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Conservation of the Flat Roofs at the National Mosque, Kuala Lumpur, Malaysia

A Ghafar Bin Ahmad, *Professor*
School of Housing, Building and Planning, Universiti Sains Malaysia

Regular inspections were carried out by all parties to ensure the quality of workmanship after the installation of glazed porcelain mosaics and the application of waterproofing coating on the flat roofs of the National Mosque.

Introduction

Built in 1965 at a cost of RM10 million (USD2.42 million), the National Mosque (or *Masjid Negara*) is one of Southeast Asia's largest mosques with a unique modern design embodying contemporary expressions of traditional Islamic art, calligraphy and orientation. Jointly designed by three architects of the Public Works Department (or *Jabatan Kerja Raya-JKR*), namely Howard Ashley, Hisham Albakri and Baharuddin Kassim, the National Mosque features a 73-metre-high minaret and an 18-pointed star concrete main roof reflecting an open umbrella, with the cap of the minaret resembling a folded one. The multi-fold umbrella-like roof symbolises a renewed awakening and the aspirations of a newly-independent nation, as Malaysia had gained her independence from the British on 31st August 1957. Apart from the multi-fold umbrella-like roof, the National Mosque also has massive flat roofs covering a total area of approximately 13,000m^2. The flat roofs accommodate many mosaic-finished domes, mosaic-finished pyramid roofs, sunken roofs and skylight roofs. The differing designs of the roof types are rare and hardly found in any mosque design in the country.

The National Mosque boasts a large prayer hall that can accommodate up to 15,000 worshipers at any one time, especially for the Friday prayer. The main prayer hall is surrounded by a covered deep verandah which serves a dual function, that of an additional space for prayer and also for cross-ventilation in response to the local climatic conditions. The mosque complex also has a multipurpose hall, mausoleum, library and administration office as well as open courtyards with reflecting pools and water fountains. The mausoleum is reserved for the tombs of national heroes of the country. Located on a 13-acre landscaped garden near the Lake Garden in the heart of Kuala Lumpur, the National Mosque is one of the main tourist attractions in the capital city. Both Muslims and non-Muslims alike are only allowed into the mosque building wearing a modest attire of robes and headscarves as a sense of submission, peace and respect.

The National Mosque underwent major renovation works in 1987 including treatment of surface cracks and roof leakage. However, the renovation works did not comply with standard conservation principles and guidelines.

Twenty years later in 2007, the National Mosque and its mausoleum were listed as a National Heritage under the National Heritage Act 2005 (Act 645). Thirty years after the last renovation works, the National Mosque is now faced with several building defects and problems including roof leakage, missing mosaics on domes and pyramid roofs, aging mechanical and electrical fittings, and fading paint. The building also requires upgrading of the library, offices, floors, prayer halls, open courtyard and toilets. In 2016-2017, a dilapidation survey report and a Conservation Management Plan (or *Pelan Pengurusan Pemuliharaan*) were prepared by a local consultant architect to determine and document the nature of the building defects and conditions. The Conservation Management Plan also identifies the heritage values of the building and outlines the proposed conservation policies and strategies to protect its architectural and cultural significance. Both reports were submitted to the Department of National Heritage (DNH), Malaysia for review and endorsement.

In January 2016, the Government of Malaysia through the Department of Islamic Development Malaysia (or *Jabatan Kemajuan Islam Malaysia-JAKIM*), Public Works Department (JKR Malaysia and JKR Federal Territory of Kuala Lumpur) and the Islamic Religious Council of Federal Territory (or *Majlis Agama Islam Wilayah Persekutuan-MAIWP*) had allocated an amount of RM44,491,963 (USD10,678,071) to two local building contractors to conserve the National Mosque in two parcels. Parcel One, which was completed in July 2018, involved treatment of the flat roofs including the mosaic-finished domes, mosaic-finished pyramid roofs, sunken roofs and application of waterproofing coating at a contract value of RM9,299,963 (USD2,231,991). Parcel Two involves upgrading and conservation works for the library, administration office, prayer halls, floors, ceiling, open courtyards, toilets, wiring, air-conditioning system, and indoor and outdoor lighting. It also includes new construction works such as covered walkways, a new elevator and an administration building. The contract value of Parcel Two is RM35,192,000 (USD8,446,080) and it is expected to be completed in July 2019. This article focuses on the scope of works involved in Parcel One which covers scientific tests on existing roof structures, treatment of the flat roofs including the mosaic-finished domes, mosaic-finished pyramid roofs, sunken roofs and installation of waterproofing coating on the flat roofs.

