The reconstruction of the al Hadba Minaret in the al Nuri Mosque in Mosul, symbol and outstanding Historic Heritage of the City

M. R. Acetoso[1], S. De Vito[2], and V.M. Santoro[3]

[1]*Architect, Senior Project Manager, UNESCO, email: mr.acetoso@unesco.org*
[2]*Engineer, BCD Progetti srl, Rome, Italy, email: stefanodevito100@gmail.com*
[3]*Engineer, CEO IGeS World srl, Rome, Italy, email: iges@igessnc.com*

ABSTRACT

The al-Hadba Minaret of the Al Nuri Mosque, an outstanding Monument of the Middle East historical architecture located in a large square on the right embankment of the Tigris River, has represented the symbol of the city until 2017, when ISIL, before its withdrawal, bombed the Complex. The typical arched shape of the Minaret gave it its proper name – Hadba means Hunch in Arabic. Among the causes of deformations: mostly constructive flaws related to the inhomogeneous mechanical characteristics of the original bricks, transformation of the urban areas all around its bases, and soil settlements of the foundation induced by the 4-meter filling of the square aimed at defending the city from the river floods. In the late '70s interventions based on underpinning of the Minaret only resulted in slowing the speed of leaning. In 2018 Unesco launched the Program *Revive the Spirit of Mosul*, that foresaw the reconstruction of the Minaret where and as it was, reproducing the deformed shape of the shaft, following the wish of the local community. A detailed geotechnical investigation program and a deep architectural study of the Monument was conducted as basis to prepare a detailed design of reconstruction. A new foundation, external to the Minaret – supported by deep 1000- and 1200-mm diameter bored piles - was designed to bear the loads transferred by a complex nailing connection element with the original mat. The reconstruction ended in February 2025, with the inauguration of the overall Complex of the Mosque and its hand over to the local community.
Keywords: Al-Hadba Minaret, Mosul, UNESCO Revive the Spirit, Heritage Reconstruction, Deep Foundation Piles, Structural Deformations.

FOREWORD

The Al-Hadba Minaret in Mosul (Iraq) represents, jointly with the Al- Nuri Mosque, an historical landmark of the city of Mosul. Its name "Hadba"- "Hunchback" in Arabic - came from the deformed "banana" shape (see Figure 1), historically assumed during its long span life. The Minaret was severely damaged in 2017, following an intentional devastating shell explosion, that brought it to collapse. The Mosque and the related appurtenances of the Complex also suffered major damages or total loss. In 2018, UNESCO launched a big Restoration Program, called "Revive the Spirit of Mosul" that, among several other Projects, foresaw the reconstruction of the Minaret "where and as it was", reproducing the deformed shape of the shaft, following the wish of the local community.

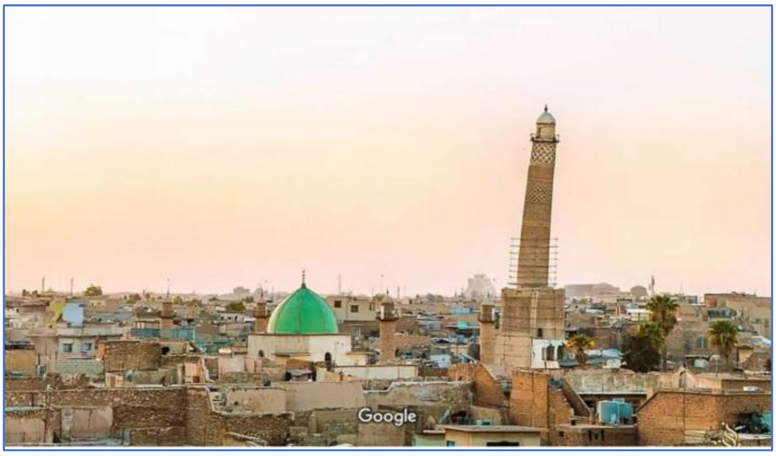


Figure 1. *General view of the Al-Nuri Mosque complex and the Al-Hadba Minaret before 2017.*

Based on institutional documentation and extensive geotechnical and archaeological investigations, the reconstruction (Oct 2023–Feb 2025) implemented a new foundation of deep piles connected to the original remains via steel ribs. The project faithfully restores the Minaret's historical masonry composition and staircase geometry.

HISTORICAL BACKGROUND

Commissioned in 1170–72 by Nur al-Din, ruler of Aleppo, the Al-Nuri Mosque complex emerged during a period of Muslim world fragmentation. While the Abbasid Caliphate's power waned against the Fatimids, Umayyads, and Seljuks, the region faced migrations from the Asian Steppe and the arrival of European Crusaders. Building on his father Imad Zengi's success at Edessa, Nur al-Din unified the Muslim front through strategic military action and alliances. He implemented a vast building program of mosques and madrasas across the Mosul-Damascus-Aleppo axis. By stabilizing commercial revenues and protecting religious minorities, Nur al-Din's governance provided the essential foundation for Saladin's subsequent rise and the consolidation of the Ayyubid dynasty

GEOLOGY AND GEOTECHNICS

Located in the Tigris's Low Folded Zone, the area features Miocene-Pliocene units and Quaternary deposits. A key factor is the Fatha Formation, whose soluble gypsum beds are prone to piping and karstification—risks that previously necessitated retrofitting the Mosul Dam. The local rocky substratum (Pilaspi, Fatha, and Injanah) acts as an efficient aquifer within a natural depression that accumulates rain and groundwater. This rising, often contaminated water table threatens stability through chemical erosion and soil weakening. Archaeological evidence showing historical ground levels 4 meters below the current surface confirms that the site was originally filled to mitigate river flooding.

