Tomb of Jam Nizam Al Din

Makli World Heritage Site

Province of Sindh – Islamic Republic of Pakistan

Structural Damage assessment and recommended consolidation measures

Acknowledgements

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Contents

1. Executive Summary

This report encapsulates the findings of a field trip to the necropolis of Makli in mid-February 2018. The field trip focussed on the recording and assessment of structural damages of the tomb of Jam Nizam al Din, which is considered one of the most important monuments within the world heritage site of Makli.

The study identifies two weak areas of the structure: Firstly, the subsidence of the eastern half of the monument, which is built next to a cliff that steps down eleven meters to the riverbed of a former tributary of the Indus river. Secondly, the perturbation of the most prominent feature of the tomb: the beautifully decorated central pilaster of the western façade, which is surmounted by the Darshan Jharoka balcony structure.

Subsidence of the eastern half of the monument: The proximity of the monument to the cliff as well as the deficient soil characteristics of the supporting ground have caused severe structural problems. The tomb has been built on top of a deeper soil layer of fine silt, which provides insufficient bearing resistance. Due to the ongoing erosion of the cliff and the receding location of its rim, the deeper layer of fine silt is not equally contained laterally in all directions. The bearing pressure exerted by the significant self-weight of the tomb causes not only subsidence (i.e. vertical settlement), but also the – though very slow but steady – lateral movement of the fine silt layer towards the bluff. Hence, the foundation walls of the eastern part of the tomb suffer from both subsidence as well as from the horizontal deformation of the deeper strata. The monument must have experienced settlement problems throughout its lifetime. However, the ongoing erosion of the cliff exacerbates the situation and accelerates the deterioration of the monument. In order to safeguard the monument it is essential to improve the soil characteristics of the subsoil and to contain the lateral movement of the deeper strata of fine silt. The situation should be addressed with a triad of geotechnical measures: firstly, the subsoil of the existing foundation walls should be improved with grout injections (lime or bentonite). As a prerequisite for this procedure, a thorough geo-radar scan of the subsoil inside and outside of the tomb is mandatory in order to detect any anthropogenic materials or artefacts. Secondly, the horizontal movement of the lower strata should be retained by a permeable assembly of bored piles. The small spacing between the piles will prevent any perturbation of the ground water flow, as the creation of a water barrier inside of the soil would have severe detrimental effects (for this reason, any insertion of a monolithic retaining wall should be strictly avoided). The pile assembly will need to be tied back into lower soil strata with injection anchors in order to provide sufficient horizontal stability. Lastly, the cliff needs to be protected against the ongoing erosion. As this problem is not limited to the site of Jam Nizam al Din alone (though most severe here), a comprehensive solution should be conceived for the entire site. This slope stabilization plan needs to be coordinated with archaeologist and landscape architects.

Darshan Jharoka balcony structure: the passage of time as well as a series of past earthquakes have caused a variety of cracks and dislodgements at the ornate central pilaster of the western façade and the balcony structure. Many of the intricate stone elements have also suffered from heavy handed repair works and the use of cement mortar or the replacement of lost elements with ill-fitting components in the past. It is recommended to repair and strengthen the upper part of the balcony during by means of an anastylosis of the upper part of the drystone masonry. In order to improve the keying between the central pilaster and the main structure and to enhance the seismic resistance of the upper part of the balcony structure, the (concealed and reversible) inclusion of glass fibre reinforcement should be investigated.

2. Layout and history of the tomb of Jam Nizam al Din

The tomb of Jam Nizam Al Din Shah, also known as Jam Nindo, was built one year after his death in 1509. The tomb is part of the cluster of monuments on "Samma hill" – a high plateau in the northern parts of the necropolis of Makli. It is situated next to the ridge of the plateau, with an approximately 11.0m drop in terrain to the riverbed of a former tributary of the Indus. The geometry of the structure is roughly based on a cuboid – with a square footprint of 11.17m x 11.27m – and a height of approximately 8.50m above grade level. Purportedly, the outer dimensions were chosen to be vaguely reminiscent of the geometry of the Kaaba in Mecca.

The monument comprises a massive construction of stone masonry and renders a unique array of devotional carvings of outstanding quality on its wall faces. The masonry of the structure displays the highest level of artisanship. The most prominent feature of the monument are unmistakably its stone carvings at the central pilaster of the western facade.

