three of these illustrations, we see a remarkable feature that characterized this minaret before it was restored—it originally had four, not three, stories Unfortunately, when the minaret was restored at the beginning of this century, the third floor was not rebuilt, and it has thus lost its uncommon feature The first story is circular and plain, the second circular and ribbed, the third was octagonal, and the fourth is composed of the usual pavilion of eight columns supporting a bulb like the top of al-Māridānī's minaret The minaret is remarkable in its elegance and in being one of the few Mamluk minarets with a circular shaft

The main portal is composed of a large pointed arch with corbels at the springing of the arch. The mausoleum on the north side of the portal has two facades on the street

This mausoleum contains the graves of several sons of Sultan al-Nāṣir Muḥammad We know that the first deceased son died in 1341 so the mosque must already have been standing at that time The mausoleum was known, however, by the name of Sultan ʿAlāʾ al-Dīn Kujuk, another son of al-Nāṣir Muḥammad, who ruled a brief time between 1341 and 1342 He was first buried elsewhere and then brought to this mausoleum two decades later, during the rule of his brother Sultan Ḥasan. Aqsunqur, himself related by marriage to the Qalāwūn family, incorporated the mausoleum into his own mosque and built a mausoleum for himself next to it where he and his son are buried A sabīl and a kuttāb have completely disappeared

The Interior

The interior presents a rather incoherent layout, as part of the arcades are carried by piers supporting cross-vaulted bays while others are carried on columns supporting a flat wooden ceiling. Originally, the mosque must have been built only on piers supporting cross-vaulted bays. Meinecke identifies this feature as Syrian Aqsunqur had been governor of Tripoli in Syria and Maqrīzī writes that he supervised the construction of the mosque himself, even to carrying materials along with the masons. The piers supporting the cross-vaults remain unique in Egyptian medieval architecture, with no later imitations. The prayer niche is enhanced by a one-bay dome on plain squinches, an archaic feature in 1347, though the combination is also found in brick in the same mosque in Kujuk's mausoleum The stone version is seen at the mausoleum domes of Umm al-Sulṭān Shaʾbān and the two domes of Tankizbughā (1359 and 1362) The prayer niche is quite remarkable with its carved white marble conch that was originally painted The lower part is paneled with polychrome marble. The pulpit is one of the few marble ones and is a masterpiece, decorated with carved bands and on both sides with large patterns inlaid with colored stones. The pulpit door's stalactites and the bulb on four columns at the top are all carved in marble

The *dikka* facing the courtyard from the sanctuary has Western style capitals that may be Crusader trophies The mosque was in poor condition by the early fifteenth century, since its endowments in Syria had by then been lost An amir added an ablution fountain in the center of the courtyard in 1412 but because of lack of funds, the mosque was used only on Fridays and special occasions

Amir Aqsunqur's masons, apparently not familiar with the vaulting system applied in the mosque's architecture, must have done a poor job of building them, for in 1652 the Amir Ibrāhīm Aghā Mustaḥfiẓān made important structural restorations of the arcades and the roof, using columns to support the southern arcaded hall At the same time, he redecorated the sanctuary with the tiles that have given the mosque its modern touristic name, "the Blue Mosque"

In the Ottoman period many sponsors of religious foundations restored old mosques that had fallen into decay or built upon their foundations and walls, rather than building new ones Such mosques then acquired the name of the restorer, and this mosque, after restoration, was sometimes called the mosque of Ibrāhīm Aghā

The tiles are of seventeenth-century Turkish Iznik style They are blue and green with typically Ottoman floral motifs, such as vases with carnations and tulips, and cypress trees. Some motifs are applied individually on each tile; others form compositions on a set of tiles. The Cairo craftsmen were not quite familiar with the art of tile paneling, and the tiles are inexpertly applied to the walls.

Ibrāhīm Aghā used the opportunity to add in the southern arcade a mausoleum for himself, also paneled with marble in Mamluk style and including a prayer niche whose decoration is quite faithful to the Bahri Mamluk marble-inlay tradition

Bibliography

ʿAbd al-Wahhāb *Masājid*, pp 152 ff

Maqrīzī *Khiṭaṭ*, II, p 309

Meinecke, Michael "Die Moschee des Amirs Aqsunqur an-Nasiri in Kairo," *Mitteilungen des Deutschen Archäologischen Instituts Abteilung Kairo*, 29 (1973), pp 9 ff

Meinecke Berg, V "Die Osmanische Fliesendekoration der Aqsunqur-Moschee in Kairo Zur Entwicklung der Iznik Fliesen des 17 Jahrhunderts" *Mitteilungen*, 29 (1973), pp 39 ff

THE MOSQUE AND THE KHANQĀH OF AMIR SHAYKHŪ (1349, 1355)

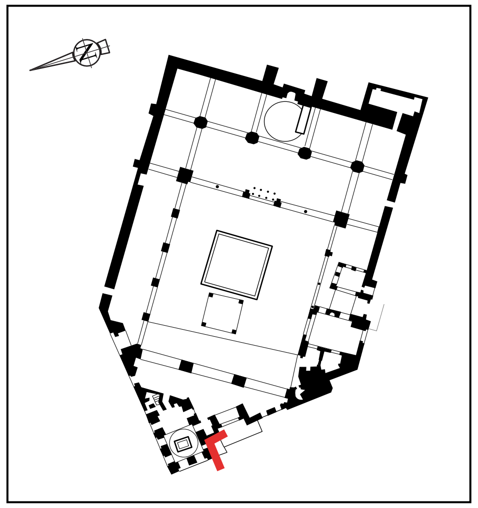
The mosque and khanqāh of Amir Shaykhū, a leading amir under Sultan Ḥasan, face each other on Ṣalība Street with similar facades and minarets, giving the complex an interesting appearance. Six years separate the foundation of Shaykhū's mosque from that of the khanqāh

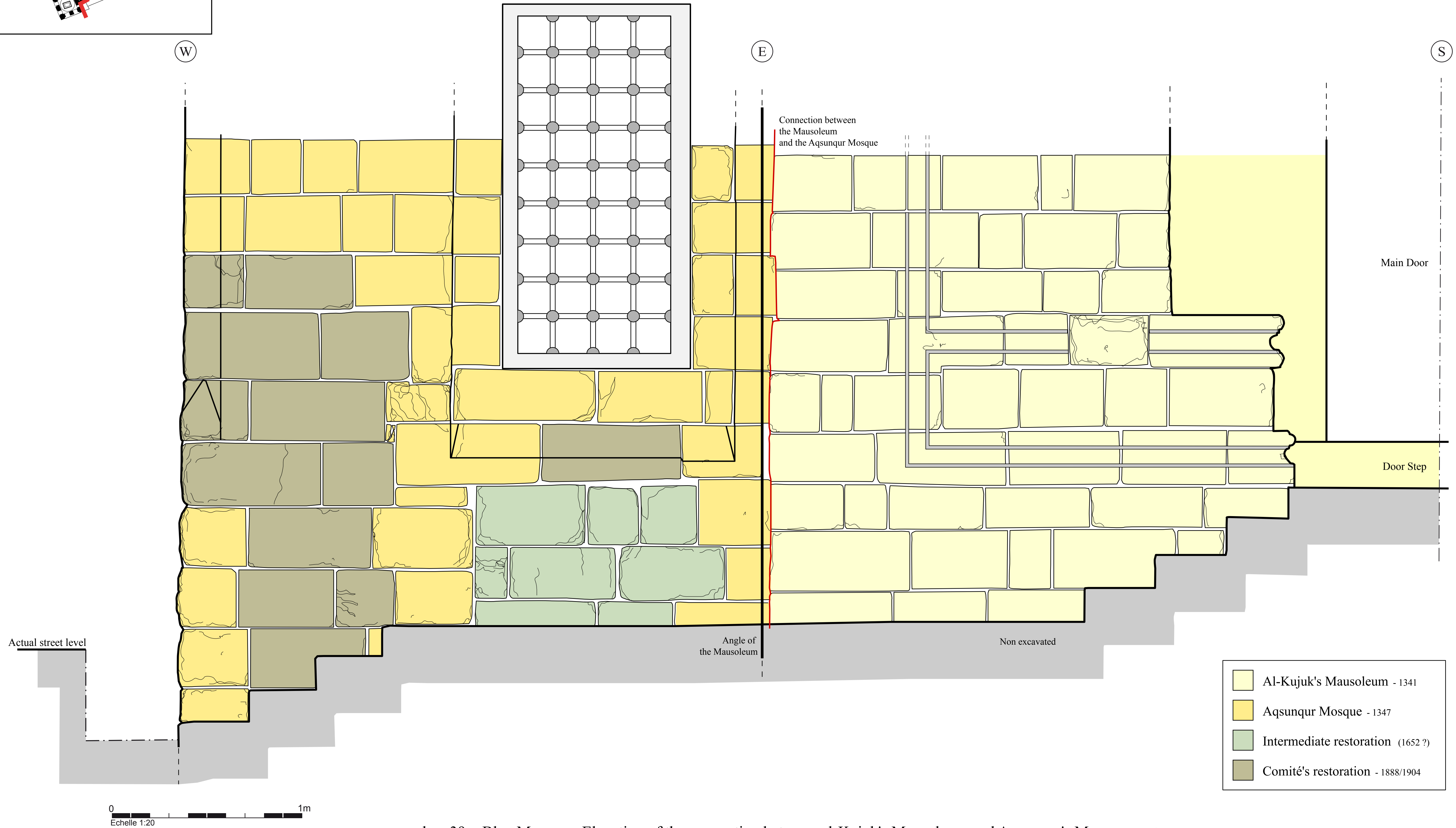
The architectural combination appears today as unique, but at one time it was not A few years earlier (1340), Amir Bashtāk built a mosque and a khanqāh facing each other across a street, with a bridge connecting them. The complex of Amir Manjaq al-Silāḥdār near the Citadel (1349) also consisted of a mosque on one side of the street and a khanqāh on the opposite side, of which only ruins remain. Some complexes in the cemetery, such as those of Barsbay, Qāytbāy, and Qurqumās, were also composed of structures on both sides of the street

The Mosque: The Exterior

The lintel and threshold of the mosque are taken from ancient Egyptian temples. A stalactite portal surmounted by the minaret leads to the vestibule The minaret is octagonal throughout and has a special feature· rather than stalactites underneath the balconies, it is decorated with carving consisting of

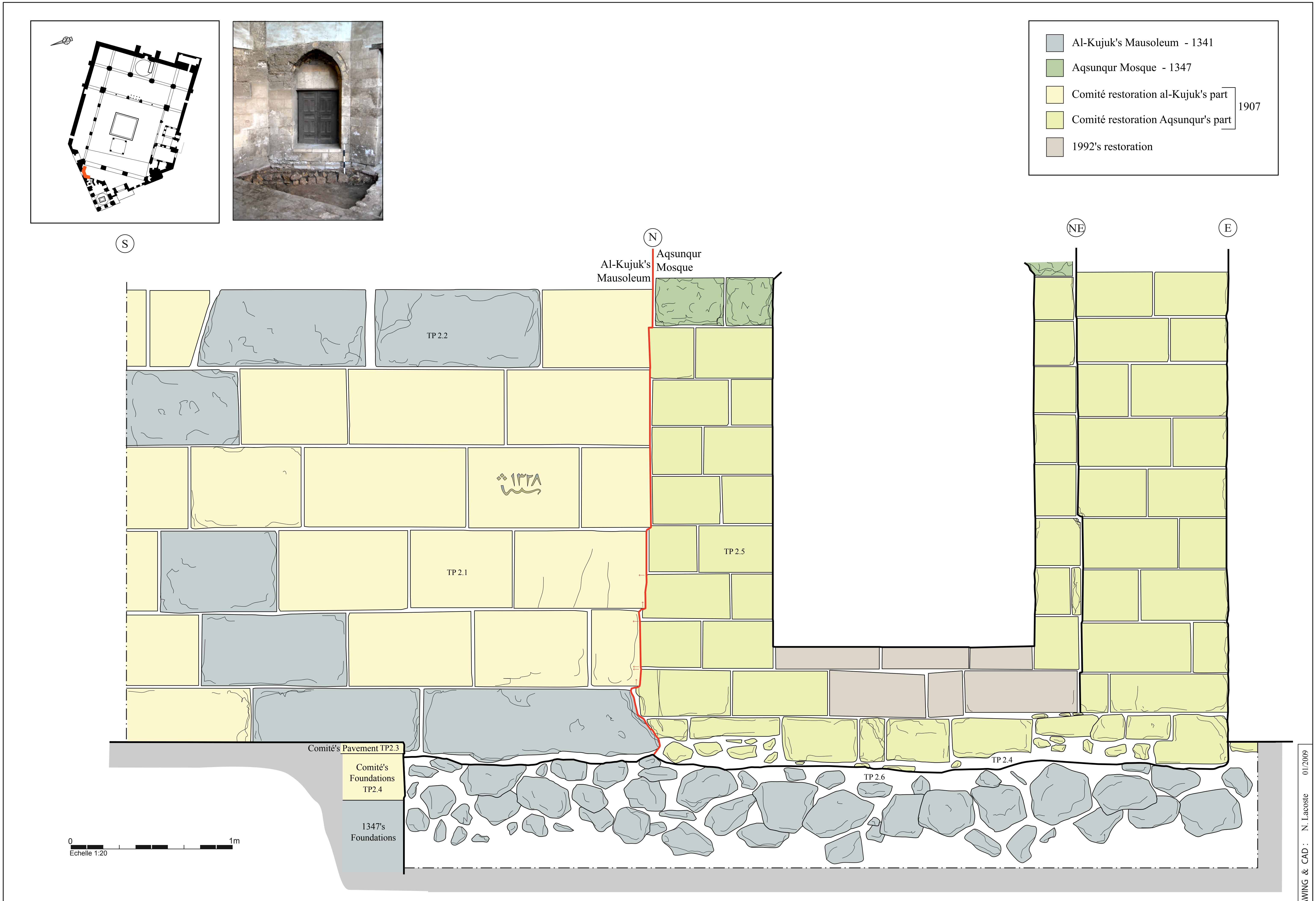
LE CAIRE.
(D'après une photographie.)



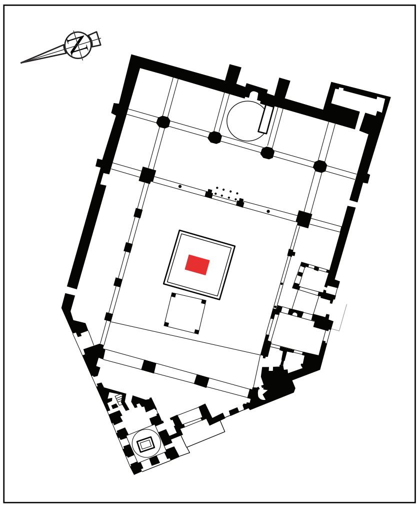


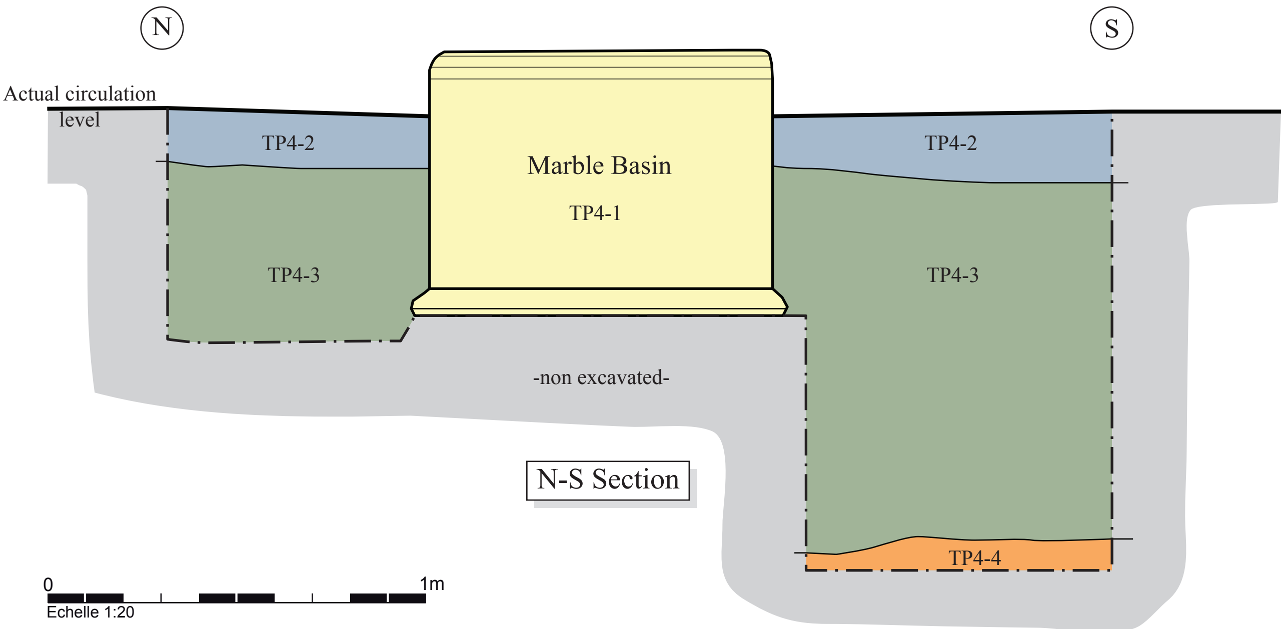
doc. 39 : Blue Mosque - Elevation of the connection between al-Kujuk's Mausoleum and Aqsunqur's Mosque, Scale 1:20.

DRAWING : A. Duvaut CAD : N. Lacoste 01/2009

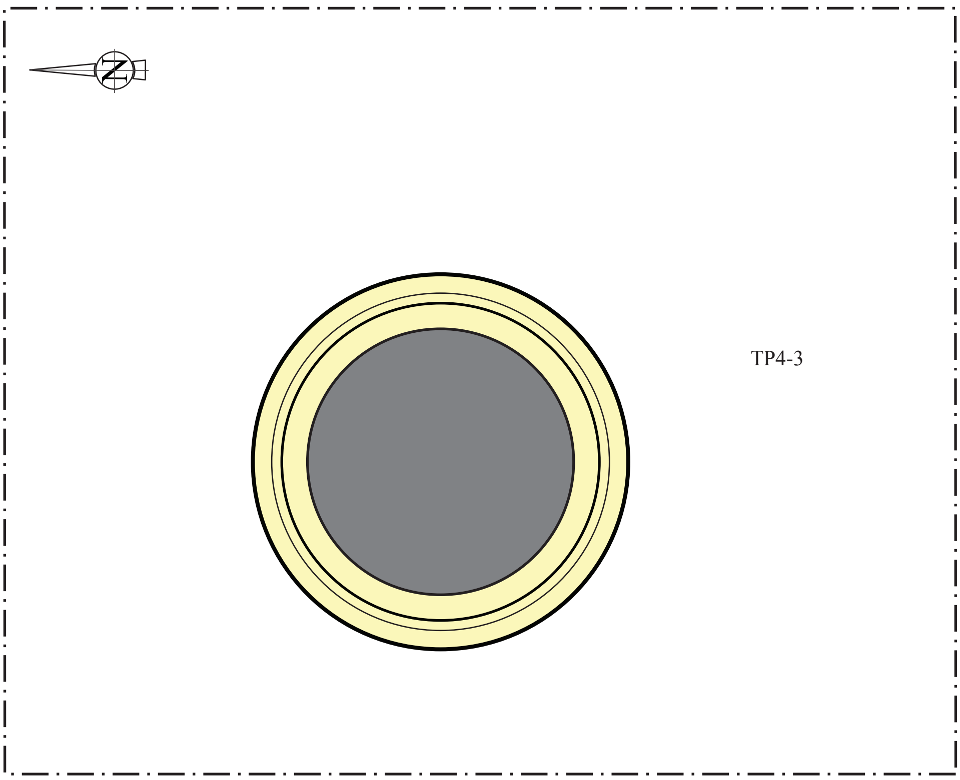


doc. 40 : Blue Mosque - Test Pit TP 2 : Elevation of the connection between al-Kujuk's Mausoleum and Aqsunqur's Mosque, Scale 1:20.



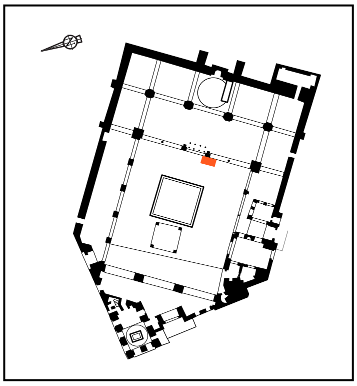


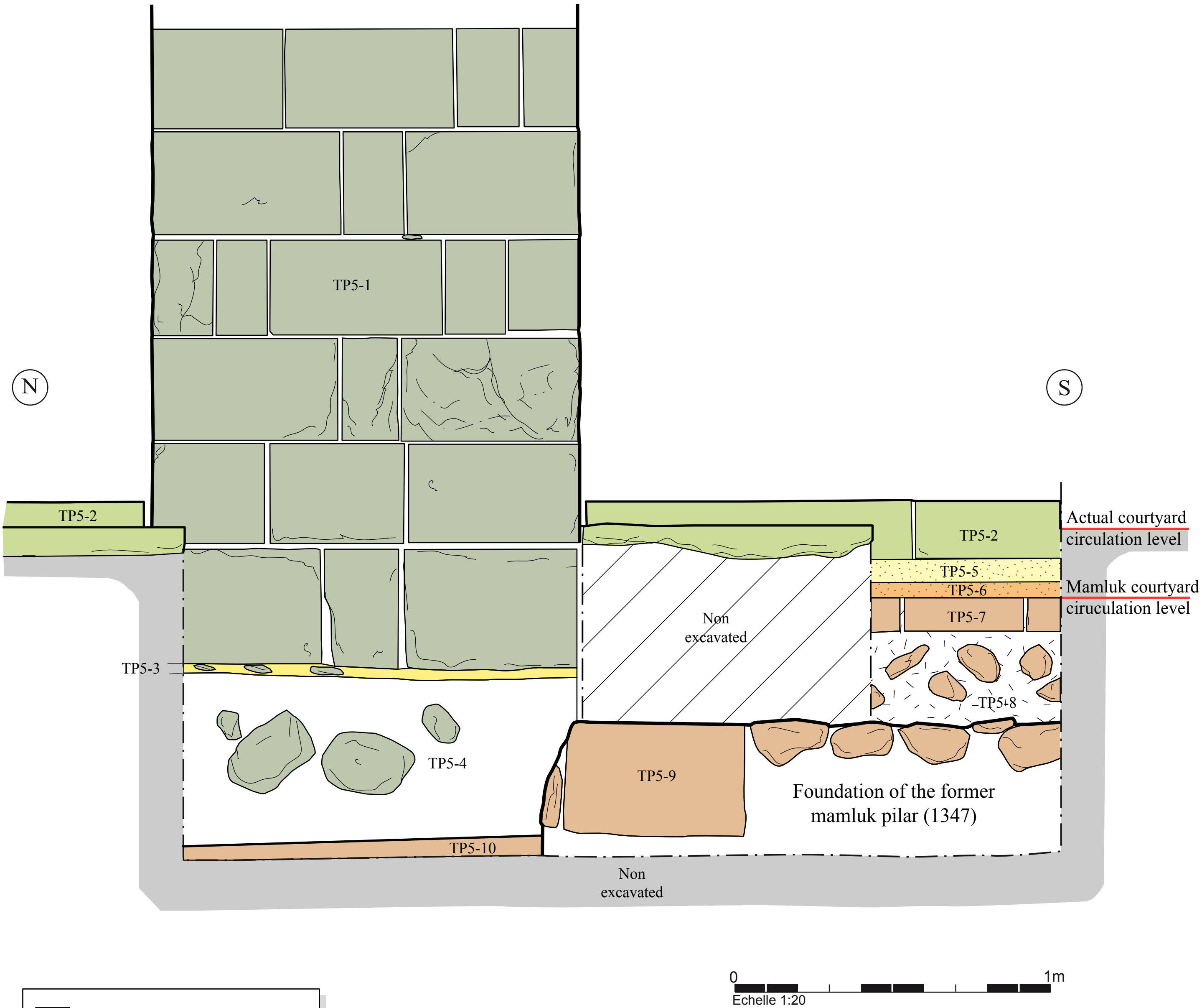
Plan



doc. 41 : Blue Mosque - Archaeological Test-Pit TP4, section and plan, scale 1:20.

Drawing & CAD : N. Lacoste 01/2009

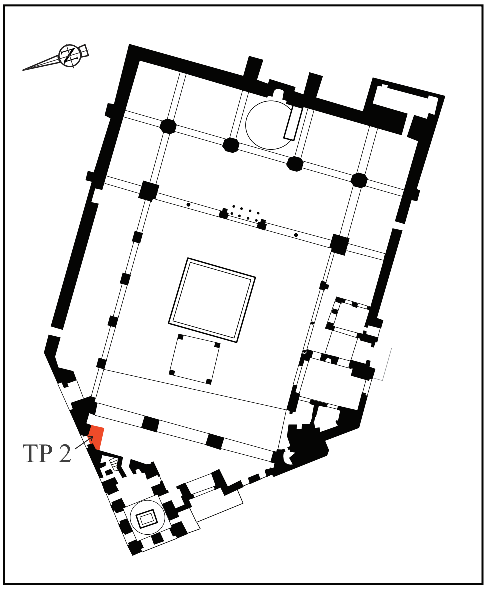


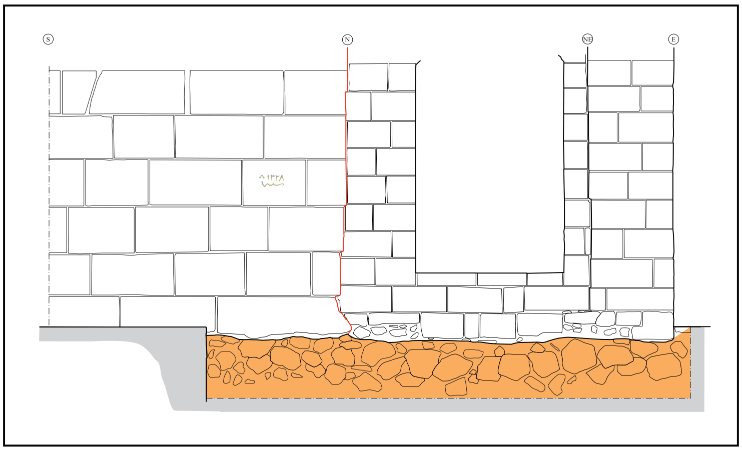


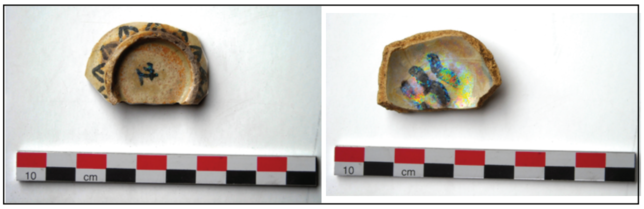
Aqsunqur Mosque - 1347	
Ottoman pilar - 1652	
Actual courtyard - 1992	

doc. 42 : Blue Mosque - Test Pit TP 5 : Elevation of a pilar's foundation in Aqsunqur's Mosque, Scale 1:20.

DRAWING & CAD : N. Lacoste 01/2009







doc. 43 : Blue Mosque - Test Pit TP 2 : Ceramic collected in the layer L TP2-6.

Structural Engineering Report on The Blue Mosque, Cairo

Stand Consulting Engineers
133 Foundling Court
The Brunswick Centre
Marchmont Street
London
WC1N 1QF

T: 0207 713 8608
E: st@standengineers.eu

Prepared by	Stuart Tappin
Issued by	Stuart Tappin
Project No	279/01
Rev	Final
Date	14 May 2011

CONTENTS

Summary

The Blue Mosque dates from 1347 and had major alterations and additions in 1652. Repairs to the structure and finishes were carried out during an extensive restoration between 1888 and 1924 and there were subsequent works in the mid-20th century to extend the buttresses on the outside of the rear wall.

There was a significant earthquake near Cairo in 1992 and we assume that this caused structural damage to parts of the mosque. Temporary supports were added during 2001 to the structure between the courtyard and the qibla wall. These supports are required to be removed as part of the current refurbishment.

The two stone marble columns to the courtyard are buttressed and have temporary support to relieve the weight of the arches each side. Both columns are partly unrestrained at their top and are out of plumb. Analysis by a structural engineer from Cairo University found that the eccentricity means that they are potentially unstable. It is not possible to introduce permanent restraint to the columns without compromising the quality of the historic building. We agree with their conclusion to use the temporary supports to rebuild both columns in an upright position. After this the temporary supports can be removed.

The temporary support to the underside of the arch directly in front of the mihrab can be removed.

A check on the loads and load paths in the arches between the qibla wall and adjacent columns should be carried out by Cairo University to confirm that the temporary supports below the arches can be removed.

There is no obvious sign of ongoing movement between the original mosque wall and the 17th century walls to the mausoleum of Ibrahim Agha Mustafahzan and so no structural repairs are proposed. We recommend that this area is monitored once the conservation of the tiled finishes has been carried out. If this records structurally significant movement then some Cintec-type ties can be added from the outside without disturbing the historic wall finishes.

The damaged finishes around the mihrab may be due to movement of the qibla wall or consolidation of the masonry. Both sides of the wall should be surveyed for verticality. Some making good of the masonry is likely to be required once the finishes have been removed.

Some of the cracks in the central dome indicate outward movement of the top of the rear wall. The movement appears to be historic and probably pre-dates the work to extend the buttresses to the rear wall. We recommend the damaged brickwork is repaired and that stainless steel bed joint reinforcement is added to help reduce the risk of future cracks in the finishes.

We recommend that stainless steel ties between the roof joists and the masonry walls are introduced to help improve the overall robustness of the structure.

As with all historic buildings a programme of regular inspections, maintenance and repairs is needed to identify and address potential problems at an early stage.

1.0 Introduction

Stuart Tappin of Stand Consulting Engineers was instructed by the Aga Khan Trust for Culture (AKTC) to prepare a structural engineering report on two areas of the Blue Mosque in Cairo. These are the proposed removal of temporary support works which were installed in 2001 and the need for remedial works to the joints in the structure between the original 14th century walls and the 17th century mausoleum of Ibrahim Agha Mustafahzan. As noted below some other areas of structural concern were identified during our visit and these are addressed in this report.

This report follows a visit to the site between 4th and 6th January 2011. During these three days we met with, and were assisted by, the AKTC's project team. On the 5th January we met with Dr Sherif Mourad, a structural engineer with Nile Consult and at Cairo University.

We began our site visit with an overview of the structure as a whole. As part of this we noted some other areas of the structure that required further study. These are the lean of the rear, qibla, wall around the mihrab (prayer niche), and cracks to the dome immediately above. We also reported on the benefit of some low-key works to improve the connection between the walls to the timber roof joists.

Our brief has been to identify the main structural engineering issues, determine what investigations are required and set out the principles of any repairs. The numerical analysis of the structure and the detailed design of any repairs shall be carried out by Nile Consult.

This report contains a summary of the existing structure followed by observations and comments on the condition. It notes the areas where investigations or surveys are required to help with our understanding of the existing structure and to develop appropriate conservation-based structural repairs. The report also provides outline proposals of work to mitigate the main structural defects.

The mosque is a significant historic building in its own right and an important part of the Historic Cairo World Heritage Site. Our approach is therefore based on internationally agreed good practice for historic buildings. This includes the need to develop an understanding of the existing structure before carrying out any interventions, the retention of historic fabric wherever possible, the use of compatible materials and reversibility where repair works are carried out. This 'step-by-step' approach does mean that not all of the structural issues will be addressed and therefore a programme of future inspections, maintenance and repairs is required to identify and deal with problems at an early stage.

We received a copy of survey drawings together with three reports: an archaeological survey report dated 4-30 January 2009 prepared by Nicolas Lacoste; a Geotechnical Investigation Report dated July 2009 prepared by Geo-consultants; and a report Building Material Analysis, undated but we understand was issued during September 2009, by G+W Science and Engineering. We received a copy of Nile Consult's report on 26th April 2011.

The dates and historic drawings within this report are based on a combination of the existing reports, our observations on site and a general knowledge of historic buildings. This is not the definitive record on the buildings history and reference should be made to the archaeologist's report for all details of the development of the mosque.

2.0 Site Geology

2.1 An initial site investigation was commissioned by the AKTC and carried out during July 2009. This comprised four boreholes; two within the mosque and two just outside the walls. The locations are shown on our drawing SK 20. The findings and results of tests are in the report by Geo-Consultants dated July 2009.

2.2 The two boreholes within the mosque found “fill”, described as a mixture of silt, sand, pebbles, gravel and clay to a depth of 8.2m to 8.5m below ground level. Below this was brown lime pebbles and coarse sand with some silt over weathered limestone. One of the external boreholes, BH 3, found similar “fill” to 9.0 metres. The fill in BH 4 included broken bricks and extended to a depth of 12.50 metres over the same weathered limestone recorded in the internal boreholes.

2.3 An archaeological investigation during January 2009 included some excavations to the foundations but the form and depth of the foundations were not confirmed.

2.4 During our visit we recommended that trial pits be dug to investigate the foundations and underlying ground conditions to the courtyard columns and the rear wall of the mosque. These are noted on drawing SK 20. The work was carried out after our visit and the findings are included in Appendix C.

2.5 Cairo lies within an active seismic zone and an earthquake with a magnitude of 5.8 at its epicentre about 35 kilometres south of the city happened on 12th October 1992. This was the largest earthquake in Egypt since 1848 and it caused structural damage throughout Cairo including a number of nearby historic buildings. There is no record of the damage to the mosque but it has not been used for the prayer since 1992. We can therefore deduce that some damage must have been observed. The discussions regarding temporary support started in 1999 and shoring was installed during 2001.

3.0 Historical Development and Summary Description of the Existing Structure

3.1 The first building on the site was the mausoleum of al-Kujuk dating from 1341. This was then incorporated into the northwest corner of the mosque built in 1347 for Aqsunqur, the son-in-law of Sultan al-Nasir Muhammad. This was a loadbearing masonry structure with external walls and internal columns supporting a vaulted roof around a central, open courtyard.

3.2 In 1652 the Ottoman Amir, Ibrahim Agha Mustafahzan, acquired the mosque and surrounding buildings. It seems that the columns to three sides of the courtyard were rebuilt and the adjacent vaults were replaced with a flat timber roof. The replacement supports around the courtyard were built in a different position to the original construction and are not in line with the original piers in front of the qibla wall. Two of the supports are slender marble columns approximately 380 mm in diameter. The recent trial pits showed these columns to be founded on irregular stonework to a depth of 1030mm and 1800mm below ground level.

3.3 The 17th century roofs on the two sides of the courtyard are formed of 150mm deep x 125 mm wide timber joists at about 500mm centres, with deep timber beams supporting joists to the outer bay in front of the qibla wall. Mustafahzan also constructed a mausoleum for himself inside the southwest corner and added buildings against the southwest elevation of the mosque.

3.4 Between 1888 and 1924 the mosque was repaired by the Comité de Conservation des Monuments de l'Art Arabes. Based the materials used and the detailing it is likely that the tie rods and pattress plates between the northeast elevation and the courtyard, together with the rolled steel beams within the flat roof, all date from this period. The buttresses against the outside face of the qibla wall may also be from this date. The "middle 20th century" photograph included in Appendix B shows these buttresses before they were extended. We assume that the additions to the buttresses were made because of ongoing movement of the structure in this area. This movement is visible on the distortions to the internal stone finishes around the mihrab and cracks in the dome.

3.5 After the 1992 earthquake in Cairo the discussion on introducing temporary support commenced in 1999 and steel and timber supports were added in 2001. There is no record of why the supports were installed. We assume there was concern about the stability of the relatively slender marble columns on the courtyard, but support was also added below some of the arches between the massive masonry piers.

3.6 An assumed summary of the structure at the key dates is shown on drawings SK 1 to SK 3 and the existing structure is summarised on drawings SK 10 and SK 11.