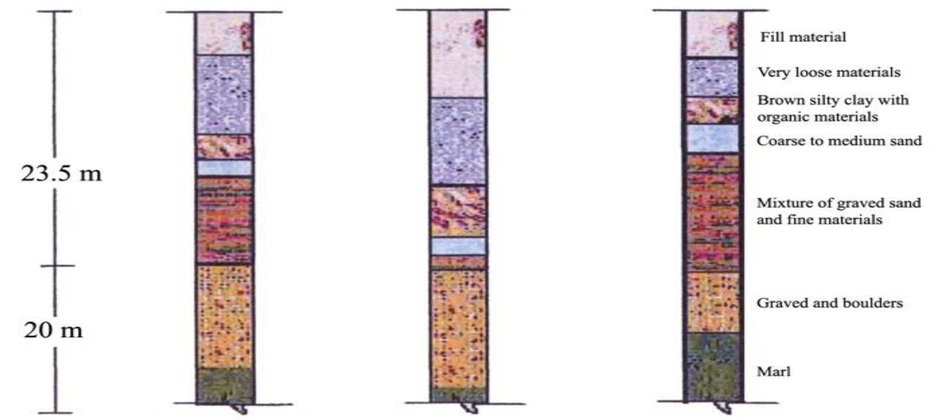


Figure 2. *Stratigraphy of the foundation soil profile at the Al-Hadba Minaret. Adapted and translated from Al-Lila, M. T. H., Khattab, S. E., & Khalil, A. H. (2009), Study of the Stability of the Minaret.*

DAMAGE EVOLUTION

Overview

Interventions on the Minaret have not been systematically recorded throughout its 835-year history, and some uncertainty remains regarding the exact extent of recent works. Architectural evidence suggests that the first reinforcements were implemented shortly after construction ended in 1172, likely following the 1202 earthquake that destabilized the tower toward the east. To counteract this, a propping wall was added to the eastern basement, the previously hollow base was filled to create a solid volume, and the lower portion of the slender trunk was encased within a squared secondary "nut."
Beyond decorative restorations, two significant intervention campaigns occurred in the 20th century: the renewal of the lantern balcony in the 1920s and a complete rebuilding of the Mosque in the 1940s. However, a marked increase in the progression rate of the Minaret's bending eventually necessitated a comprehensive consolidation campaign in 1984 to address the building's structural integrity.

Despite this effort, there remains widespread scepticism about the actual implementation of part of the project, largely due to the survey conducted by Prof. Tayyeb (who excavated the south side of the tower- see figure 3, without finding the expected pile network) and the absence of any detailed execution Report from Fondedile. Actually, during the implementation of the new Project, many more root piles were detected around the Minaret's shaft.

***Figure 3**. Excavation on the South side of the foundation of the Minaret from professor Tayyeb's documentation.*

Interpretation of the damage pattern

The Minaret's deformation stems from centuries of interacting factors. Irregular foundation soil caused initial settlements, and the 1202 earthquake triggered the first inclination. Early interventions like filling the base may have inadvertently worsened the unbalancing process. Dynamic loads, including 18th-century seismic activity and the inhomogeneous quality of the materials, notably of the used bricks, wind forces, even unlikely, exacerbated the damage. Thermal cycles and wind also weakened mortar joints and the decorative shell. Late 20th-century acceleration is linked to altered groundwater conditions from rapid urbanization, chemical contamination, and pipe leakages. These fluctuations significantly reduce the resistance of the site's soluble soils, causing rotation through shear failure

***Figure 4.** Tilting of the wall and crushed masonry (left). The outer brick texture hides a more chaotic masonry layout in the volume underneath (right).*

The detail of the open sections under the expelled plaster shows irregular masonry with mostly unsquared blocks embedded in a thick mortar matrix. It is unlike that the eastern building might have assumed a propping function. The crack through the weaker section of the lantern in a recent photo and in the sketches realised by Pagliero (see Figure 4) during his survey shows the persistence of the same damage through the time, despite the tower Restoration and Strengthening.

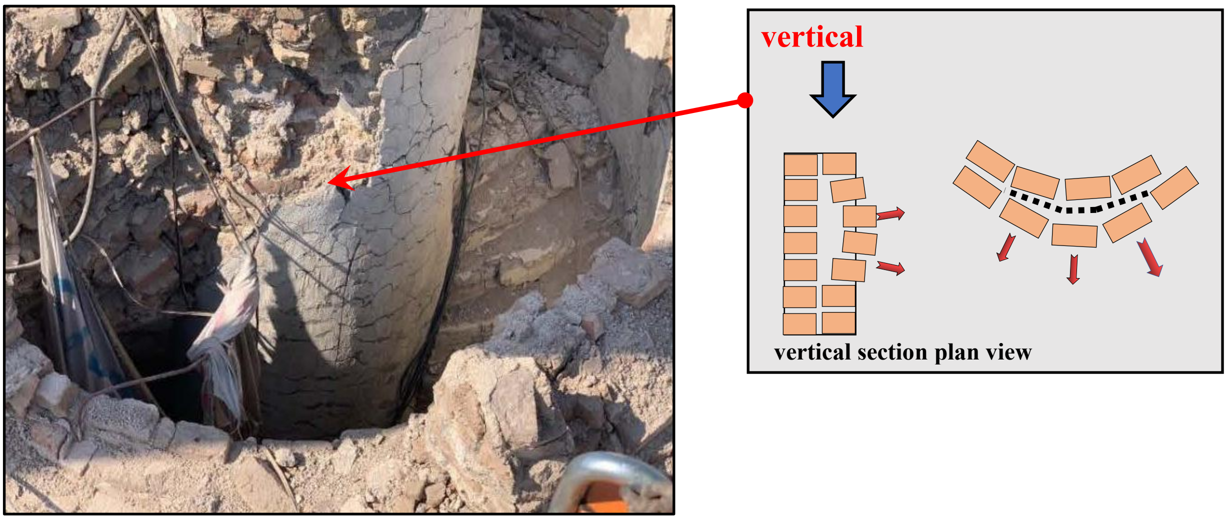


Figure 5. *Detail: residual shaft of the Minaret (De Vito 2019) (left). Trunk masonry under vertical load Damage model (right).*

The overall bending of the Minaret results from the cumulative contribution of base rotation and shaft curvature. While the former is related to differential settlements of the foundation soil, the latter is caused by the elastic and plastic deformation of the masonry.