2.1 Architectural layout of the monument

The main chamber of the tomb is accessed through an elaborately decorated entrance door at the western façade of the building. On the southern and northern wall, door openings are inserted into the walls of the ground floor (now fully or partly closed with brick infill panels). The lavishly decorated niche of the mihrab is integrated in the western wall of the building.

The main chamber consists of an open square space without any roof. The square layout of the inner chamber transitions by means of squinches into an octagon and further upwards into a hexadecagon. Although the transition from square to hexadecagon seems to imply the anticipated construction of a dome, the composition of the structural fabric elements not support this notion. The wall construction of the inner walls do not convey any provisions to bear the significant additional weight of a masonry dome. Furthermore, as was pointed out by the esteemed architectural historian Yasmeen Lari, the local stonemasons had neither the knowledge nor the experience to construct a real dome structure at the beginning of the sixteenth century. The observation that the masons were more familiar with the coeval trabeated construction techniques prevalent in the South-Asia than with the dome and vaulting techniques of Persia can be witnessed at various details of the tomb. So use the cusped-arch windows of the tomb a corbelled construction with projecting stones instead of a real arch-like construction with voussoir stones. It is therefore not clear if the builders were proficient enough in arch – and dome construction to vault such a large space.

2.2 Composition of stone masonry

According to Mr. Tanveer Ahmed, the stones were most likely extracted at the quarry of Jungshahi, a village 20km apart from the building site. Basic material tests conducted at a small sample at a laboratory in Munich indicate that the stone can be classified as Dolostone / Dolomite rock. This is a sedimentary carbonate rock that contains a high percentage of the mineral Dolomite $CaMg(CO_3)_2$.
Compared to limestone, it is slightly harder and less ductile (E-modulus range: 16.000 – 80.000N/mm²). Although the quality of stone is in general even and uniform, inclusions of iron can be seen at some of its surfaces.

The outer faces of the walls consist of dressed drystone masonry (ashlar). Most likely, the walls are composed of two faces of dressed stone masonry with a layer of rubble infill in between. This construction method was widely used for the vast majority of coeval monuments in the area. This assumption was further corroborated by an endoscopic survey (image 37).

The wall thicknesses vary with the cardinal directions from a minimum of approx. 1.04m at the east and north wall to approx. 1.65m at the south and west wall, which incorporate the narrow stairway to the Darshan Jharoka and the mihrab respectively. According to Mr. Tanveer Ahmed, the foundation wall on the eastern face of the building was found to be in a good condition, when he built the new retaining wall next to it in the year 1994. Mr. Ahmed mentioned that the base stone of the wall stepped out by approx. 22cm.

2.3 History of past repair and conservation works

No reliable records of past restorations and interventions of Jam Nizam al Din are available. In order to obtain a better understanding of the structural behaviour of the building in the past, a series of interviews with site managers, architects and conservation experts was carried out. According to various sources, the following timetable of past interventions and repair works could be reconstructed:

19th c. Possibly some restoration works carried out during the British reign

1956 Restoration carried out by the Department of Public Works. The door openings in the north and south walls are closed with stone masonry. The concrete flooring at the ground floor as well as the concrete layer at the top of the building are added, together with one to two courses of stone masonry bricks at the crown of the building. Gaps and cracks are patched with cement mortar.

The adjacent small pavilion north of Jam Nizam al Din (Noori Jam Tamachi) is stabilized laterally with two steel columns (I sections) at around 45° and 70°.

1960s Apparently minor restoration works without record

1970s Apparently minor restoration works without record

1981 Inscription of Makli necropolis in the World Heritage List.

1994 An L-shaped retaining wall made of concrete is built next to the existing foundation wall at the eastern side of the building. The new wall has a distance of approx. 75cm to the existing one. The space above the lower leg of the L is filled with bricks laid in cement mortar.

In the same year, all gaps and cracks of the stone masonry are filled with lime surkhi mortar.

1996 A concrete apron is placed next to the embankment on the northern side of the building in order to prevent the infiltration of rainwater into the soil.

2010 Disastrous floods and displacement people on the site

2011 *Comprehensive documentation and condition survey of the tomb by the Heritage Foundation of Pakistan*

2016 At the end of the year, the cementitious layer at the top of the building that had been put in place in the year 1956 was repaired as it showed many cracks in the north-south direction. Also some repointing of open cracks and horizontal dislodgements was carried out with cement mortar.