Procedures and Principles of Roof Treatment

Similar to other National Heritage buildings listed under the National Heritage Act 2005 (Act 645), conservation of the National Mosque is undertaken based on the best practices of building conservation in the country with regard to proper documentation and treatment in accordance with the 2017 Guidelines on Heritage Building Conservation published by the DNH. The Conservation Management Plan prepared for the National Mosque in 2017 is in accord with Section 46 of Act 645. A registered building conservator was engaged by the building contractor in order to ensure that all conservation works closely followed the said principles and guidelines as outlined by the consultants and the DNH. All work method statements and interventions including proposed new mosaics, scientific studies, laboratory tests, roof treatment and application of waterproofing coating were prepared by the building conservator and duly approved by the consultant architect and the DNH. Conservation of the flat roofs at the National Mosque was based on the following conservation principles;

i. To retain the authenticity and integrity of the domes, pyramid roofs and sunken roofs.
ii. To maintain the form and shape of the domes, pyramid roofs and sunken roofs.
iii. To minimise interventions to the building structures and fabric.
iv. To match the new mosaics with the existing mosaic-finished on the domes and pyramid roofs.
v. To harmonise the new additions to the existing building.
vi. To conduct scientific studies and laboratory tests on the roof structures and building materials.
vii. To apply proven methods and techniques for the conservation of roofs.
viii. To document and record the conditions of the roofs before, during and after treatment.

Mosaic-finished Dome, Mosaic-finished Pyramid Roofs and Sunken Roofs

As many as 95 mosaic-finished domes, 270 mosaic-finished pyramid roofs and 208 sunken roofs are erected on the flat roofs of the National Mosque. Each roof type measures 4 m×4 m at the base. The height of the dome is 1.8 m while the pyramid roof is 0.8 m from the flat roof level. The sunken roof is 1.3 m deep. These domes, pyramid roofs and sunken roofs are made of reinforced concrete with waterproofing, mosaics or protective screed on the outer layers. Only the domes and the pyramid roofs are finished with glazed porcelain mosaics. Based on on-site structural investigation, the domes consist of five layers while the pyramid roofs have three layers including the reinforced concrete structure or substrate in the inner layer followed by waterproofing coating, original glazed mosaics, tile adhesive and glazed porcelain mosaics on the outer layers. During the earlier renovation works carried out in 1987, the domes were finished with new blue glazed porcelain mosaics and the pyramid roofs were finished with grey glazed porcelain mosaics. Each glazed porcelain mosaic measures 19 mm×19 mm with a slightly convex-edged design. The thickness of each glazed porcelain mosaic is 5 mm. Some of the ageing glazed porcelain mosaics on the domes and pyramid roofs of the National Mosque were found to be missing, detached, loosened or had fallen off. This condition had caused water penetration, trapped moisture and roof leakage onto the prayer halls and other spaces underneath the flat roofs. The existing waterproofing coating had weathered away so much that it failed to prevent the roof leakage on the flat roofs. Thus, a new waterproofing coating which has been proven to be efficient and long lasting was applied in the conservation of the flat roofs.

Scientific Studies and Laboratory Tests

It is essential to assess the nature and condition of the

roof structures and building materials as well as the causes of the flat roof defects before determining the design and specifications of the roof treatments. Scientific studies, laboratory tests and exploratory investigations were all carried out meticulously and with great care in an effort to understand in detail the building condition, defects and structural integrity. This stage of investigation, testing and analysis is most important in order to minimise any intervention that could cause further damage to the existing building structures. In this project, samples of building materials were taken on site and sent to laboratories at Mapei Malaysia Sdn. Bhd. in Petaling Jaya, Selangor; MAEK Consulting Pte. Ltd. in Singapore; and the Centre for Global Archaeological Research at Universiti Sains Malaysia (USM), Penang. The results and findings from the tests and investigations formed the basis and justification for the conservation solutions and treatments. Investigations of the flat roofs of the National Mosque were carried out based on these non-destructive approaches:

i. **Dilapidation Survey**
The dilapidation survey was carried out to identify, map out and outline the current condition, various defects, distress, damage and deterioration of the flat roof before the commencement of any rectification work or development. The building defects were recorded meticulously using detailed photographic and digital documentation. It also involved investigation of any modification works carried out previously on the flat roofs. The dilapidation survey report elaborated on the nature and extent of building defects, their causes and proposed conservation treatments. A thorough investigation of the domes, pyramid roofs, sunken roofs and flat roofs was carried out by the professional consultants and building conservator. Non-destructive methods and equipment were used to determine any defects, dampness or loose or missing mosaics.

ii. **Infrared Thermography**
Infrared thermography (IRT) was used for the flat roofs to investigate sub-surface anomalies and trapped moisture. This non-destructive method is based on the principle that any trapped moisture below the wall surface finish can affect or change the rate at which heat flows through the structure. This is due to higher levels of thermal heat capacity and thermal conductivity of moisture. These changes in the heat flow can cause localised differences in surface temperature. Thus, by measuring surface temperature under conditions of heat flow, one can determine the location of dampness and the likely path of water seepage. A relatively high differential heat transfer between the mediums (such as paint, moisture and trapped air) and the plaster must exist in order for the anomalies to be detected by infrared thermography.

iii. **Ground Penetrating Radar**
Another non-destructive method used for the flat roofs was ground penetrating radar (GPR). This geophysical method uses radar pulses to produce an image of the subsurface. It generally works on the principle of reflective energy. A hand-held unit consists of a transmitting antenna and a receiving antenna for the energy. The transmitting antenna sends out a diverging beam of electromagnetic wave energy pulses in the range of 500 Mhz to 1 Ghz through a structure, while the receiving antenna receives the reflected energy pulses from materials of different dielectric properties. The received energy pulses are sent to a control unit, where they will be processed and output on a display monitor in 2D or 3D mode. Such output can determine the depth or pattern of reinforcement and any embedment or possible moisture trapped below any substrate.