4.0 Observations and Comments

4.1 Removing the temporary supports to the arches and marble columns

4.1.1 The two slender marble columns added in 1652 to the southeast of the courtyard were built on new foundations. Above the decorative stone capitals are layers of timber, as shown on drawing SK 21. The use of timber in compression within a stone structure is not found in European buildings because of the risk of timber decay. We understand that this is a common detail in Egypt to provide some flexibility under dynamic loads from an earthquake. It appears that the timber extends across the full width of the masonry, but it is possible that there is a central stone to transmit the compressive forces directly into the column below, with a 'collar' of timber to provide a dampened support from seismic loads.

4.1.2 Both columns are out of plumb. We also noted a possible on-plan rotation of the stone at the springing of the arches on the north column. There are cracks in the brickwork above the two arches which span onto this column. This is consistent with a small drop in the level of the support below as the top of the column has moved outwards.

4.1.3 The majority of the movement appears to be historic with some possibly dating from the 1992 earthquake. There is no obvious indication of any significant recent movement.

4.1.4 A drawing prepared around 2003 by The Arab Contractors, No. SR 2, records the inclination of these and the other columns around the courtyard. Both marble columns were recently re-surveyed by Nile Consult as a part of their analysis of the forces generated by the eccentricities.

4.1.5 Ideally the top of these relatively slender columns should have horizontal restraint in both directions and this would be required to comply with modern requirements for earthquake-resistant structures. There are timber beams into each side of the masonry above the columns and these appear to have some metal tie between the timber and stonework but there is no front-to-back restraint. The introduction of an additional tie will be visible and the position of these marble columns in relation to the masonry piers behind means that the installation of any lateral restraint is not straightforward. Any permanent ties would also have a significant visual impact on the space.

4.1.6 An alternative approach is to make use of the existing temporary support to carefully reinstate both columns to vertical. Only one column should be worked on at any one time. This will require some additional temporary support to the stones immediately above the timber so that the load onto the column is removed. The timber and any internal stone at this level can then be carefully dismantled to allow the column to be rotated to vertical. Some grout may be needed at the base of the column to fill voids in the joint between the marble and the pedestal below. Once the column is vertical the capital and timber above can be reinstated.

4.1.7 At this stage our view is that there should be a masonry rather than timber core. This is to avoid the risk of movement from crushing of the timber or future decay. An indicative repair detail is shown on drawing SK 22. This is subject to confirmation once the detail of the existing structure in this area has been exposed and confirmed. Once the masonry is packed tight in place a timber surround can be placed to maintain the current appearance of the structure. Some repair to the metal ties between the timber beams and stonework may be needed.

4.1.8 Once this work has been carried out the steel and timber temporary supports can be carefully removed. When works of this scale are carried out there is always the possibility of some small scale movement. We therefore recommend that the two columns are monitored, say every month for one year for any signs of movement. There may be some small scale movement as the structure settles into a new equilibrium and from thermal expansion and contraction. If there are signs of progressive movement there may be a need to remove the timber collar to install additional packing or wedges.

4.1.9 There is temporary support to the arches below the dome in front of the qibla wall and below the central dome. The arch directly in front of the mihrab is at the centre of a series of arches that are supported on massive masonry piers so that the lateral forces are resisted by the adjacent arches. There are no indication of any significant structural problems in this area and no signs of movement. We therefore see no structural reason not to remove the temporary support below this arch.

4.1.10 The arches each side of the mihrab also have a steel and timber temporary support below. Each arch spans between the buttressed qibla wall and a massive internal masonry pier. We suggest that Nile Consult carry out an analysis of this area to confirm that the loads from the arch can be safely constrained by the rear wall and the masonry pier. Once this has been confirmed the temporary support can then be removed. We recommend that initially just the timber wedges to the underside of the arch are removed, and the structure monitored for any sign of movement for one week. If there are no signs of movement the remainder of the temporary framework can be removed. Some local making good of the masonry may be required.

4.1.11 It is prudent to monitor all the arches in this area once the remedial works have been completed. This can be monthly for three months and if there are no signs of movement reduced to an interval of every three months for a further one year. If there is progressive movement the options on how to deal with it will depend on the magnitude and direction of the movement.

4.2 **The Joints in the Walls around the Mausoleum of Ibrahim Agha Mustafahzan**

4.2.1 The key to determining whether any structural remedial works are required is to understand the historic development of this area and the position of historic joints in the masonry walls. Based on what we could see it appears that there was little bond to the 14th century masonry walls when the mausoleum was added in 1652 as shown on drawing SK 23.

4.2.2 The main historic interest is the wall tiles and so their long term conservation is the key issue. Our proposed approach is therefore based on whether there is a need to carry out structural works to either address movement that is ongoing or prevent/limit movement that could lead to damage of the tiles in the future.

4.2.3 There is no indication of cracks to the plaster in the lower part of the joints and this indicates that the majority of movement between the two walls in this area is historic. The 17th century walls may be founded at a higher level than the original walls and therefore onto ground that was disturbed when the mosque was originally built. If this is the case the majority of settlement is likely to date from soon after the additions were completed. We did notice bulges and other distortions in the plane of the walls around the mausoleum which may indicate a possible delaminating of the tiles or their substrate from the core of the wall. We suggest that all walls are surveyed to check their verticality and a careful 'tapping' test be carried out to determine if there are voids behind the tiles.

4.2.4 One approach for the structural repairs in this area is to introduce ties across the joints in the masonry. This would help to limit any future movement and may also enhance the resistance to seismic loads. However they may also introduce local stress concentrations into the masonry. The works would need to be carried out without damage to the historic tiles, probably by drilling from the outside into the core of the masonry walls using Cintec ties.

4.2.5 An alternative approach is to leave the structure and use a filler between the different ages of masonry that can accommodate some small movements. This area can then be visually monitored for any ongoing movement, annually for a period of 10 years, by looking for cracks in the new filler and, possibly, some discrete tell-tales. If this indicates that movement is ongoing the repair referred to above can then be carried out. Given the lack of evidence of any significant ongoing movement this second low-key option seems reasonable.

4.3 Other Areas

4.3.1 The lean of the columns on the northeast side of the courtyard is probably longstanding and were noted by the Comité who then installed ties. The ties rods and large pattress plates seem to have controlled the movement in this area and so there is no need for any additional repairs.

4.3.2 We noted that the inside face of the rear qibla wall around the mihrab leans outwards at high level. We discussed whether the wall was built with a batter to help with the installation of the tiled finishes but as the tiles are not original it seems more likely that the lean has been caused by the outward thrust of the masonry arches below the dome. The buttresses against the outside face of this wall were probably added to resist this outward thrust.

The addition of a buttress can sometimes cause problems if it settles and either separates from the wall or, if well connected to the original construction the buttress can 'drag' the wall and lead to further movement. This may be what happened here and the buttresses were then extended in the second half of the 20th century. The recent trial pit to one of the buttresses found it to bear about 1900 mm below ground level and there were no obvious signs of problems in the foundation.

4.3.3 Some of the damage to the decorative finishes to and around the mihrab may be due to the movement of the wall or consolidation of the masonry behind the finishes. The repair to the finishes will need to be carefully undertaken with sections removed in stages, possibly with some temporary support to prevent 'bursting' of the wall.

4.3.4 The cracks in the finishes to the groin vaults and dome immediately in front of the qibla wall are mostly typical for these types of structure. They result from the masonry settling into a state of equilibrium or occur at joints in the construction between the arches spanning to the columns and the groin vault. The one location where the cracks may indicate structural movement is on the north-east and south-east parts of the dome. The shape and pattern of the cracks here is consistent with an outward movement of the top of the qibla wall.

The cracks may date from before the buttresses against the outside of the qibla wall were extended or from the 1992 earthquake. It is not possible at this stage to tell whether this movement is ongoing but we recommend that the cracked and damaged bricks are carefully removed in sequence and replaced with compatible bricks that are packed tightly in place. Some stainless steel reinforcement can be added into the bed joints to help reduce the risk of future cracks in this area. See SK 24 for an indicative detail. We recommend that visual monitoring of the repaired finishes for any movement be carried out.

4.3.5 Where the timber joists bear onto walls we suggest the addition of some steel straps fixed between the masonry and timber. This is often used in the refurbishment of existing structures in the UK and is a low-key method of enhancing the overall robustness of the structure. A typical detail is shown on drawing SK 25.

5.0 Conclusions

5.1 The structure of the mosque generally appears to be in a reasonable condition for its age and form of construction.

5.2 The 17th century alterations and additions made significant changes to the structure. The extensive repair works carried out at the end of the 19th century and during the 20th century seem to have dealt with the majority of the structural problems at that time.

5.3 Some local conservation-based repairs are needed to enhance the robustness of parts of the structure.

5.4 The two propped marble columns are out of plumb, probably as a result of dynamic loads from the 1992 earthquake and some remedial work is required. It is not feasible to introduce new lateral restraints to tie the top of the columns without compromising the quality of the mosque. Our proposal therefore is to make use of the temporary support to carry out works to reinstate the two columns to an upright position before the temporary supports are removed.

5.5 There is no obvious need for the temporary support to the arch immediately in front of the mihrab and so this can be removed.

5.6 It is probable that the temporary support to the arch each side of the mihrab can be removed but we recommend that Nile Consult carry out an analysis of this area to confirm that the loads from the two arches can be safely constrained by the buttressed rear wall and the massive masonry piers.

5.7 The open joints in the tile finishes to the Ibrahim Agha Mustafahzan mausoleum appear to be at joints in the masonry at the different ages of construction. As there is no obvious sign of structurally significant ongoing movement we do not propose any major structural interventions at this stage. Once the finishes have been consolidated and repaired the structure should be monitored for movement.

5.8 Some of the cracks in the central dome look to be associated with historic outward movement of the rear wall. It is likely that this movement occurred before the buttresses were extended. Some stainless steel ties in repaired masonry will help to limit any future cracks within the masonry dome.

5.9 Stainless steel ties between the timber roof joists and the masonry walls will help to locally enhance the robustness of the structure and control future movement.

Appendix A

Structural Drawings

Appendix B

Photographs

Appendix C

Trial Pit Records from January 2011 carried out by AKTC

Structural Analysis Report

Blue Mosque

Presented to

AKCS - E
Aga Khan Cultural Services - Egypt

Prepared by

NileConsult

Prof. Dr. Sherif A. Mourad
Faculty of Engineering, Cairo University

Table of Contents

Structural Analysis Report

Blue Mosque

1. Introduction and Background:

Established 1347, the Mosque of Prince Aqsunqur al-Nassery is located on the Darb al-Ahmar road. It is well-known as the "Blue Mosque", as the East wall, the Qibla, is tiled from floor to ceiling in blue-colored ceramic tiles (Majolica). The south-eastern wall is tiled from the floor to 4.75 m height except the area around the Mihrab is tiled from the floor to the ceiling/springing of dome. The Mosque follows the traditional hypostyle plan, a Durqa'a (central courtyard) surrounded by four porticoes, the largest of which is the main prayer hall with two Iwans (side aisles). Piers (rather than marble columns) are used to sustain cross-vaults. Both square and octagonal pillars support the arches giving it an unusual and unique aspect.

Upon the request of AKCS-E, an earlier mission report was issued to assess the on-going site restoration of the Blue Mosque (Aqsonqur) and study the structural condition of the existing part of the mosque's roof and present proposals concerning the reinforcement and consolidation of deteriorated or damaged areas. The report focused mainly on restoration of areas of the roof and consolidation of cracks in bricks.

The present report presents the results of the structural analysis performed using a finite analysis program to model the behavior of the structure. The model is based on geometrical, geotechnical, and material data provided by the AKCS-E team.
This report addresses the following:

- Assessment and analysis of the condition of arches and their stability.
- Evaluation of the existing shoring.
- Assessment of the mausoleum wall and its connection with the exterior wall.
- Evaluation of the apparent bulging of the western façade wall.
- Finite element model and calculations to support the above.

The report includes three appendices; the first incorporate site photos, the second presents the plans and sections prepared by AKCS-E team for use in the restoration works, and the third provides sample plots from the finite element model.

2. Site Observation:

The mosque entrance is a small one on Bab El-Wazir street, which leads to the central courtyard, surrounded by three-sides of repeated bays. The mosque is famous for the quibla wall, with well-preserved blue ceramic tiles along the entire wall. The roofs of the bays are supported on load-bearing walls as well as stone piers and arches. The structural system of the roof is either stone cross-vaults or wooden joists, and sometimes both. The main observations during the site visit may be summarized as follows:

- There are several arches along the court and inside that are heavily shored both in-plane and out-of-plane directions.
- Currently, some parts of roof are shored. In particular, some cracks in zone "R" are being repaired, whereas other cracks are yet to be addressed.
- Inspection from the roof revealed that the roofing layers as well as the wooden joists in some areas have been removed and replaced as part of the repair works.
- It was noted that a second wall (parapet) support appears across the vault in zone "R" and it corresponds to a crack that appears from below.
- It was also noted that one of the vaults in zone "R" stops before it reaches the arch support, and that the same location corresponds to a visible crack that appears below.
- When part of the roof layers were removed in zone "Q", most of the wooden joists appeared to be in acceptable condition. However, the beams did not span the entire bay, but are supported at one end of the panel and at the middle.
- Underneath the wooden joists in zone "Q", cross-vaults are visible and some rubble filling on top.
- A couple of steel beams were visible close to the arch support for the wooden joists in zone "Q" without any clear indication of its function.
- The intermediate support for the beams in zone "Q" is provided by wooden beams and intermediate pedestals on top of the vault along the mid-span.

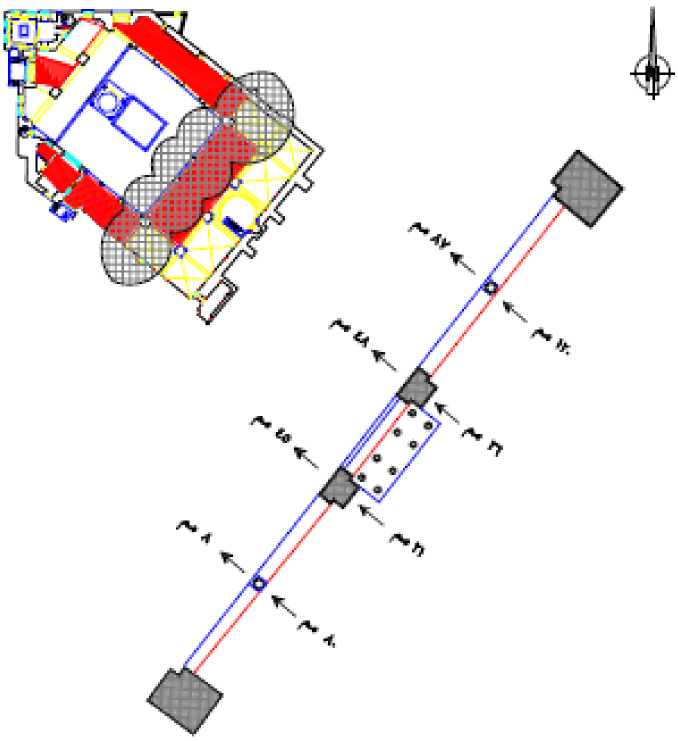
This report focuses on two elements of the mosque. The first is the arches at the court where heavy steel shoring is observed (Picture A1 and A2), and the second is the mausoleum with the bulging walls decorated with tiles (Pictures A3 and A4). Close inspection of these two elements revealed the following:

- It is reported that the heavy shoring to the arches along the court was introduced following observed damage from the October 12, 1992 earthquake. They are supposed to restrain the arches both in-plane and out-of-plane.
- Close observation revealed that there is no full contact between the wooden shoring elements and the stone arch, which indicates that the shoring is not fully effective (more likely, ineffective at all).
- The two marble columns supporting the arches are visibly out-of-plumb and not contributing to the vertical stability of the system.
- The walls at the mausoleum featured many cracks and bulging, which had negative impact on the ceramic tiles and the bond between the tiles and walls.
- Deformations of the mausoleum walls indicate excessive axial deformation. This may be due to overloading or, more likely, deterioration of the wall material.

3. Survey of Inclination

In order to examine the current status of the court arches and mausoleum, a detailed survey of these two zones was performed. The survey aimed at determining the present inclination of the “vertical” elements (walls and columns) in addition to fixing some points that would allow re-doing the survey to determine

whether there is any evidence of movement during or after the repair of the damaged elements.
The survey included the columns and wall pillar of the south-east arches along the courtyard in order to identify the inclination. It also incorporates the mausoleum walls, including the wall parallel to the external wall, and the two perpendicular walls.
Figure 1 indicates the inclination of the top level of the pier or column supporting the arches relative to the lower point. From the figure we observe that the entire wall – in general, is inclined towards the north-west direction. However, the inclination of the two faces of the piers and columns is not the same. Taking the average inclination of both sides as an indication of the inclination of the element, we find that the average displacement of the top point of the piers is about 35 mm, whereas that of the right column is 44 mm, and the left column is 103 mm. It is clear that the left column is inclined with a slope more that twice that of the piers, whereas the right column is inclined with a slope close to that of the adjacent piers.



شكل رقم (١) يبين الميل الرأسى عمودى على اتجاه الحائط
للحائط الاوسط الداخلى بالمسجد الازرق
بالارصاد التى تمت بتاريخ ١٨-١-٢٠١١

Fig. 1: Results of initial survey of inclinations for the south-east arches along the court.

4. Load Assessment:

4.1. Dead and Live loads Assumptions

The walls were analyzed under full dead and live loads from different levels. The dead loads consist of the weight of all permanent construction and were computed based on the roofing layers used. The live loads are in accordance with the Egyptian code for force and load computation in structures and buildings, 2003, for accessible roof. Hence, live loads were considered equal to 0.2 t/m^2.

In addition, the own weight of the massive walls and arches were evaluated. The unit weight used in the analysis will be according to Section 6.

4.2. Wind loads Assumptions

In accordance with Egyptian code provisions for force and load computation in structures and buildings, 2003. The wind load acts on the external façade of the walls. The considered base wind pressure (q) is 90KN/m^2 and the height factor (k) is varied according to Table 1.

Table 1. Height factor as given in the Egyptian Code

Height(m)	k
0-10	1.0
10-20	1.1
20-30	1.3
30-50	1.5
50-80	1.7

Accordingly, wind pressure will be calculated as:

$$P = C_e \times k \times q$$

Where C_e is the exposure factor and is considered equal to 0.8.

Wind loading is generally dominant in tall flexible structures (such as minarets). However, due to the fact that the elements under study are relatively short and massive, no further investigation was done for the wind effect, and only seismic loading was considered in the stress analysis.

4.3. Seismic loads Assumptions

The equivalent static and response spectrum methods were used to evaluate the additional stresses due to earthquake loading.

The equivalent static base shear (V) is calculated according to the UBC-97 provisions for seismic loads as follows:

$$V = \frac{C_v I}{RT} W$$

Considering that the total base shear will not exceed:

$$V = \frac{C_a I}{R} W$$

And, it will not be less than:

$$V = (0.11 C_a I) W$$

Where,

C_v Seismic coefficient, as given in Table 16-R

I Importance factor

R Numerical coefficient representative of the overstrength and ductility as given in Table 16-N

T Elastic fundamental period of vibration, in seconds, of the concerned structure

C_a Seismic coefficient, as given in Table 16-Q

W The total seismic reactive weight

For the studied models, the force reduction factor is considered equal to 2.2 to account only for the overstrength of the solid block masonry walls. The largest permissible importance factor suggested by code (1.25) was used due to the historical importance of the building. The elastic fundamental period is calculated using the dynamic analysis using the software program.

As for the response spectrum analysis, it was conducted according to the UBC considering a peak ground acceleration level equal to 0.15g.

5. Geotechnical Study

The geotechnical investigation provided by AKCS-E indicated from the examination of the boreholes that the successive layers of subsurface are:

- A fill layer with depth ranging between 8.20 to 11.20 m, consisting of a heterogeneous mixture of sand, silt, bricks, and limestone pieces. The top 2.0 m of the fill layer was a heterogeneous mixture of sand, silt, and limestone pebbles. The rest of the fill layer includes a higher percentage of clay. The fill layer in general is in the range of medium dense condition.
- The next layer is a layer of siliceous sand mixed with some silt and limestone pebbles, continuing to a depth of about 12.0 m.
- The lowermost layer is a highly weathered limestone layer.

The test pits were used to determine the foundation level of the walls and it was found that the foundation level ranged between 4.0 and 5.0 m below the existing ground level. The foundation was found to be an integrated continuous block wall with protrusion of about 250 mm from both sides, with no indications of disintegration or discontinuities along the foundations. No ground water was encountered till the end of the boreholes (15.0 m).

The foundation of the walls (4.0 to 5.0 m deep) is generally resting on a fill layer consisting of a mixture of limestone pieces, sand, silt, and clay of a thickness ranging between 4.0 to 6.0 m. This fill layer is considered a general practice in historical construction, Due to the fact that this layer is medium dense to very dense (SPT 24 to 52), and is mostly dry with no water table affecting it, no expectations of further elastic settlement is foreseen. However, an elaborate drainage system should be designed and executed to avoid the infiltration of water from the surrounding sources.

In addition to the a/m geotechnical study, AKCS-E team also made four open pits in order to examine the foundation conditions on site (Fig. D1). The first open pit was at the south-east external wall (Fig. D2), and a stone base was encountered while excavating at a depth of about 2.0 m. This base extended about 500 mm from the wall above ground. The second and third test pits were adjacent to the two columns at the court side (Figs. D3 and D4). It was found that beneath the tiles, there is a loose sand layer of about 300 mm, then a layer of irregular stone base 600 to 1400 mm, followed by a solid layer.

6. Material Properties:

Material properties were determined by testing and reporting by Prof. Hanaa Yousef Ghorab performed in September 2009. The report main findings are as follows

6.1 Stones

The characteristics of the stones are:

The original stone is a dolomite. It is composed of 46% dolomite, 50% quartz and feldspar, and 2.79% gypsum. The stone shows the lowest water absorption capacity (1.9%) and the highest density (2.3g/cc). Due to its long exposure in air, its moisture content is the highest among the three stones of the façade and interior of the mosque and attains a value of 2.4%.

The two new stones (Hashma and white) are limestone. Both are composed of about 97% calcite, and an average of about 2.7% sand. They differ in their appearance where Hashma stone is brownish and the white stone is off white. The physical and mechanical properties of Hashma stone is better than the white stone. It shows a compressive strength of about 191 Kg/cm^2 and a density of 2.2g/cc. The strength of the white stone is lower and shows a value of about 127 kg/cm^2 and is less dense (2.0g/cc). Both stones have low moisture content of about 0.47%. The Hashma shall be used for the arches and external walls.

6.2 Mortar

The mortar sample taken from the statictite of the 1st minaret balcony is composed of 56% calcite, 32% gypsum, 5.9% hemihydrate and 5% sand (Table 7). The precipitation of the gypsum phase seems to be clearly hindered by the addition of a natural gel which might act as an organic additive.

6.3 Bricks

The properties of the red bricks comply with the Egyptian specifications which state a minimum compressive strength value of 40 kg/cm2, the average strength of 5 specimens and the strength of the tested samples amounts to 99.30kg/cm2. The repeated dimensions of the samples, also their volume, weight, density and water absorption capacity, are acceptable.

6.4 Wood

In spite of the better compressive strength of the original wood compared to the new one and its better water absorption capacity, however, the old sample is dry and cracks while processing. The use of the new one is recommended.

A number of fungi are identified in the wood samples. In order to treat and protect the specimens, an experiment was carried out on the effect of ultraviolet radiation on the microorganism isolated. The radiation was performed at a wavelength of 54 nanometer and has positively limited the growth of the microorganisms. It can be applied successfully in the site. The wood can be further protected through sealing the structure with reagents against the humidity. The use of pesticides controlling the growth of the microorganisms is also possible but needs detailed investigations before application.

For the purpose of analysis, the following properties were considered:

For the bricks

- Unit weight 1.00 kg/cm^3.
- Compressive strength 40 kg/cm^2.
- Tensile strength 8.0 kg/cm^2.
- Modulus of Elasticity (E) = 60,000 kg/m^2
- Poisson ratio (υ) = 0.25

For the stone

- Unit weight 2.00 kg/cm^3.
- Compressive strength 190 kg/cm^2.
- Tensile strength 19.0 kg/cm^2.
- Modulus of Elasticity (E) = 100,000 kg/m^2
- Poisson ratio (υ) = 0.25

7. Diagnosis of the Mechanisms for Damage:

It is well known that the appearance of cracks in a structural element is a sign of overstressing. The same is true for abnormal or excessive inclination or bulging. In this section, we shall outline possible reasons for the deterioration observed in the two zones of the Blue Mosque previously mentioned. The following possible reasons will be investigated:

1. Overstressing due to vertical loads.
2. Overstressing due to seismic loading.
3. Overstressing due to differential settlement at the foundations.

In addition, the repair strategy also includes replacement of damaged bricks or blocks and mortar filling in order to counteract the deterioration of the mechanical and physical properties of the stone and mortar used in the construction of the monument.

Evaluation of the stresses in various structural elements shall be performed using the finite element method. The geometry of the wall as well as the geotechnical information and mechanical properties were provided by AKCS-E experts and used to produce the numerical model representing the entire mosque. The model was subjected to loads as seen relevant and the stresses were computed for various load combination scenarios. The stresses computed from the various load combinations were compared with acceptable levels of stress for such construction. In addition, the observed deformations and crack patterns were used to complement the study to reach a conclusion for the reasons of deterioration. The load cases were considered:

7.1. Overstressing due to vertical loads:

The vertical (gravity) loading that the wall is subjected to is mainly from the own weight of the wall as well as the floors attached to the wall. These loads were included in the finite element model in order to evaluate the contribution of the own weight and floor loads to the stresses. Local effects at the loading line as well as effect of eccentricity of the load were considered.

7.2. Overstressing due to seismic loading:

It is known that several moderate earthquakes have hit Cairo since the construction of the Blue Mosque. The most recent is the 1992 October 12 earthquake. It is also known that vulnerability of historical buildings to seismic loading is high due to the deterioration of the structural elements and lack of maintenance and repair throughout the life of the structure. The effect of seismic loading shall be included in the finite element model as a separate case of loading in order to evaluate the additional stresses that may result due to such loading. Analysis shall be performed using the equivalent static method as well as response spectrum to compute the stresses due to earthquake loading, in accordance to the Egyptian code for loads and forces, which is similar to the EuroCode.

7.3. Overstressing due to differential settlement:

One of the reasons for overstressing of structures, particularly massive long walls, is the differential settlement at different foundations. This effect is amplified by the variation of the type of soil and/or foundation level along the wall length. For the Blue Mosque, the detailed geotechnical study has determined the foundation level and soil parameters under the wall, and provided insight on the possibility of differential settlement in the Mosque. This variation in soil parameters shall be modeled by representing the soil under the wall by elastic springs, and changing the spring stiffness depending on the outcome of the subsurface studies.

8. Monitoring the Progress of Damage:

In order to assess the structural integrity of the elements in question and ensure that it has reached a stable equilibrium stage, the points that were chosen for monitoring shall be re-measured during the repair and several months afterwards. The measurements are taken in order to check that during of the period of observation, no significant deterioration is noted and therefore, it may be concluded that the structure is stable during the short period of observation. However, due to the fact that the material of construction is deteriorated and the wall may be subject to a variety of environmental loads, a continuous monitoring system is strongly recommended. As an alternative, frequent detailed visual inspections should be conducted.

9. Structural Assessment:

After documentation of damage observed, estimation of mechanical properties of construction materials, and recording deformations and/or inclinations of the monument, and after receiving the results of the geotechnical investigation and information gained on the foundation level and sub-surface soil properties as well as simple monitoring of the cracks; this section discusses the structural assessment phase of the concerned structure.

In order to establish the numerical model, information gained from the geometrical survey as well as geotechnical and material properties is compiled in order to construct a finite element model to simulate the behavior of the wall and estimate the stresses in different elements under various loading conditions. The structural model is used to examine various loading scenarios and predict the crack patterns based on estimating the maximum tensile stresses in the structural elements. The model shall also be used to examine the dynamic characteristics of the structure (natural frequencies and corresponding mode shapes). Analysis of the model output (deformations, stresses, …) is used to draw conclusions and recommendations to justify the current cracks and avoid any further damage.

9.1. Finite Element Modeling

A 3-D model was used to analyze Blue mosque monastery walls under various loads. The 3-D model was used to simulate the response of the structural elements under static loads, and used for checking settlement and internal stresses in walls. Quadratic solid elements with variable thickness are used to represent the walls. Hence, each node has six degrees of freedom: three translational and three rotational. Shell element size was restricted to 0.5m and the ratio between element sides is kept in the range 1:1 as possible. Solid elements were removed from opening locations such as doors and windows.

On the other hand, several critical zones were selected to study the effect of vertical and lateral loads on the walls. These zones (arched zone, cemetery zone, and main dome) were selected to model various locations and configurations of the monument walls as illustrated in Fig. 2.

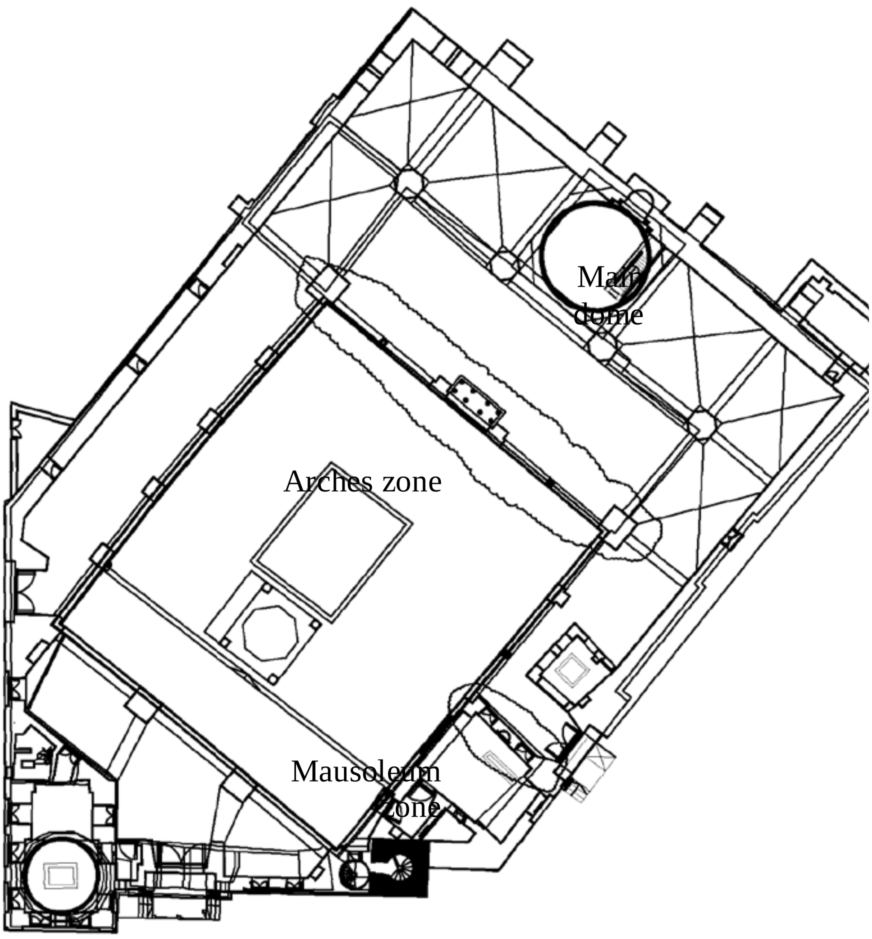


Fig 2. Location of various zones considered in modelling.

Modeling of the monument considered geometrical, loading, and soil conditions aspects. As for the geometrical aspect, these models were built using the given AutoCAD drawings then extracted to the used software analysis program. In addition, horizontal restraints were assigned to the location of the floors as per site observations. The loading conditions used in these models were explained in Section 7.2 and 7.3 according to dead, live, and seismic load cases.

9.2. Load Combinations:

The following load combinations were considered for checking the various sectional structural elements for the different used models:

1) D.L. + L.L.
2) D.L. + S_R
3) D.L. + S_R + L.L.
4) Differential Settlement.
5) Column Removal.

Where:

D.L. Dead load case

L.L. Live load case

S_R Seismic load case using response spectrum method

These combinations are then combined in an envelope case which shows the maximum positive and negative responses among the various combined cases.

9.3. Results:

The results of the analysis of the Blue Mosque focused on predicting the location of expected cracks at the zones of increased tensile stresses in walls as it is well known that the appearance of cracks in a structural element is a sign of overstressing. In this study, the considered possible reasons for cracks observed in the perimeter walls of Blue Mosque are as follows:

1. Overstressing due to vertical loads.
2. Overstressing due to seismic loading.

Evaluation of tensile stresses in the walls is performed using the finite element method. The geometry of the wall as well as the mechanical properties are taken as previously discussed in this report and are used to produce the numerical models representing the perimeter wall for Blue Mosque. The models are subjected to loads and deformations as seen relevant and the stresses are computed for various load combination scenarios. The stresses computed from the various load combinations are compared with the acceptable levels of stress for such construction. In the following tables, the results of the numerical models for different load cases are summarized. The allowable stresses for the various loading conditions and material are based on the materials testing report and the loading condition under consideration. For bricks and stone, the factor of safety shall be 3 for the vertical loads and 2 for the seismic loading. This would make the allowable compressive stresses under vertical loading for bricks around 33 kg/cm^2 and 50 kg/cm^2 for seismic loading. For stones, the allowable compressive stresses under vertical loading is 63 kg/cm^2 and 95 kg/cm^2 for seismic loading. Tensile stresses are typically 1/8 to 1/10 the compressive stresses.

Table 2: The stresses due to different cases at arches zone

Case \ Stress	Horizontal (kg/cm^2)		Vertical (kg/cm^2)	
	Comp.	Tension	Comp.	Tension
Vertical loads (D+L)	-4.7	2.0	-11.1	0.8
Response spectrum	-5.2	5.2	-37.6	37.6
Differential settlement	-7.8	5.1	-16.7	1.3
2 inclined columns removed	-3.1	2.8	-4.8	0.9

Table 3: The stresses due to different cases at cemetery zone

Case \ Stress	Horizontal (kg/cm^2)		Vertical (kg/cm^2)	
	Comp.	Tension	Comp.	Tension
Vertical loads (D+L)	-0.5	0.4	-4.1	0.2
Response spectrum	-3.2	3.2	-3.1	3.1

Table 4: The stresses due to different cases at main dome

Stress / Case	Horizontal (kg/cm²)		Vertical (kg/cm²)	
	Comp.	Tension	Comp.	Tension
Vertical loads (D+L)	-2.3	3.2	-3.6	2.4
Response spectrum	-1.8	1.8	-1.8	1.8

The stress plots are shown in Appendix C. Picture C-1 shows an overall view of the 3-D model. Pictures C-2, C-3, and C-4 show a plot for the deformed shape under vertical, seismic loading in X-direction, and seismic loading in Y-direction. Pictures C-5 to C-9 show the first five mode shapes resulting from free vibration analysis. Pictures C-10 to C-12 show the stresses in the three principal directions under vertical loading, whereas Pictures C-13 to C-15 show the same under seismic loading.

In order to focus on the elements under study, Pictures C-16 and C-17 show the stress distribution of the arches under vertical loading whereas Pictures C-18 and C-19 show the stress distribution under seismic loading. Pictures C-20 and C-21 show the stress distribution in the Mausoleum walls under vertical loading whereas Pictures C-22 and C-23 show the stress distribution under seismic loading. Pictures C-24 and C-25 show the stress distribution in the main dome under vertical loading whereas Pictures C-26 and C-27 show the stress distribution under seismic loading. The stresses in the arches were also investigated due to differential settlement along the arch line. In order to do so, the base of the arches was replaced by springs to simulate the differential settlement (Picture C-28). Picture C-29 and C-30 show the stress distribution of the arches under vertical load due to settlement of the arches support. Furthermore, the finite element model was analyzed assuming the two inclined columns were not present. Pictures C-31 and C-32 show the stress distribution in the arches under vertical loading due to column removal.

Comparing the maximum stresses under various loading revealed that there is a substantial increase in vertical stresses in the arches zone due to seismic loading. This may explain the reason why the columns got deformed. The level of stresses is larger than the typical capacity of stone and mortar.