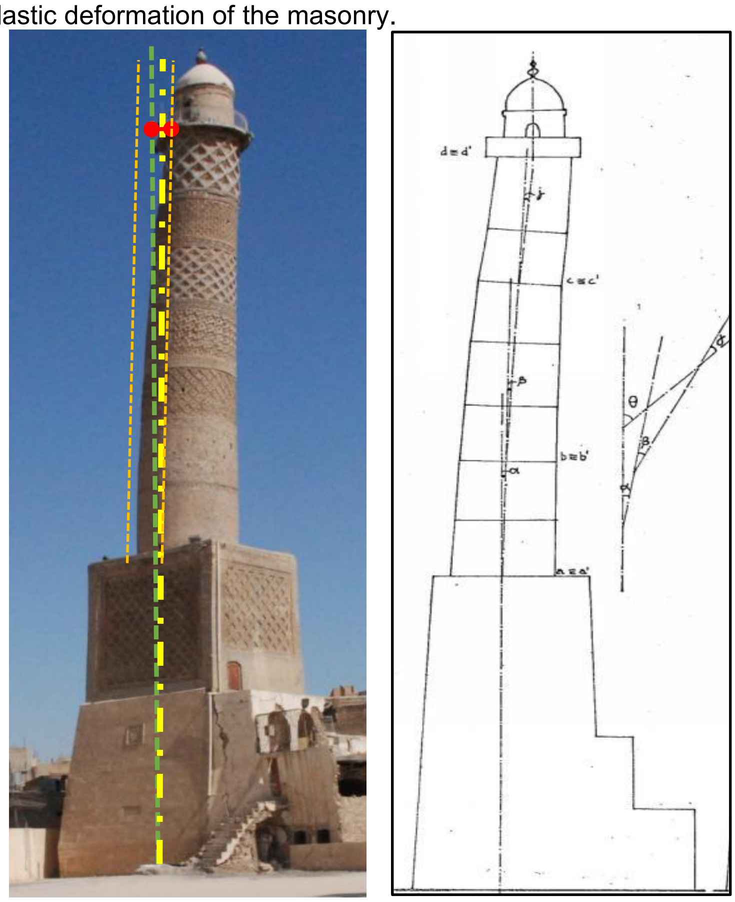


Figure 6*. The leaning of the Minaret - curvature and bending components.*

Although these two components are not strictly consequential, they are interrelated and have mutually influenced each other over the centuries (see Figure 7). Notably, the surveyed torsion of the trunk indicates that an independent deformation trend developed within the shaft, distinct from simple in-plane bending.

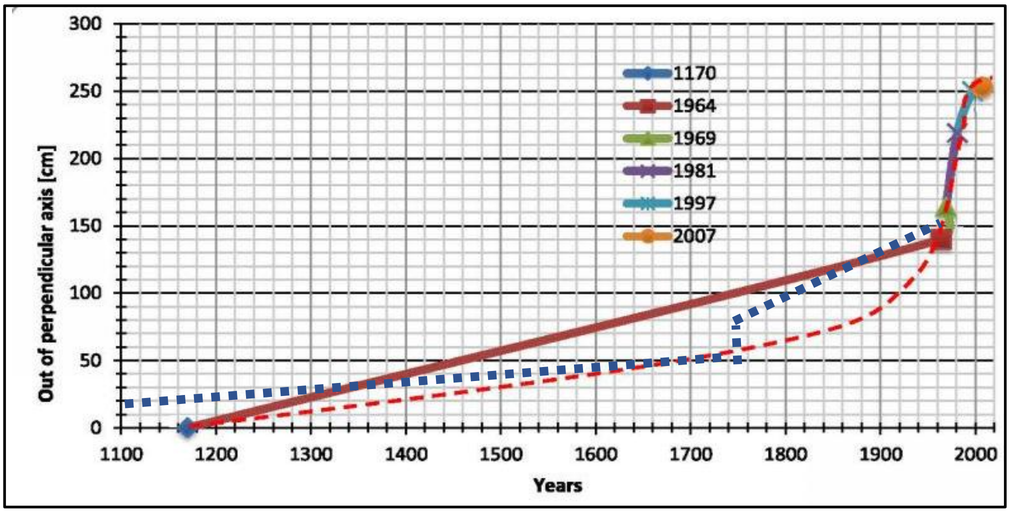


***Figure 7**. Overall bending evolution.*

The Al Hadba Minaret stood for over 800 years without substantial interventions altering its structural behavior. By 2015, the condition of the shaft appeared critical, leading to proposals for thorough joint reinforcement. Meanwhile, recent excavations have cast doubt on the effectiveness of the 1984 foundation works, as evidence from the debris reveals the limited impact of previously introduced reinforcements and nailing. In historical terms, the bent silhouette has characterized the Mosul skyline for at least 250 years, since the late 18th century. The rate of inclination increased significantly during the second half of the 20th century, before the tower appeared to stabilize toward the century's end.
The Minaret's degradation stems from a synergy of historical events and long-term trends. Seismic activity in 1202 and 1781 likely initiated structural destabilization, as supported by architectural reinforcements and travel chronicles. These events were compounded by altered groundwater conditions due to urbanization, which compromised the chemically sensitive soil and led to a new, unstable equilibrium through foundation settlement.