2017 At the beginning of the year crack meters are installed inside the building and at the top of the structure

2018 Additional crack meters are installed at various critical locations of the structure

3. Settlement problem at the eastern side of the tomb

3.1 Current structural condition

The south and north wall of the tomb show serious dislodgements of the dressed stone masonry. The subsidence of the eastern part of the building caused an uneven overall settlement of the structure, leading to severe perturbations of the stone masonry above. The history of the formation of cracks and dislodgements due to subsidence can be followed very clearly at the centres of the south and north wall. Here, the positioning of the door and window openings in the symmetry axis of the massive masonry walls created a weak point in the structure that acts like a hinge within the structure. Whereas the western half of the building remains stable, the eastern half of the building suffers from continuing subsidence and horizontal movement of the ground. Consequently, cracks and horizontal gaps in the masonry propagate upwards in the symmetry lines of the south and north wall.

It is quite likely that the unsatisfactory soil conditions became already apparent during the construction of the monument or shortly afterwards. The traces of continuing repair works during the 20th century and before suggest that the uneven settlement of the building has been ongoing for a very long time, albeit perhaps on a somewhat slower pace.

In 1994, a retaining wall was built just next to the eastern foundation wall. The L-shaped wall made of reinforced concrete and was embedded in brickwork. It now forms the embankment next to the slope. In the same campaign, the cracks in the masonry walls were also repaired and repointed with red coloured lime mortar (surkhi). As the newly built retaining wall is not tied into the soil and only runs parallel to the existing foundation wall, it did nothing to stop nor contain the movement. In fact, soon after the retaining wall was built, new cracks formed along the retaining wall and in the masonry, particularly on the northern side of the building. The observation that the horizontal movement at the northern side - which is also bit closer to the edge of the cliff - is more acute than at the southern side can be witnessed at the encasement of the retaining wall at the eastern face of the building. Here, a longitudinal crack in south-north direction has formed just above the embedded reinforced concrete wall. The crack opens up from approx. 2mm at the southern end to about 20mm at the northern end.

During the 1994 restoration of the monument, all apparent cracks were patched with matching stone pieces and surkhi lime mortar. Today, it can clearly be seen that these cracks have meanwhile opened up by approx. 18 mm at the northern wall (image 12). At the southern wall, no significant openings next to the conservation works of 1994 are apparent. At the maximum, slight openings of about 3-4mm might have formed since the 1994 intervention. Since the installation of the crack meters at various locations at the building by the end of 2017, no movement could be discerned. However, the accuracy of the installed crack meters is not high enough to discern small movements below 1mm. The crack openings on the north wall suggest an ongoing movement of approx. 1 mm per year on the northern side and about a third of that on the southern side of the monument.

3.2 Diagnosis

During the “comprehensive documentation and condition survey” carried out by the Heritage Foundation of Pakistan in 2011, a geotechnical survey was undertaken by “Consolidated Engineering Services” (ces) engineers from Karachi (with support from UNESCO). CES drilled four 15m deep boreholes around the monument and analysed the soil of the varying layers. The report of their mission stated that the top layer of earth was originally limestone. Due to exposure to the elements, it had disintegrated into smaller pieces. Immediately below the fragments of rock is an approximately 4.5m (15 feet) layer of lime stone and below this is a 4.5m (15 feet) layer of “shale”, followed again by a layer of limestone.

The term “shale” is used by ces to identify “dense silt”, a clayish loam with markedly plastic behaviour. The physical properties of the material change if inundated or exposed to water for a longer period. In this instance, the stiffness of the material decreases noticeably. Furthermore, if exposed to the weather, this material can deteriorate and disintegrate quite rapidly. The erosion process of the cliff was already described by ces in their final report: since the soft layer of loam erodes quite quickly under atmospheric exposure, it leads to the landslip of the limestone layer above. The ongoing erosion of the bluff can be witnessed at the example of a sepulchral structure below Jam Nizam al Din, which has been partly carried away due to the ongoing degradation of the slope (See image 7).