It is also noted that there is a substantial increase in horizontal stresses in the Mausoleum wall due to seismic loading. However, the level of stresses is not high, so the main reason for the large deformation is probably due to deterioration of the materials.

A soft copy of the SAP2000 finite element model is provided in Appendix E.

10. Conclusions

The analysis of the structure using the finite element model has shown concentration of stresses at specific locations of the arches and Mausoleum walls. The increased stresses are believed to be mainly due to seismic loading. In addition, the deterioration of materials and mortar increase the probability of cracking due to overstressing. Although the current situation of cracks is generally stable, material deterioration may cause rapid degradation and therefore concrete steps should be taken to improve the materials and repair the cracks.

For the arch columns, the present inclination of the two marble columns renders them inactive in the load transfer system. It is important to reinstate the two columns to contribute in the vertical load carrying system, making use of the existing shoring. After the repair, the shoring may be removed.

For the Mausoleum wall, it is important to improve the strength of the walls and ensure proper connection at the wall corners in order to provide sufficient load carrying capacity for the walls. After doing so, the cracking and bulging should be repaired and the tiles properly fixed.

Another report (Structural Repair Report) shall be issued at a latter stage to document the proposed repair strategy and details.

11. Recommendations

Based on the analyses performed, it is recommended:

For the Arches zone:

- Review the existing shoring of arches, and ensure that there is proper contact with the stone arches prior to removal of the columns.
- Ensure that the structural elements are properly repaired (replace defective stone, repair grout, clean stone, …).
- Remove the two inclined columns and re-instate them with a proper vertical alignment.

For the Mausoleum:

- Repair defective stone elements.
- Grout the rubble fill within the walls.
- Removal of the ceramic should be done only as an exception and in the minimum possible areas.

Structural Consultant

Dr. Sherif A. Mourad
NileConsult

Appendix A

Some of the pictures taken during site visits.

Picture A1: Steel shoring for the courtyard arches.

Picture A2: Details of contact between shoring and arches.

Picture A3: Mausoleum general view.

Picture A4: Bulging Mausoleum walls and cracked and fallen ceramic tiles.

Appendix B

ACAD drawings used in the study.

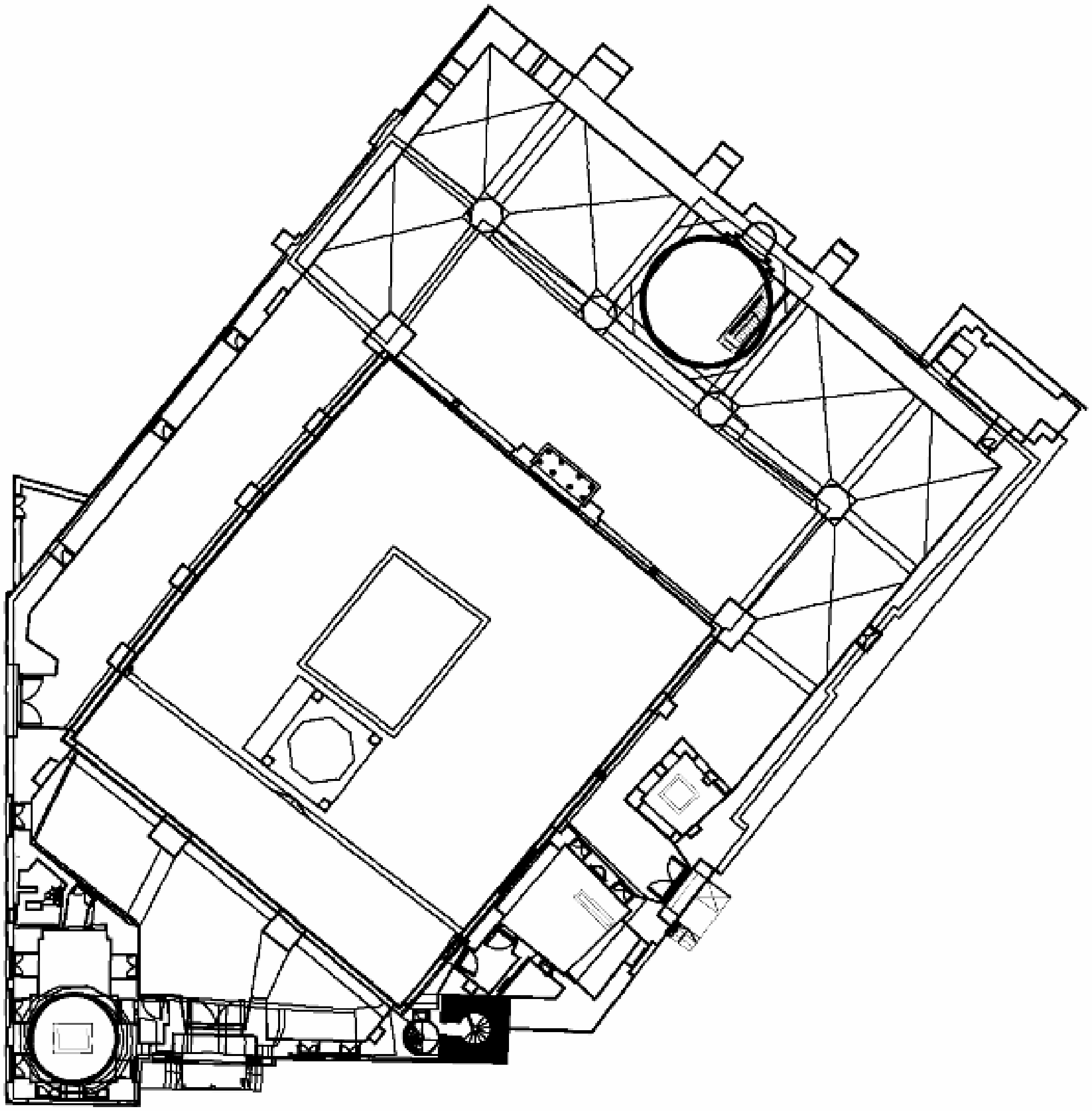


Fig. B1: Plan of the Blue Mosque.

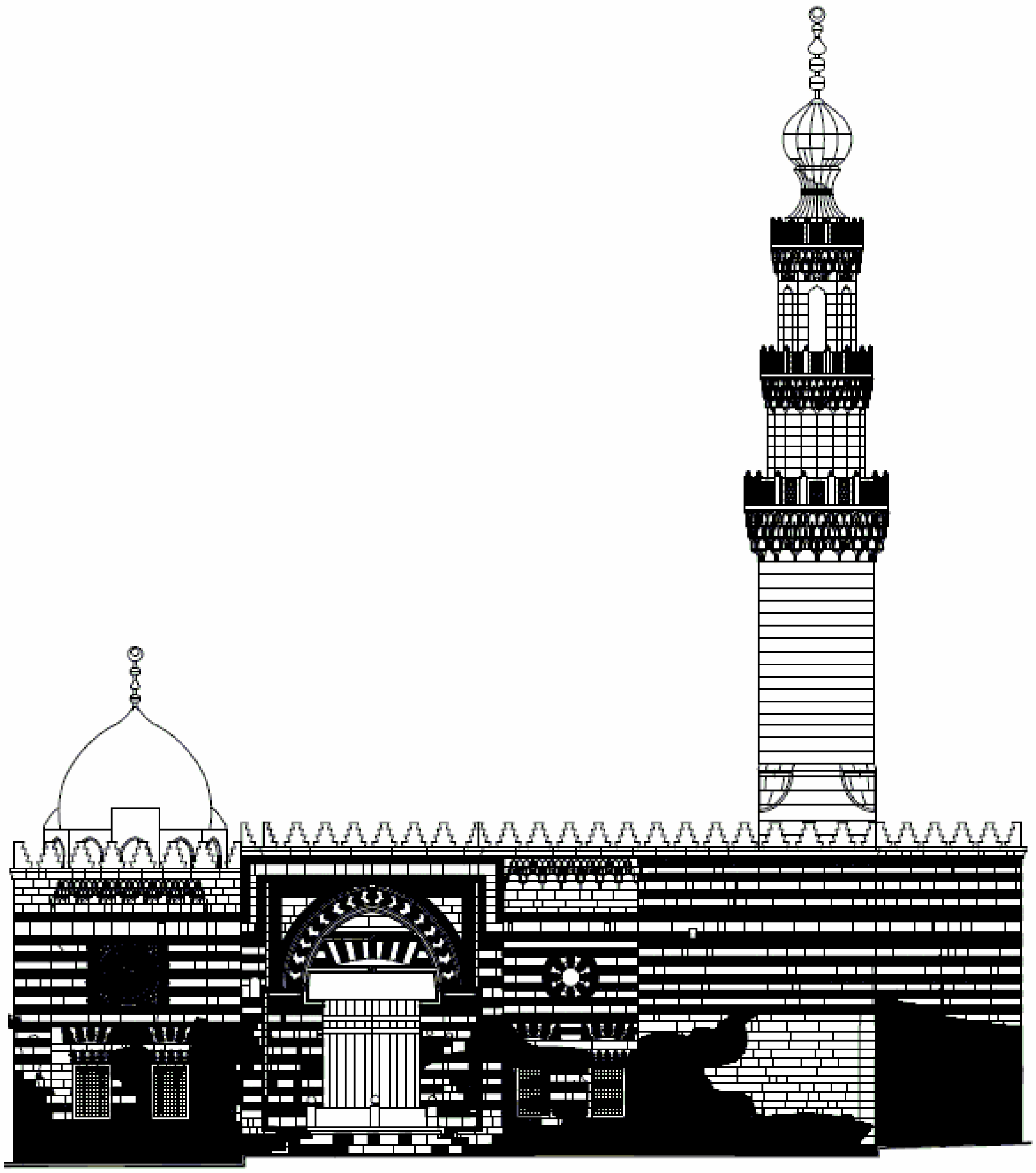


Fig. B2: Elevation of the Blue Mosque.

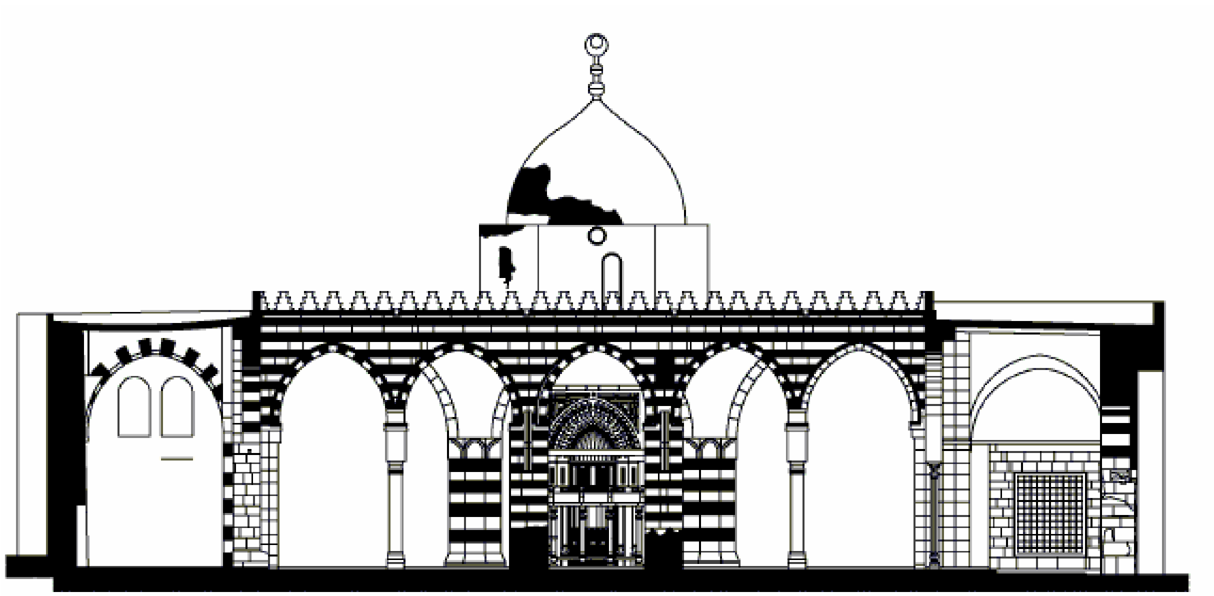
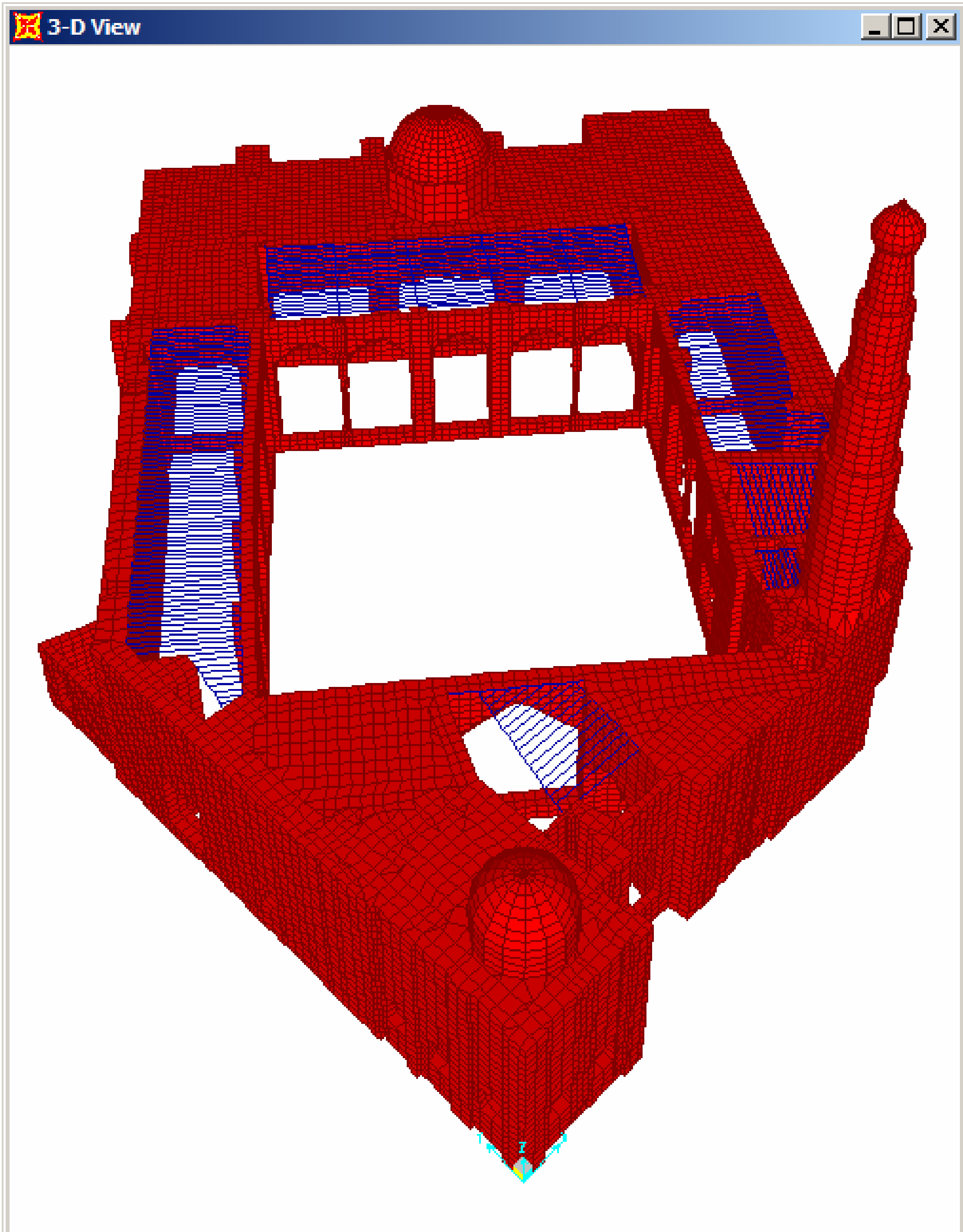


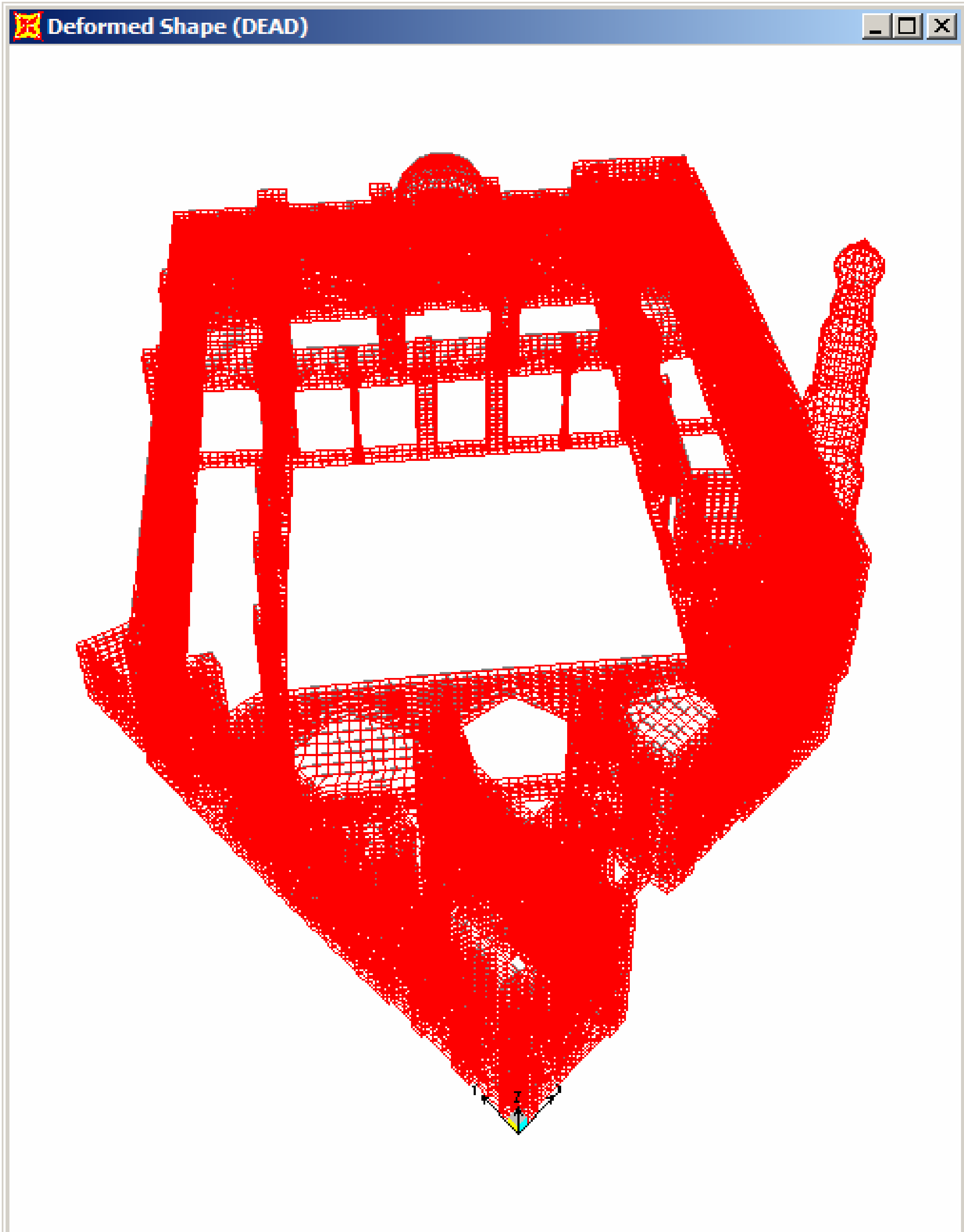
Fig. B3: Section through the courtyard of the Blue Mosque.

Appendix C

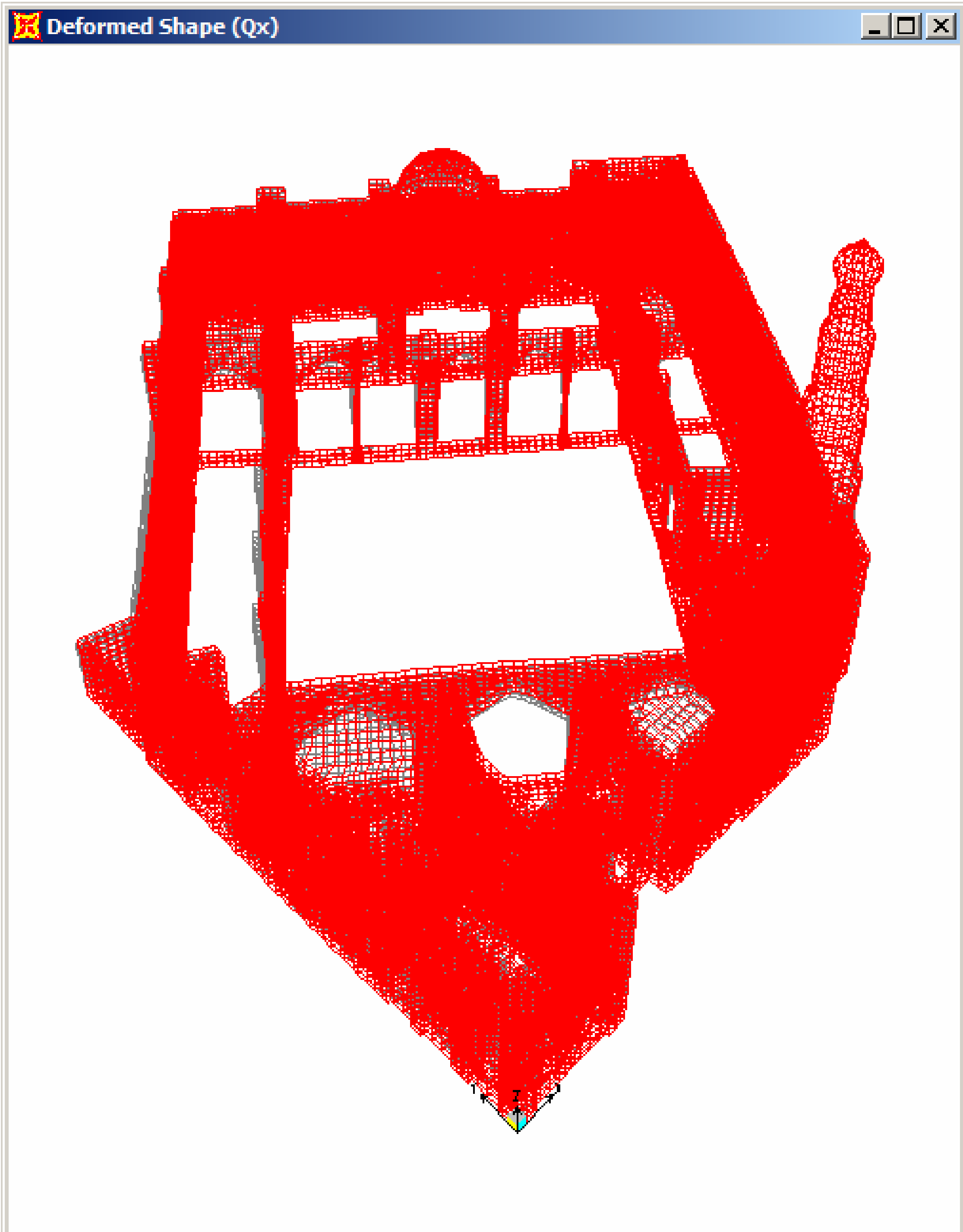
Plots from the finite element analysis.



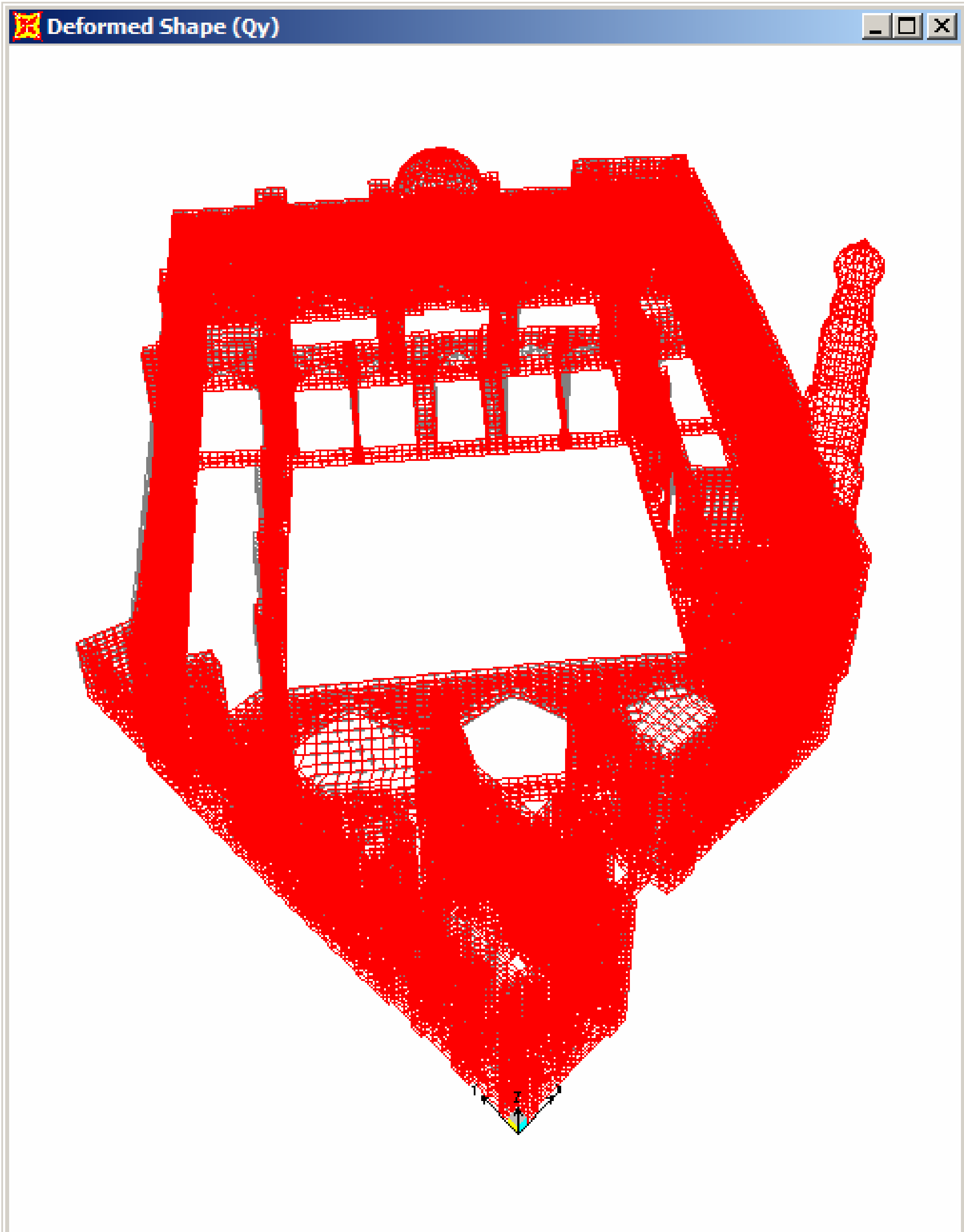
Picture (C-1): 3D finite elements model for Blue Mosque.



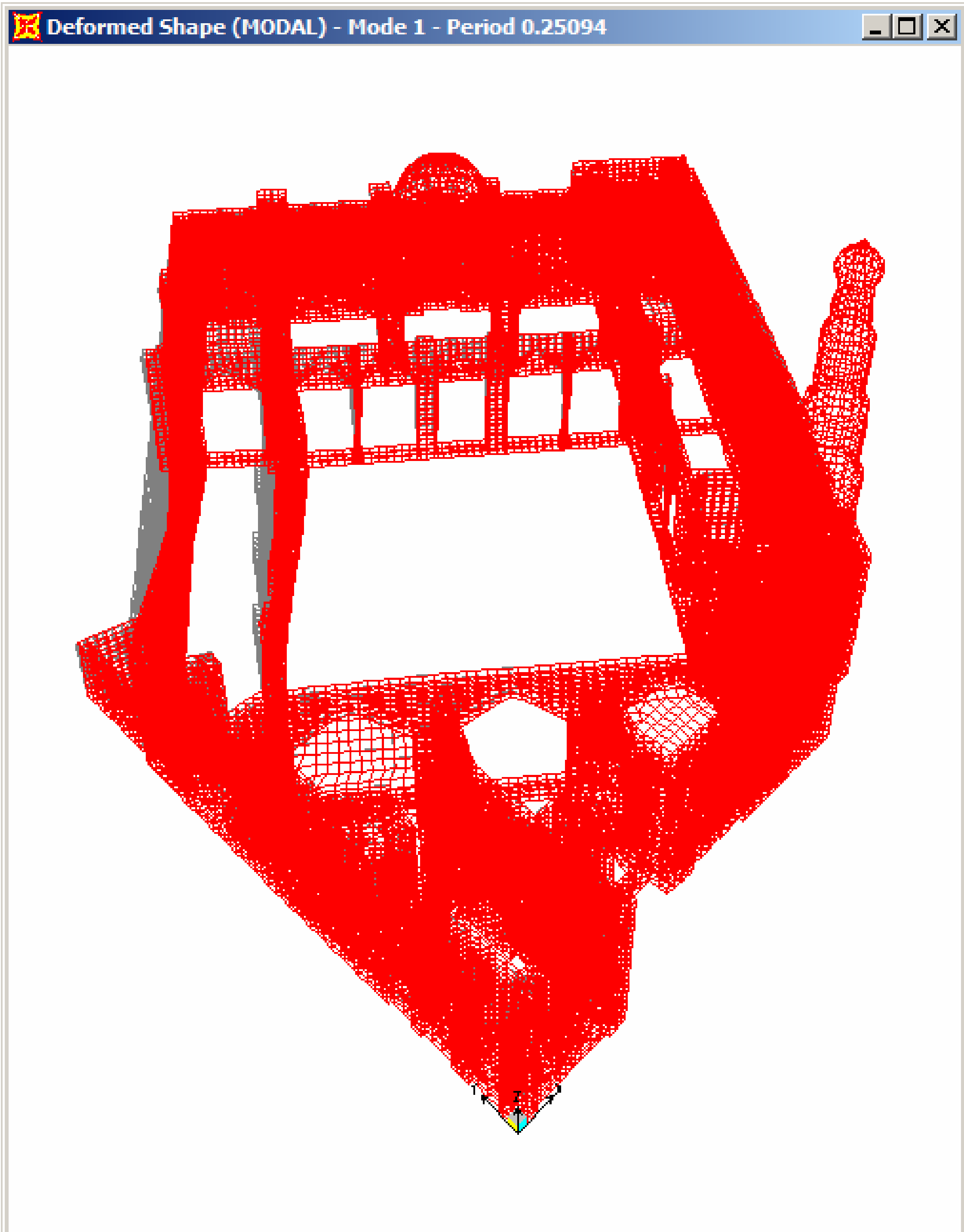
Picture (C-2): Deformed shape under dead and live loads effect.



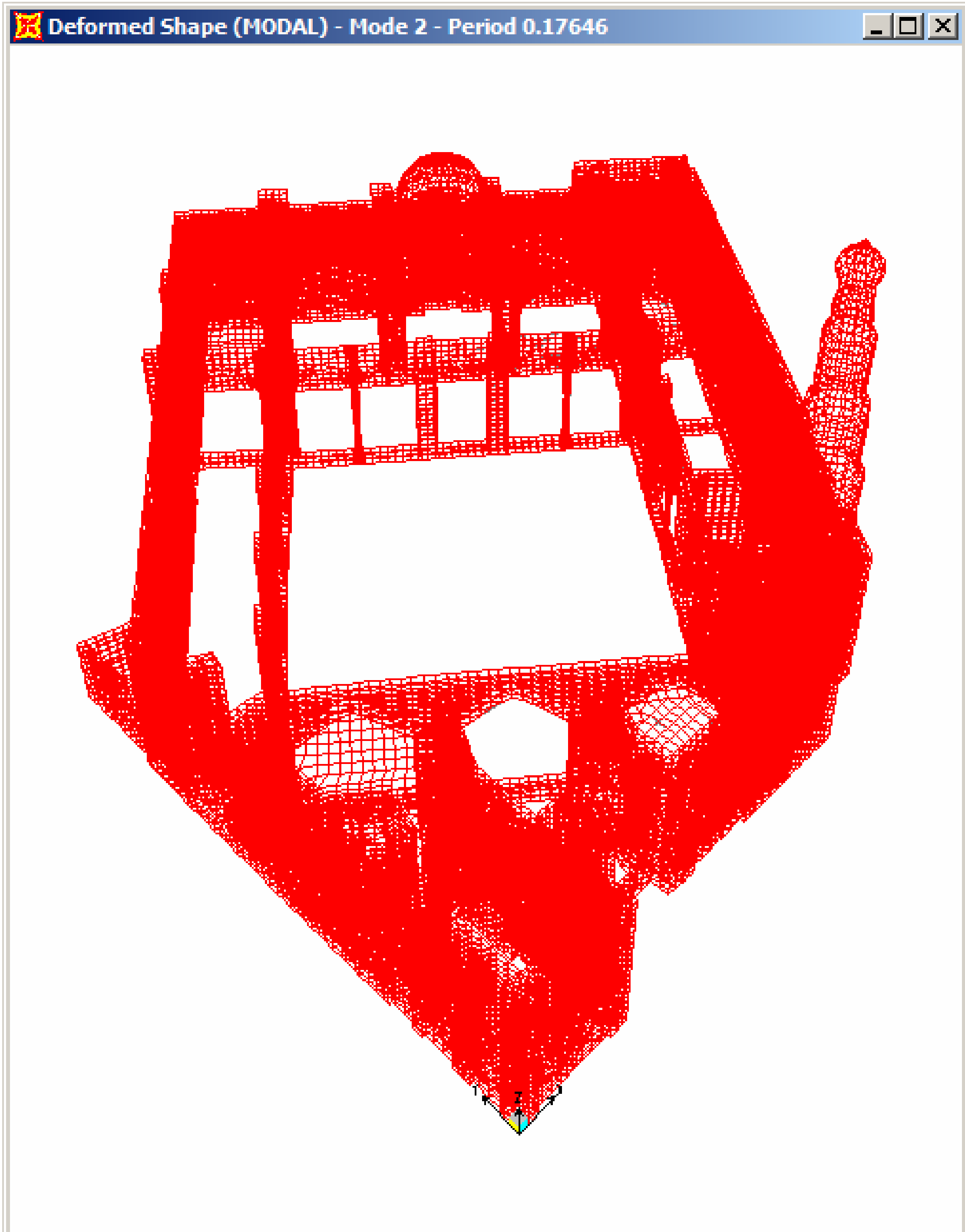
Picture (C-3): Deformed shape under seismic loads effect in X-direction.