A multiple-cause hypothesis best explains the evidence: uneven soil response under increasing eccentric loads, intensified by water-related physical and chemical variations. Structurally, the disconnection between the core, skin, and shaft represents a fundamental weakness. Post-collapse analysis of the debris confirms this vulnerability, revealing an internal masonry texture of chaotic volumes and unsquared blocks behind the decorative outer skin.

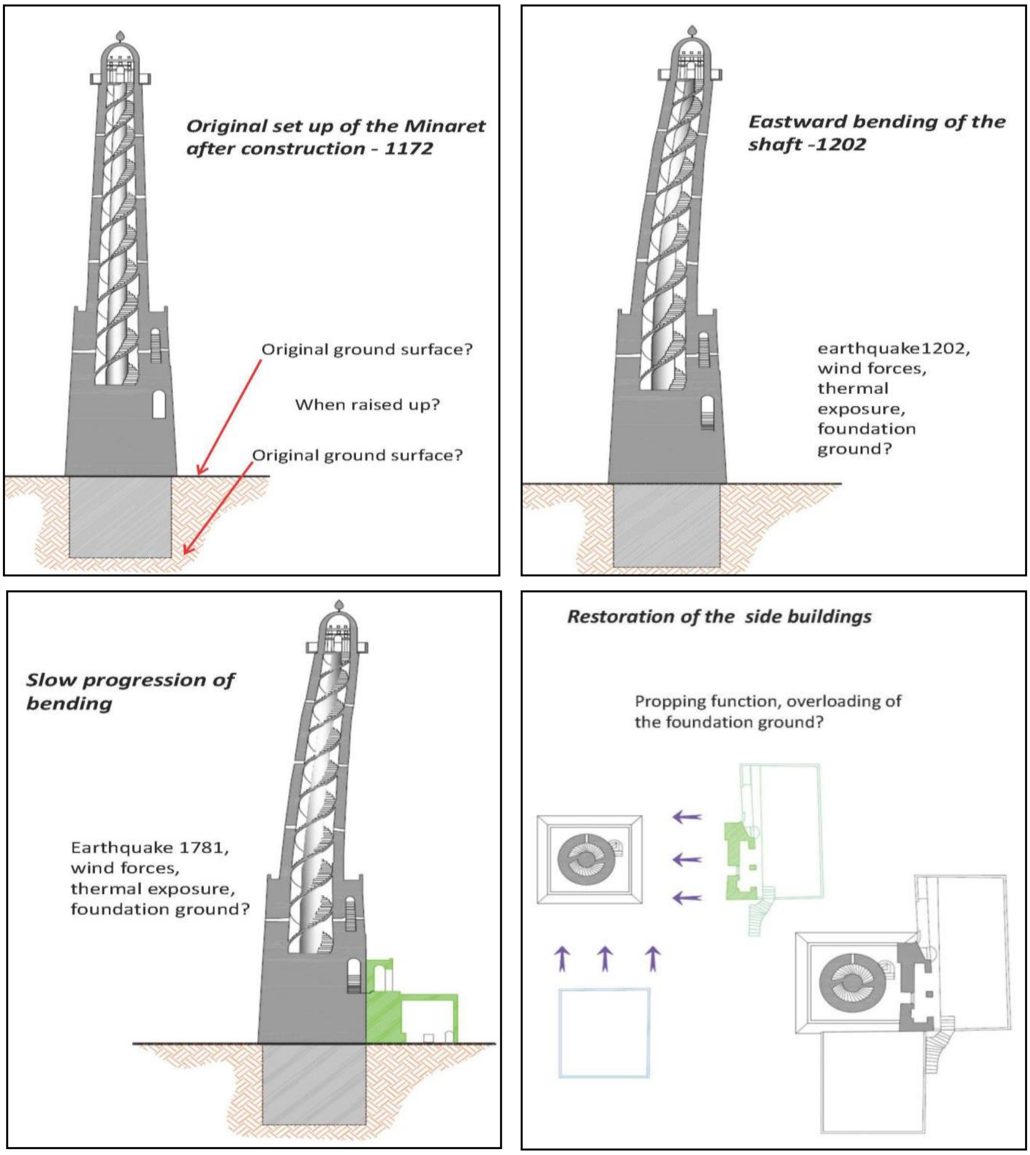


Figure 8. *Possible scenario of damage evolution.*

GEOTECHNICAL INVESTIGATIONS

Geotechnical investigations were conducted at the al-Nuri Complex in Nineveh to assess the mechanical parameters of the foundation soils and to detect the causes of settlements. Three boreholes of 30 m length were drilled in the vicinity of the Minaret and two more boreholes,15 m long, and one of 18 m were drilled around the Dome area – see figure 9.

Table 1*. Summary of borehole depths and groundwater levels.*

borehole	*borehole depth(m)*	*Water table*	*Soil*
BH-MS-1	*15.00*	*7.00*	*Multiple layers*
BH-MS-2	*15.00*	*7.50*	*Multiple layers*
BH-MS-3	*18.00*	*7.80*	*Multiple layers*
BH-MN-1	*30.00*	*9.00*	*Multiple layers*

BH-MN-2	*30.00*	*9.00*	*Multiple layers*
BH-MN-3	*30.00*	*9.80*	*Multiple layers*