The ongoing erosion of the layer of loam at the cliff has an important effect of the stability of Jam Nizam al Din: under normal conditions, the weak layer of loam would be contained in every direction and not able to expand in any direction. However, as the ongoing erosion of the cliff has already substantially decreased the distance between the edge of the cliff and the foundations of the tomb. Consequently, the layer of loam is not equally constrained in all directions any more. Subjected to the heavy mass of the tomb, it will expand eastwards, as the decreasing distance to the cliff provides no restraint any more horizontal expansion in this direction. This effect is exacerbated if the moisture content of the layer rises. For this reason, it is quite harmful that the waterspout currently dewaters directly into the gap between the existing foundation wall and the retaining wall (image 13).

In effect, this means that the foundations (i.e. their eastern part) are not only subjected to vertical settlement but also to horizontal movement. This can be seen very clearly at image 18.

3.3 Proposed intervention

In order to contain the ongoing movement in the best possible way, the author recommends a multi-tiered approach. It will consist of the improvement of the soil adjacent and below of the existing foundations with injections, the containment of the soft clayish soil layer by means of a permeable bored pile wall, as well as an coordinated solution to secure and retain the cliff areas in the entire core zone.

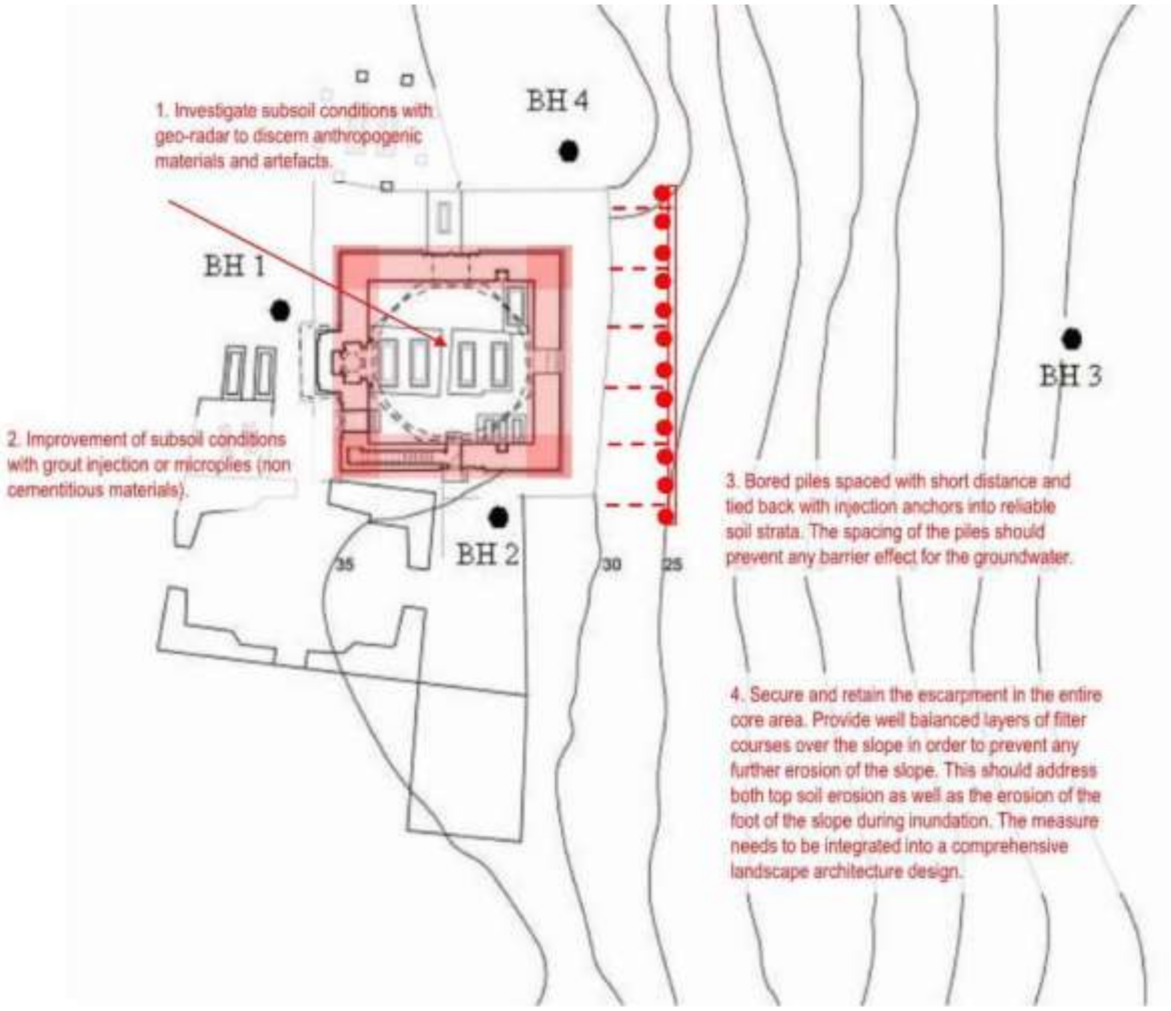
a) <u>Grout injections / Micropiles</u>

In order to decrease the actual bearing pressure beneath the existing foundations and to improve the conditions of the load bearing strata, it is recommended to investigate the applicability of grout injections or micropiles.

As a grouting material of the micropiles, cementitious mixtures should be avoided for their incompatible mechanical characteristics. Instead, lime-based injection materials should be considered. As another alternative bentonite, a grouting material that also exists in nature, should be investigated.

In order to understand the current situation of the existing foundation walls better – to assess their quality and to ascertain their depth, test pits should be dug at three locations (outside of the south and north wall doorways as well as on the northeast corner).

This intervention should only be considered after a thorough investigation of the soil conditions within the tomb. In order to avoid any potential disturbance of archaeological artefacts, a geo-radar study should be performed first.



b) <u>Permeable pile wall</u>

In order to contain the movement of the tomb, an open pile wall should be inserted in the soil approx. 3.0m off the newly built retaining wall of 1994. It is important that these piles are aligned with a clear spacing in order to not disturb the equilibrium of the water table beneath the surface. For this reason, the insertion of any wall should be strictly avoided. The resulting barrier effect would quite likely be detrimental. A horizontal beam should connect the piles and serve as a basis for the injection anchors. The anchors themselves should be tied into the lower limestone layer.