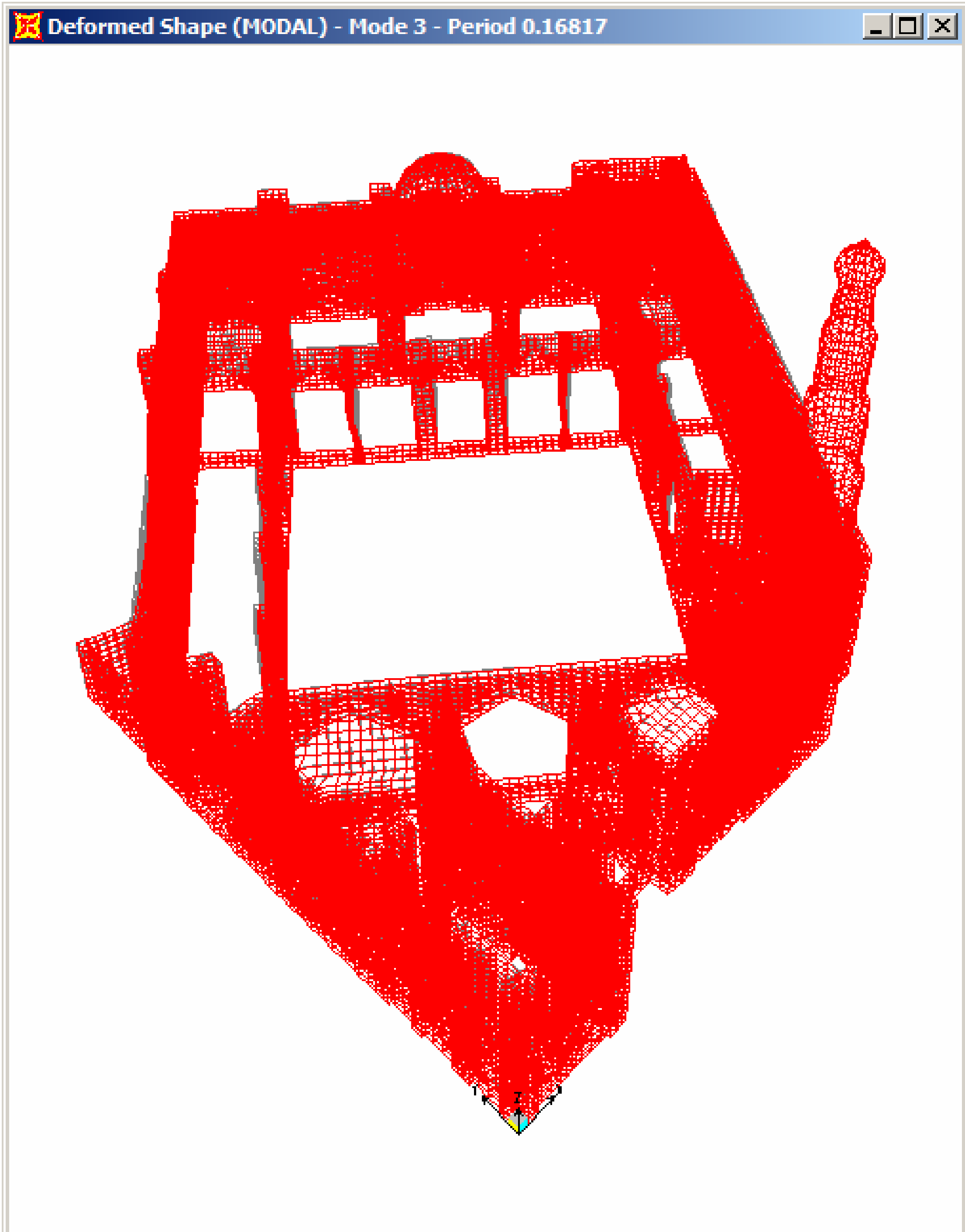
Picture (C-4): Deformed shape under seismic loads effect in Y-direction.



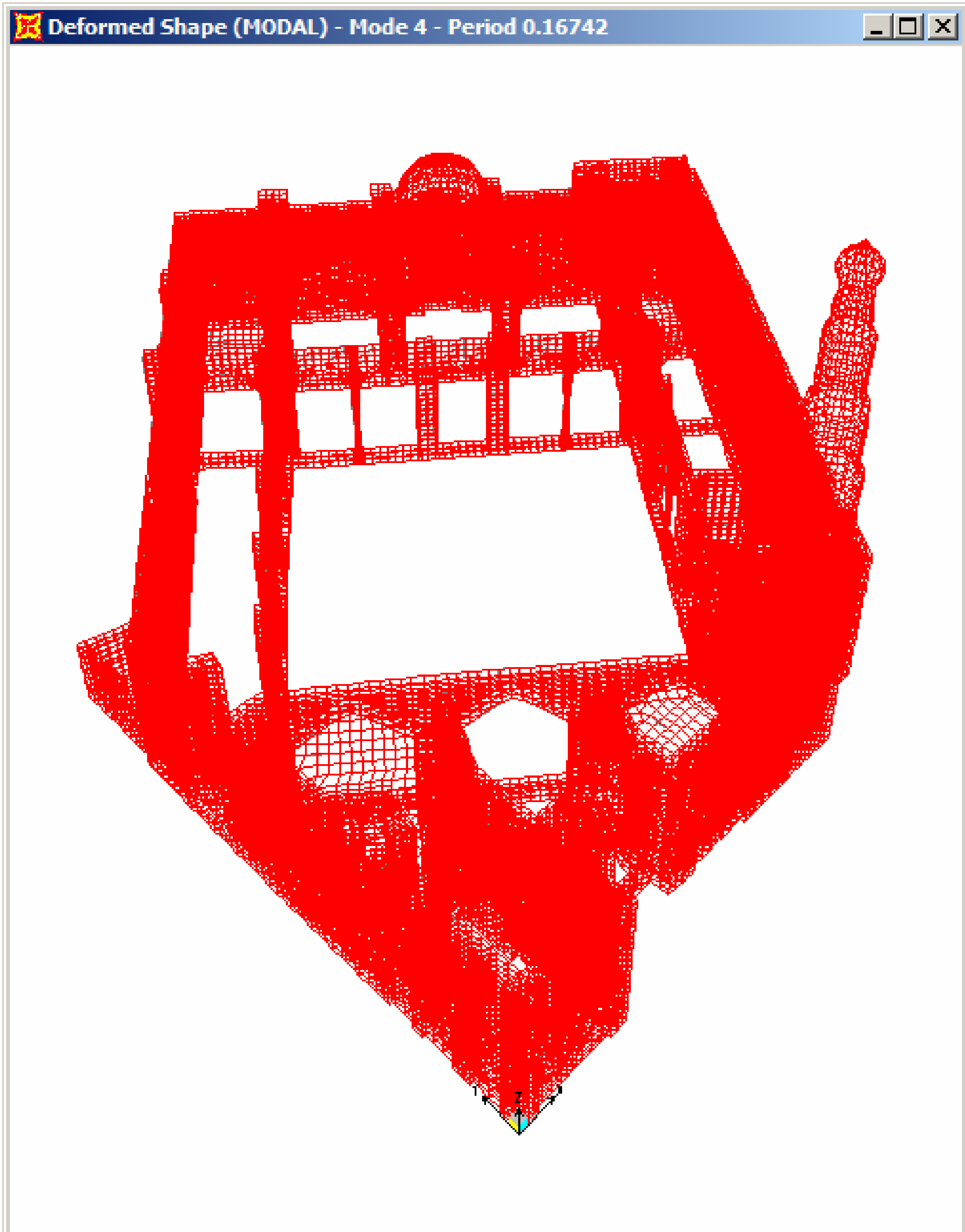
Picture (C-5): Mode shape No. 1.



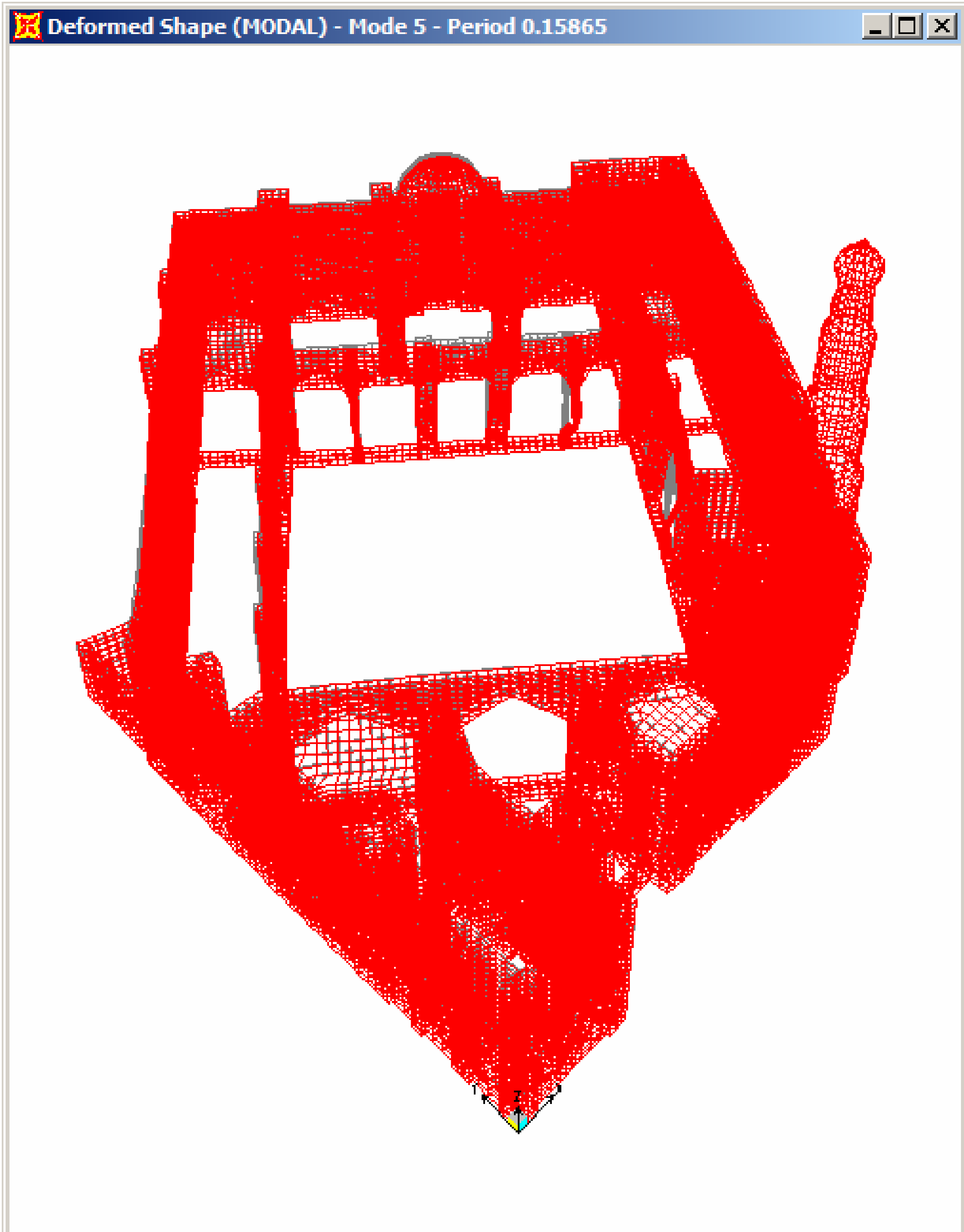
Picture (C-6): Mode shape No. 2.



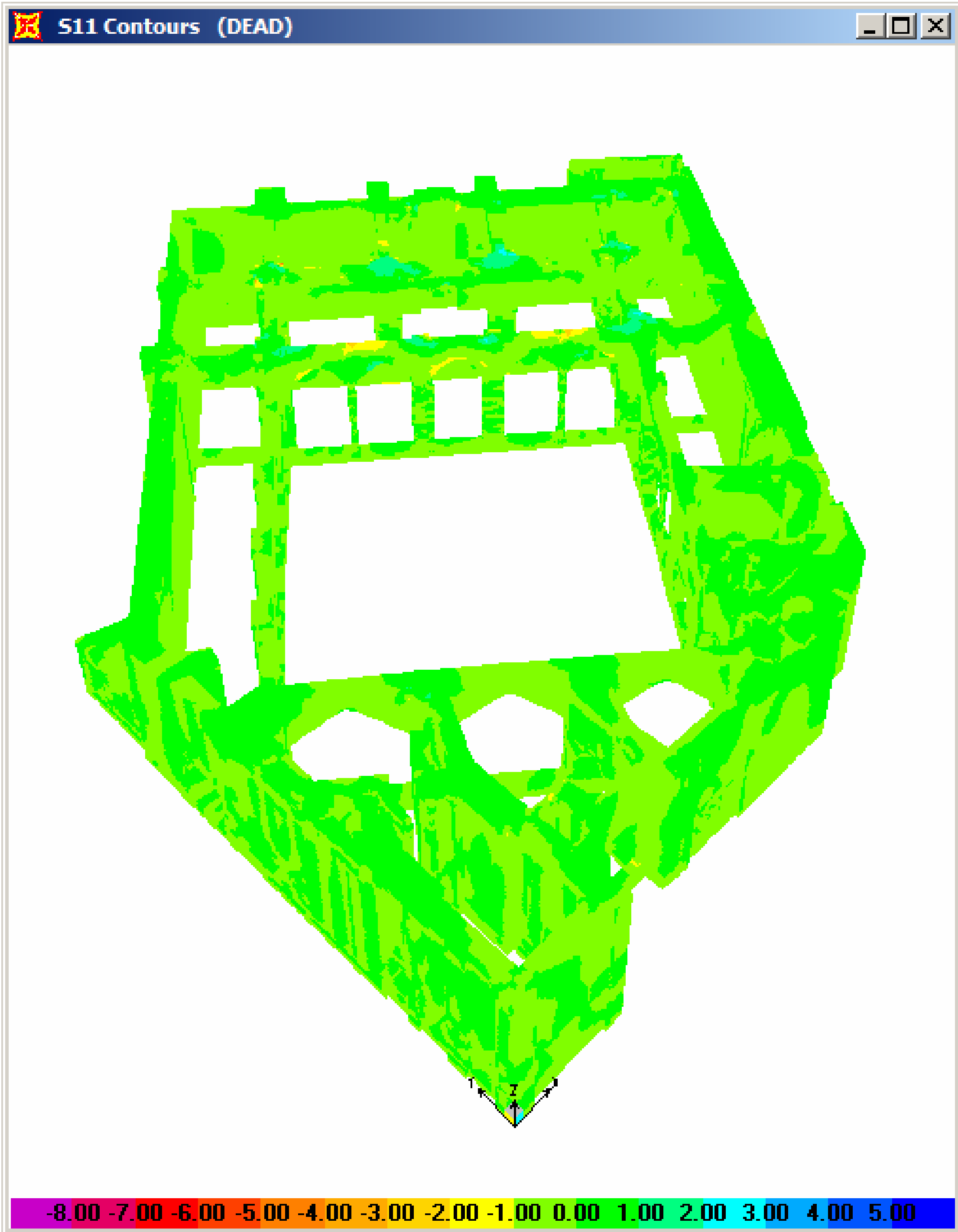
Picture (C-7): Mode shape No. 3.



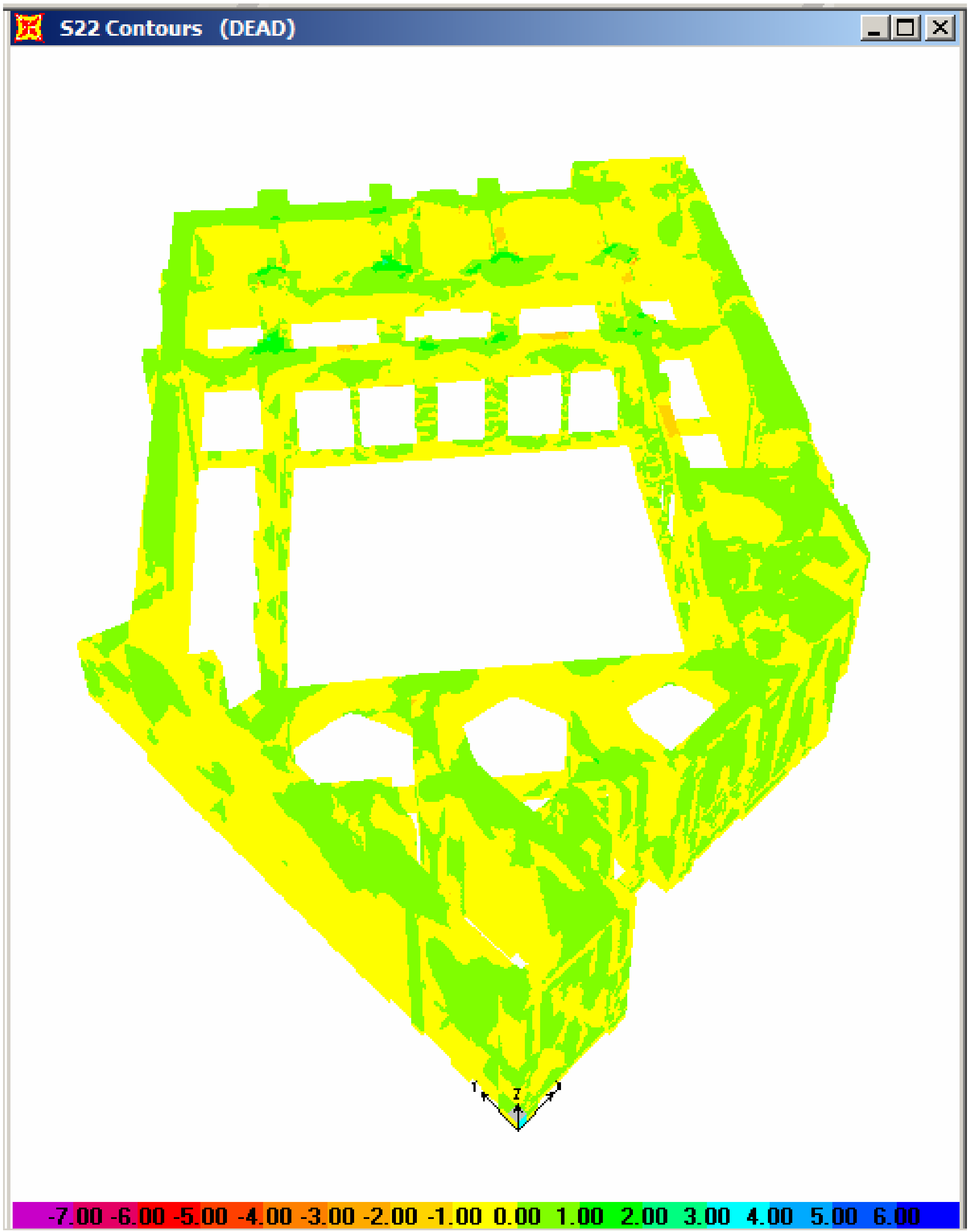
Picture (C-8): Mode shape No. 4.



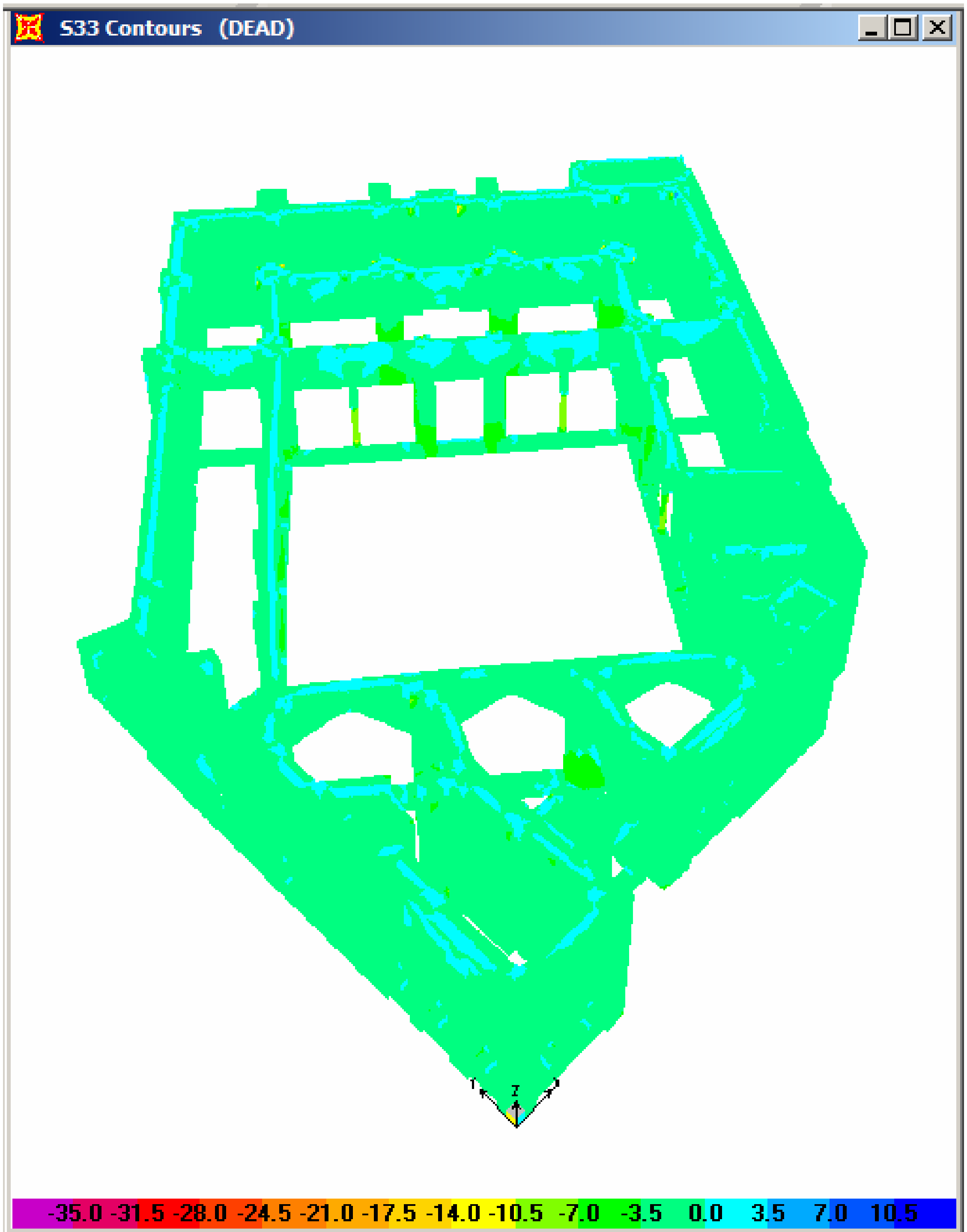
Picture (C-9): Mode shape No. 5.



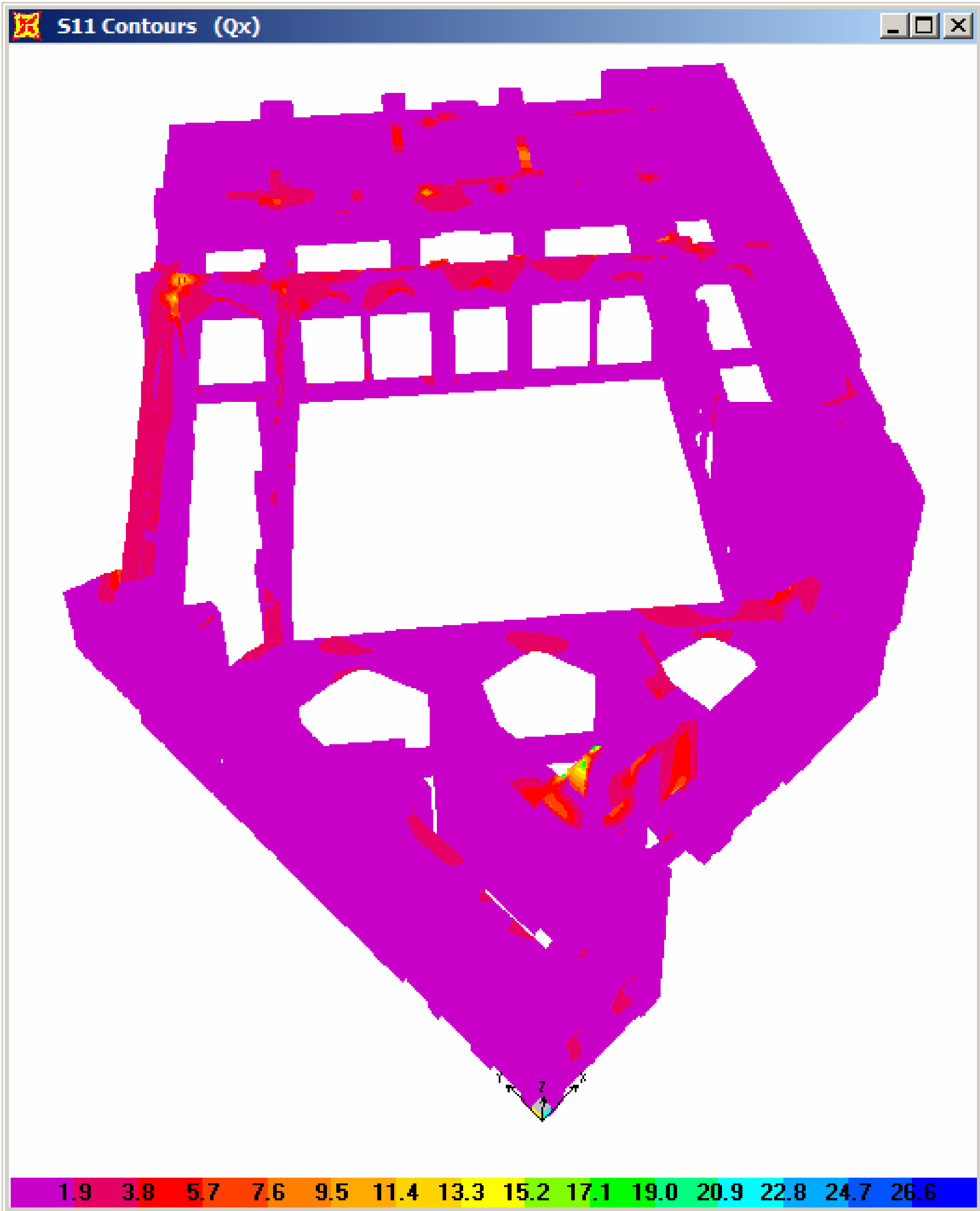
Picture (C-10): Horizontal stresses (S11) under dead and live loads effect.



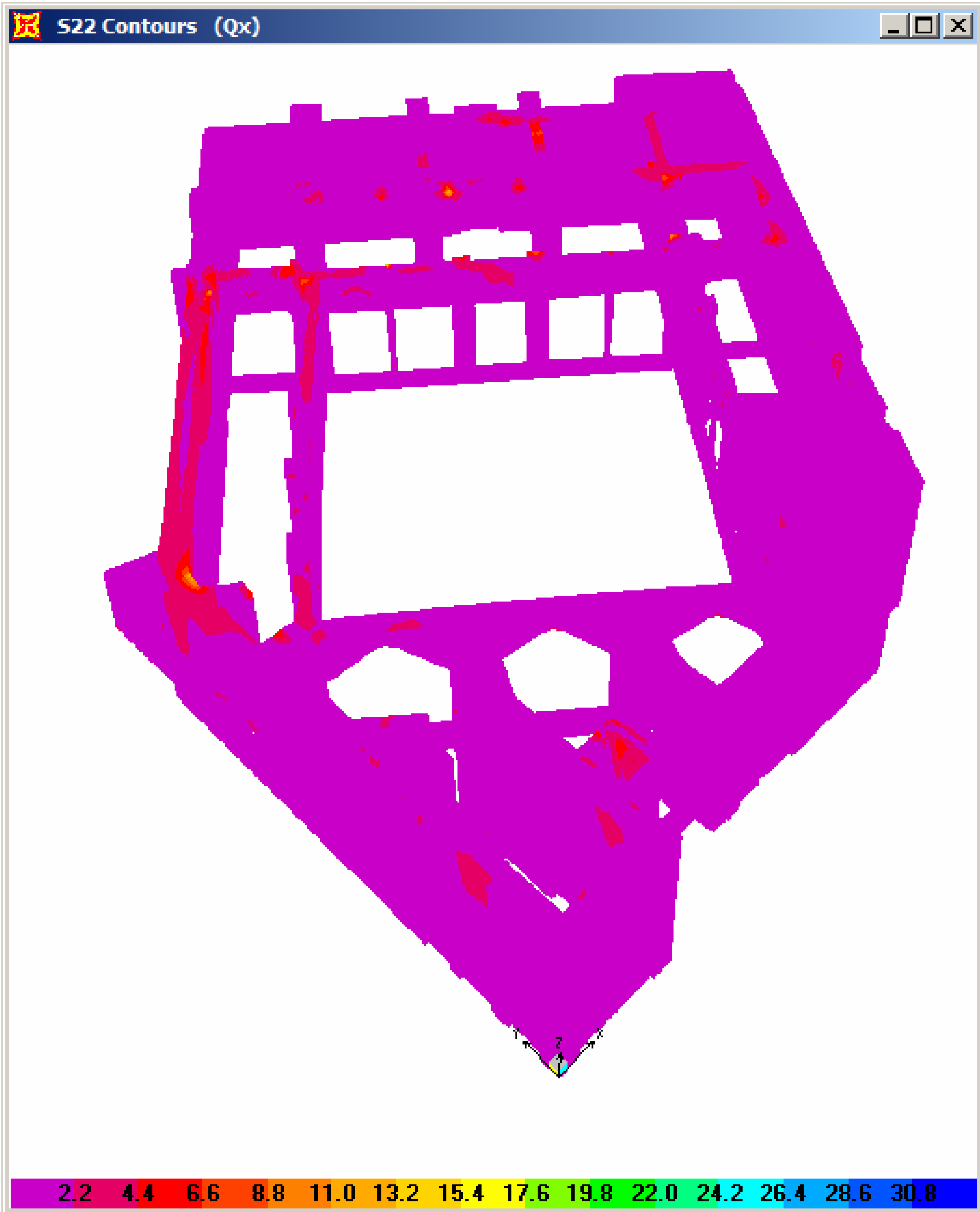
Picture (C-11): Horizontal stresses (S22) under dead and live loads effect.



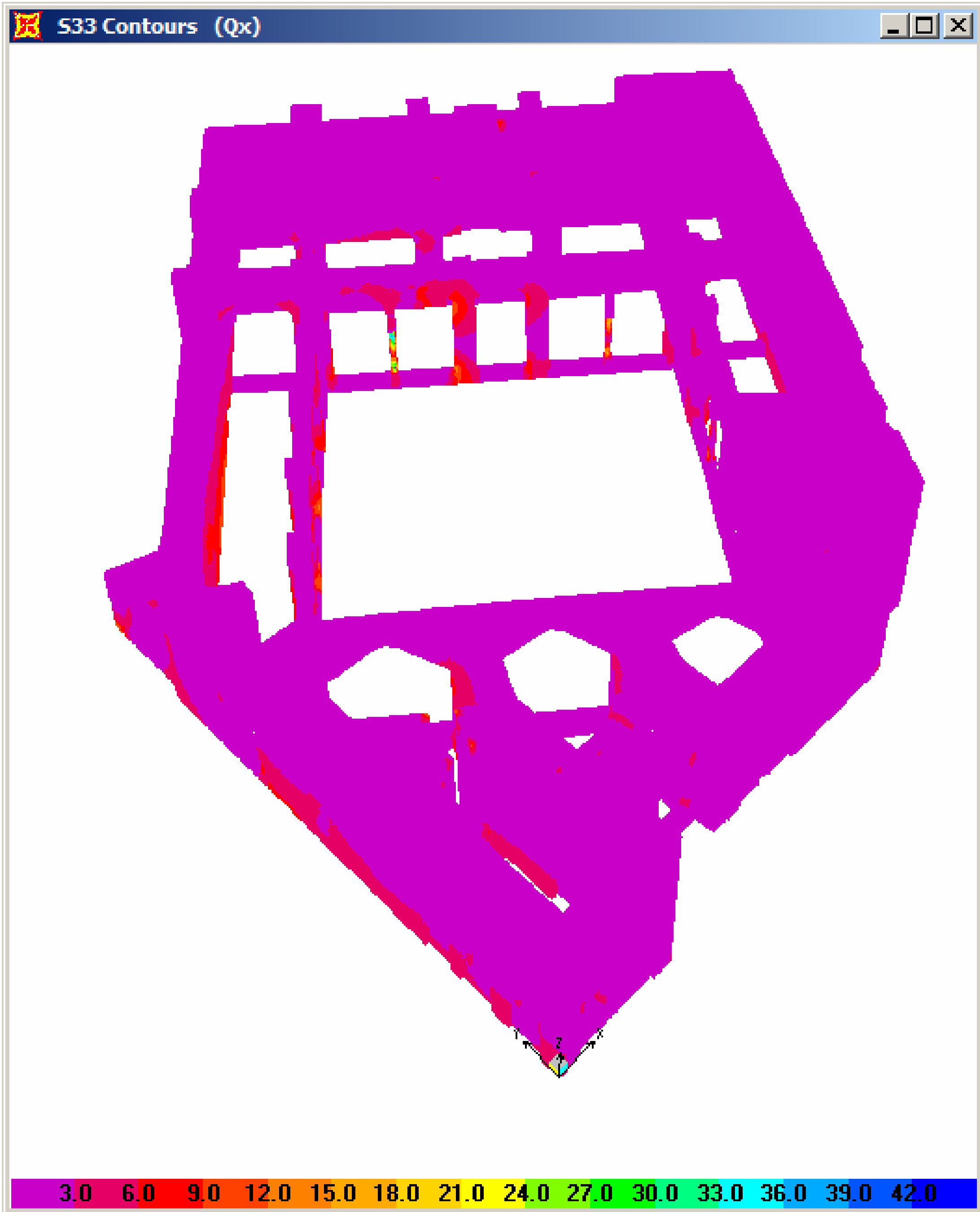
Picture (C-12): Vertical stresses (S33) under dead and live loads effect.



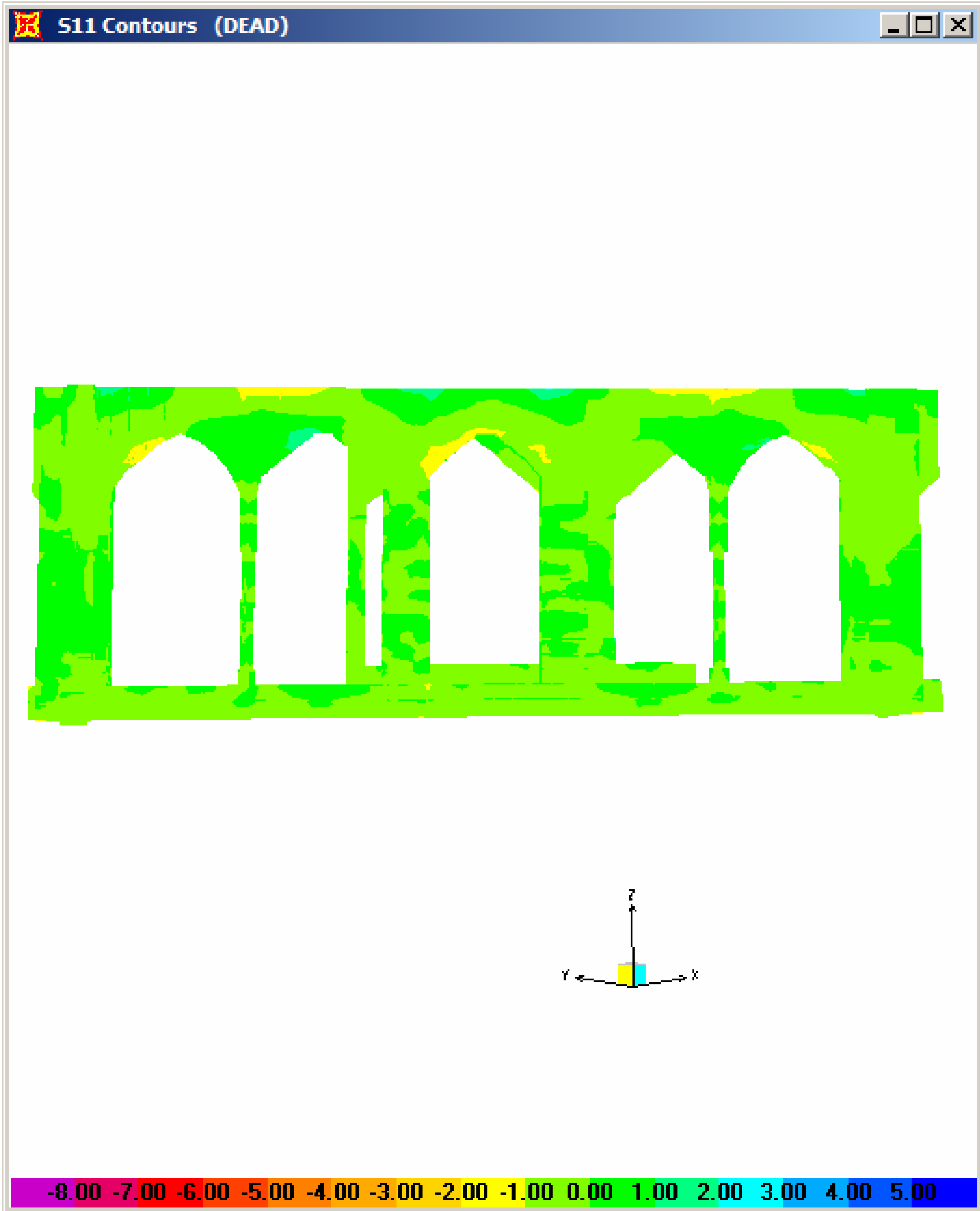
Picture (C-13): Horizontal stresses (S11) under seismic load effect.