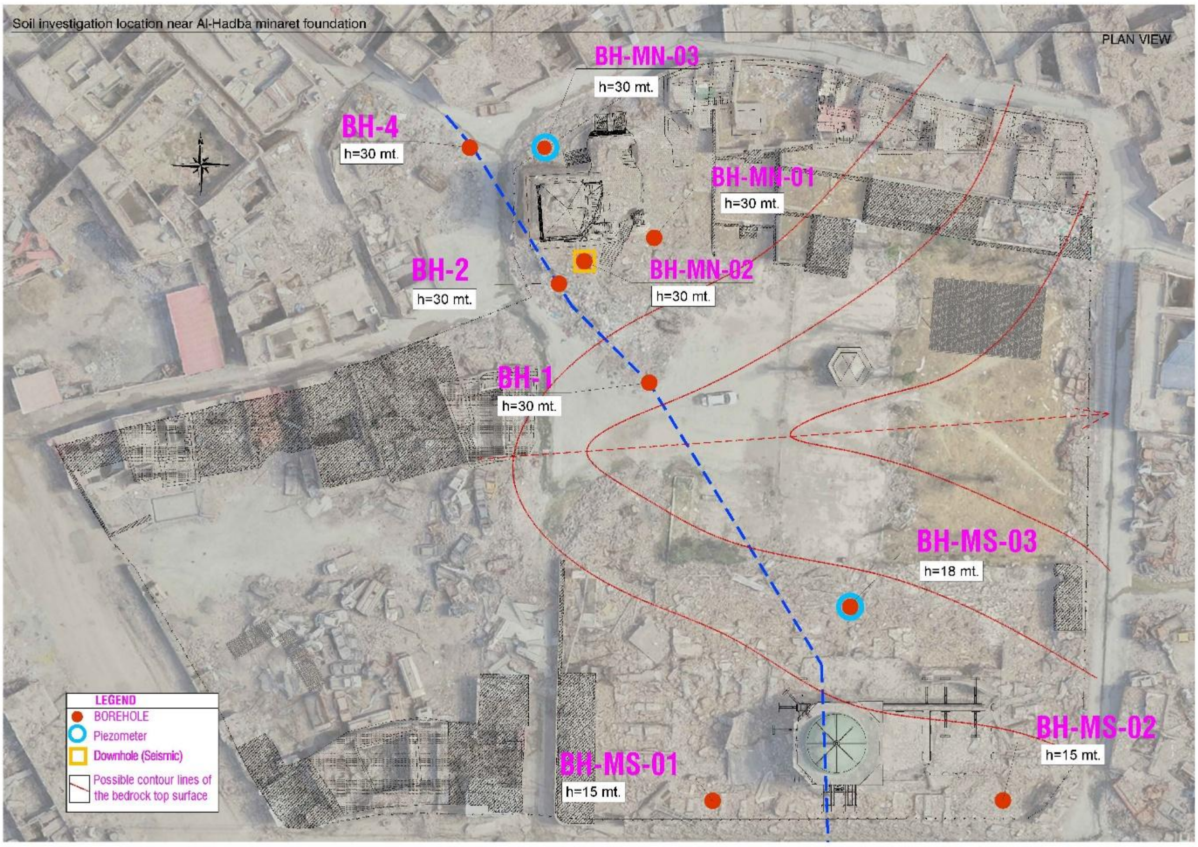
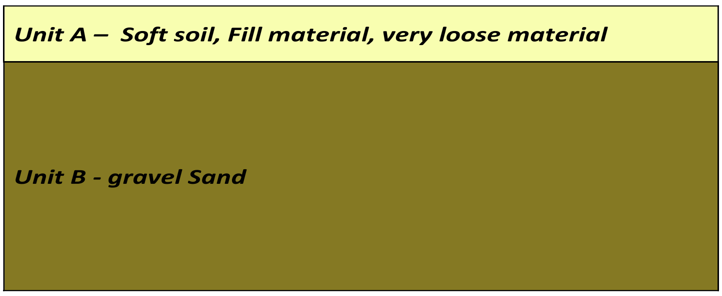


Figure 9*. Soil investigation location near Al-Hadba minaret foundation.*

The main geotechnical parameters of the 2 soil types recognized are shown in table 2 and figures-10,11 and 12.

Table 2*. geotechnical characterization.*

Unit	*Depth*		*Layer thickness*	*Unit weight*	*Friction angle*	*Drained cohesion*	*Und. Cohesion*	*SPT*	*Shear modulus*	*Poisson ratio*
	from	*to*	*H*	*γ*	*φ'*	*c'*	c_u	N_{SPT}	*G*	*N*
	[m]	*[m]*	*[m]*	*[kN/m³]*	*[°]*	*[kPa]*	*[kPa]*	*[-]*	*[MPa]*	*[-]*
Unit A	*0.0*	*5.5*	*5.5*	*18.0*	*30*	*0.0*	*130.00*	*17.00*	*100.00*	*0.47*
Unit B	*5.5*	*32.5*	*27.0*	*18.5*	*35*	*0.0*	*210.00*	*25.00*	*884.52*	*0.42*