iv. **Petrography**
A petrographic test is a microscopic method used to examine the mineralogical and chemical characteristics of rocks or concrete samples. These samples can be taken from lump samples or cores. Samples of original mosaics and mortar or plaster on the domes and pyramid roofs of the National Mosque were extracted and subjected to petrographic testing to determine their composition and condition such as type of binder, distribution of aggregates including shape and size distribution, pore characteristics, binder-aggregates interface or bond, secondary reaction, salt formation, cracks and fissures. The petrographic testing was carried out using a combination of different microscopy from stereo zoom microscopes to digital microscopes to a magnification of 500x on hand and polished sections. Thin sections were prepared for examination with a polarising and fluorescent microscope (PFM) under transmitted and reflected light.

v. **X-Ray Florescence**
X-ray florescence (XRF) testing is a non-destructive analytical technique used to determine the elemental composition of building materials such as concrete, plaster and mortar. It is a process whereby electrons are displaced from their atomic orbital position, releasing a burst of energy that is characteristic of a specific element. An XRF analyser determines the chemistry of a sample by measuring the fluorescent (or secondary) X-rays emitted from a sample when it is excited by a primary X-ray source. Results from the XRF tests were very important and useful to propose new building materials on the flat roofs.

vi. **Pull-off Adhesive Test on Mosaic Layer**
In-situ pull-off adhesive tests were carried out on the domes to determine the bond strength of "Kerapoxy" epoxy tile adhesive between the polyurea coating surface and the existing mosaic layer. A pull-off tester was used for the test and the bond value was determined by taking the load at failure divided by the dolly area which was adhered on the tile. The average bond strength was 2.5 N/mm^2 which was

acceptable. The failure mode was also observed and it was found that all test specimens failed at the existing substrate but not at the new epoxy adhesive bond interface. This indicated that the bonding strength of the new epoxy adhesive was stronger against the original substrate or structure.

Conservation Works

During the conservation of the flat roofs the National Mosque, the building was divided into five zones. Zones 1 and 5 consisted of the covered verandah areas to the south and north. Zones 2, 3 and 4 comprised the main prayer hall. The conservation of the flat roofs at the National Mosque included the reinstallation of mosaics on the domes and pyramid roofs, rehabilitation of substrate and application of waterproofing coating on the flat roofs. The National Mosque was open to the public, including foreign tourists, throughout the construction period. Religious activities and celebrations were held as usual at the mosque including Friday prayer, breaking fast and *Tarawih* prayer in the Muslim fasting month of Ramadhan, as well as *Eidul Fitri* and *Eidul Adha* prayers. The fact that the mosque remained open during the entire construction period posed a great challenge to the building contractor and workers in terms of site security, safety, cleanliness, noise pollution and site management. Thus, on-site technical and site meetings among the consultants, building contractors, government agencies and the client were held regularly to ensure that the project went smoothly and was completed as scheduled. The conservation works of the flat roofs at the National Mosque were carried out based on the following stages:

Stage 1: Preparation of Site

i. Provide temporary scaffold access to the rooftop complete with security guardrail to avoid disturbing the daily operation of the mosque and to disallow access to unauthorised persons and the public.
ii. Provide temporary netting protection along the edge of the perimeter parapet wall against falling objects during the surface preparation work.
iii. Provide temporary tents and canvas sheets to protect the domes and pyramid roofs against direct sunlight and heavy rain during the installation of the new layer of glazed porcelain mosaics.
iv. Provide daily housekeeping to upkeep and maintain the cleanliness and tidiness of the mosque.

Stage 2: Reproduction of Glazed Porcelain Mosaics

i. Verify the quantity of new mosaics required.
ii. Determine the design and reproduce new glazed porcelain mosaics based on the colour and characteristics of the original glazed porcelain mosaics such as composition, shape, form, size, thickness and type of surface.
iii. The new glazed porcelain mosaics were custom-made to match the original as closely as possible, and they were imported from Jingdezhen, the "Porcelain Capital", in Jiangxi province, China.
iv. The new glazed porcelain mosaics were handled with extra care. They were kept in a safe warehouse in Kelang, Selangor upon arrival from China before being delivered on site in batches during the installation stage.

Stage 3: Preparation of Mock-ups

i. Conduct mock-ups to verify the contractor's ability to install a given product in accordance with the stated specifications. The mock-ups could demonstrate the level of workmanship or constructability of a component, and also form a benchmark for approval.
ii. The mock-ups on site provided the owner or consultant with a means for comparison by which to judge the acceptability of the installed work.
iii. The mock-ups also helped the owner or consultant to determine the workability and acceptability of the proposed design.