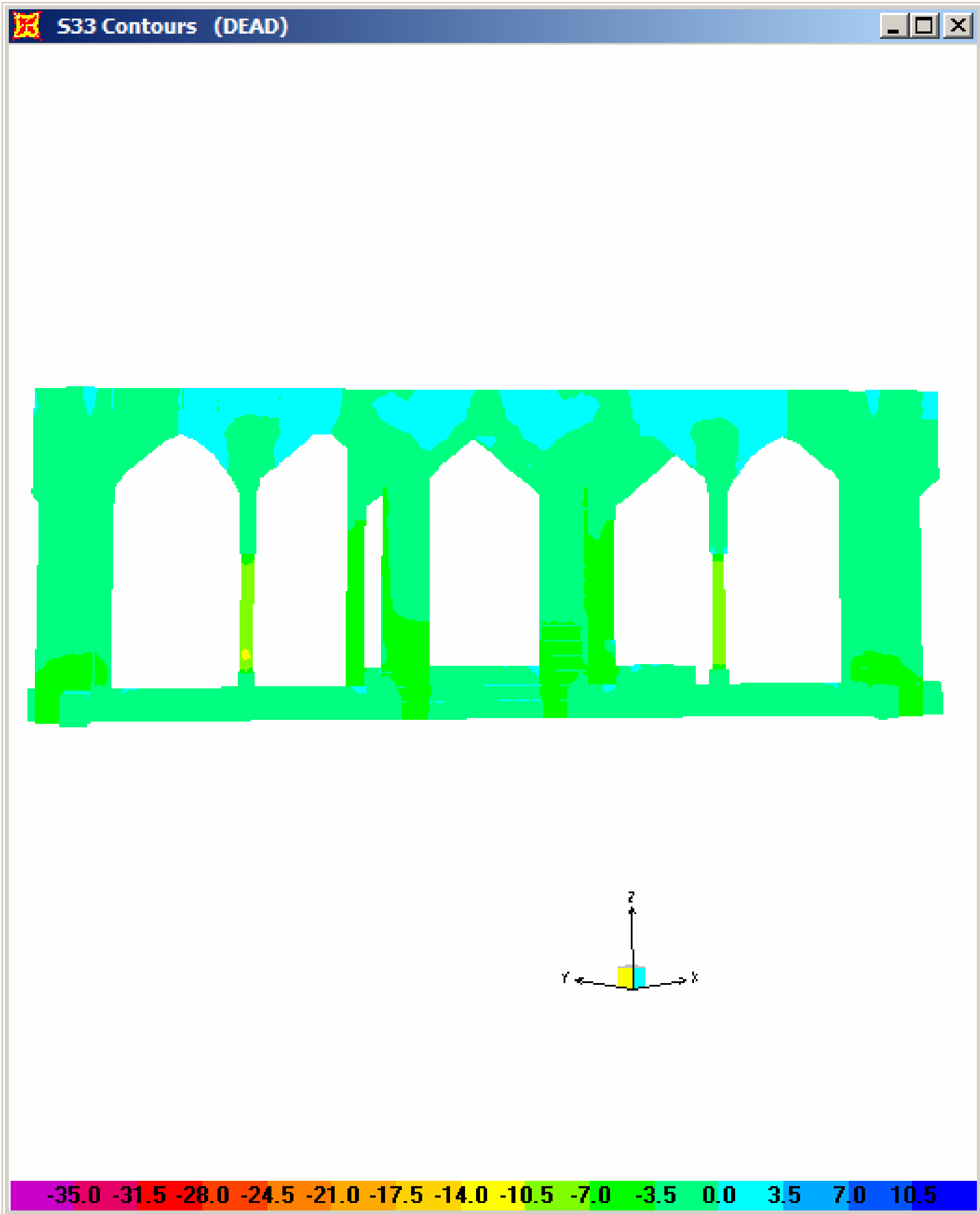
Picture (C-14): Horizontal stresses (S22) under seismic load effect.



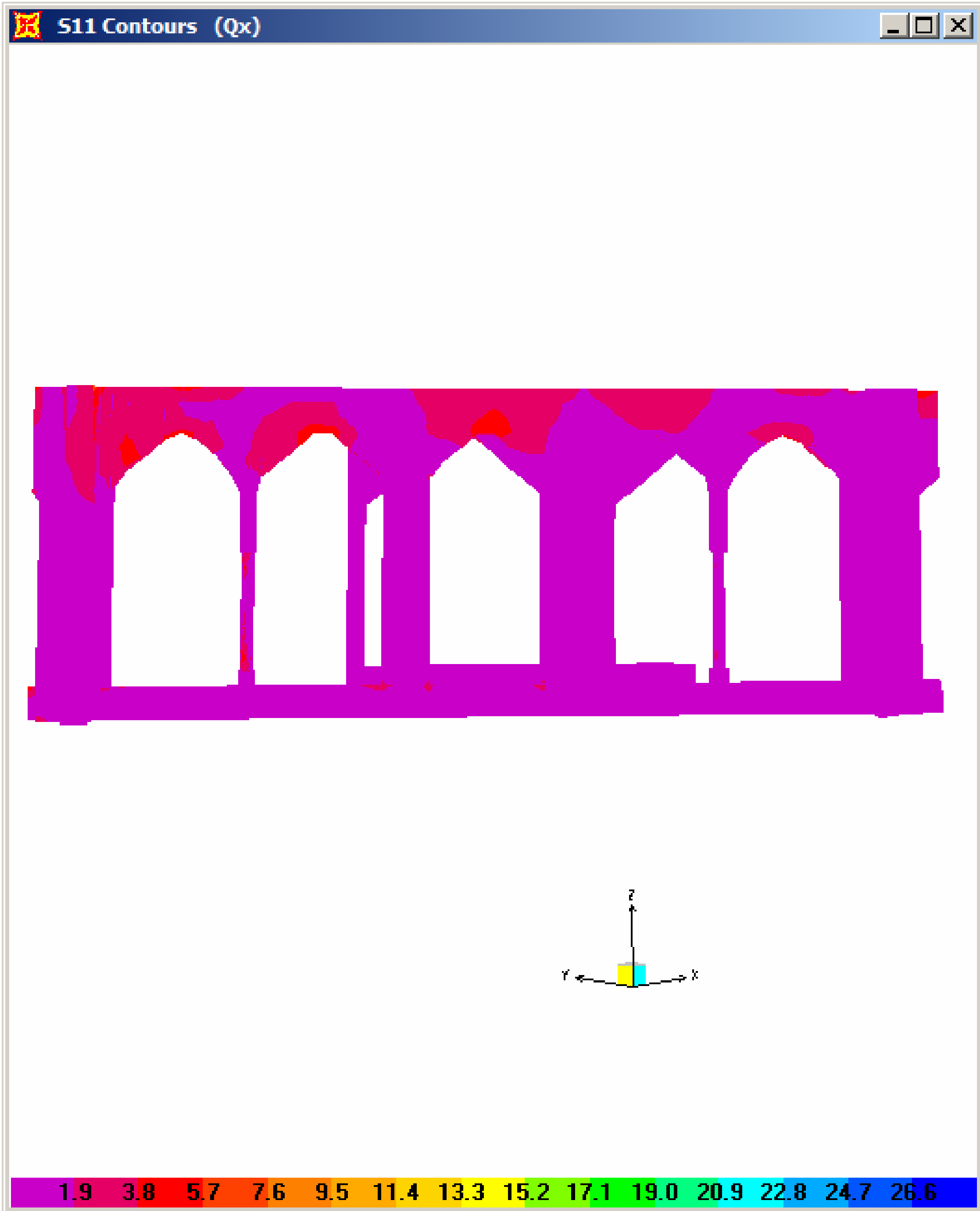
Picture (C-15): Vertical stresses (S33) under seismic load effect.



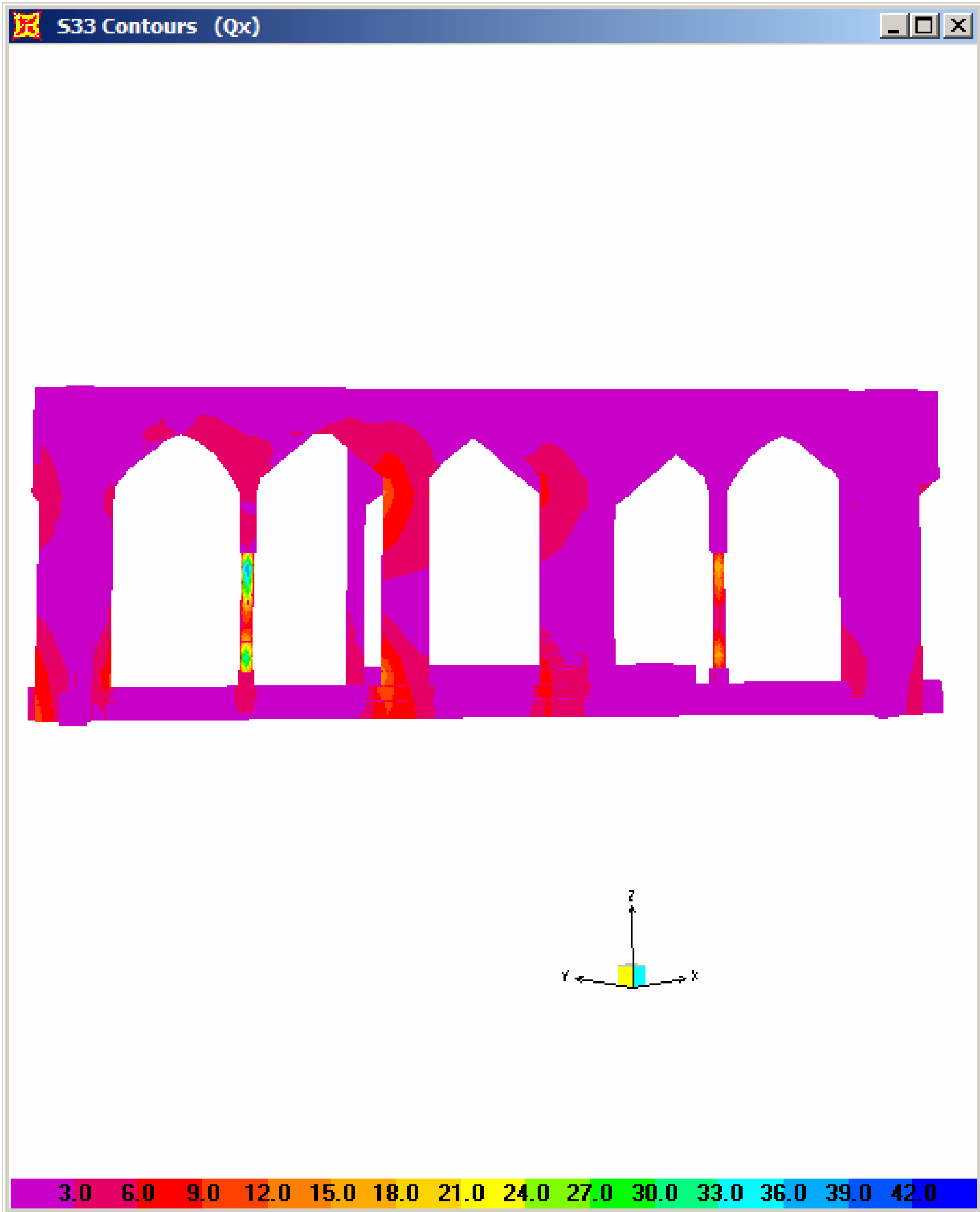
Picture (C-16): Horizontal stresses under dead and live loads effect in arches zone.



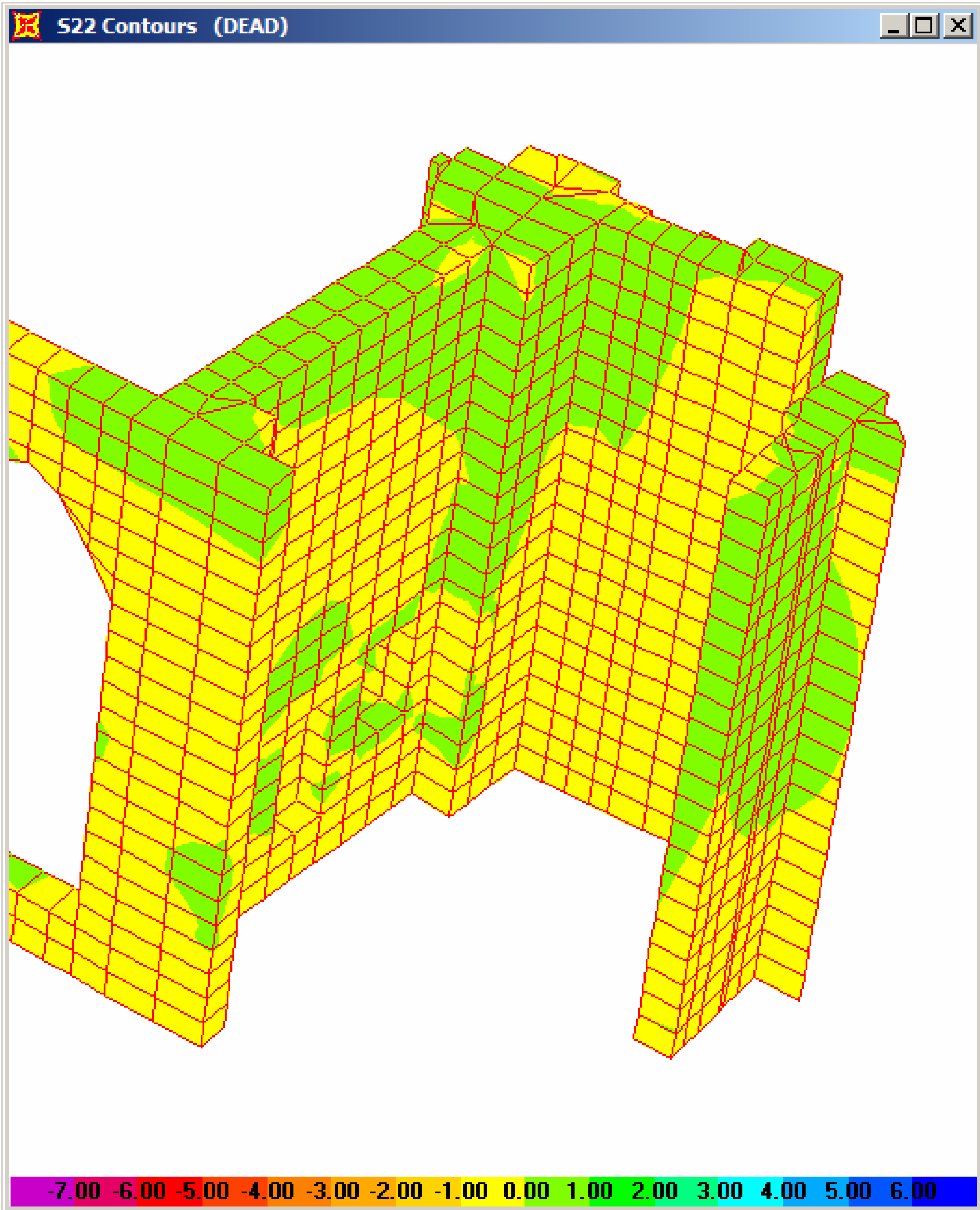
Picture (C-17): Vertical stresses under dead and live loads effect in arches zone.



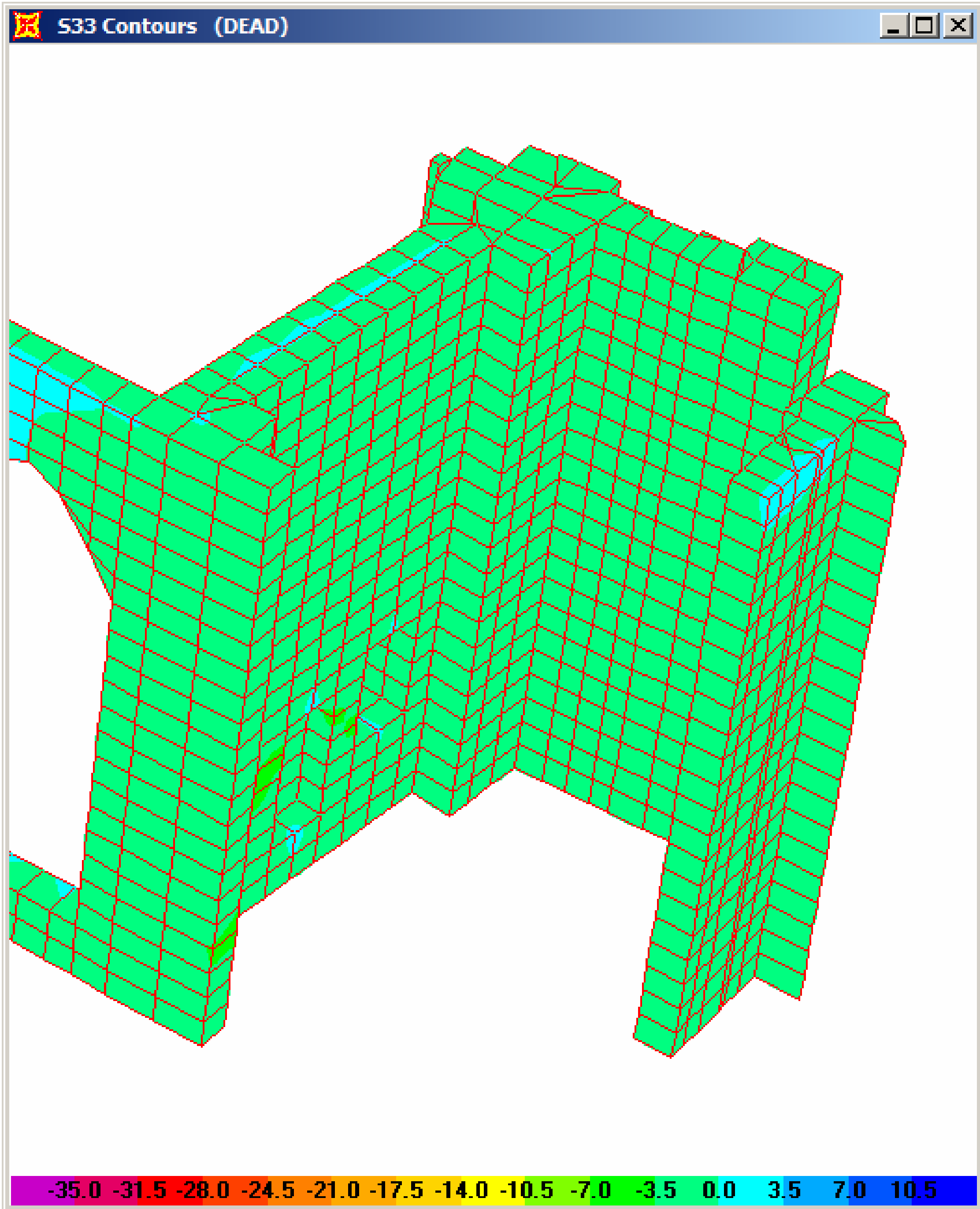
Picture (C-18): Horizontal stresses under seismic load effect in arches zone.



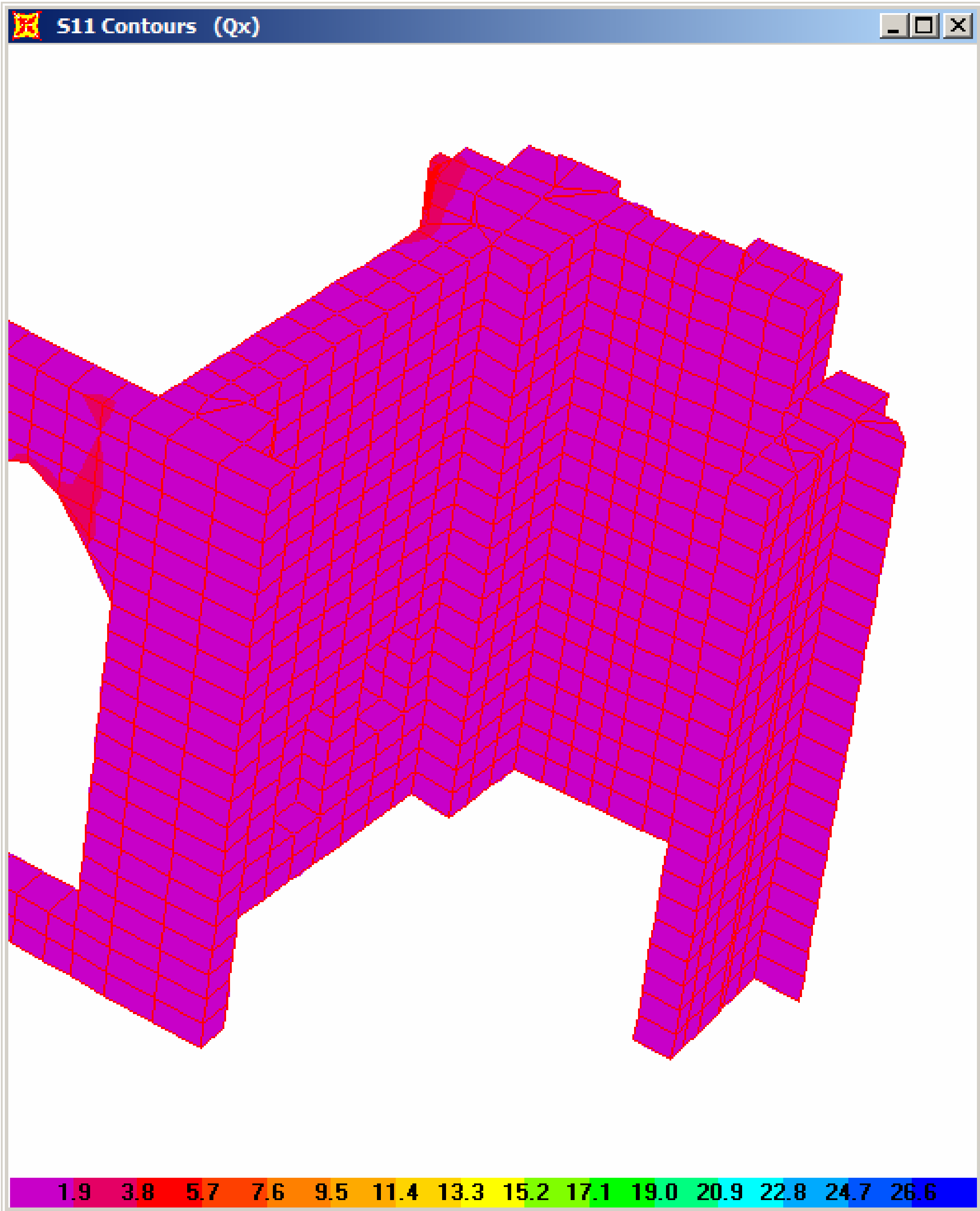
Picture (C-19): Vertical stresses under seismic load effect in arches zone.



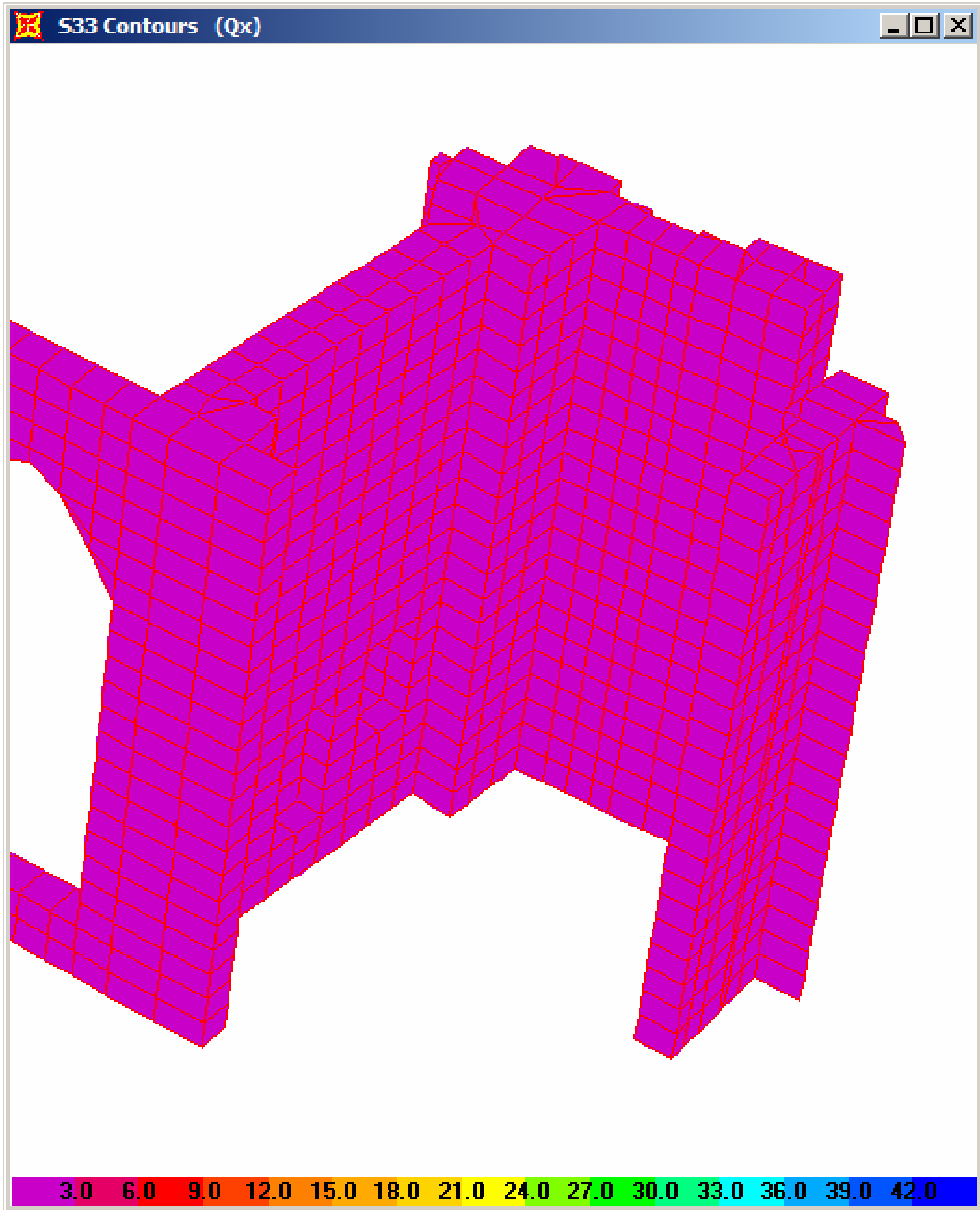
Picture (C-20): Horizontal stresses under D and L loads effect in cemetery zone.



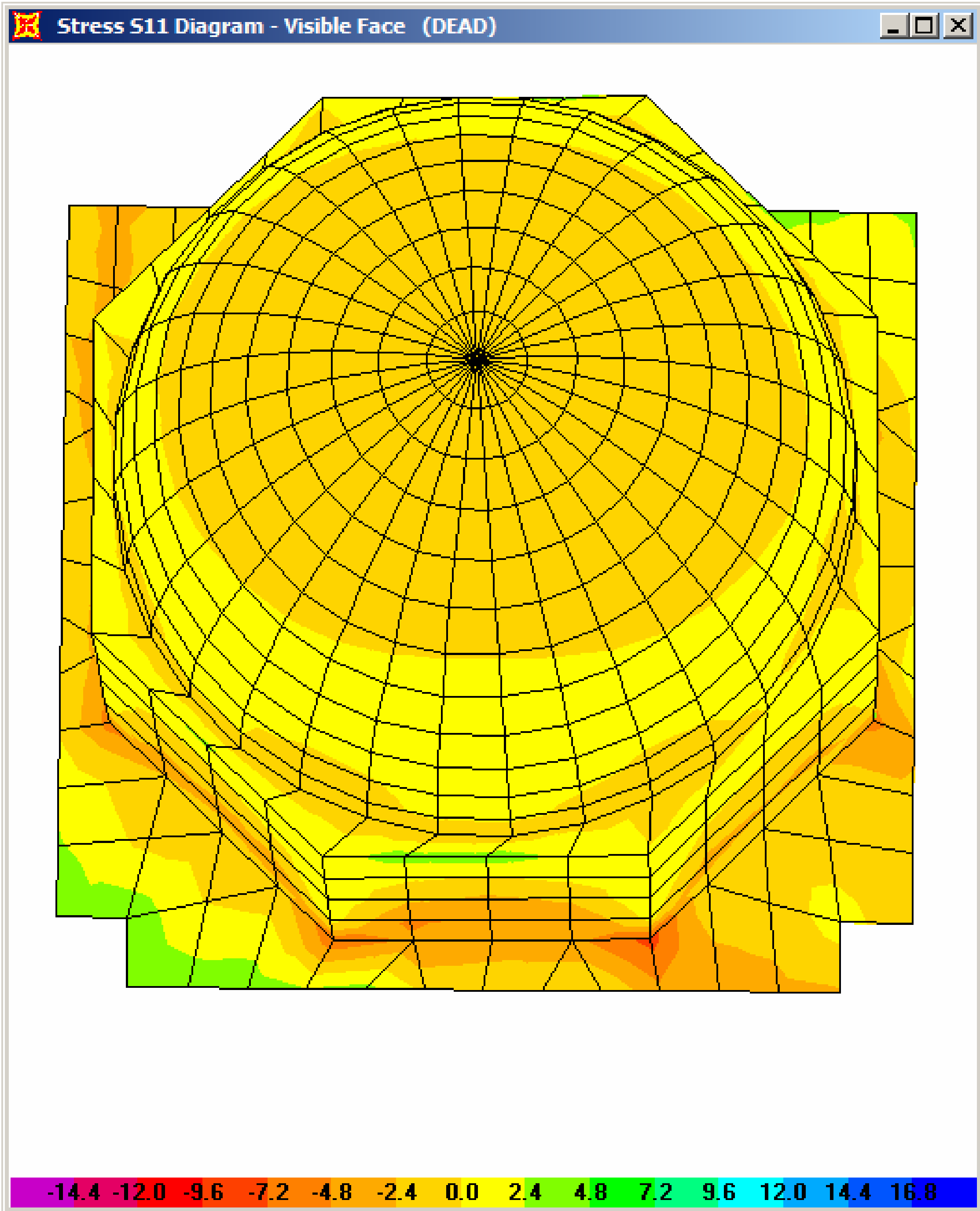
Picture (C-21): Vertical stresses under D and L loads effect in cemetery zone.



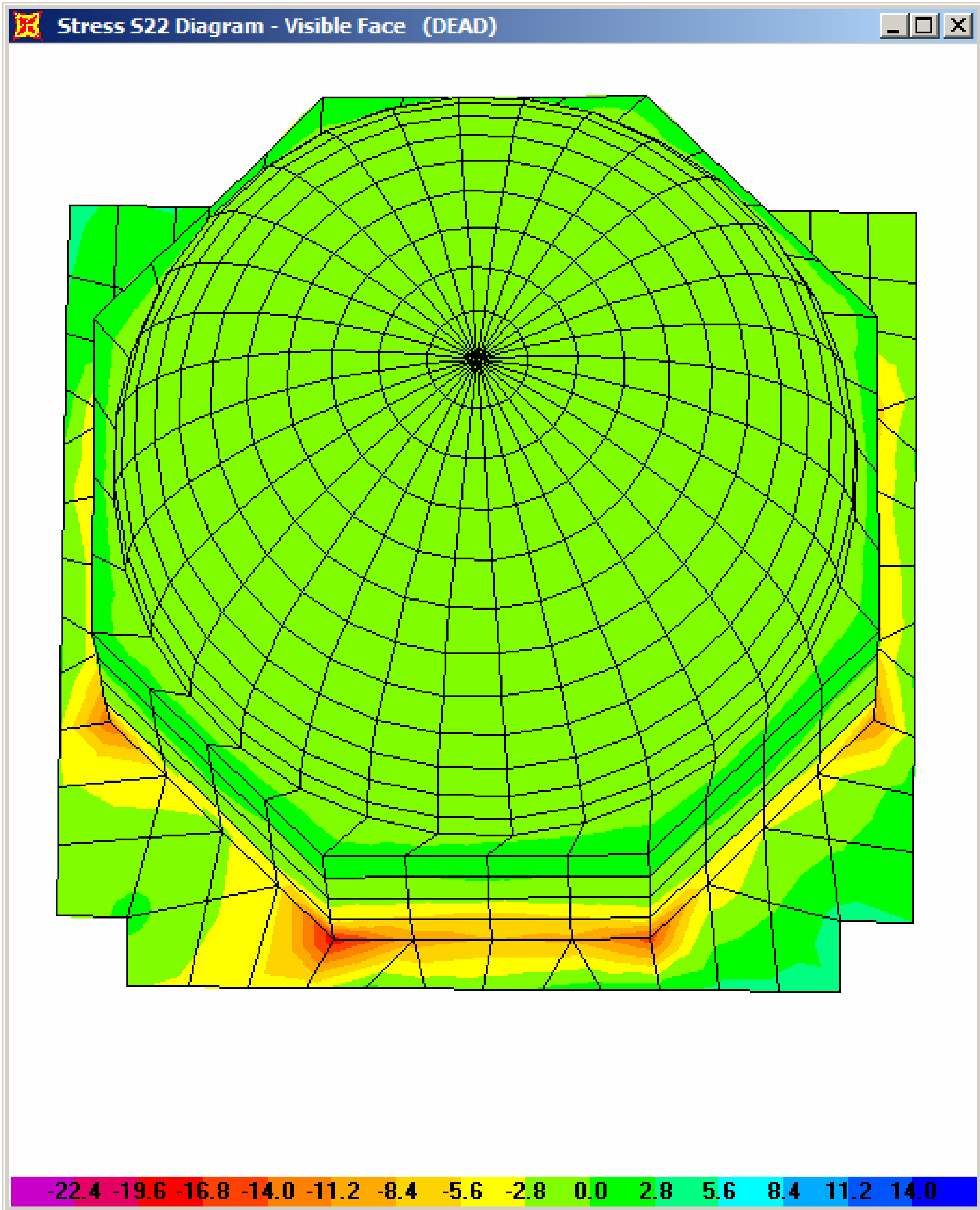
Picture (C-22): Horizontal stresses under seismic load effect in cemetery zone.