(Only recently, another retrofitting scheme was conceived by ESS-I-AAR consulting engineers from Karachi for the Endowment Fund Trust (EFT). This scheme consists of an invasive U-shaped retaining wall system. Due to its imposing and disproportionate size this structure would not be fitting into the sensitive surroundings. Apart from that, it is likely that the RC retaining walls will significantly change the water table at the foundation level which might have detrimental effects on the settlement. As this solution is also just embedded into the surrounding soil, it is no clear how it should provide enough resistance against movement.)

c) Slope stabilization strategy

In order to secure the cliff area against further erosion, a comprehensive solution needs to be developed. For this purpose, a geotechnical slope stabilization with granular filters (and geotextiles) needs to be designed. This measure should protect both, the rim of the bluff as well as the bottom of the cliff in case of flooding of the riverbed. Although the erosion problem is most acute at the tomb of Jam Nizam al Din, it can also be noticed at many other locations along the cliff.

For the development of a slope stabilization strategy, the close collaboration between a geotechnical engineer, archaeologists and a landscape architect is imperative.

4. Darshan Jharoka

4.1 Current structural condition

The prominent balcony structure at the Western face of the monument – the Darshan Jharoka – is the most prominent feature of the tomb of Jam Nizam al Din. The quality of the stone carving is of exquisite beauty and finesse. The central risalit of Darshan Jharoka shows partial detachment from the west wall of the tomb. Vertical gaps have opened up between the balcony structure and the main building due to insufficient keying of stone elements between the two parts.

A variety of earthquakes (1668, 1819, 1945, 1947) have affected the site of Makli in the past. As only minimal differential settlements can be detected in this area, it is very likely that the cracks and dislodgements originate not from subsidence but from past earthquakes and tremors.

The earthquake damages at the Darshan Jharoka and the ensuing heavy-handed repair works have led to a structurally unsound und improper condition of much of the upper part of the balcony area. Gaps and dislodgements in the stone masonry have been patched or repointed - often in a very unsightly manner. The majority of the historic iron clamps that were once joining the stone slabs are missing.
Original parts like door jambs, pilasters and other elements are missing. Most notably, the original column on the north-western corner of the balcony has been replaced by a mismatching column of unknown origin. As this element is too high, it also causes disturbance at the lintels above, which are not aligned horizontally as a result.