Stage 4: Preparation of Surfaces

Preparation of surfaces was divided into two categories as follows:

1. The mosaic-finished dome and pyramid roofs:
   i. Entirely remove the outer-most or non-original layer of glazed porcelain mosaics until the existing original layer of waterproofing coating is found by using an oscillating tool. The tool reduces the vibration and noise pollution to a minimum. It provides the least level of disturbance or nuisance to the public or the conduct of prayers inside the mosque.
   ii. Entirely remove the existing layer of waterproofing coating until the original layer of glazed porcelain mosaics is exposed by using an 11,000 psi high pressure hydro jet. Similar to an oscillating tool, the hydro jet provides the least degree of disturbance or nuisance to the public or the conduct of prayers inside the mosque.
   iii. Any noticeable cracks in the dome or pyramid roofs to be grooved cut and sealed with epoxy adhesive.

2. The flat roofs and sunken roofs with exposed waterproofing coating layers:
   i. Entirely remove the existing waterproofing coating layer from the top surface of the concrete until the concrete is exposed by using an 11,000 psi high pressure hydro jet.
   ii. Any noticeable cracks in the dome or pyramid roofs to be grooved cut and sealed with epoxy adhesive.

Stage 5: Rehabilitation of Reinforced Concrete Structure or Substrate

i. Delaminated cementitious bedding render underneath the mosaic finish for dome and pyramid roofs to be anchored mechanically into the reinforced concrete structure by using the "Helifix-DryFix" stainless steel helical pinning system.
ii. Drill 6.5 mm-diameter pilot holes through the bedding render into the reinforced concrete structure or substrate to a depth of 40 mm and at 450 mm intervals.
iii. Drive 8 mm-diameter "Helifix-Dryfix" stainless steel

helical pins through the pilot holes and into the reinforced concrete structure or substrate to secure and anchor the render mechanically.

iv. Any badly damaged or deteriorated render (on the dome and pyramid roofs) or concrete topping (on the flat and sunken roofs) to be removed until sound substrate is found.

v. Make good the render or concrete topping with "Planitop G40SP" polymer modified cementitious repair mortar, complete with "Planicrete SP" latex bonding agent.

Stage 6: Application of Waterproofing Coating

i. Apply a thin layer of "Primer SN" epoxy scratch coat on the prepared surface in order to prepare for the new waterproofing system.

ii. Spray 2 mm-thick "Purtop-1000" pure polyurea waterproofing coating on the primed surface.

iii. The exposed pure polyurea coated area such as the flat roofs and sunken roofs to be protected and finished with "Mapecoat PU15" aliphatic UV resistant polyurethane top coat.

Stage 7: Laying Glazed Porcelain Mosaics on Dome and Pyramid Roofs

i. Ensure that the surface of domes and pyramid roofs are clean, dry and free of any loose particles.

ii. Mix resin (Part A) and hardener (Part B) of "Kerapoxy" tile adhesive by using a drill mixer until a homogeneous and consistent colour is obtained.

iii. Spread the tile adhesive on the surfaces of domes and pyramid roofs by using a notched trowel.

iv. Place the mosaic sheet firmly into the wet adhesive. Push the mosaic back and forth to collapse the mortar ridges in order to achieve maximum coverage.

v. The arrangement and alignment of new mosaics must follow or match the original ones.

vi. Remove excess mortar from the joint area and allow it to cure for at least one day.

vii. Mix "Keracolor FF" pointing or grouting mortar with "Fugolastic" admixture.

viii. Fill the mosaic joints completely with the pointing mortar by using a rubber float. Remove excess grout from the surface while it is still fresh.

ix. While the grout loses its plasticity and becames matt over a period of 10-20 minutes, clean the excess grout with a damp sponge. Let it cure for another 3 days.

x. A typical sequence for laying glazed porcelain mosaics for domes and pyramid roofs is as follows:

1. Lay mosaics to form the ridge of the roof as control lines (4 ridges).
2. Set the horizontal bottom line as a benchmark.
3. Set the vertical centre line and begin the first sheet of mosaics at the lowest centre point of the dome or pyramid roof, working towards the left and right until meeting the ridges at the ends.
4. Follow the sequence at the second tier of mosaics, working upwards until reaching the top of the roof.
5. Trace and cut the mosaics to fill in the blank areas along the vicinity of the ridges.

xi. A total of 13,482,953 new glazed porcelain mosaic pieces were used to cover 5,302 m^2 of the surface areas of the domes and the pyramid roofs (2,553.6 m^2 for the domes and 2,748.4 m^2 for the pyramid roofs).