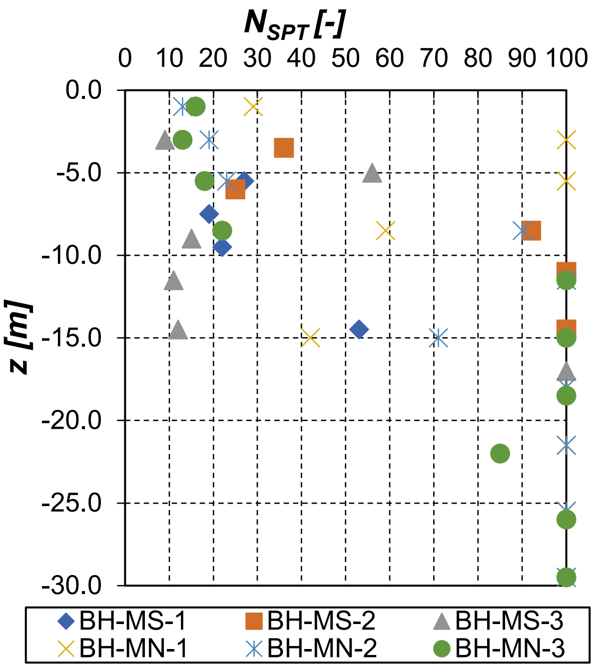


Figure 10. *Nspt plot vs depth.*

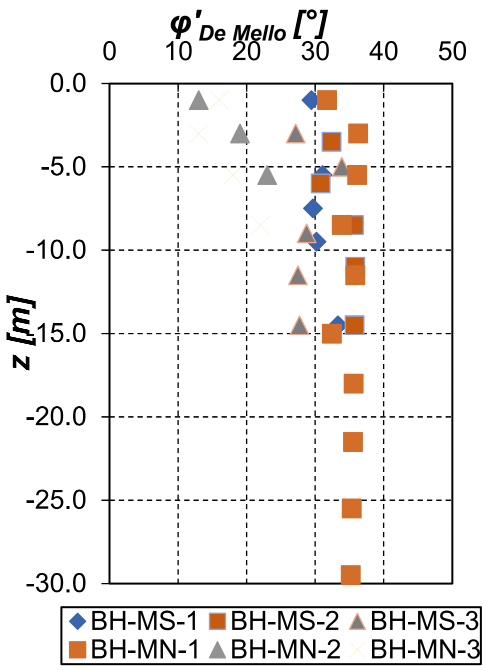


Figure 11. *Friction angle (De Mello formula) vs depth.*

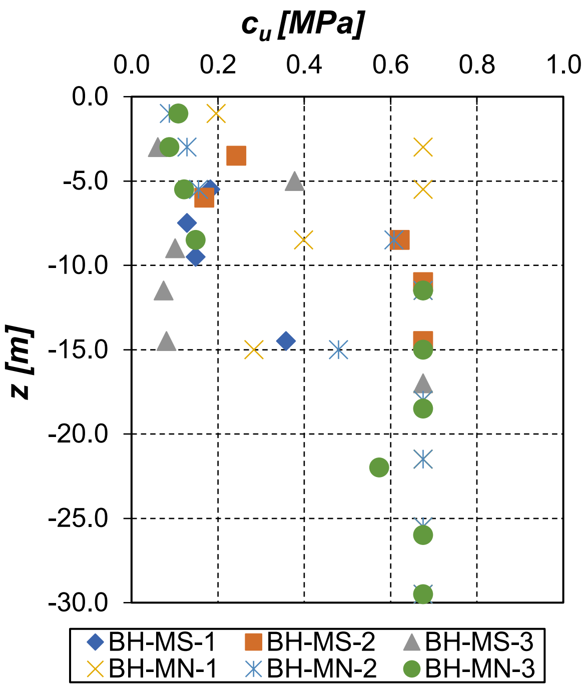


Figure 10. *Undrained cohesion vs depth.*

PROJECT DESCRIPTION

The new foundation system for the Al-Hadba Minaret is designed as a hybrid complex of large-diameter drilled piles and base tie anchors. The 21 piles are engineered to transfer the monument's total load—comprising both the existing base "nut" and the reconstructed shaft—to the deeper, competent soil layers identified during geotechnical surveys.

Due to the hardness of the lower marly-limestone bedrock, which precludes large-diameter drilling to avoid damaging vibrations, base tie anchors connect the pile shafts to the supporting rigid base via small-diameter drilling.

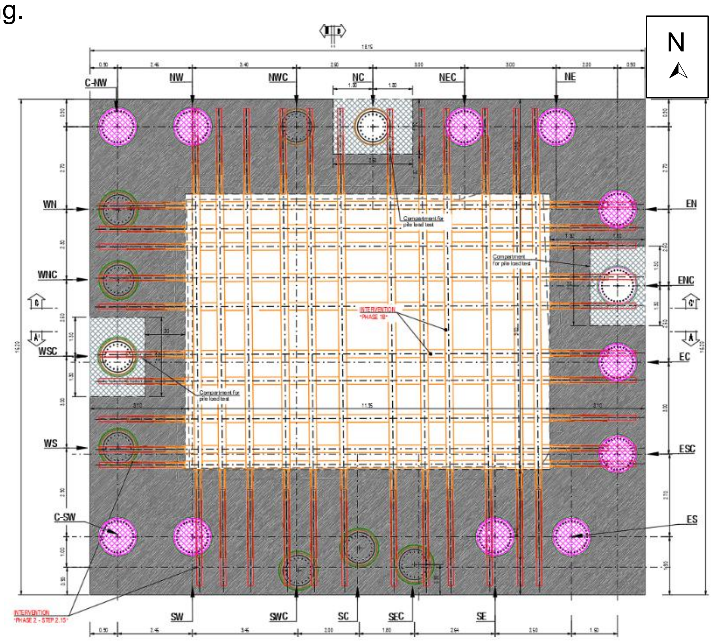


Figure 11. *plan view of the 21-pile layout with ring beam.*

N. 21 foundation piles are built, of which N.12 piles with diameter of 1200 mm and N. 9 piles, already built, with a diameter of 1000 mm.
The pile heads are integrated through a reinforced concrete ring beam that encases the sides of the historic nut and connects to horizontal micropile reinforcements crossing the core. This configuration ensures a "natural" load transfer governed by relative rigidity; the full bearing capacity of the new piles will be mobilized as the historic foundation undergoes forthcoming soil settlements. Seismic analysis confirms the robustness of this design, showing a capacity to manage overcharges of approximately +90% under project earthquake conditions. Once the static load transfer is complete, the piles will operate at 50% of their theoretical design value, providing an extensive safety margin for the monument's long-term stability (see Figure 14).