Currently, there seems to be no ongoing deformation at the Darshan Jharoka. This observation is substantiated by the fact that the repointed areas in the niche of the mihrab (carried out 1994) are still intact and show no signs of movement.

4.2 Proposed intervention

Although the Darshan Jharoka is not in imminent danger, it has suffered significantly in the past due to earthquake damages and inappropriate repair works. This has overall led to a significant weakening of its structural integrity. As the structure of the balcony with its long cantilevers is already very ambitious, only a small tremor could already lead to substantial further damage of the stone elements.

It is recommended to repair and strengthen the upper part of the balcony during by means of an anastylosis of the upper part of the drystone masonry. For this purpose, the cracked and dislodged stone down to approx. 1.8m below the balcony structure should be carefully disassembled. The cracked or damaged stone elements should be repaired in a stone conservation laboratory (to be set up inside of the entrance office facilities). The anastylosis and stone conservation works must be carried out by stone conservation experts with proven experience and expertise in the conservation of comparable monuments. In order to improve the keying between the central pilaster and the main structure and to enhance the seismic resistance of the upper part of the balcony structure, the (concealed and reversible) inclusion of glass fibre reinforcement should be investigated.

5. Recommended next steps and outlook

The following steps should be taken as soon as possible to ensure a timely response to safeguard the tomb of Jam Nizam al Din:

1. High-precision crack meters should be installed at various locations of the structure to monitor the movement of the tomb more accurately
2. All crack meters need to be monitored and recorded at least once per month (with photographs)
3. A geo-radar analysis of the subsoil inside and around the tomb should be carried out in order to locate any anthropogenic materials and artefacts
4. If the outcome of the geo-radar analysis allows, test pits should be dug at least two locations in order to assess the depth of the existing foundations wall and their quality. Ideally, the test pits should be located at the center of the south and north walls in order to see how the existing crack pattern propagates downwards.
5. Small probes of the stone and mortar should be taken in order to undertake material tests to study the chemical structure of the stone as well as its mechanical properties like compressive strength and E-modulus.
6. Based on the outcome of the steps 1 – 3, a detailed structural engineering design should be prepared.

6. Photographic Survey

Image 1: Samma cluster at the northern end of Makli necropolis. The cuboid volume of the Jam Nizam al Din tomb can be seen on the right.

Image 2: Western face of Jam Nizam al Din tomb.

Image 3: South-west corner with remnants of an older sepulchral structure south of Jam NIzam al Din.

Image 4: South façade of Jam Nizam al Din.

Image 5: South-east corner of Jam Nizam al Din.

Image 6: View from the slope to the south-east corner of the building.

Image 7: Remnants of a tomb structure south-east of Jam Nizam al Din. The structure collapsed due to the erosion of the slope.

Image 8: View from the dry riverbed below to the eastern face of the building.

Image 9: View from the dry riverbed below to the north-eastern corner of the building.

Image 10: North-eastern corner of the building with the masonry encased retaining wall installed in 1994 and (in the foreground) the concrete apron installed in 1996.

Image 11: North facade of Jam Nizam al Din, showing the sealed northern doorway and the series of cracks above.

Image 12: Upper part of north façade with opening gaps between the stone elements (some former infill patches caved outwards and are missing, the maximum opening since 1994 measures approx. 18mm.)

Image 13: Encasement of the added retaining wall (1994), showing a horizontal gap with increasing width from south to north. Note that the waterspout that drains the central space dewaters directly into the crack between the foundation wall and the newly built retaining wall, which is encased in the plinth (built in 1994). The water is trapped in the gap in between and is funnelled directly to the moisture-sensitive clayish layer below the foundation walls.

Image 14: North-east corner of Jam Nizam al Din with the encased retaining wall (built in 1994) and – below, right side, the newly added apron made of cement mortar for rainwater protection.

Image 15: Central space of the tomb, looking east.