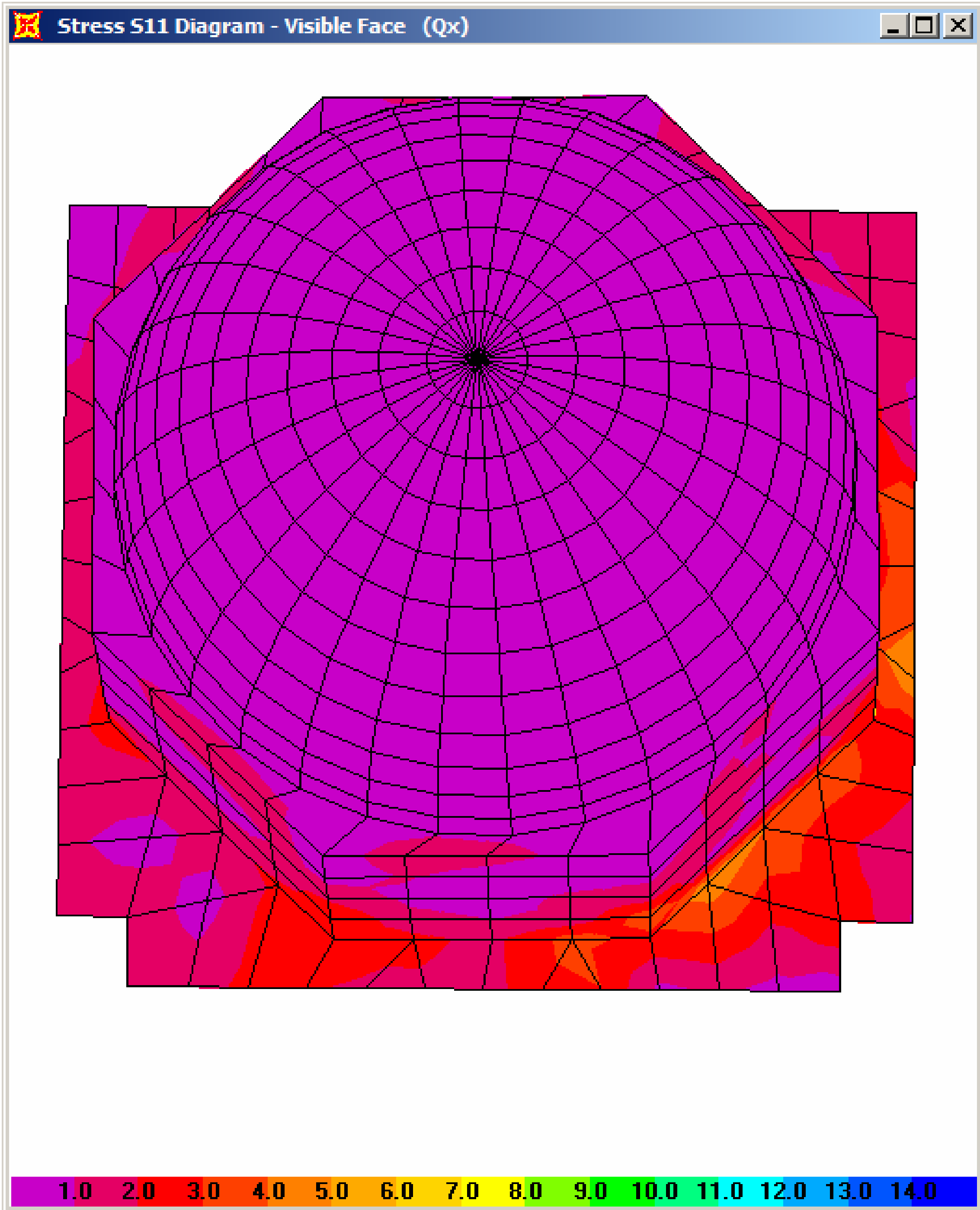
Picture (C-23): Vertical stresses under seismic load effect in cemetery zone.



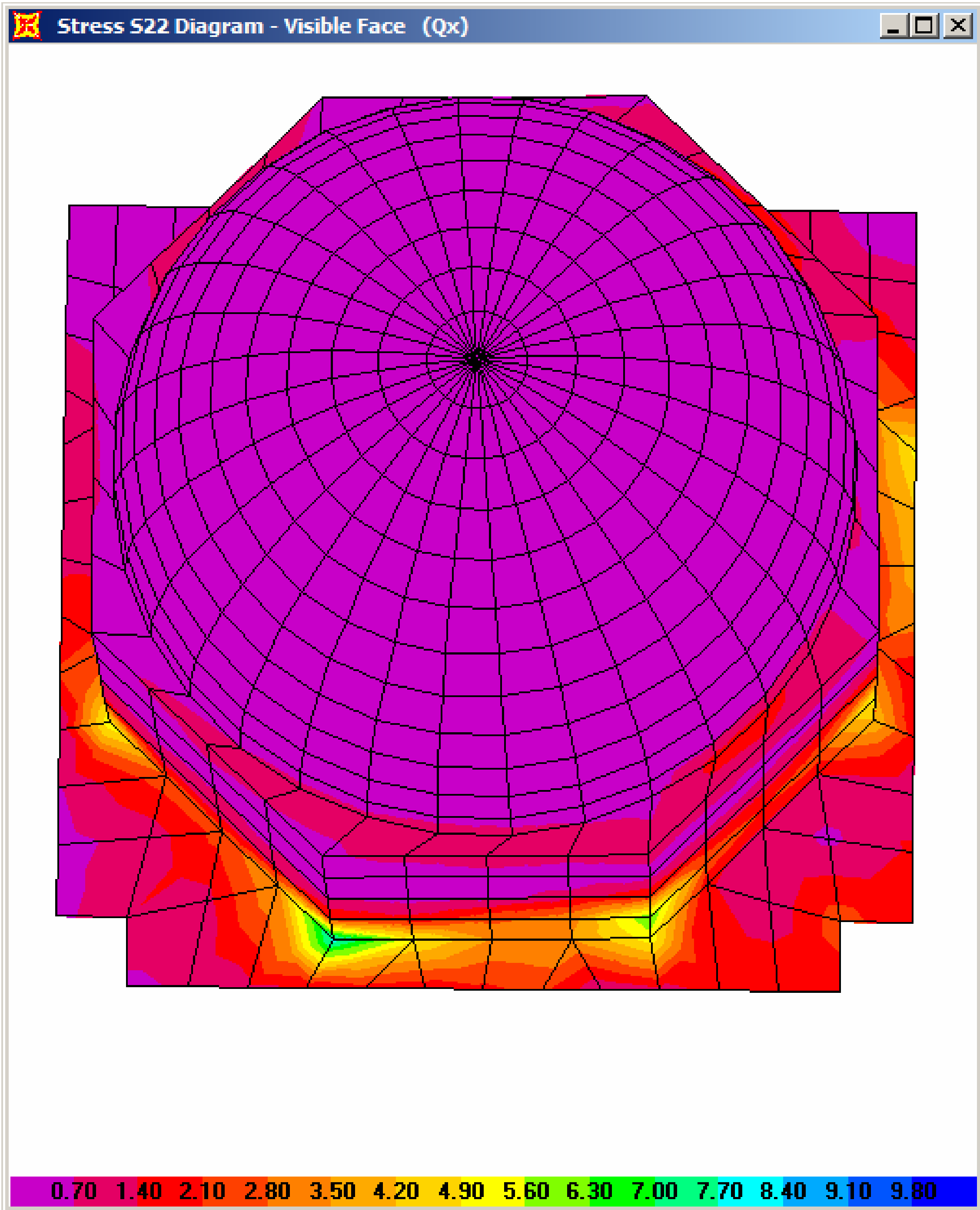
Picture (C-24): Horizontal stresses under dead and live loads effect in main dome.



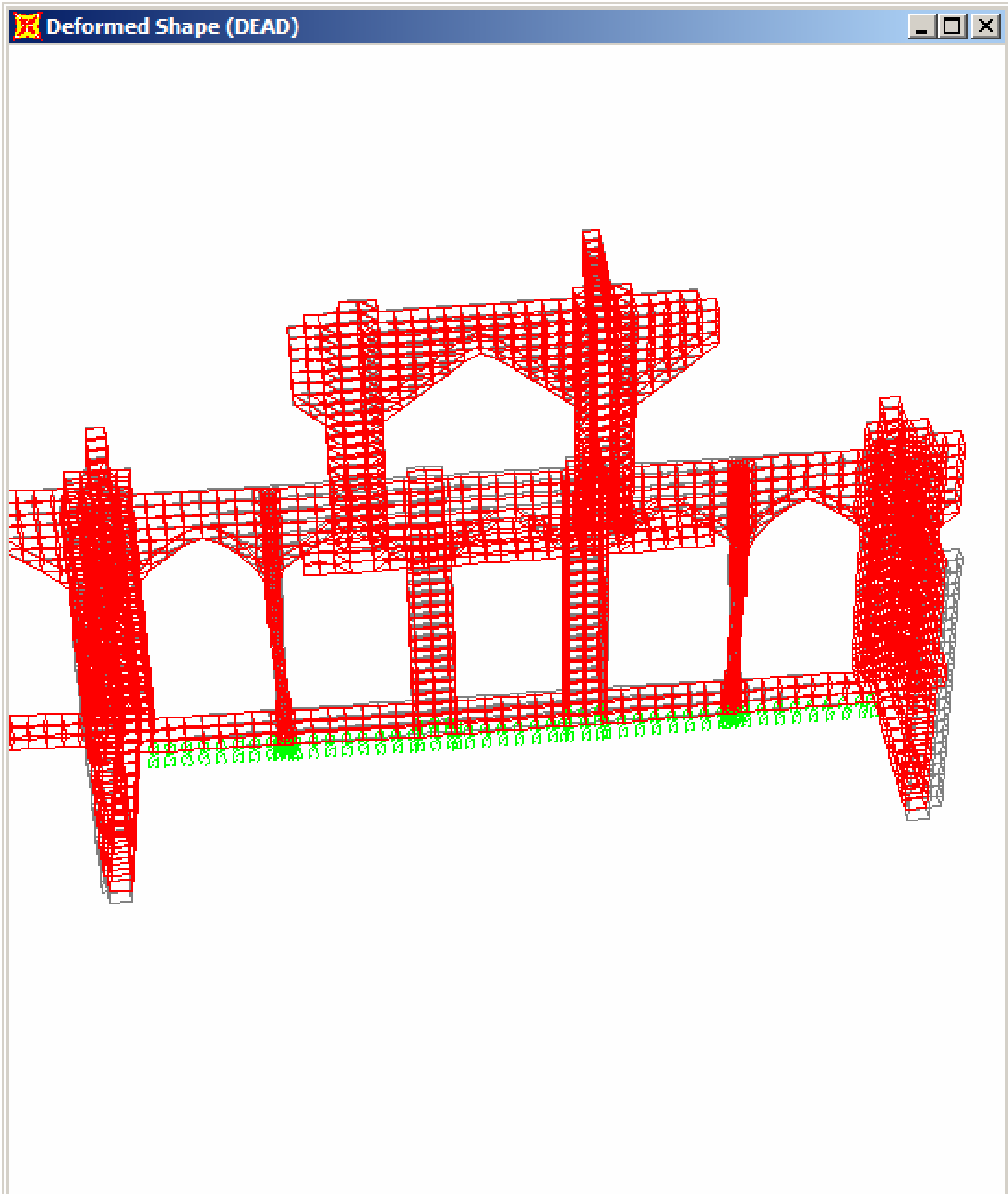
Picture (C-25): Vertical stresses under dead and live loads effect in main dome.



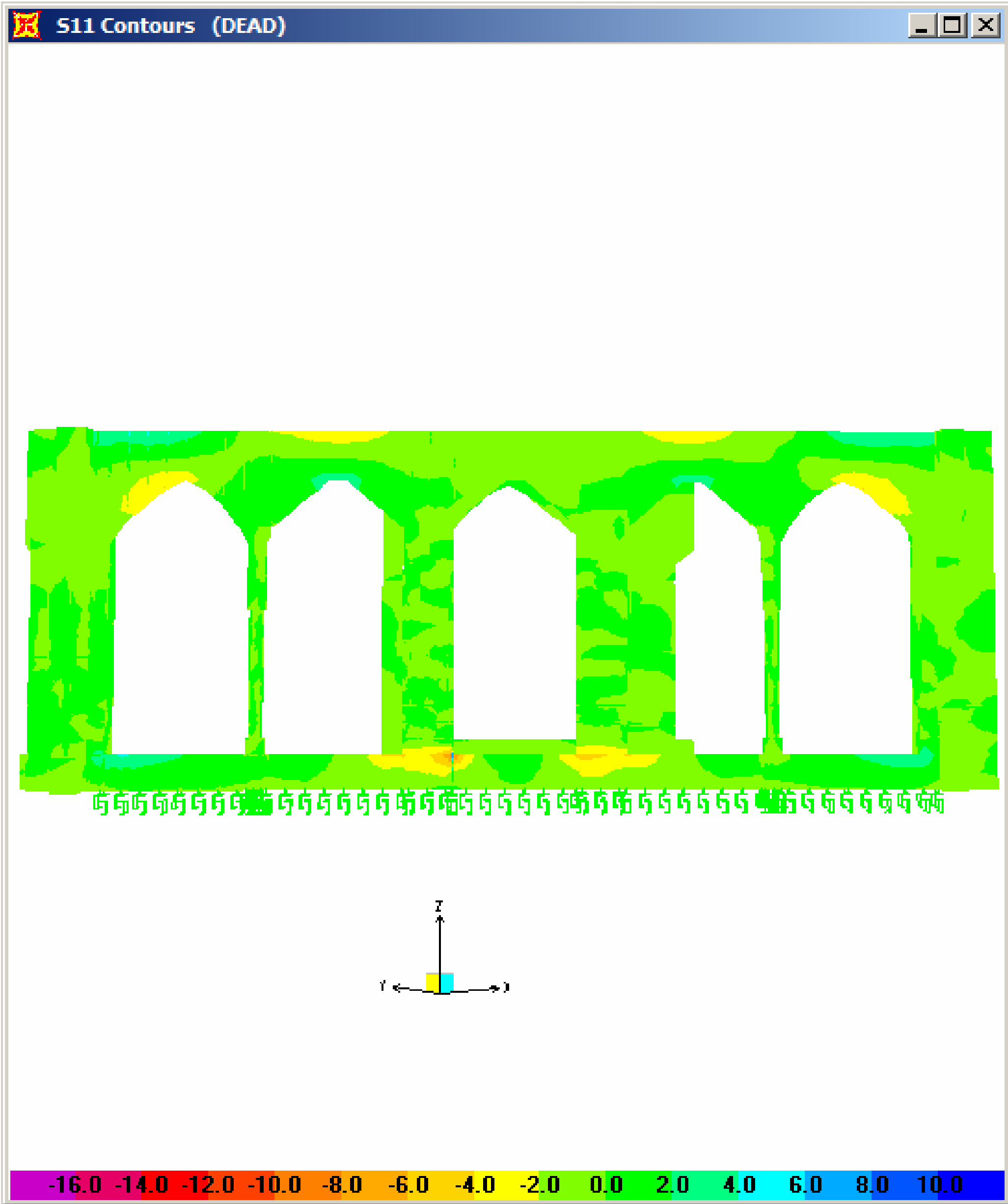
Picture (C-26): Horizontal stresses under seismic load effect in main dome.



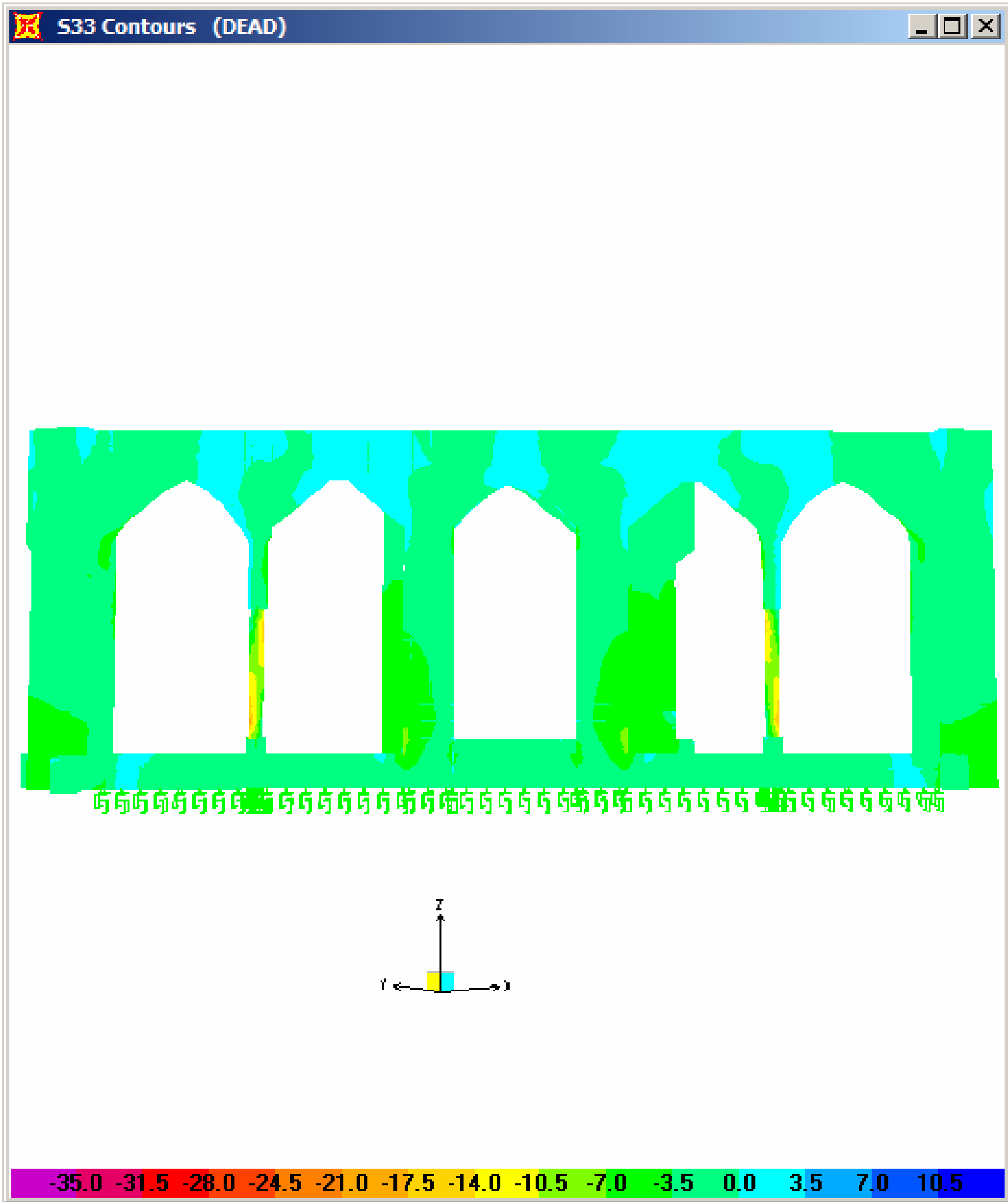
Picture (C-27): Vertical stresses under seismic load effect in main dome.



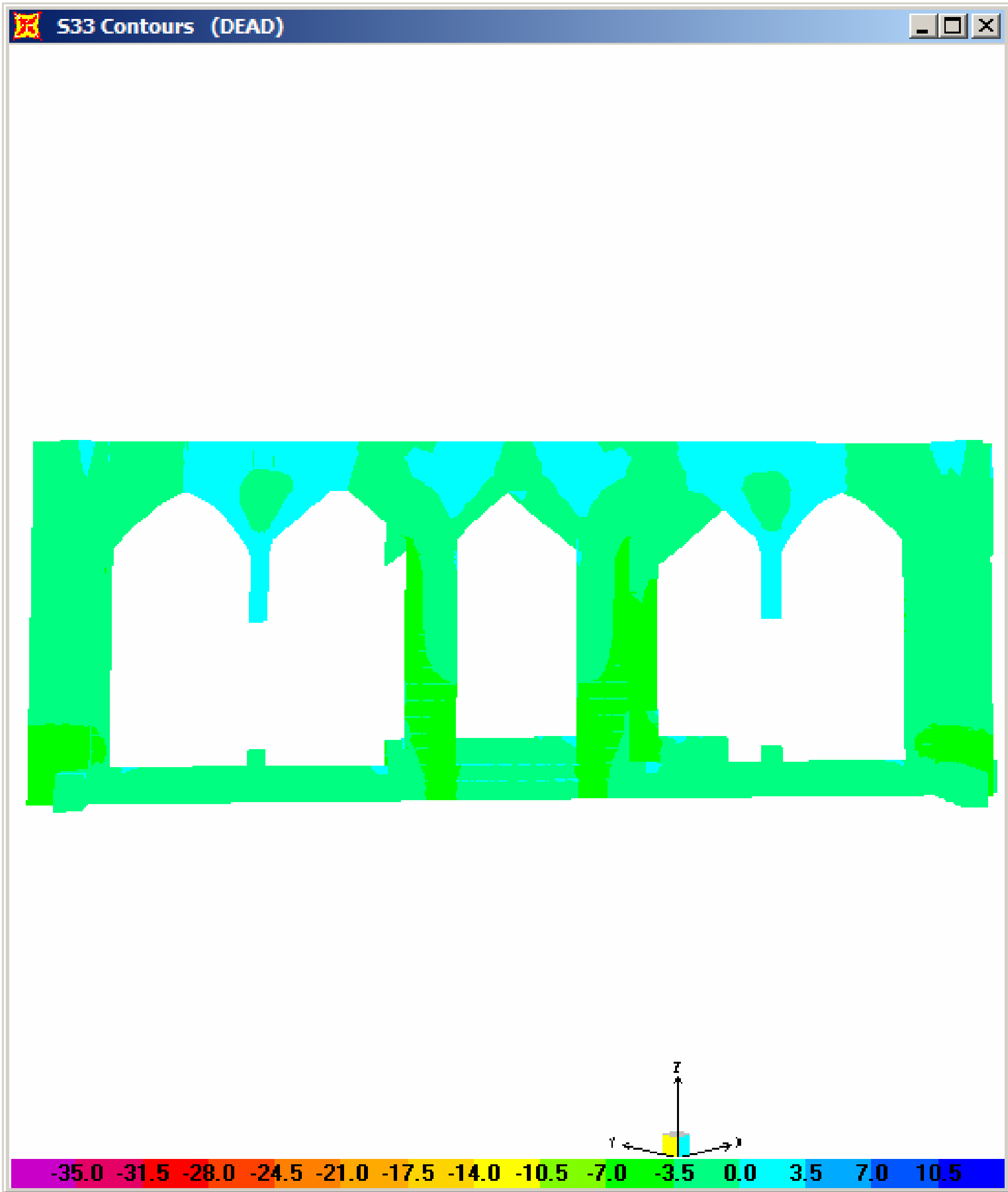
Picture (C-28): Statical system and deformation for the arches assuming settlement along their support line.



Picture (C-29): Horizontal stresses in the arches due to settlement.



Picture (C-30): Vertical stresses in the arches due to settlement.



Picture (C-31): Horizontal stresses in the arches due to column removal.

Picture (C-32): Vertical stresses in the arches due to column removal.

Appendix D

Location and details of open pits.

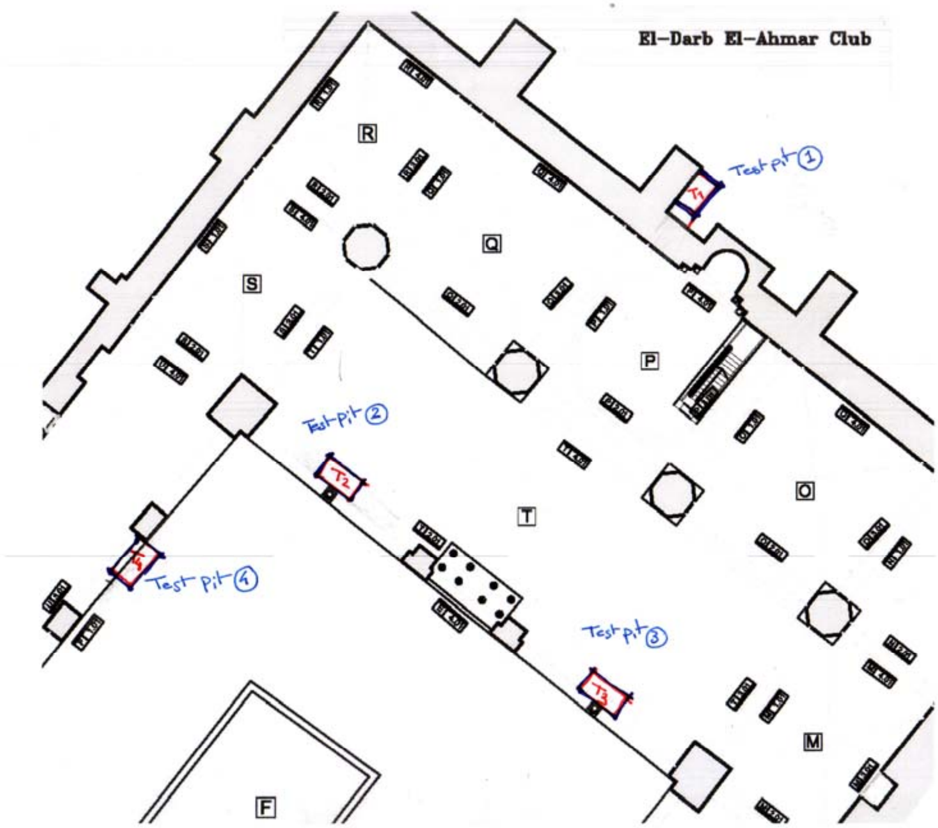


Fig. D1: Location of four open pits to examine the foundations.

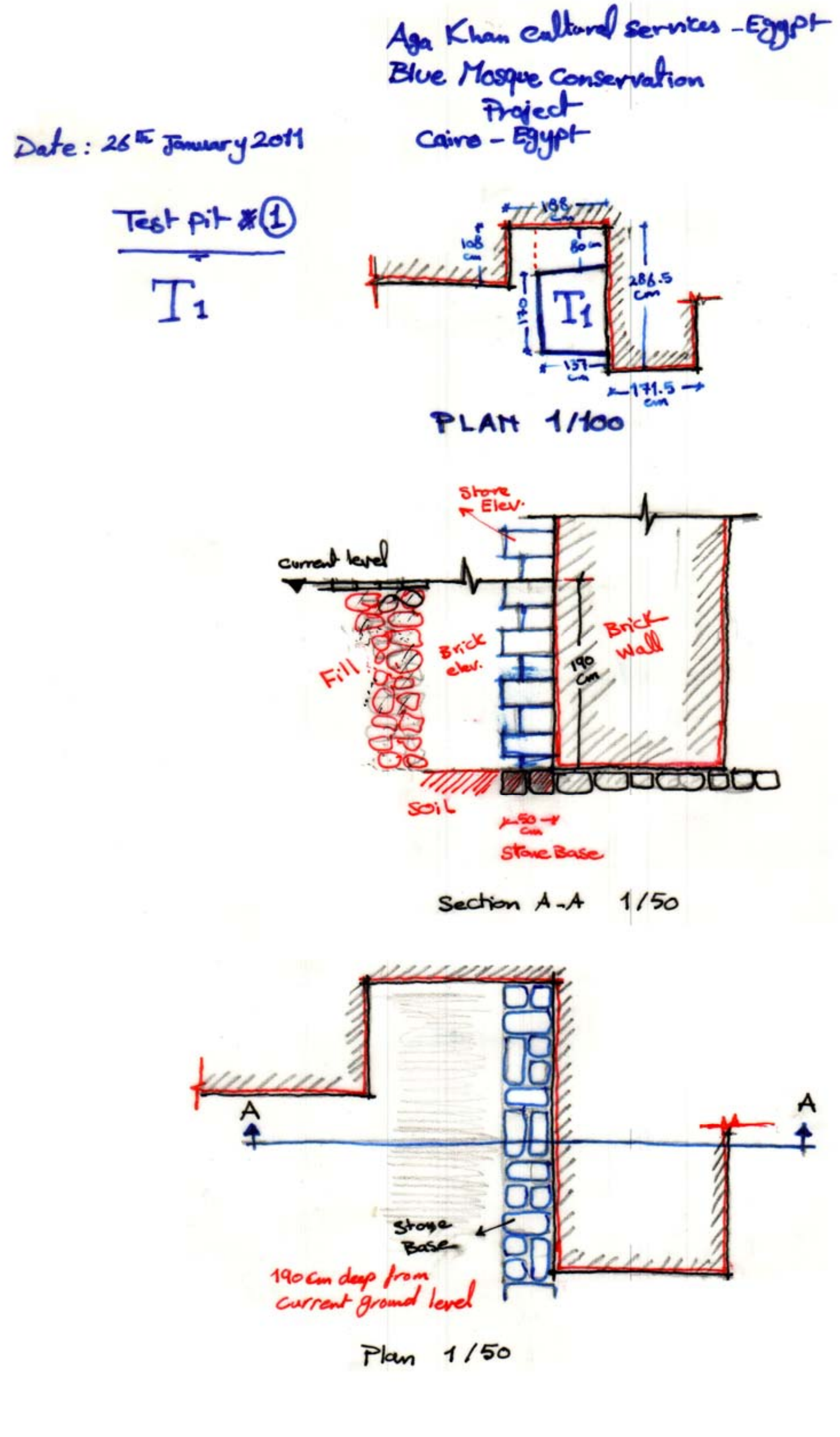


Fig. D2: Details of first open pit at external wall.

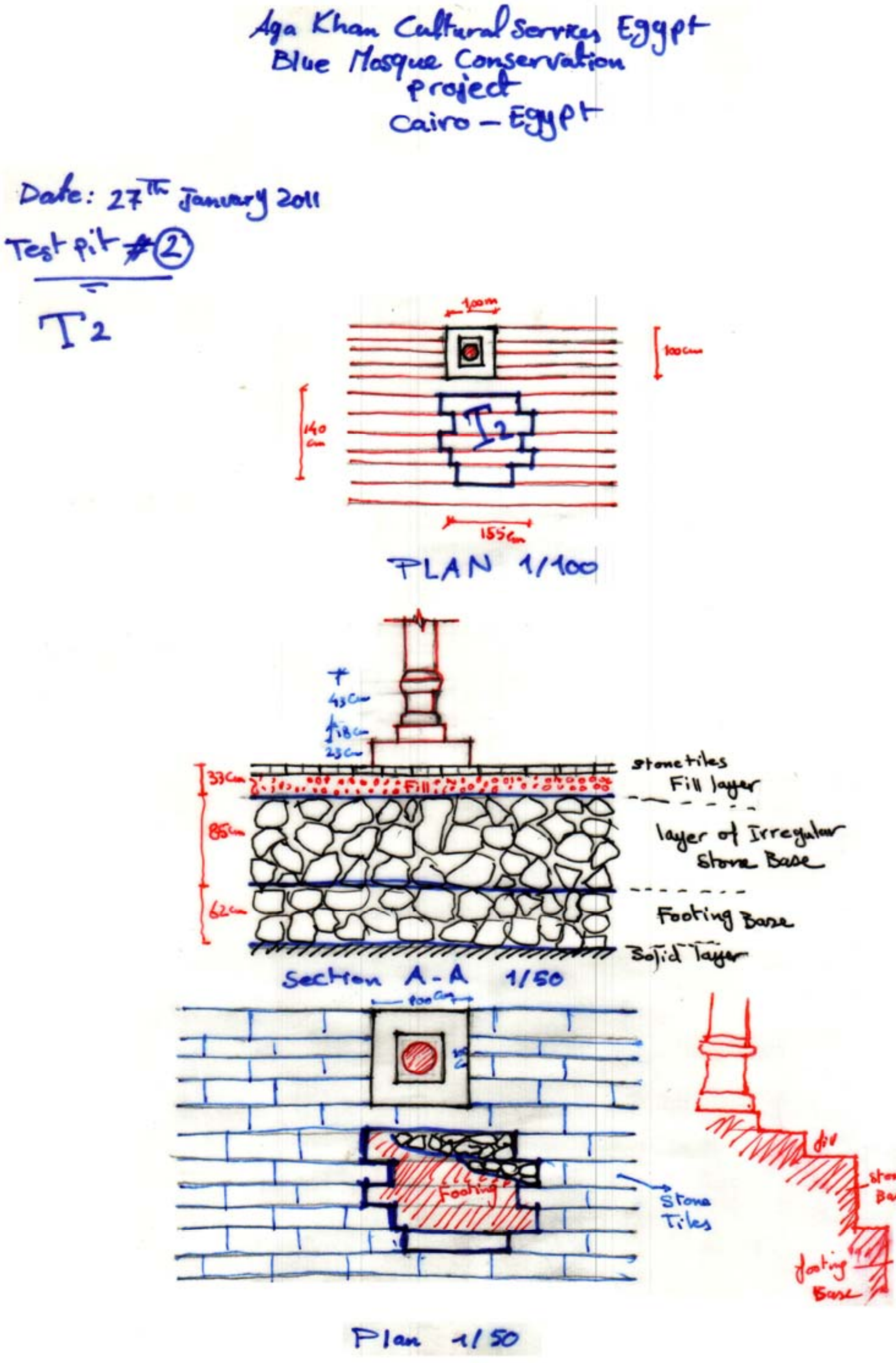


Fig. D3: Details of second open pit at the left inclined court column.

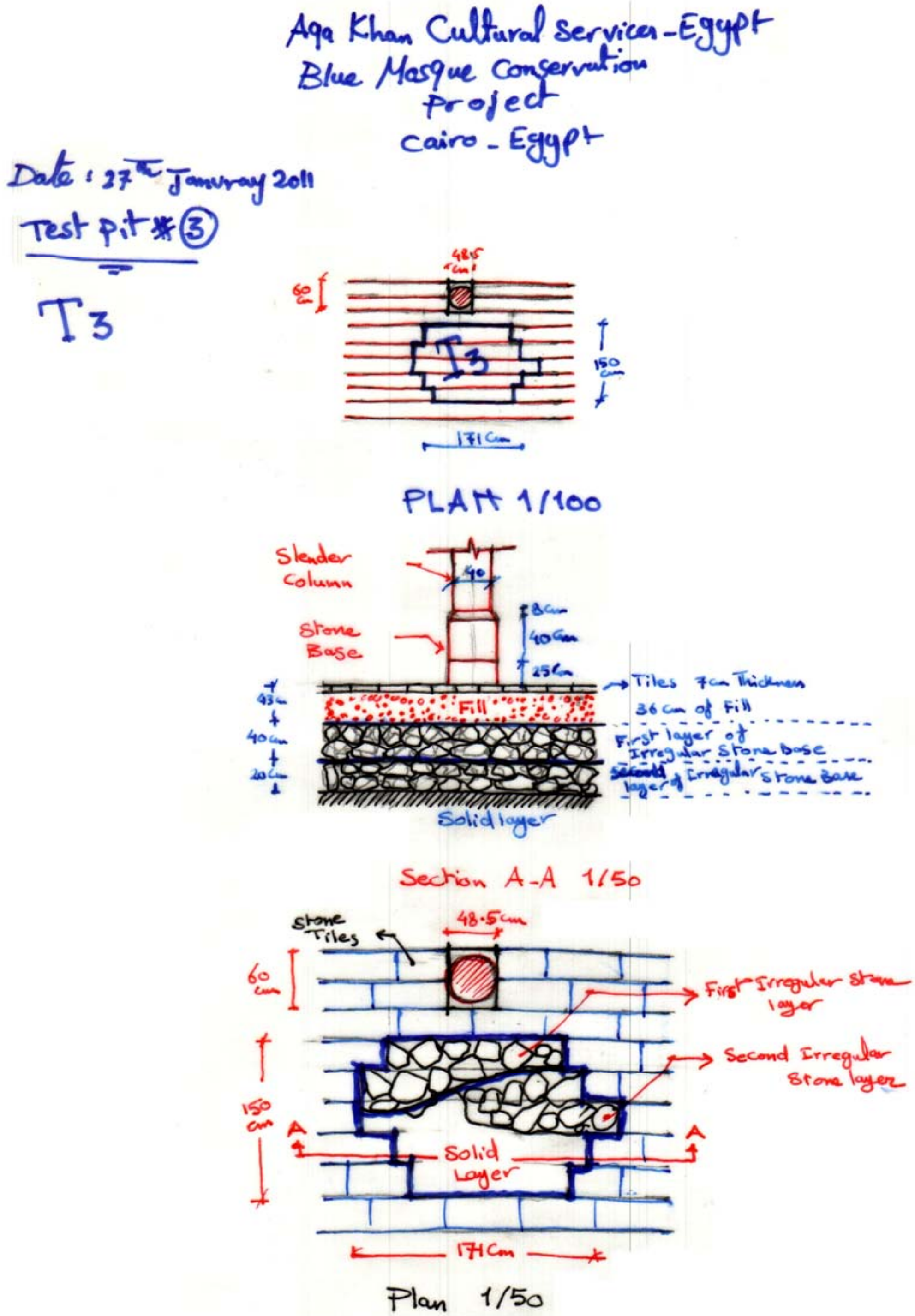


Fig. D4: Details of third open pit at the right inclined court column.