Based on the geotechnical parameters adopted for Units A and B and the pile geometry, the vertical bearing capacity of the piles was evaluated using Terzaghi's formulation. For Ø1200 mm piles, the Bearing capacity - Drained gives a lateral unit shear resistance of τ_s = 74.29 kPa and a total lateral resistance of R_s = 8,402.49 kN, while the base resistance reaches R_b = 11,130.13 kN. After applying the correlation factor (ξ = 1.45) and partial safety factors ($\gamma_{R,s}$ = 1.15, $\gamma_{R,b}$ = 1.35), the design bearing capacities become $R_{s,d}$ = 5,038.97 kN and $R_{b,d}$ = 5,685.89 kN, leading to a total design vertical strength of R_d = 9,938.55 kN including the pile self-weight.

For Ø1000 mm piles, the drained resistances are R_s = 7,002.07 kN and R_b = 7,485.72 kN, with characteristic values $R_{s,k}$ = 4,829.02 kN and $R_{b,k}$ = 5,162.56 kN after applying ξ = 1.45. The corresponding design capacities are $R_{s,d}$ = 4,199.14 kN and $R_{b,d}$ = 3,824.12 kN, resulting in a design vertical strength of R_d = 7,477.22 kN including self-weight.

Pile NE as the most loaded element, with a maximum axial demand of N = 4,297.4 kN under seismic loading in the Y-direction at elevation −0.90 m, which remains below the design strengths of both pile types.

MODELLING APPROACH AND SETTLEMENTS MONITORING SYSTEM

The minaret is modelled as a layered composite system comprising a structural inner core and a decorative brick skin, reflecting the actual constructive morphology of the tower. For seismic dynamic analyses, a cracked (reduced) stiffness is adopted.

Moreover, time-dependent effects have been evaluated, including long-term masonry creep under sustained gravitational loading and both daily and seasonal thermal gradients. Regarding internal strengthening, the FEM models incorporate exclusively the contribution of steel ties positioned beneath the masonry steps of the helicoidal staircase.

On the other hand, three micropiles have been built outside the Minaret plan to place the fixed reference stations, in order to allow the automatic reading of all the survey benchmarks through a robotic laser alignment pointing. The length of the micropile is 30 meters, 200 mm diameter as they shall be considered as rigid points.

Loads and load conditions

Dead Loads

The gravitational load resulting from the weight of all structural and non-structural components has been taken into account according to the volumes involved and the specific weights of the materials that are transferred to the foundation from the upper elevation of the Minaret (shaft and nut).

Table 3. *Material Unit weights.*

Material	*[kN/m³]*
Brickwork	*18.00*
Old stonework	*21.00*
Stonework	*22.00*
Concrete	*25.00*
Timber	*6.00*
Metalwork	*13.73*

Wind loads

Compression and depression forces applied on the upper shaft of the tower amount to an equivalent horizontal static force of 105 kN, acting at a height of 33 m above the ground level. The resulting bending moment transmitted to the foundations is then 3500 kNm, which is a much lower solicitation as compared to the seismic actions (less than 1/20) for which the structure will be verified.

Seismic loads

Based on Iraq's seismic zoning, the design spectrum is scaled using the PGA (peak ground acceleration) from probabilistic seismic hazard analysis. For a 50-year reference period and a 98% fractile, the corresponding event has a 2475-year return period, representing a rare but critical earthquake scenario that governs the structural design. The plotted values have a 2% chance of exceedance in 50 years as referred to the site class B.

Load combinations

The most severe load combination derives from the seismic actions along the East-West axis, computed together with the dead loads.

Table 4.*Load case summary.*

LOAD CASE	*N [kN]*	*M,x [kNm]*	*M,y [kNm]*	*M,torq [kNm]*	*V,x [kNm]*	*V,y [kNm]*
Dead Load	*36,680.3*	*2,587.2*	*11,790.5*	-	-	-
Earthquake X dir	-	*31,468.4*	*104,894.6*	*1,556.5*	*9,322.3*	*2,796.7*
Earthquake Y dir	-	*104,894.6*	*31,468.4*	*3,193.8*	*2,796.7*	*9,322.3*

The reference transmission level of the horizontal seismic effects to the foundation is taken at Z=-0.90 m. The centre of gravity of the whole superstructure is located at Z=10.40 m.

Furthermore, for design wind, the maximum predicted displacement at the top of the minaret (48.45 m) is 0.018 m and under design earthquake loading, the maximum CQC displacement at the same reference height reaches 0.050 m, confirming that the seismic demand governs over wind in terms of lateral top displacement.

Connection between new piles/ring beam and historic base

The foundation system consists of 21 large-diameter rotary bored piles of Ø1000 mm and Ø1200 mm, each with a shaft length of 30 metres, whose heads are united by a reinforced concrete ring beam cast at −4.00 m elevation forming a closed perimeter around the historic nut. The piles are divided into two groups: twelve Ø1200 mm blind piles drilled from ground level on the north, east, and south sides using a temporary Ø1300 mm casing for the uppermost 9 metres, and nine Ø1000 mm open piles drilled through pre-installed Ø1200 mm casings on the remaining sides. It is important to distinguish these new structural piles from the vertical micropiles uncovered during the 2021 archaeological excavations, which are remnants of the 1981 Fondedile intervention — 10-12 per each side, 200–250 mm diameter shaft with a 50 mm steel core — and form no part of the new design. The critical connection between the historic masonry nut and the new ring beam is achieved through the Phase 1b nailing element, consisting of horizontal micropile bars passing through the core of the nut acting together with an H-shaped steel beam of 200 mm section extended from the nut and welded to the ring beam (see figure 14). The construction method and sequencing were governed by three principal constraints: the archaeological sensitivity of the excavation area, which required pile casings to be pre-installed before any excavation and directly produced the blind-versus-open pile distinction; the unresolved presence of historic micropiles in the subsoil, which necessitated a phased and progressive drilling approach; and the geotechnical conditions revealed by the GPR survey, namely extensive near-surface cavitation and historic water passageways within the first 2.5 to 4.0 metres of ground, which — combined with the fragility of the leaning masonry nut — made driven piles unacceptable and confirmed the adoption of the low-vibration rotary bored pile technique.