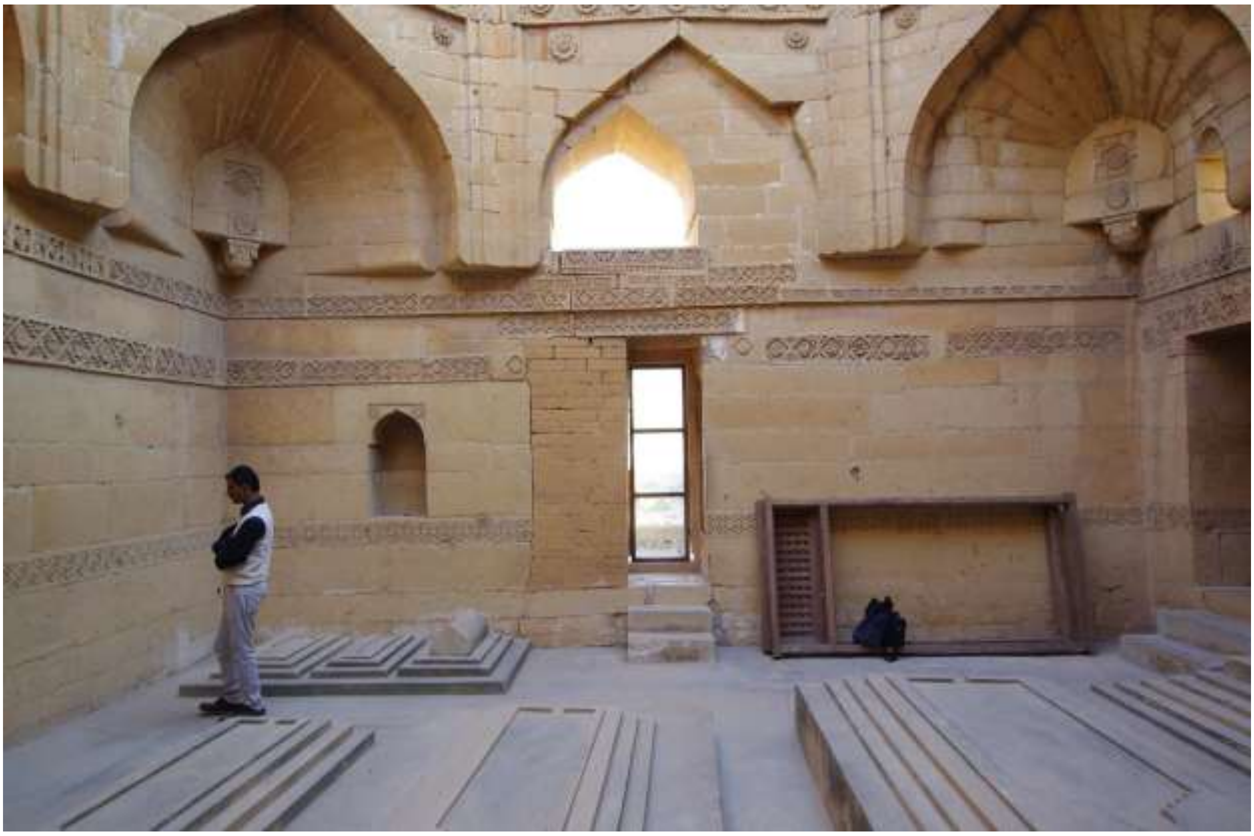


Image 16: Central space of the tomb, looking south (the infill of the south gateway was most likely added in 1956).