Conclusion

The conservation of the flat roofs at the National Mosque in Kuala Lumpur depicts an outstanding masterpiece of well-orchestrated efforts by all consultants, building contractors and government agencies involved in the project. The flat roof conservation project proved to be very challenging because it involved different designs of roof types, each requiring a different, specific approach. The various stages of the roof conservation in Parcel One and Parcel Two of the National Mosque also required good coordination and communication among building contractors, sub-contractors, building conservators and material suppliers to ensure that the project logistics and schedule were well-managed. It is crucial to engage competent building conservators, consultants, local experts and skilled workers to manage documentation and to undertake project execution efficiently since the National Mosque is open to the public, religious activities and tourists throughout the entire period of the works for both Parcel One and Parcel Two. Detailed research, scientific studies, laboratory tests and technical meetings were carried out at regular intervals to facilitate coordination to ensure timely progress of the works. Non-destructive tests were adopted for the project in an effect to reduce the level of noise pollution, mainly to the users of and visitors to the National Mosque. The tests would also minimise any interventions to the building structure and fabric, hence retaining the authenticity and integrity of the domes, pyramid roofs and sunken roofs. Rainy weather is a critical factor in the hot and humid climatic conditions in Malaysia. Therefore, temporary tents were erected and canvas sheets were used to cover each dome and pyramid roof during the mosaic installation stage in order to protect them from direct sunlight and heavy rain. The outsourcing of new glazed porcelain mosaics from China also involved a meticulous technical process, particularly regarding the mosaic design, reproduction, replication, delivery and coordination. Nonetheless, despite all these challenges, the flat roofs of the National Mosque have been conserved and reinstated successfully. It is hoped that the conservation of the flat roofs at the National Mosque enhances public awareness in safeguarding the National Heritage buildings of Malaysia.

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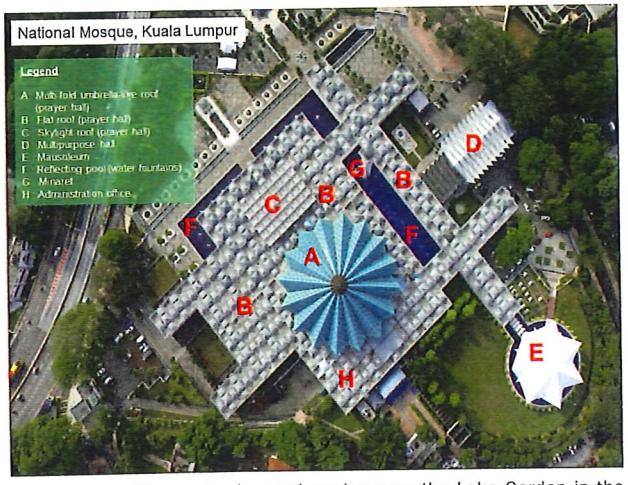
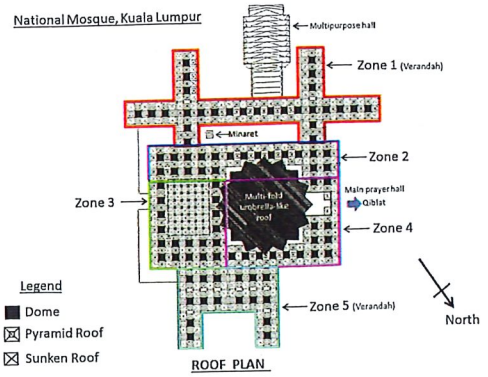
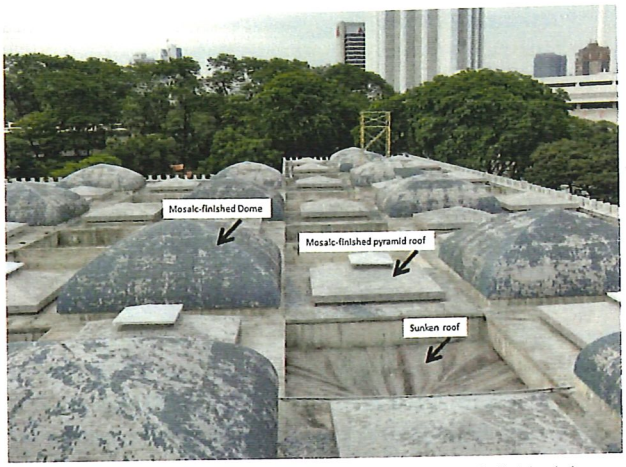
Built in 1965, the National Mosque (or *Masjid Negara*) features a 73 m-high minaret and an 18-pointed star concrete main roof reflecting an open umbrella, while the cap of the minaret resembles a folded one.



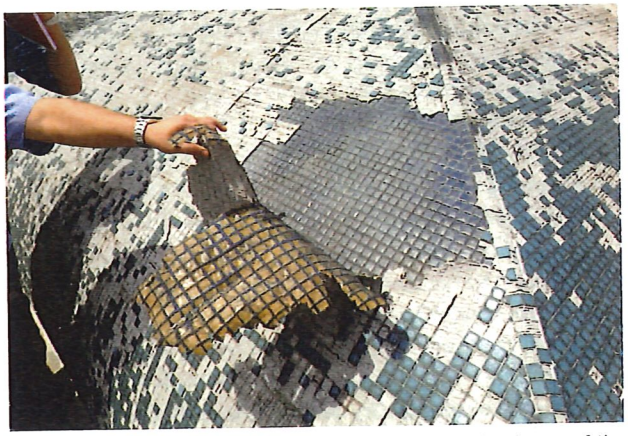
Located on a 13-acre landscaped garden near the Lake Garden in the heart of Kuala Lumpur, the mosque complex has a massive flat roof area of approximately 13,000 m^2, prayer halls, a multipurpose hall, mausoleum, library and administration office, as well as open courtyards with reflecting pools and water fountains.