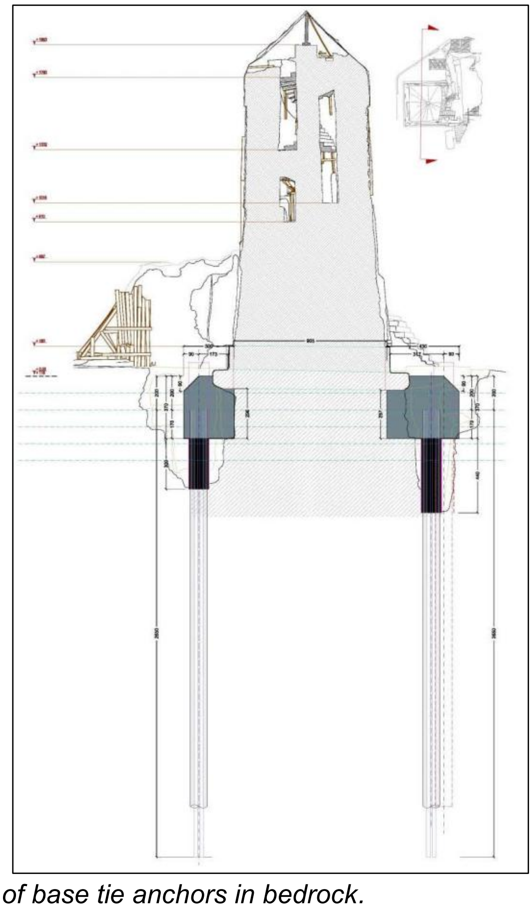


Figure 12. *schematic section of base tie anchors in bedrock.*

CONCLUSION

The structural history of the Al-Hadba Minaret reflects the enduring challenges posed by Mosul's complex geological and political landscape. The observed deformations—a combination of base rotation and shaft curvature—result from centuries of environmental stresses, including seismic activity, severe thermal cycles, weaknesses in the homogeneity of the original constructive materials (notably the bricks), and the unique karstification processes of the Fatha Formation. Historical evidence confirms that while the monument was stabilized through various interventions over 800 years, the acceleration of bending in the late 20th century necessitated a radical Engineering solution.

The current reconstruction successfully balances modern Structural requirements with the preservation of Historical Authenticity. By implementing a deep pile foundation system and a reinforced concrete ring beam, the project ensures a controlled load transfer that accommodates natural soil settlements while providing a significant safety margin against seismic events. This intervention does not merely restore a fallen landmark; it stabilizes the iconic silhouette of the Al-Hadba, ensuring its permanence in the Mosul skyline as a symbol of cultural resilience and advanced conservation engineering.

Figure 13. *The Minaret after reconstruction.*

ACKNOWLEDGEMENTS

The authors express their deepest gratitude to the UNESCO Iraqi Office in Mosul for the continuous support and strategic coordination within the framework of the "Revive the Spirit of Mosul" initiative. Special thanks are extended to the local technical staff and the Mosul architectural community, whose profound dedication, cultural insight, and field expertise were instrumental in the successful execution of the diagnostic phase and the subsequent reconstruction. The project stands as a tribute to their resilience and commitment to preserving the heritage of their city.

REFERENCES

Asbridge, T. (2010). The Crusades: The War for the Holy Land. Simon & Schuster. London, U.K.

Battuta, I. (1354). Voyages d´Ibn Batoutah (Tuhfat al-Nussar fi Chara'ib al-Amsar wa-Aja'ib al-Asfar). Ed. Defrémery, C. & Sanguinetti, B.R. (1874). Tangeri, Marocco.

Blasi, C. (2015). Stabilization and Conservation of Al-Hadba Minaret in Mosul. Unesco Report. Firenze, Italia.

Bruno, A. (1967). Stabilization project of the Al Hadba Minaret. Torino, Italia.

De Vito, S. (2020). Execution of Temporary stabilization measures at the Al Nouri Mosque complex. Unesco Report. Mosul, Iraq.

Giubair, I. (1184). The Travels of Ibn Jubayr: Diary of a Mecca Pilgrim. Ed. Erdmann (1964). Granada, Spain.

Herzfeld, E. & Sarre, F. (1920). Archäologische Reise im Euphrat- und Tigris-Gebiet. Band II-IV. Berlin, Germania.

Hourani, A. (2005). A History of the Arab Peoples. Oxford University Press. Oxford, U.K.

Houtsma, M.T., Wensinck, A.J. & Gibb, H.A.R. (1936). Enzyklopädie des Islam. 4 Vol. Leipzig, Germania.

Justa, P. (2020). Stabilization and Conservation of Al-Hadba Minaret in Mosul. Unesco Report. Prague, Czech Republic.

National Geophysical Data Center (NGDC-NOAA). (2020). Significant earthquakes in the Middle East Area. Boulder, CO, USA.

Niebuhr, C. (1774). Reisebeschreibung nach Arabien und anderen umliegenden Ländern. 1774-78. Kopenhagen, Denmark.

Pagliero, R. (1964). Conservation of two Monuments in Mosul. Torino, Italia.

Safra, J. & Aguilar-Cauz, J. (2005). The New Encyclopaedia Britannica - Micropaedia. Vol. 12. Chicago, USA / London, U.K.

Tabbaa, Y. (2002). The Mosque of Nur al-Din in Mosul 1170-1172. Annales Islamologiques 36. Cairo.

Wagner, R. (1893). Mit Moltke und Mühlbach zusammen unter dem Halbmond (1837). Berlin, Germania.