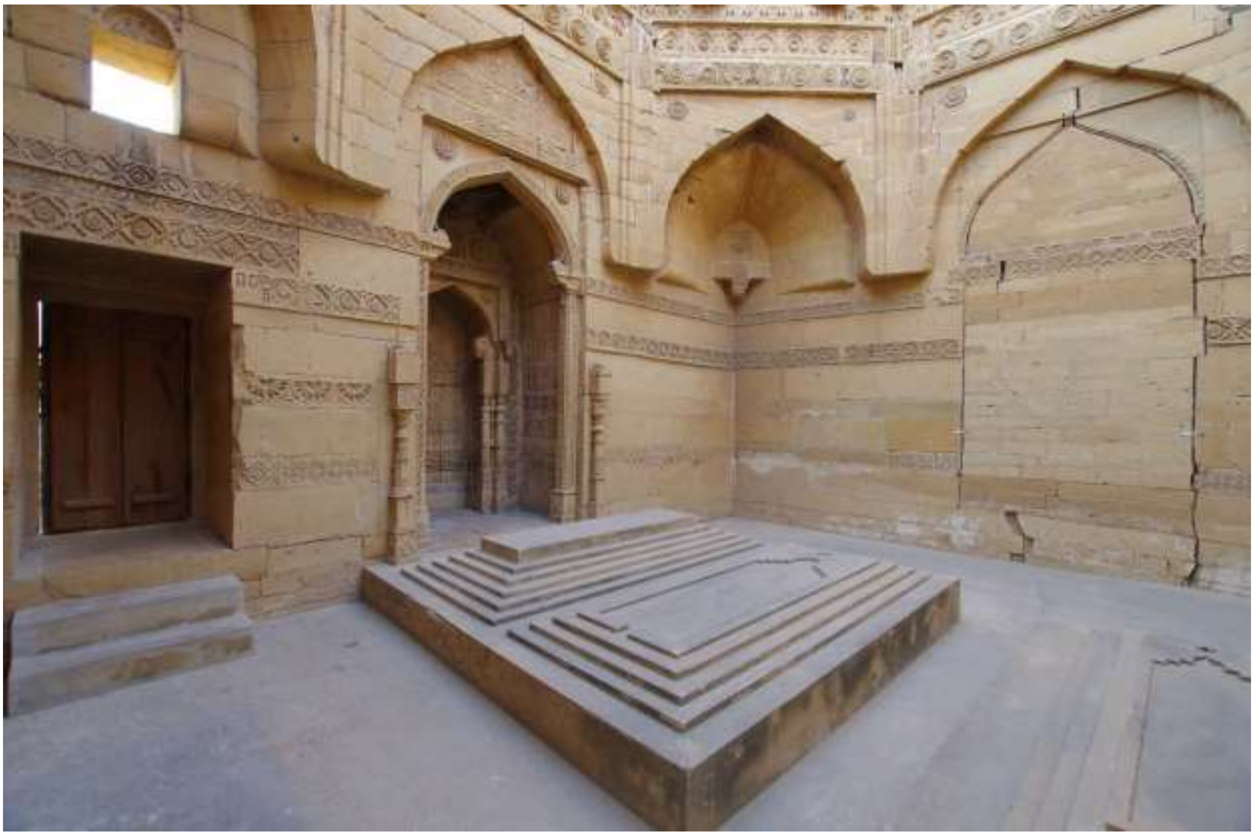


Image 17: North-west corner of the central space of the tomb with the mihrab.

Image 18: Sealed northern doorway with installed crack-meters. The lower (previously sealed!) crack through the lowest three courses shows very clearly that the foundations of the monument are not only subject to vertical settlement but also to horizontal sliding.

Image 19: Inner face of western wall with the mihrab.

Image 20 a/b: Repointed former cracks inside of the mihrab (carried out in 1994)

Image 21: Central space of the tomb, looking upwards.

Image 22: Central space of the tomb, looking upwards, showing the transition from square via octagon to hexadecagon.

Image 23: Central space of the tomb with squinches seen from below.

Image 24: Central risalit, looking upwards, with severe cracks below the protruding balcony structure and elements bulging outwards left of the symmetry axis.

Images 25 a/b: Lower part of central risalit from north / south – with a continuous vertical gap on the north side.

Image 26: Vestibule of the Darshan Jharoka, looking east.

Image 27: Vestibule of the Darshan Jharoka, looking west.

Image 28: Vestibule of the Darshan Jharoka, looking south-west.

Image 29: Vestibule of the Darshan Jharoka, looking north-west.

Image 30: Vestibule of the Darshan Jharoka, looking south, with the broken lintel above the doorway.

Image 31: Vestibule of the Darshan Jharoka, stone planks with missing iron clamps.

Image 32: Upper entablature of balcony structure, looking north. The disruption and perturbation of the structural elements is clearly visible, with wide (partly repointed) gaps, dislodgements and misalignments and lost original elements (e.g. post on the left hand side).

Image 33: Upper entablature of balcony structure, looking south.

Image 34: Top view of the balcony structure, showing the severe dislodgements and misalignments.

Image 35: Top level with cement flooring and the two added courses of stones (1956).

Image 36: Top level with cement flooring and the two added courses of stones (probably carried out in 1956 by the department of public works).

Image 37: Endoscopic view of a cavity next to the gateway at the northern wall, showing the inner layer of rubble stones.

Image 38: Endoscopic view of crack between the detached central pilaster and the main structure. It shows a patched crack within the mihrab niche (taken from the opposite site).