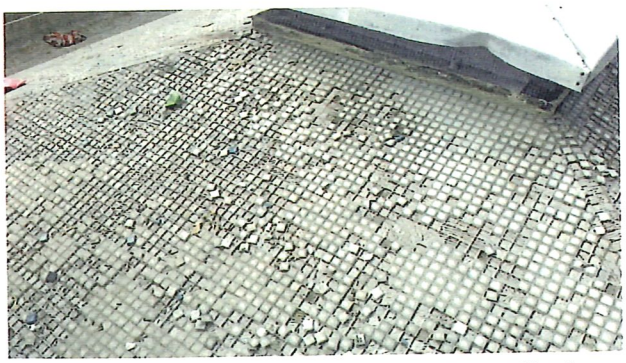
During the conservation of the flat roofs of the National Mosque, the building was divided into five zones. Zones 1 and 5 consist of the covered verandah areas in the south and north, whilst Zones 2, 3 and 4 comprise the main prayer hall.



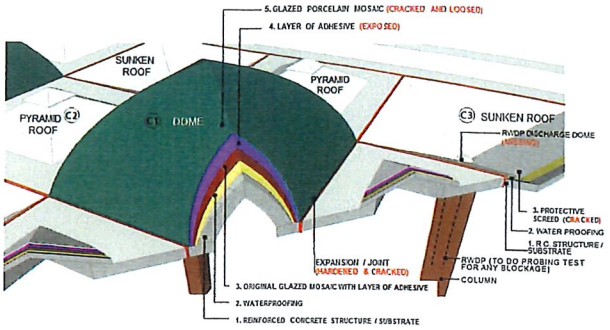
The flat roofs of the National Mosque accommodate mosaic-finished domes, mosaic-finished pyramid roofs, sunken roofs and skylight roofs. Each roof type measures 4 m×4 m at the base. The height of the dome is 1.8 m, the pyramid roof is 0.8 m and the sunken roof is 1.3 m deep.



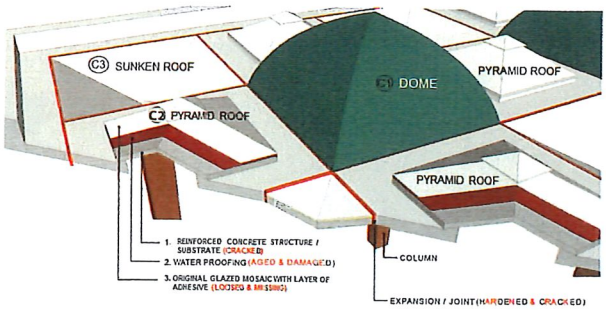
The ageing top layer of glazed porcelain mosaics on the domes of the National Mosque were found to be either missing, detached, loosened or to have fallen off, exposing the old layer of waterproofing coating and the original mosaics. This condition had caused water penetration, trapped moisture and roof leakage onto the prayer halls and other spaces underneath the flat roofs.



Similar to the domes, the glazed porcelain mosaics on the pyramid roofs were found to be either missing, detached, loosened or to have fallen off, exposing the old layer of waterproofing coating.

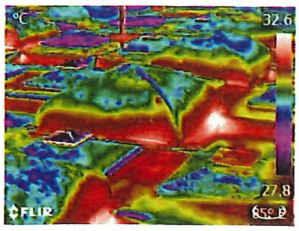


Based on on-site structural investigations, the domes consist of five layers while the sunken roofs have three layers including a reinforced concrete structure or substrate in the inner layer. Each dome has layers of waterproofing coating, original glazed mosaics, tile adhesive and glazed porcelain mosaics on the outer layers.



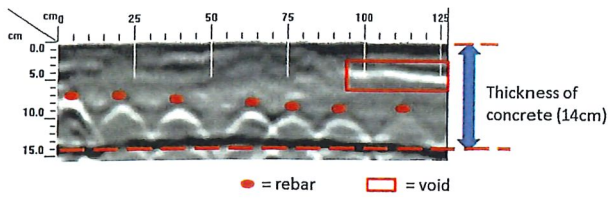
The pyramid roof has three layers including a reinforced concrete substrate or structure in the inner layer. Structural investigations showed that the pyramid roofs had building defects including cracks, damaged waterproofing coating, and loosened or missing original glazed porcelain mosaics.

Thermographic scanner (camera)



Infrared thermography (IRT) was used on the flat roofs to investigate sub-surface anomalies and trapped moisture in the domes, pyramid roof and sunken roof. The cold spots in blue indicates trapped moisture, whilst the hot spots in yellow are a sign of delamination or subsurface voids.

A ground penetrating radar (GPR) scanning device was placed on the dome surfaces to determine the depth or pattern of reinforcement and any embedment or possible moisture trapped underneath the substrate or structure.