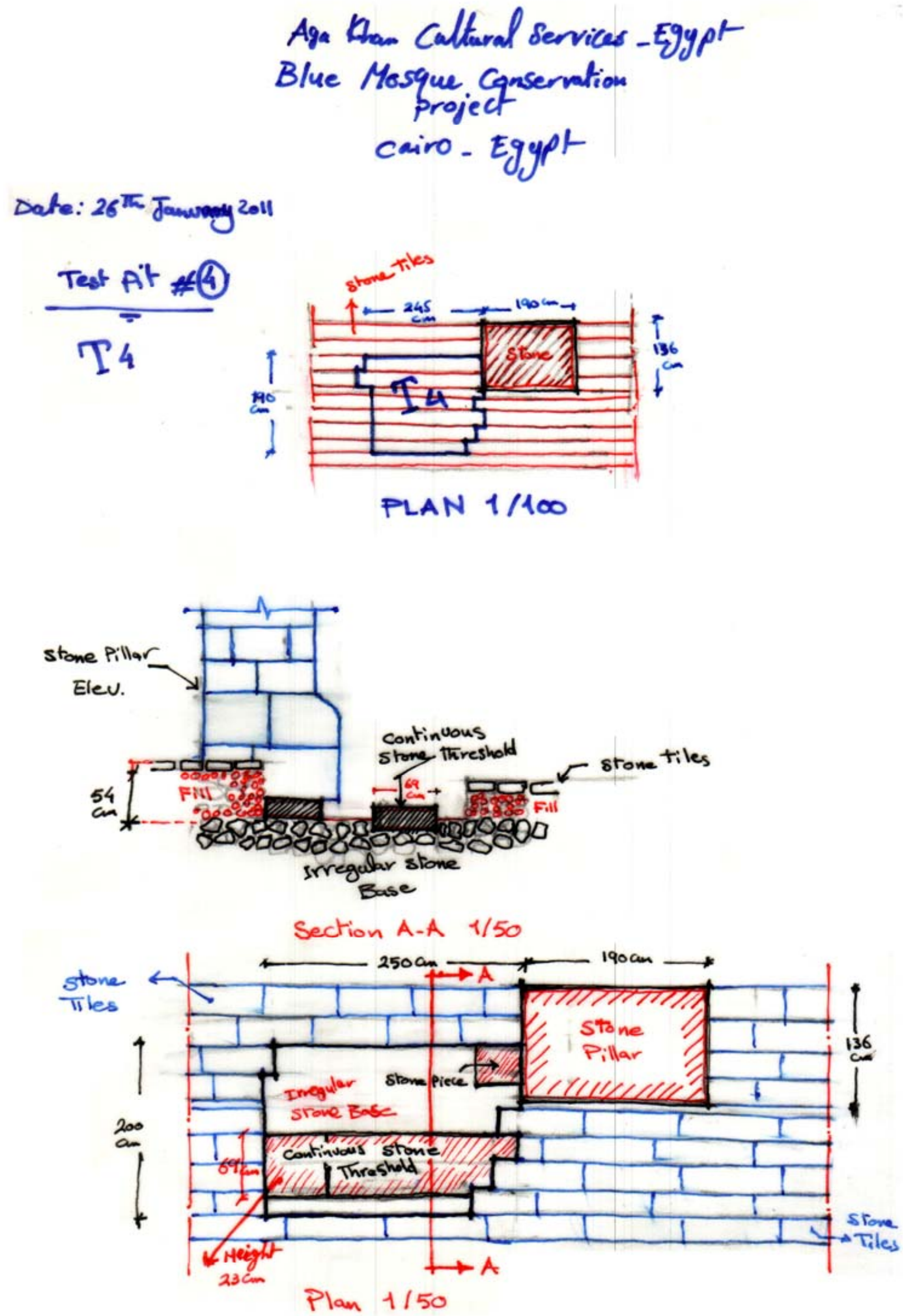


Fig. D5: Details of forth open pit at one of the court arches.

Appendix E

Calculations – CD for SAP2000 model.

INTRO

TRADING & CONTRACTING

MESSRS: AGAKHAN CUTLURAL SERVICES- EGYPT

DATE: Tuesday 11th October 2011 REF: EA/RB/822/2011

Attn : Eng. Dina Bakhoum
Conservation Programmer Manager

SUBJECT: Restoration of the Blue Mosque- Bab El Wazeer

Dear Eng Dina,

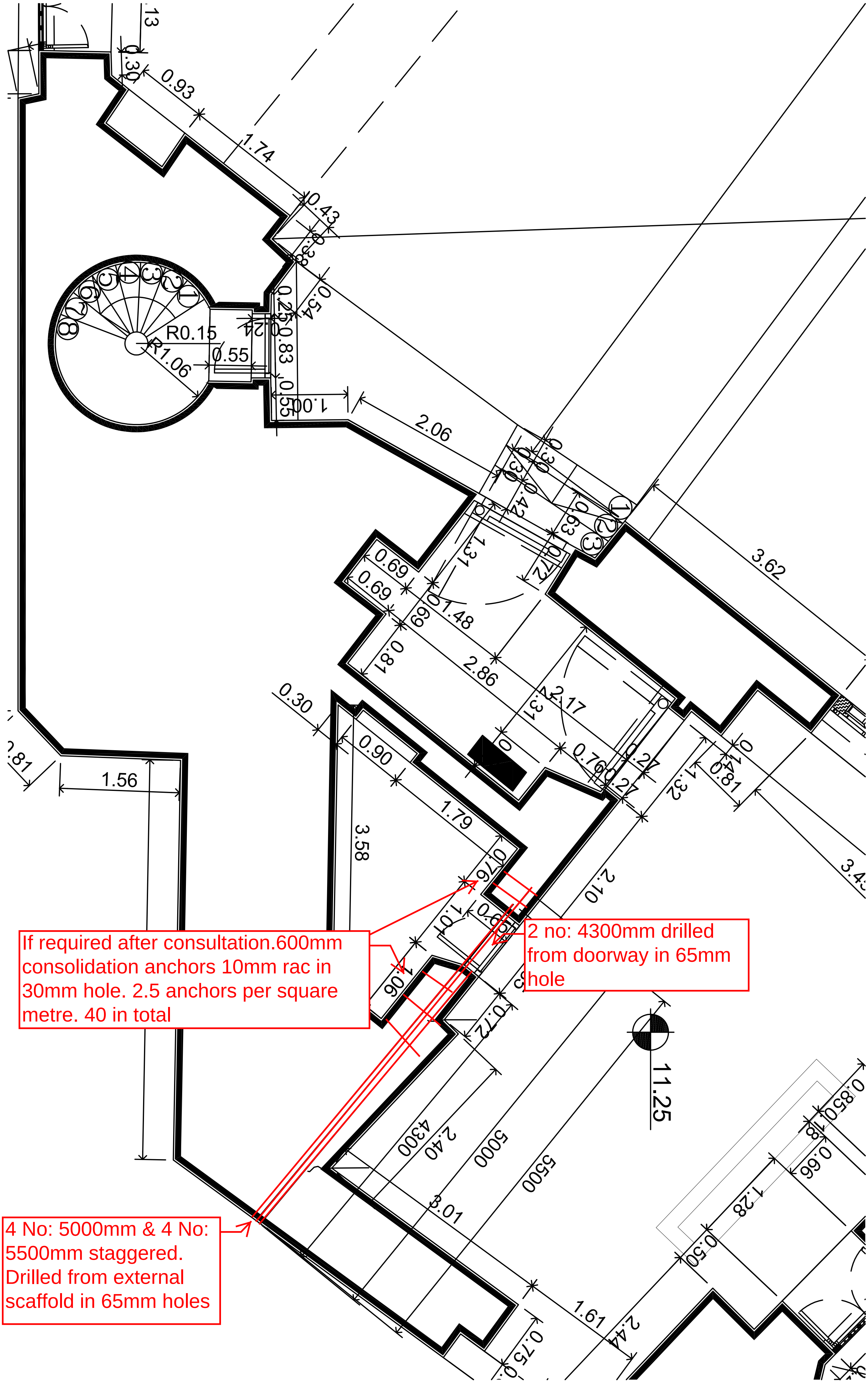
Ref to the above mentioned subject , please find attached the wall of the Mausoleum stitching proposal using Cintec system according to the recommendations of the structural repair report prepaid by Nile Consult , in case of your approval we will submit the related commercial offer .

Thank you and best regards.

Eng. Emad Azmy

General Manager

INTRO TRADING & CONTRACTING
4. Hussein El Meemar St. Cairo - Egypt
TEL: +(202) 2574 73 74 / + (202) 25785378
FAX: +(202) 2579 23 95 / + (202) 25796611
Email: info@introgroup.org



If required after consultation.600mm consolidation anchors 10mm rac in 30mm hole. 2.5 anchors per square metre. 40 in total
2 no: 4300mm drilled from doorway in 65mm hole
4 No: 5000mm & 4 No: 5500mm staggered. Drilled from external scaffold in 65mm holes
0.93
1.74
0.43
0.54
R0.15
R1.06
0.55
0.83
1.00
2.06
3.62
0.69
0.69
1.48
2.86
2.17
0.81
0.30
0.90
1.79
1.56
3.58
0.76
1.01
0.90
0.72
2.10
1.32
11.25
4300
2.40
5000
5500
3.01
1.61
1.28
0.66
0.50
0.75

Technical Report No. (2)

For

SURVEYING MONITORING SYSTEM FOR SOME STRUCTURES INSIDE THE AQSUNQUR MOSQUE (The Blue Mosque)

Presented To

AGA KHAN TRUST FOR CULTURE

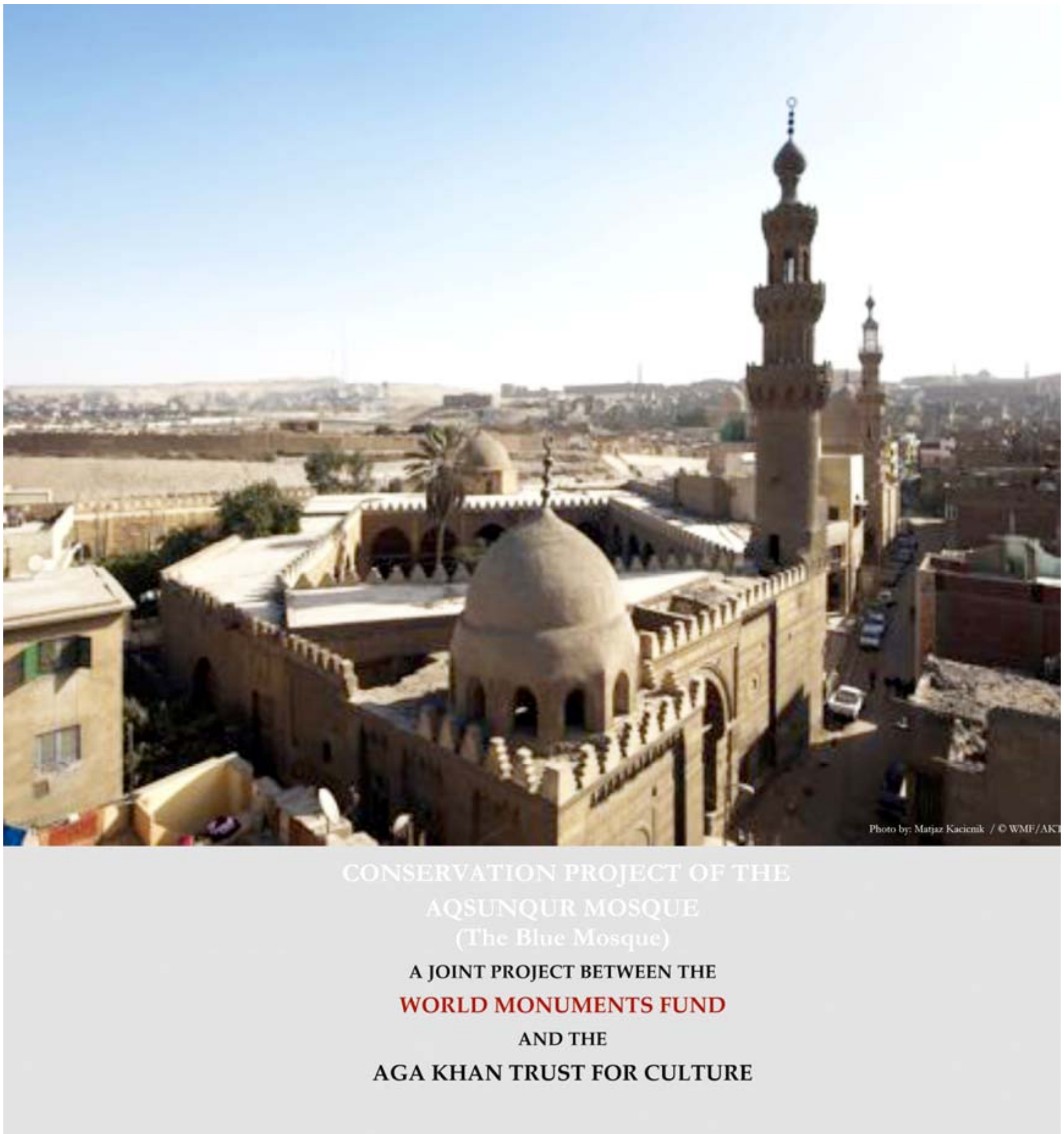
Historic Cities Programme

Prepared By

مكتب النيل للإستشارات الهندسية

NILECONSULT

17 December 2012



SURVEYING MONITORING SYSTEM FOR SOME STRUCTURES INSIDE THE AQSUNQUR MOSQUE (The Blue Mosque)

17 December 2012

Table of Contents

Introduction

This technical report is prepared to introduce the horizontal and vertical surveying measurements for some structures inside the AQSUNQUR MOSQUE (The Blue Mosque) near Al-Azhar Park, Cairo Governorate during the conservation period which AGA KHAN TRUST FOR CULTURE (Historic Cities Programme) performing in the site. The following satellite images depicts the location of the mosque and its surroundings. The surveying team supervised by Dr. Ashraf Nasr, the surveying and mapping consultant of Nile Consultant did fix several surveying monitoring points on the two structures under investigation inside the mosque. Measurements of these points were performed on Monday 18/1/2011. These measurements are considered as the initial measurements for the monitoring process throughout the conservation period.

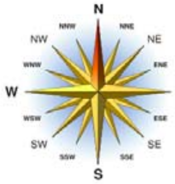


Image (1): Satellite image depicts the location of the AQSUNQUR MOSQUE (The Blue Mosque)

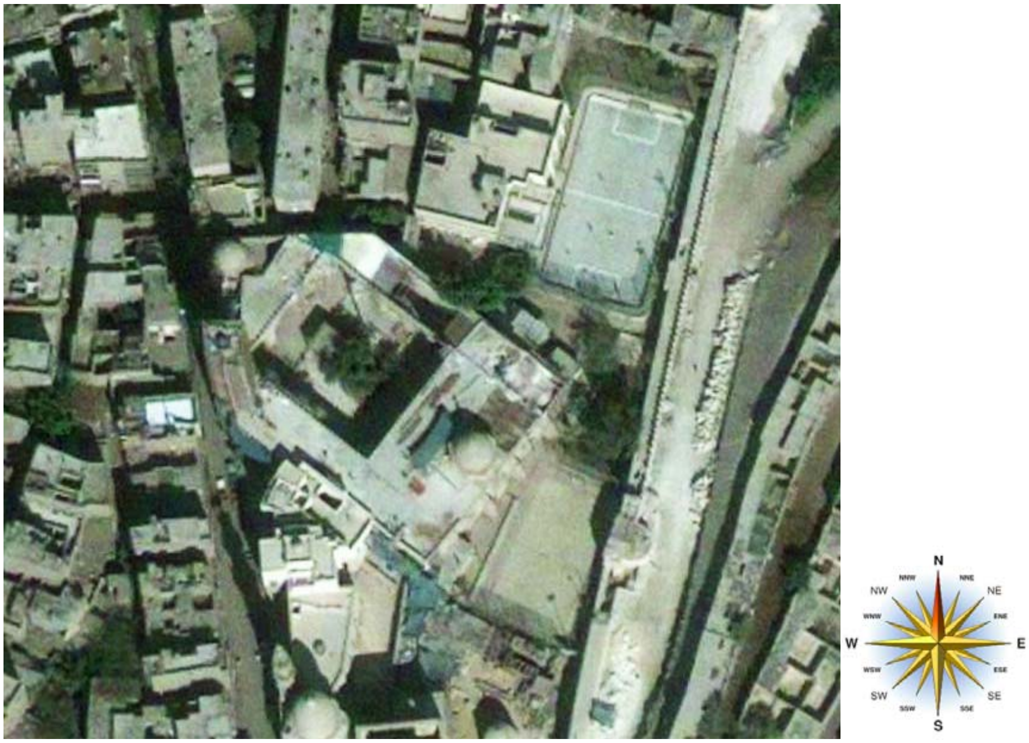


Image (2): Satellite image depicts AQSUNQUR MOSQUE
(The Blue Mosque)

Second set of measurements were observed on Monday 13\6\2011 and third set of measurements were observed on Monday 17\12\2012. The final measurements were performed for the remaining surveying points left after construction (many points were lost during the construction period). This report includes the introduction, method of measurements, results of the monitoring process, and its analysis.

Monitoring System

The monitoring system is separated into several monitoring subsystem; one system for each face of walls of the structures under investigation. For each face of the walls a set of monitoring points were fixed on the walls at the beginning of the observation period. Initial readings for the coordinates of these points were taken using 1”-total station instrument. These coordinates were considered as initial coordinates to be compared with the coordinates of same points in the upcoming measuring process in order to monitor any discrepancies which indicate any horizontal and vertical movements for these points. Two structures are investigated in this monitoring process, the first one

is the room of tomb inside the Blue Mosque and the second on is an interior wall inside the mosque.
For the room of tomb, three walls were investigated two of them were monitored from both faces as shown in figure (1). For Face #1, 9 monitoring points were observed and 6 monitoring points on the opposite side of this wall (Face #2) were observed as shown in Figures (1) & (2) & (3). For Face #3, 6 monitoring points were observed as well as 6 monitoring points on the opposite side of this wall (Face #4) as shown in Figures (1) & (4) & (5). For Face #5, 9 monitoring points were observed as shown in Figures (1) & (6). For this room, only surveying points on Face #2 and Face #4 were found and measured

For the interior wall inside the mosque, 14 monitoring points from each face of this wall were observed, Face #6 & Face #7 as shown in Figures (7) & (8) & (9). For this wall, only most of surveying points on Face #7 were found and measured.

The initial set of observations was performed on Monday 18/1/2011 while the second set of observations was performed on Monday 13/6/2011 and the third set of observations was performed on Monday 17/12/2012. Comparison between these sets of measurements (coordinates of the monitoring points) is performed and the results will be discussed in the following section.

Results and Analysis

Results of measurements performed on Monday 17/12/2012 indicate the followings:

A. Monitoring Horizontal and Vertical Movements of the Walls of the Room of Tomb Inside the Blue Mosque

1. Face #1

Due to missing of surveying points, measuring of this face could not be performed. Table (1) contains the old data observed on the two sets of measurements observed earlier on Monday 18/1/2011 and the new set measured on Monday 13/6/2011.

2. Face #2

Table (2) contains the horizontal and vertical coordinates of the 6 monitoring points fixed in face #2 as shown in Figures (1) & (3). Table (2) includes the sets of coordinates measured in the initial observations on Monday 18/1/2011 and the new sets measured on Monday 13/6/2011 and on Monday 17/12/2012. The final set of coordinates was compared with those coordinates measured in the initial observations. Discrepancies of these coordinates indicate any horizontal and vertical movements of these points. Inspecting this table one can notice that for most of the coordinates show no evidence of any significant movements in both the horizontal and vertical direction for the monitoring points during the period of observations and the discrepancies in these coordinates are due to the precision of the measurements while some of these coordinates show very minor change in the coordinates of some of the monitoring points during the period of observations (precision of the horizontal and vertical measurements is ± 1mm).

3. Face #3

Due to missing of surveying points, measuring of this face could not be performed. Table (3) contains the old data observed on the two sets of measurements observed earlier on Monday 18/1/2011 and the new set measured on Monday 13/6/2011.

4. Face #4

Table (4) contains the horizontal and vertical coordinates of the 6 monitoring points fixed in face #2 as shown in Figures (1) & (5). Table (4) includes the sets of coordinates measured in the initial observations on Monday 18/1/2011 and the new sets measured on Monday 13/6/2011 and on Monday 17/12/2012. The final set of coordinates was compared with those coordinates measured in the initial observations. Discrepancies of these coordinates indicate any horizontal and vertical movements of these points. Inspecting this table one can notice that for most of the coordinates show no evidence of any significant movements in both the horizontal and vertical direction for the monitoring points during the period of observations and the discrepancies in these coordinates are due to the precision of the measurements while some of these coordinates show very minor change in the coordinates of some of the monitoring points during the period of observations (precision of the horizontal and vertical measurements is ± 1mm).

5. **Face #5**

Due to missing of surveying points, measuring of this face could not be performed. Table (5) contains the old data observed on the two sets of measurements observed earlier on Monday 18/1/2011 and the new set measured on Monday 13/6/2011.

B. Monitoring Horizontal and Vertical Movements of the Interior Wall Inside the Blue Mosque

1. **Face #6**

Due to missing of surveying points, measuring of this face could not be performed. Table (6) contains the old data observed on the two sets of measurements observed earlier on Monday 18/1/2011 and the new set measured on Monday 13/6/2011.

2. **Face #7**

5 of the 14 monitoring points were lost during construction. Table (7) contains the new data for the remaining 9 monitoring points as well as the old data for the 5 missing points. Table (7) contains the horizontal and vertical coordinates of the monitoring points fixed in face #7 as shown in Figures (7) & (9). Table (7) includes both sets of coordinates measured in the initial observations on Monday 18/1/2011 and the new set measured on Monday 13/6/2011 and on Monday 17/12/2012. The final set of coordinates was compared with those coordinates measured in the initial observations. Discrepancies of these coordinates indicate any horizontal and vertical movements of these points. Inspecting this table one can notice that for most of the coordinates show no evidence of any significant movements in both the horizontal and vertical direction for the monitoring points during the period of observations and the discrepancies in these coordinates are due to the precision of the measurements while some of these coordinates show very minor change in the coordinates of some of the monitoring points during the period of observations (precision of the horizontal and vertical measurements is ± 1mm).

Surveying measurements and report preparation are performed by:

Dr. Ashraf Nasr

Table 1: Horizontal Coordinates and Elevations of the points on Face # 1

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
1	X	996.8425	996.8417	Lost				-0.8
	Y	1003.4747	1003.4743	Lost				-0.4
	H	13.0520	13.0521	Lost				0.1
2	X	996.8448	996.8444	Lost				-0.4
	Y	1003.4735	1003.4728	Lost				-0.7
	H	16.3598	16.3593	Lost				-0.5
3	X	996.7396	996.7388	Lost				-0.8
	Y	1003.4670	1003.4665	Lost				-0.5
	H	18.4165	18.4168	Lost				0.3

Direction of horizontal & vertical movements are illustrated in Figures (1) & (2)

*Continued………*Table 1: Horizontal Coordinates and Elevations of the points on Face # 1

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
4	X	1001.4867	1001.4860	Lost				-0.7
	Y	1003.3967	1003.3962	Lost				-0.5
	H	13.0480	13.0479	Lost				-0.1
5	X	1001.5109	1001.5102	Lost				-0.7
	Y	1003.3975	1003.3966	Lost				-0.9
	H	16.1511	16.1505	Lost				-0.6
6	X	1001.4776	1001.4771	Lost				-0.5
	Y	1003.3845	1003.3842	Lost				-0.3
	H	18.4034	18.4038	Lost				0.4

Direction of horizontal & vertical movements are illustrated in Figures (1) & (2)

*Continued………*Table 1: Horizontal Coordinates and Elevations of the points on Face # 1

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
7	X	1003.9857	1003.9849	Lost				-0.8
	Y	1002.6025	1002.6027	Lost				0.2
	H	13.5703	13.5702	Lost				-0.1
8	X	1004.1502	1004.1498	Lost				-0.4
	Y	1002.5974	1002.5976	Lost				0.2
	H	14.7909	14.7910	Lost				0.1
9	X	1004.0200	1004.0194	Lost				-0.6
	Y	1002.4509	1002.4511	Lost				0.2
	H	17.2560	17.2564	Lost				0.4

Direction of horizontal & vertical movements are illustrated in Figures (1) & (2)

Table 2: Horizontal Coordinates and Elevations of the points on Face # 2

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
1	X	1000.6392	1000.6032*	1000.6030				-0.2
	Y	1003.6327	1003.6356*	1003.6350				-0.6
	H	12.5243	12.7086*	12.7073				-1.3
2	X	1000.6280	1000.6288*	1000.6285				-0.3
	Y	1003.6272	1003.6290*	1003.6285				-0.5
	H	15.1813	15.1565*	15.1550				-1.5
3	X	1000.5668	1000.6548*	1000.6545				-0.3
	Y	1003.6284	1003.6279*	1003.6285				0.6
	H	17.3055	17.3356*	17.3345				-1.1

* New datum because of missing points

Direction of horizontal & vertical movements are illustrated in Figures (1) & (3)

*Continued………*Table 2: Horizontal Coordinates and Elevations of the points on Face # 2

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
4	X	994.9611	995.2583*	995.2595				1.2
	Y	1003.6594	1003.6614*	1003.6603				-1.1
	H	12.6194	12.6098*	12.6084				-1.4
5	X	994.9463	995.7308*	995.7320				1.2
	Y	1003.6631	1003.6627*	1003.6614				-1.3
	H	15.1381	15.6244*	15.6230				-1.4
6	X	995.0895	995.3862*	995.3850				-1.2
	Y	1003.6680	1003.6630*	1003.6640				1.0
	H	17.1529	17.2034*	17.2040				0.6

* New datum because of missing points

Direction of horizontal & vertical movements are illustrated in Figures (1) & (3)

Table 3: Horizontal Coordinates and Elevations of the points on Face # 3

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
1	X	997.8880	997.8887	Lost				0.7
	Y	1004.3866	1004.3866	Lost				0.0
	H	13.6853	13.6852	Lost				-0.1
2	X	997.9876	997.9881	Lost				0.5
	Y	1004.4145	1004.4140	Lost				-0.5
	H	15.0626	15.0619	Lost				-0.7
3	X	998.0004	998.0011	Lost				0.7
	Y	1004.4709	1004.4712	Lost				0.3
	H	17.2195	17.2200	Lost				0.5

Direction of horizontal & vertical movements are illustrated in Figures (1) & (4)

*Continued………*Table 3: Horizontal Coordinates and Elevations of the points on Face # 3

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
4	X	1000.3678	1000.3685	Lost				0.7
	Y	1004.4242	1004.4233	Lost				-0.9
	H	13.3028	13.3037	Lost				0.9
5	X	1000.3568	1000.3578	Lost				1.0
	Y	1004.4540	1004.4542	Lost				0.2
	H	15.0411	15.0415	Lost				0.4
6	X	1000.2635	1000.2643	Lost				0.8
	Y	1004.4725	1004.4731	Lost				0.6
	H	17.2866	17.2869	Lost				0.3

Direction of horizontal & vertical movements are illustrated in Figures (1) & (4)

Table 4: Horizontal Coordinates and Elevations of the points on Face # 4

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
1	X	999.3287	999.3282	999.3281				-0.6
	Y	1007.0735	1007.0726	1007.0742				0.7
	H	14.1631	14.1636	14.1626				-0.5
2	X	999.3456	999.3452	999.3450				-0.6
	Y	1007.0347	1007.0339	1007.0350				0.3
	H	16.2430	16.2433	16.2422				-0.8
3	X	999.3068	999.3059	999.3060				-0.8
	Y	1006.8563	1006.8566	1006.8572				0.9
	H	19.0617	19.0627	19.0610				-0.7

Direction of horizontal & vertical movements are illustrated in Figures (1) & (5)

*Continued………*Table 4: Horizontal Coordinates and Elevations of the points on Face # 4

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
4	X	994.8766	994.8767	994.8765				-0.1
	Y	1006.7876	1006.7869	1006.7870				-0.6
	H	13.9085	13.9088	13.9071				-1.4
5	X	994.8784	994.8785	994.8785				0.1
	Y	1006.7466	1006.7458	1006.7460				-0.6
	H	16.4074	16.4071	16.4059				-1.5
6	X	994.8554	994.8549	994.8550				-0.4
	Y	1006.7405	1006.7396	1006.7410				0.5
	H	18.9515	18.9512	18.9510				-0.5

Direction of horizontal & vertical movements are illustrated in Figures (1) & (5)

Table 5: Horizontal Coordinates and Elevations of the points on Face # 5

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
1	X	2001.2513	2001.2517	Lost				0.4
	Y	2003.8477	2003.8486	Lost				0.9
	H	13.3257	13.3254	Lost				-0.3
2	X	2001.0193	2001.0190	Lost				-0.3
	Y	2003.8583	2003.8582	Lost				-0.1
	H	15.2462	15.2457	Lost				-0.5
3	X	2000.9860	2000.9856	Lost				-0.4
	Y	2003.8595	2003.8586	Lost				-0.9
	H	17.3930	17.3922	Lost				-0.8

Direction of horizontal & vertical movements are illustrated in Figures (1) & (6)

*Continued………*Table 5: Horizontal Coordinates and Elevations of the points on Face # 5

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
4	X	1995.9272	1995.9275	Lost				0.3
	Y	2003.9716	2003.9709	Lost				-0.7
	H	13.3180	13.3172	Lost				-0.8
5	X	1995.9564	1995.9555	Lost				-0.9
	Y	2003.9812	2003.9811	Lost				-0.1
	H	15.4557	15.4547	Lost				-1.0
6	X	1995.9080	1995.9077	Lost				-0.3
	Y	2003.9721	2003.9717	Lost				-0.4
	H	17.8275	17.8267	Lost				-0.8

Direction of horizontal & vertical movements are illustrated in Figures (1) & (6)

*Continued………*Table 5: Horizontal Coordinates and Elevations of the points on Face # 5

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
7	X	1993.6300	1993.6305	Lost				0.5
	Y	2003.7976	2003.7969	Lost				-0.7
	H	13.3394	13.3386	Lost				-0.8
8	X	1993.6020	1993.6017	Lost				-0.3
	Y	2003.8065	2003.8061	Lost				-0.4
	H	15.6565	15.6559	Lost				-0.6
9	X	1993.7716	1993.7711	Lost				-0.5
	Y	2003.7650	2003.7657	Lost				0.7
	H	17.5694	17.5686	Lost				-0.8

Direction of horizontal & vertical movements are illustrated in Figures (1) & (6)

Table 6: Horizontal Coordinates and Elevations of the points on Face # 6

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
1	X	999.9995	999.9994	Lost				-0.1
	Y	1006.0431	1006.0423	Lost				-0.8
	H	10.8268	10.8271	Lost				0.3
2	X	999.9671	999.9668	Lost				-0.3
	Y	1006.0371	1006.0380	Lost				0.9
	H	13.7582	13.7586	Lost				0.4
3	X	999.9766	999.9763	Lost				-0.3
	Y	1005.8422	1005.8431	Lost				0.9
	H	14.6862	14.6869	Lost				0.7
4	X	1000.0352	1000.0350	Lost				-0.2
	Y	1005.8873	1005.8874	Lost				0.1
	H	16.0189	16.0194	Lost				0.5

Direction of horizontal & vertical movements are illustrated in Figures (7) & (8)

Continued………Table 6: Horizontal Coordinates and Elevations of the points on Face # 6

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
5	X	994.7151	994.7154	Lost				0.3
	Y	1006.1388	1006.1379	Lost				-0.9
	H	11.4102	11.4109	Lost				0.7
6	X	994.7047	994.7045	Lost				-0.2
	Y	1006.1239	1006.1230	Lost				-0.9
	H	13.4763	13.4771	Lost				0.8
7	X	994.9094	994.9096	Lost				0.2
	Y	1006.0945	1006.0935	Lost				-1.0
	H	15.6701	15.6707	Lost				0.6

Direction of horizontal & vertical movements are illustrated in Figures (7) & (8)

*Continued………*Table 6: Horizontal Coordinates and Elevations of the points on Face # 6

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
8	X	988.9951	988.9894*	Lost				----
	Y	1006.2774	1006.2757*	Lost				----
	H	11.4189	11.4940*	Lost				----
9	X	989.0444	989.0437	Lost				-0.7
	Y	1006.2507	1006.2499	Lost				-0.8
	H	13.5030	13.5030	Lost				0.0
10	X	988.8030	988.8028	Lost				-0.2
	Y	1006.2288	1006.2281	Lost				-0.7
	H	15.7116	15.7113	Lost				-0.3

* New datum because of missing points

Direction of horizontal & vertical movements are illustrated in Figures (7) & (8)

*Continued………*Table 6: Horizontal Coordinates and Elevations of the points on Face # 6

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
11	X	983.8994	983.8990	Lost				-0.4
	Y	1006.5743	1006.5736	Lost				-0.7
	H	11.1947	11.1941	Lost				-0.6
12	X	983.8868	983.8865	Lost				-0.3
	Y	1006.4854	1006.4850	Lost				-0.4
	H	13.6939	13.6931	Lost				-0.8
13	X	983.8119	983.8114	Lost				-0.5
	Y	1006.2609	1006.2607	Lost				-0.2
	H	14.7246	14.7243	Lost				-0.3
14	X	983.7760	983.8387*	Lost				----
	Y	1006.2776	1006.2743*	Lost				----
	H	15.7618	15.7690*	Lost				----

* New datum because of missing points

Direction of horizontal & vertical movements are illustrated in Figures (7) & (8)

Table 7: Horizontal Coordinates and Elevations of the points on Face # 7

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
1	X	994.6485	994.6482	994.6480				-0.5
	Y	1006.8801	1006.8796	1006.8813				1.2
	H	10.8726	10.8729	10.8732				0.6
2	X	994.7111	994.7106	994.7110				-0.1
	Y	1006.9607	1006.9604	1006.9622				1.5
	H	13.6340	13.6339	13.6350				1.0
3	X	994.6802	994.6801	994.6800				-0.2
	Y	1006.7469	1006.7461	1006.7483				1.4
	H	14.5110	14.5111	14.5110				0.0
4	X	994.6893	994.6896	994.6900				0.7
	Y	1006.7200	1006.7194	1006.7206				0.6
	H	15.3882	15.3877	15.3875				-0.7

Direction of horizontal & vertical movements are illustrated in Figures (7) & (9)

*Continued………*Table 7: Horizontal Coordinates and Elevations of the points on Face # 7

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
5	X	999.8855	999.8852	999.8850				-0.5
	Y	1005.8721	1005.8721	1005.8720				-0.1
	H	10.8232	10.8235	10.8240				0.8
6	X	999.8951	999.8949	999.8945				-0.6
	Y	1005.8834	1005.8830	1005.8830				-0.4
	H	13.3979	13.3979	13.3985				0.6
7	X	999.8326	999.8318	999.8320				-0.6
	Y	1005.8933	1005.8936	1005.8940				0.7
	H	15.4525	15.4525	15.4535				1.0

Direction of horizontal & vertical movements are illustrated in Figures (7) & (9)

*Continued………*Table 7: Horizontal Coordinates and Elevations of the points on Face # 7

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
8	X	1005.5502	1005.5507	1005.5510				0.8
	Y	1005.8115	1005.8105	1005.8125				1.0
	H	10.8503	10.8509	10.8510				0.7
9	X	1005.5440	1005.5448	1005.5445				0.5
	Y	1005.8238	1005.8235	1005.8235				-0.3
	H	13.2810	13.2813	13.2820				1.0
10	X	1005.6692	1005.6698	Lost				0.6
	Y	1005.8375	1005.8368	Lost				-0.7
	H	15.3944	15.3952	Lost				0.8

Direction of horizontal & vertical movements are illustrated in Figures (7) & (9)

*Continued………*Table 7: Horizontal Coordinates and Elevations of the points on Face # 7

Point #		H-Coordinates and Elevations 18/01/2011	H-Coordinates and Elevations 13/06/2011	H-Coordinates and Elevations 17/12/2012	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	H-Coordinates and Elevations 00/00/0000	Displacement (mm)
11	X	1010.7605	1010.7612	Lost				0.7
	Y	1006.5789	1006.5781	Lost				-0.8
	H	11.0306	11.0311	Lost				0.5
12	X	1010.7797	1010.7803	Lost				0.6
	Y	1006.6994	1006.6989	Lost				-0.5
	H	13.5536	13.5543	Lost				0.7
13	X	1010.7701	1010.7701	Lost				0.0
	Y	1006.5257	1006.5251	Lost				-0.6
	H	14.4315	14.4321	Lost				0.6
14	X	1010.7872	1010.7875	Lost				0.3
	Y	1006.5149	1006.5158	Lost				0.9
	H	15.3323	15.3332	Lost				0.9