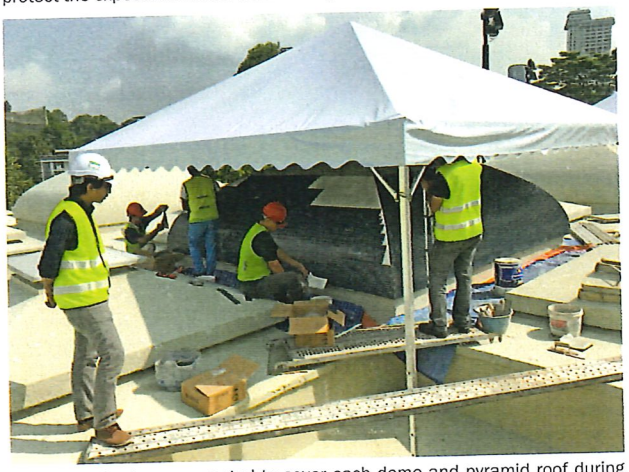
Results from the ground penetrating radar (GPR) scan on the domes revealed that the thickness of concrete substrate or structure was 14 cm. The GPR scanned image also showed the location of rebars and voids inside the domes.

Samples of building materials from the domes including concrete substrate or structure were cored to examine the mineralogical and chemical characteristics (petrography test); and also to determine the elemental composition (X-ray florescence test).

In-situ pull-off adhesive tests were carried out on the dome to determine the bond strength of "Kerapoxy" epoxy tile adhesive between the polyurea coating surface and the exisiting mosaic layer. The result showed that the average bond strength was 2.5 N/mm^2, which was acceptable.

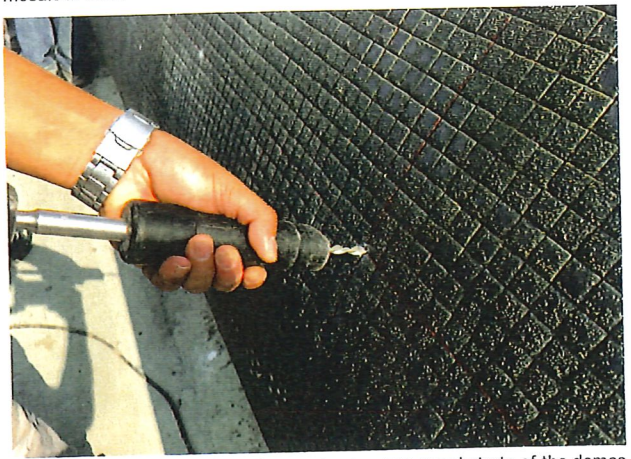
An oscillating tool was used to carefully remove the outer-most or non-original layer of glazed porcelain mosaics on the domes and pyramid roofs until the existing original layer of waterproofing coating was found. The tool reduced the vibration and noise pollution disturbing the public and the conduct of prayers inside the mosque.

Canvas sheets were used to cover the domes and pyramid roofs after the outer-most layer of glazed porcelain mosaics had been removed. This was to protect the exposed surfaces from water penetration.



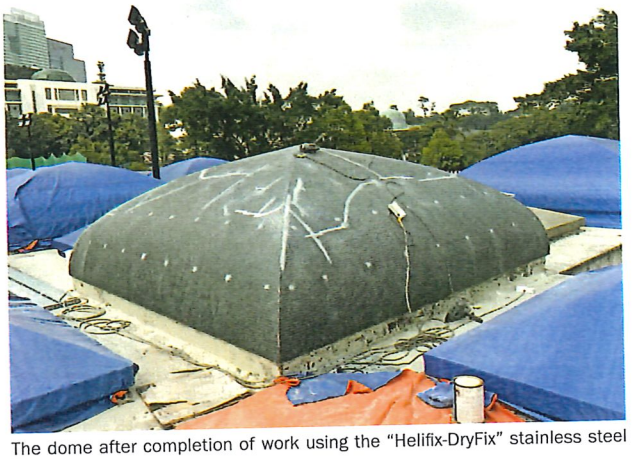
Temporary tents were erected to cover each dome and pyramid roof during the mosaic installation stage in order to protect them from direct sunlight and heavy rain.

Removal of the existing layer of waterproofing coating on domes by using an 11,000 psi high pressure hydro jet, revealing the original glazed porcelain mosaic in blue.

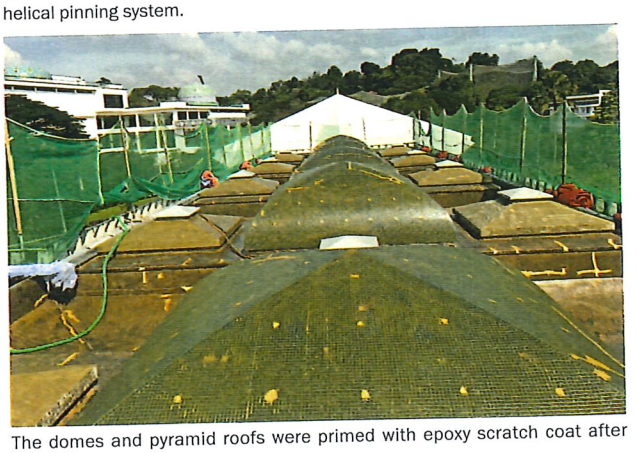


Rehabilitation of the reinforced concrete structure or substrate of the domes was carried out by driving 8 mm-diameter "Helifix-Dryfix" stainless steel helical pins through the pilot holes and into the reinforced concrete structure or substrate.

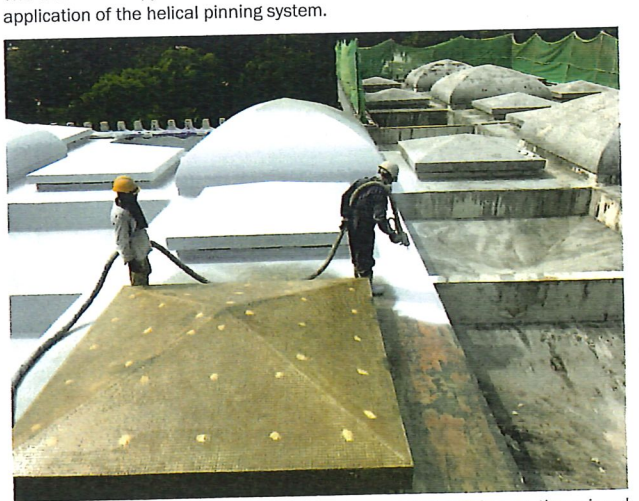
Equipment used to secure and anchor the reinforced concrete substrate or structure of the domes and pyramid roofs, including a load tester, stainless steel DryFix tie-pins and pin drivers.



The dome after completion of work using the "Helifix-DryFix" stainless steel helical pinning system.

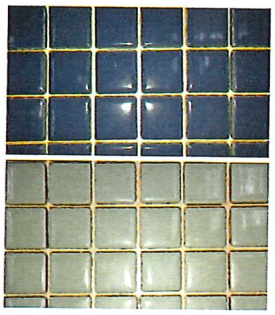


The domes and pyramid roofs were primed with epoxy scratch coat after application of the helical pinning system.



The spraying of 2 mm-thick polyurea waterproofing coating on the primed surfaces of the domes and pyramid roofs.

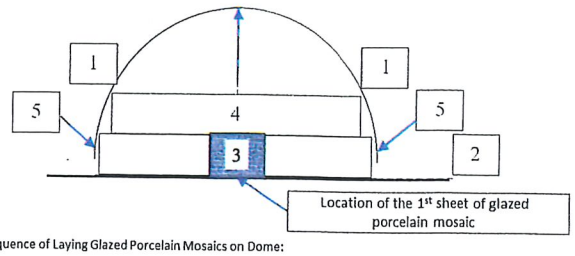
The flat roofs of the National Mosque covered by polyurea waterproofing coating.



New blue glazed porcelain mosaics for the domes and grey glazed porcelain mosaics for the pyramid roofs that match the original mosaics. Each glazed porcelain mosaic measures 19 mm×19 mm with a slightly convex-edged design. The thickness of each glazed porcelain mosaic is 5 mm.

Spreading the tile adhesive on the surfaces of the dome by using a notched trowel before layering the sheet of glazed porcelain mosaics.

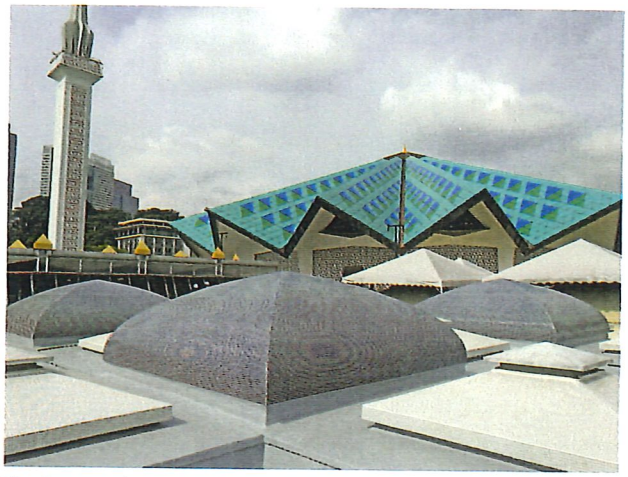
The installation of new glazed porcelain mosaics on the dome was carried out from the bottom layer and working upwards.



Sequence of Laying Glazed Porcelain Mosaics on Dome:

1. Lay mosaic to form the ridge of the roof as control lines (4 ridges).
2. Set the horizontal bottom line as a bench mark.
3. Set the vertical centre line and begin the first sheet of mosaic at the lowest and center of the dome or pyramid roof, working towards left and right until meeting the ridges at the ends.
4. Follow the sequence at the second tier of mosaic working upwards until the top of the roof.
5. Trace and cut the mosaics to fill in the blank area along the vicinity of ridges.

The layering new glazed porcelain mosaics on domes begins with the first sheet of mosaics at the lowest centre point of the dome or pyramid roof and working towards the left and right until meeting the ridges at the ends.



The domes and pyramid roofs of the National Mosque after the installation of new glazed porcelain mosaics.

Upon completion, a total of 13,482,953 new glazed porcelain mosaic pieces were used to cover 95 domes and 270 pyramid roofs on the flat roofs of the National Mosque.

An aerial view of the National Mosque with its newly conserved flat roofs.