Direction of horizontal & vertical movements are illustrated in Figures (7) & (9)

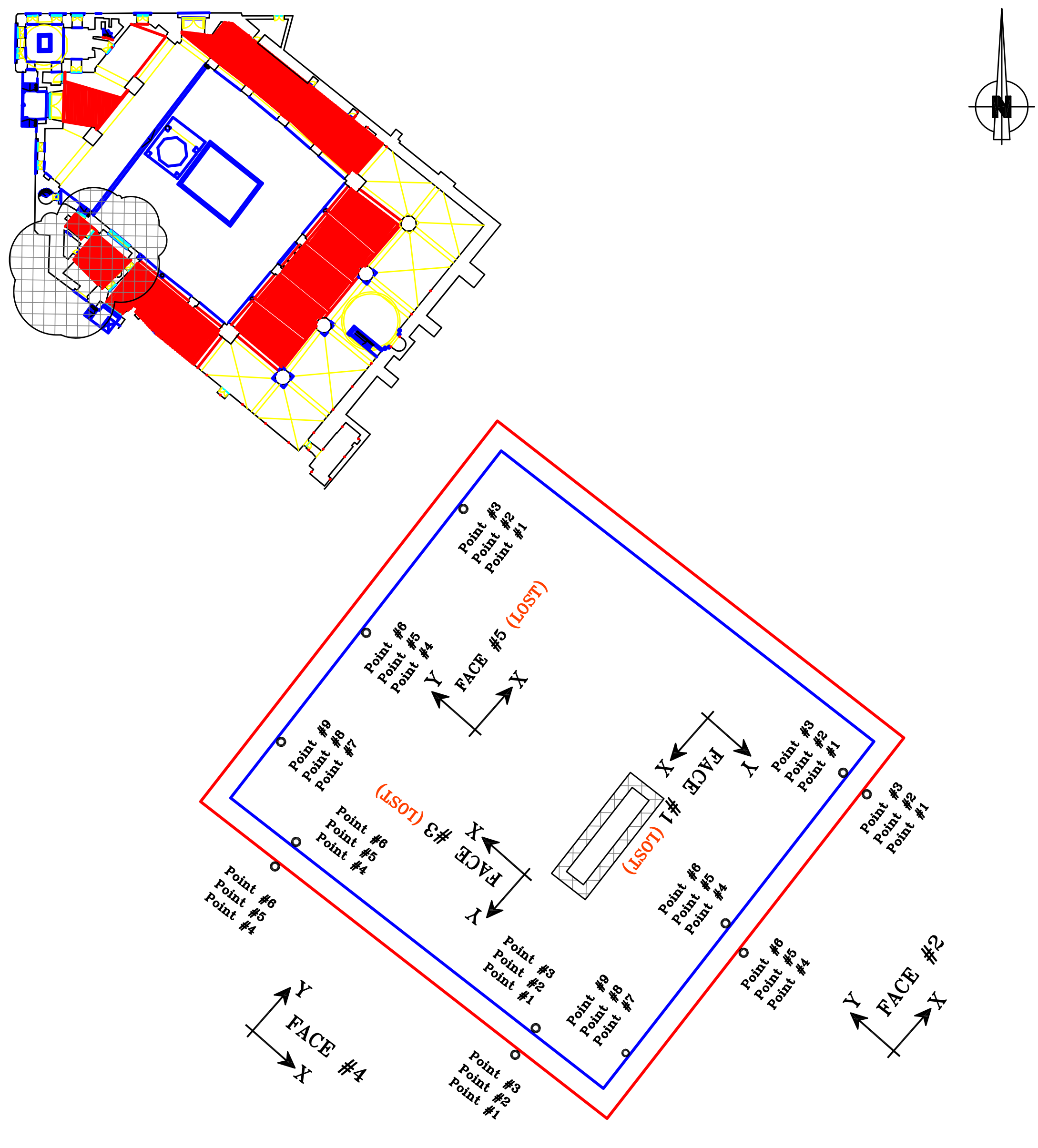
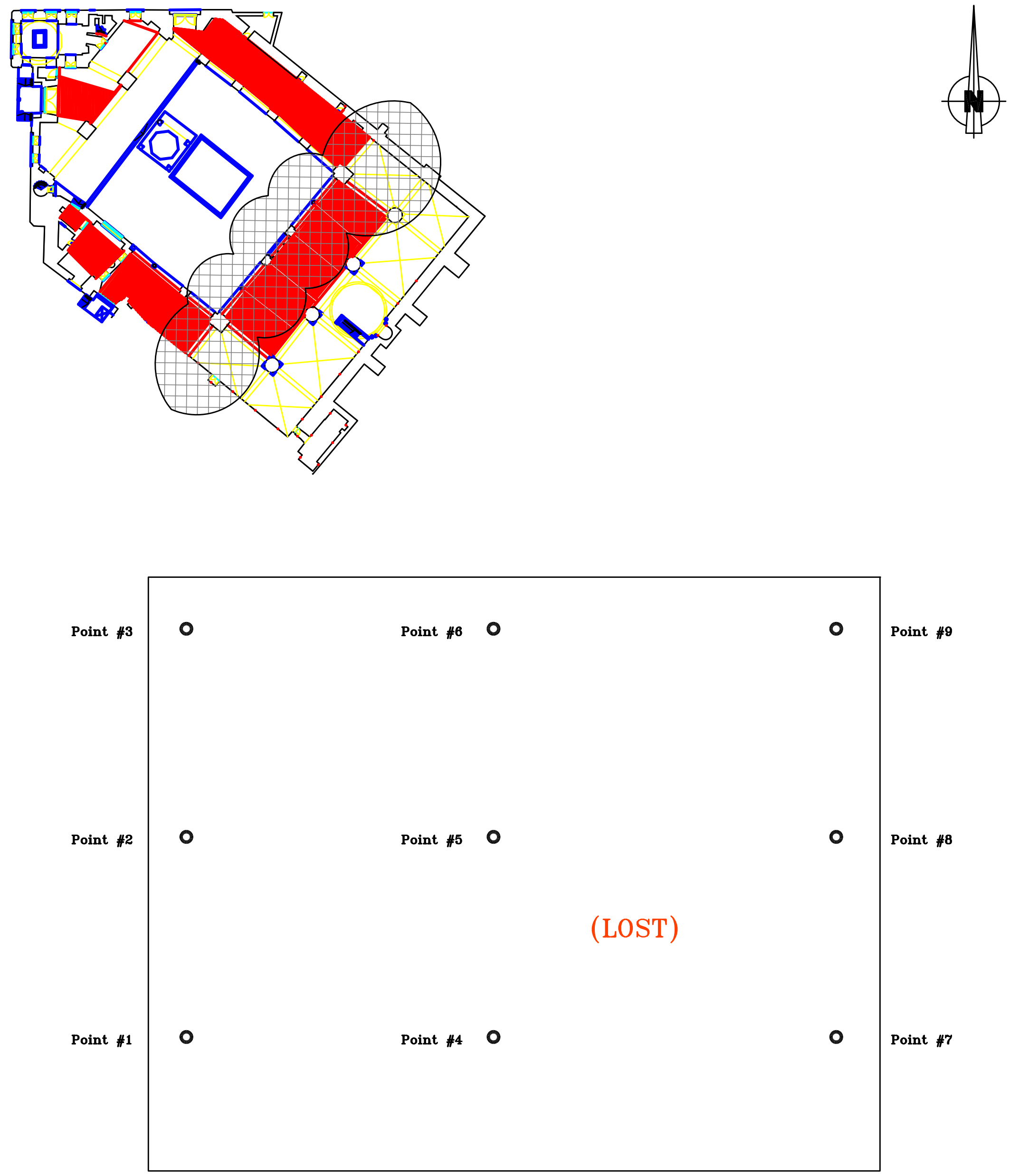


Figure (1): Plan Layout depicts location of
The monitoring points on Faces #1&#2&#3&#4&#5
of the room of tomb inside the Blue Mosque



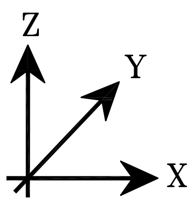
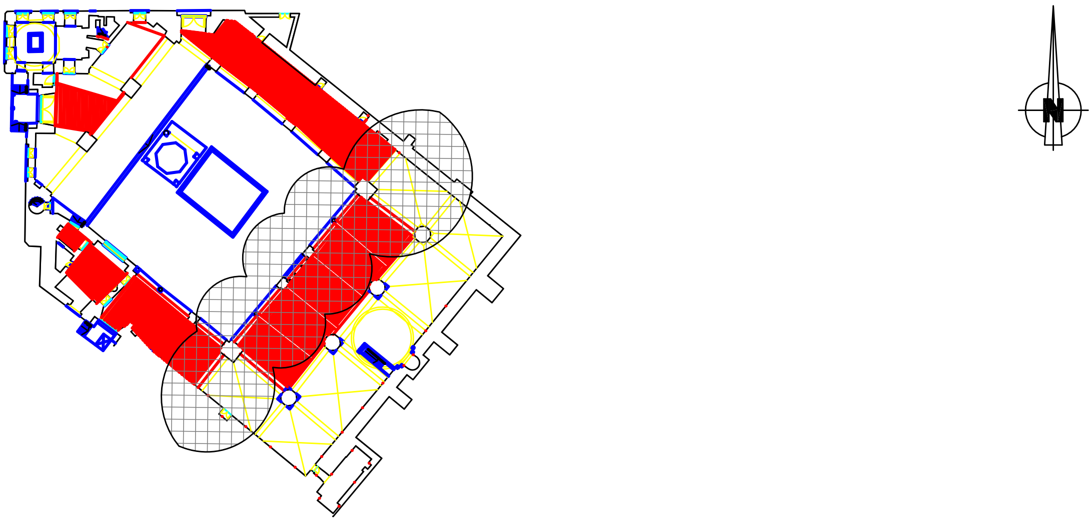
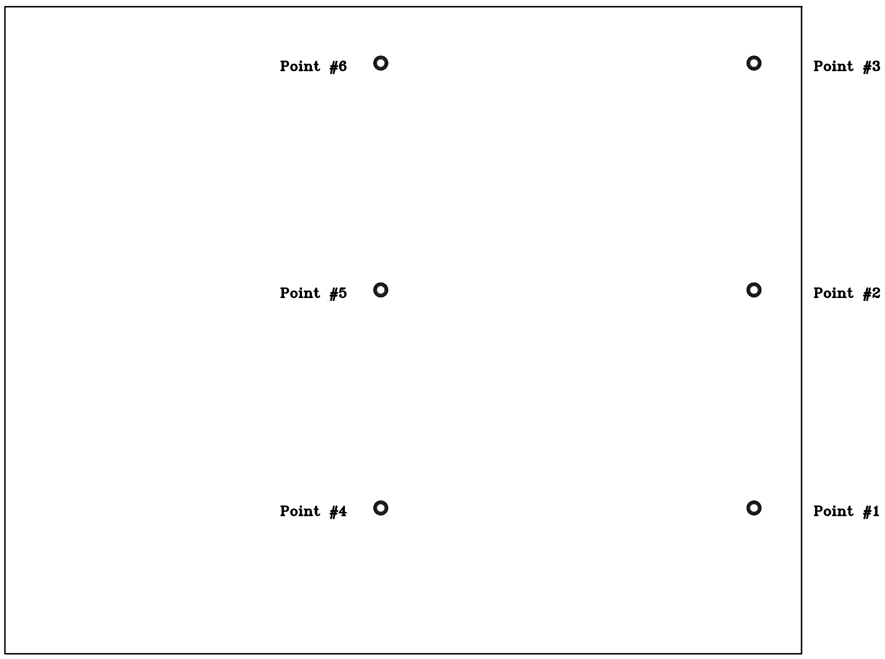


Figure (2): Elevation Layout depicts Location of the monitoring points on Face #1 of the room of tomb inside the Blue Mosque





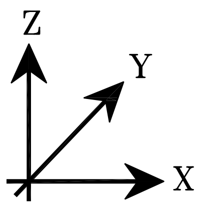
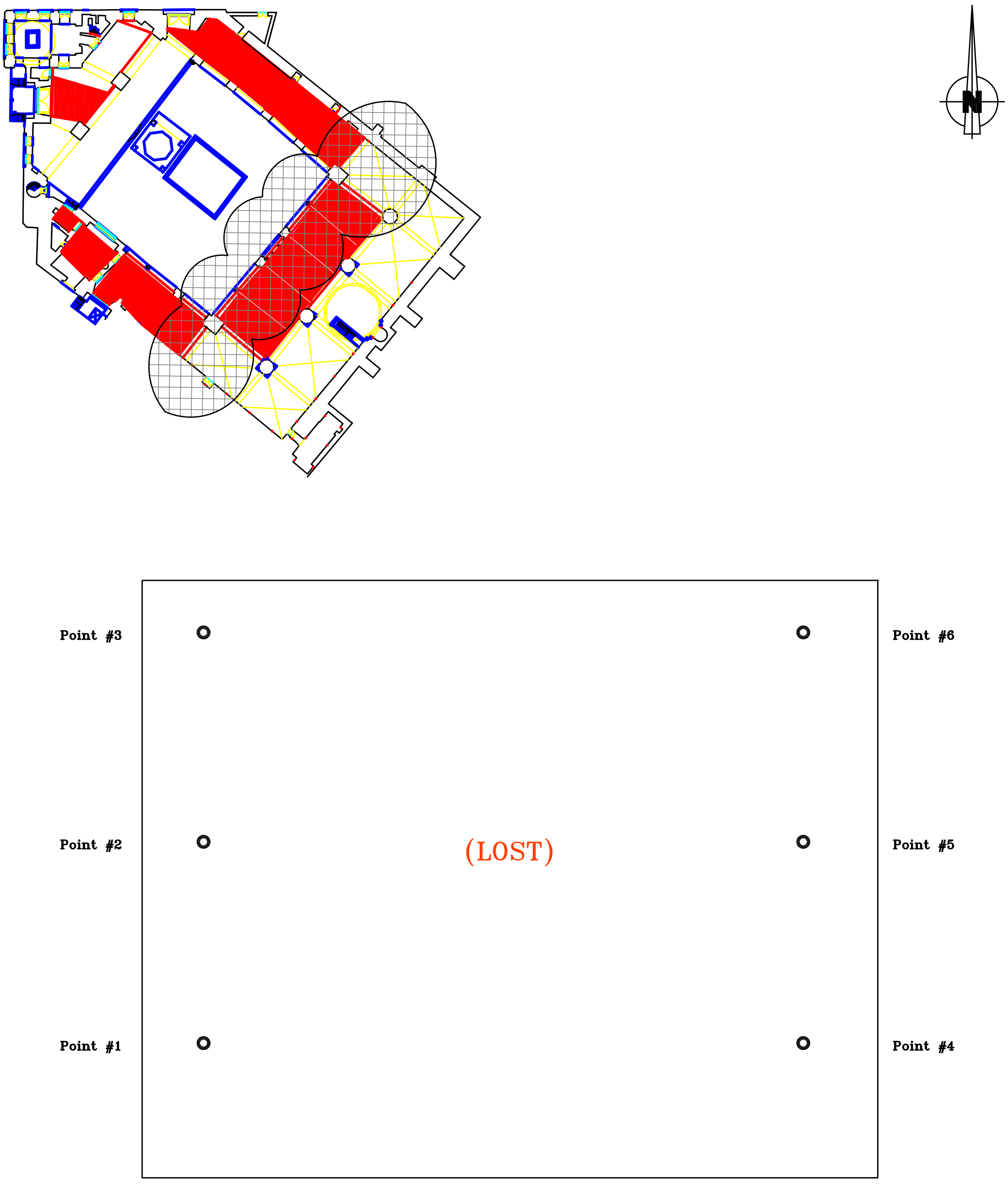


Figure (3): Elevation Layout depicts Location of the monitoring points on Face #2 of the room of tomb inside the Blue Mosque



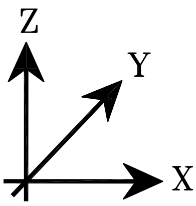
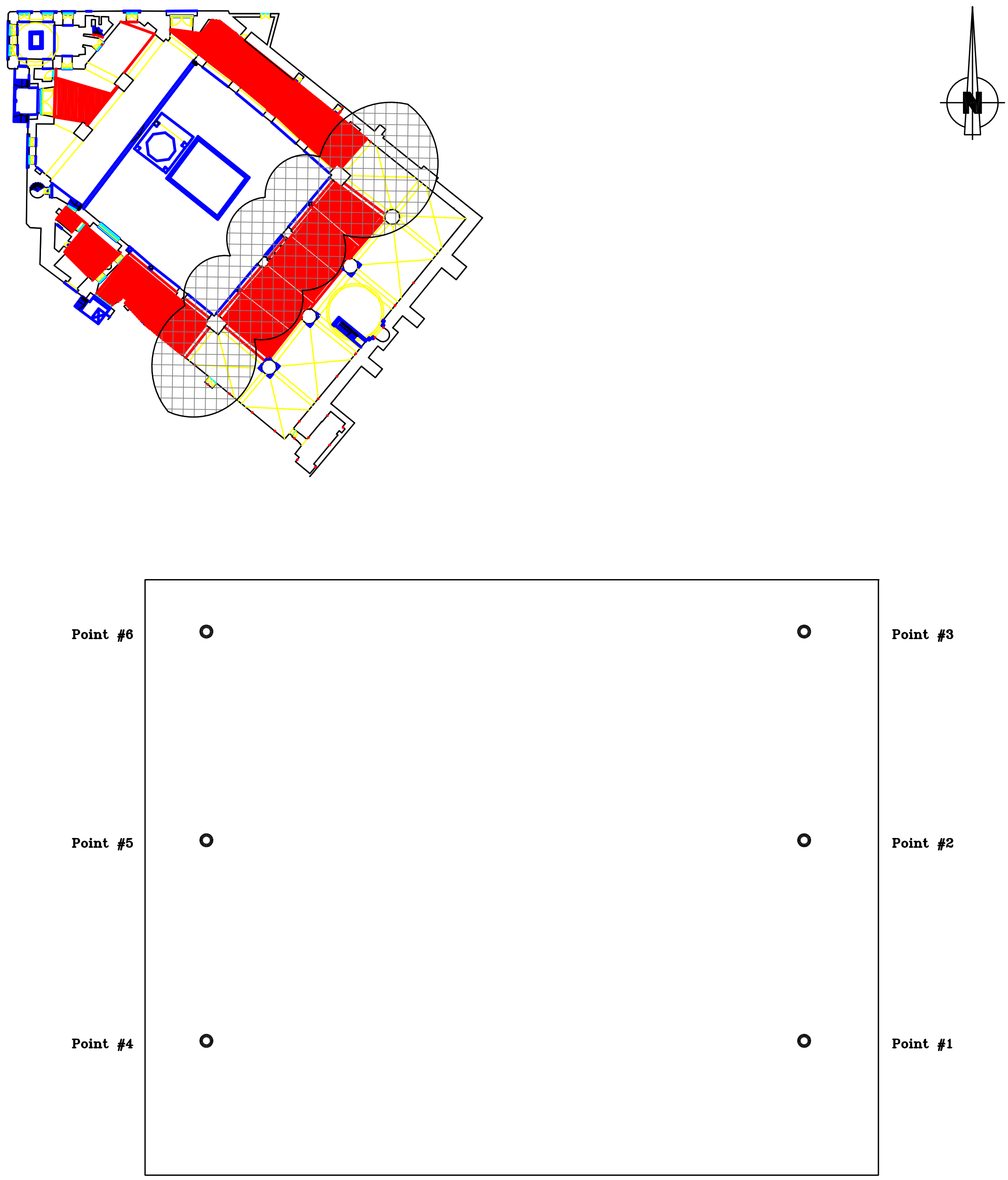


Figure (4): Elevation Layout depicts Location of the monitoring points on Face #3 of the room of tomb inside the Blue Mosque



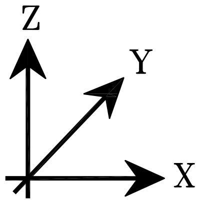
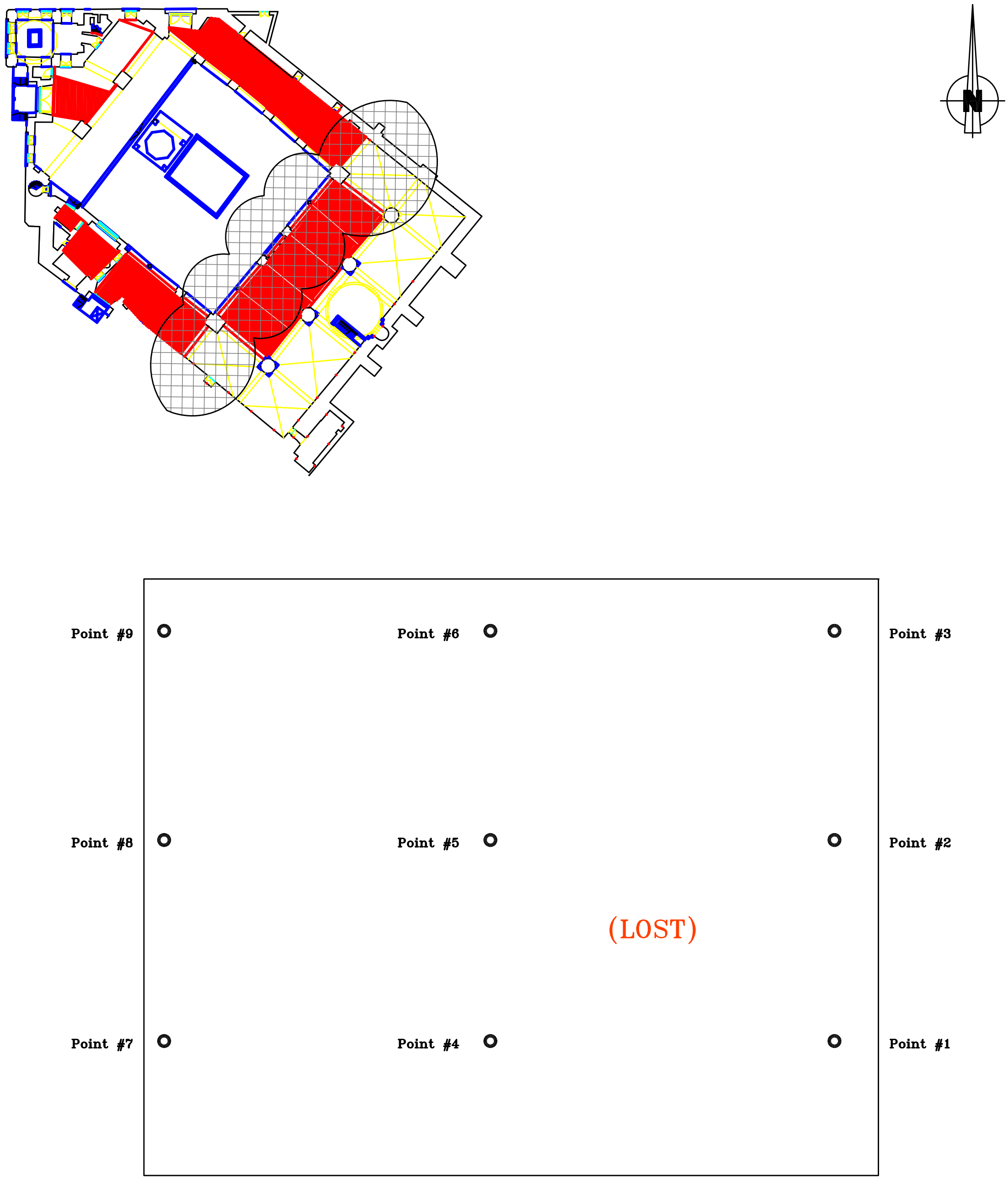


Figure (5): Elevation Layout depicts Location of the monitoring points on Face #4 of the room of tomb inside the Blue Mosque



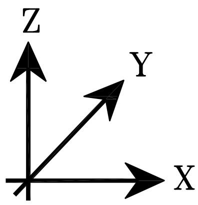


Figure (6): Elevation Layout depicts Location of the monitoring points on Face #5 of the room of tomb inside the Blue Mosque

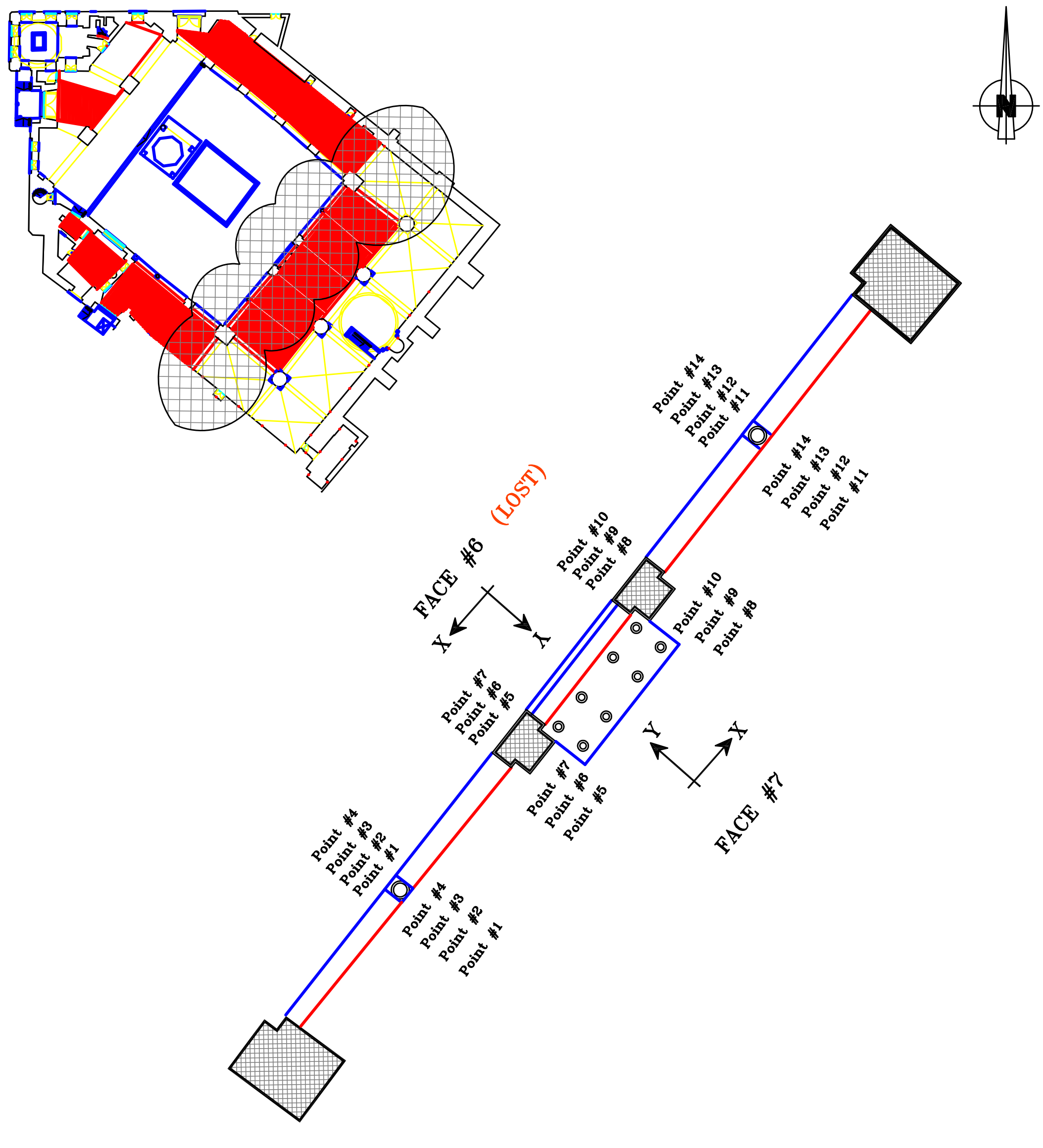


Figure (7): Plan Layout depicts location of The monitoring points on Face #6 & Face #7 of the interior wall inside the Blue Mosque

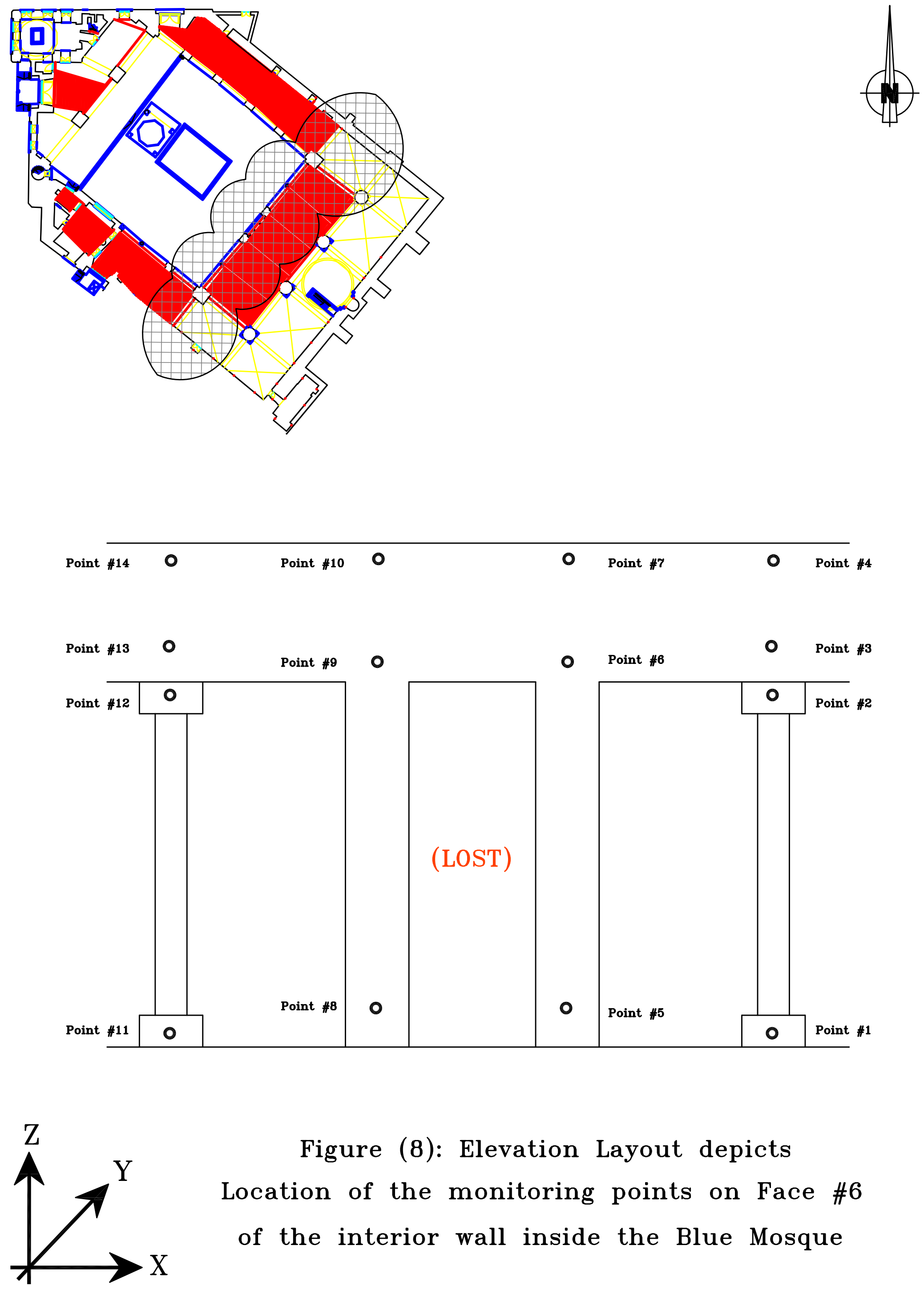
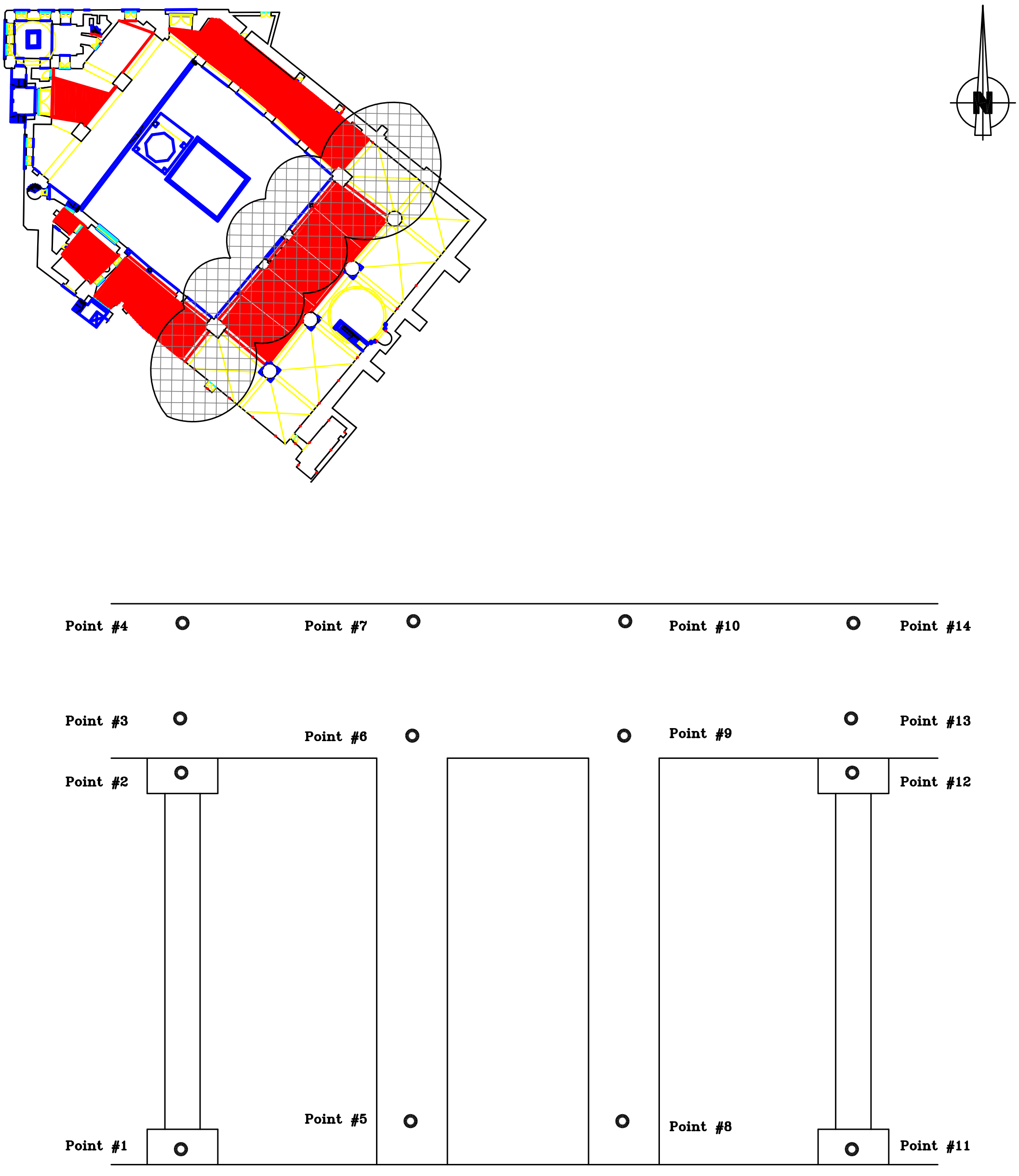


Figure (8): Elevation Layout depicts Location of the monitoring points on Face #6 of the interior wall inside the Blue Mosque



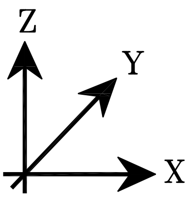


Figure (9): Elevation Layout depicts Location of the monitoring points on Face #7 of the interior wall inside the Blue Mosque