

Stabilization and Conservation of Minaret Choli in Erbil, Iraq

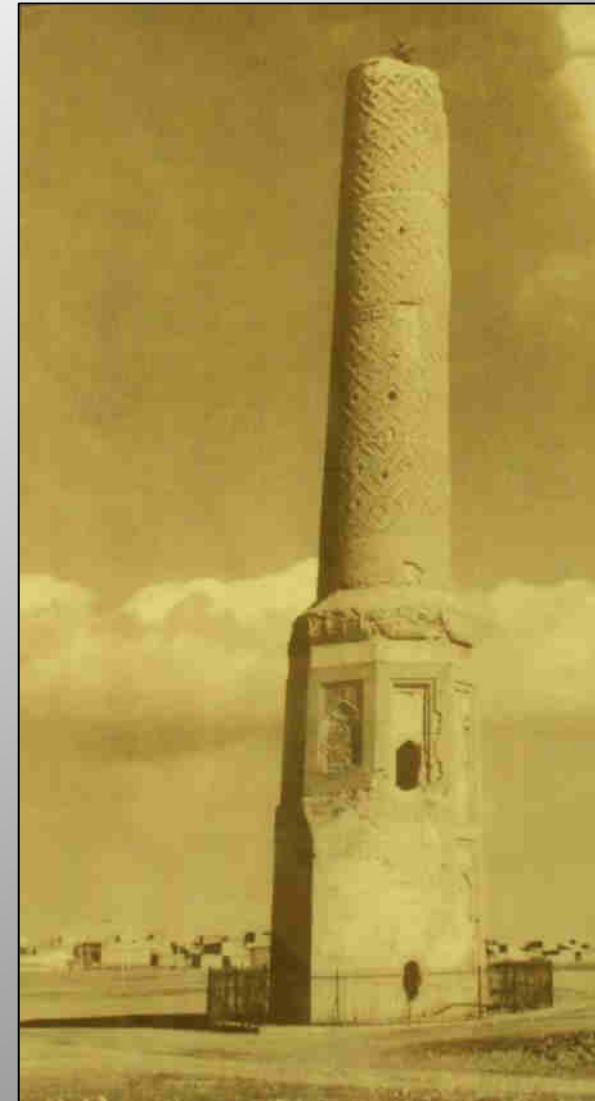


**presented by Petr Justa
Gema Art Group, Prague, Czech Republic**

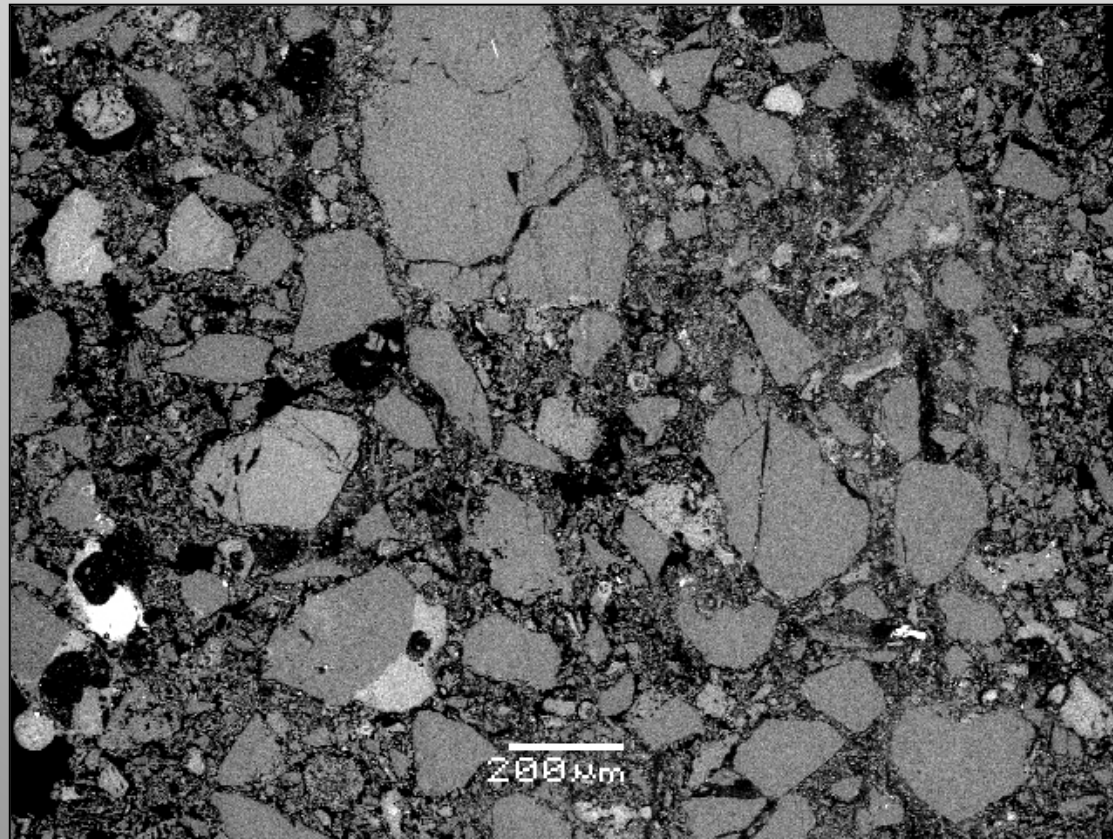
- The minaret is situated 900 m west of the southern gate of the Erbil citadel.
- Construction ascribed to the atabeg al-Mudhaffar Din Kokburi (ca. 1190 AD),
- only remaining relic of a large mosque, the earliest phase might be of late Umayyad or early Abbasid period



History



I. RESEARCH



GEOPHYSICAL/GEOLOGICAL STUDIES

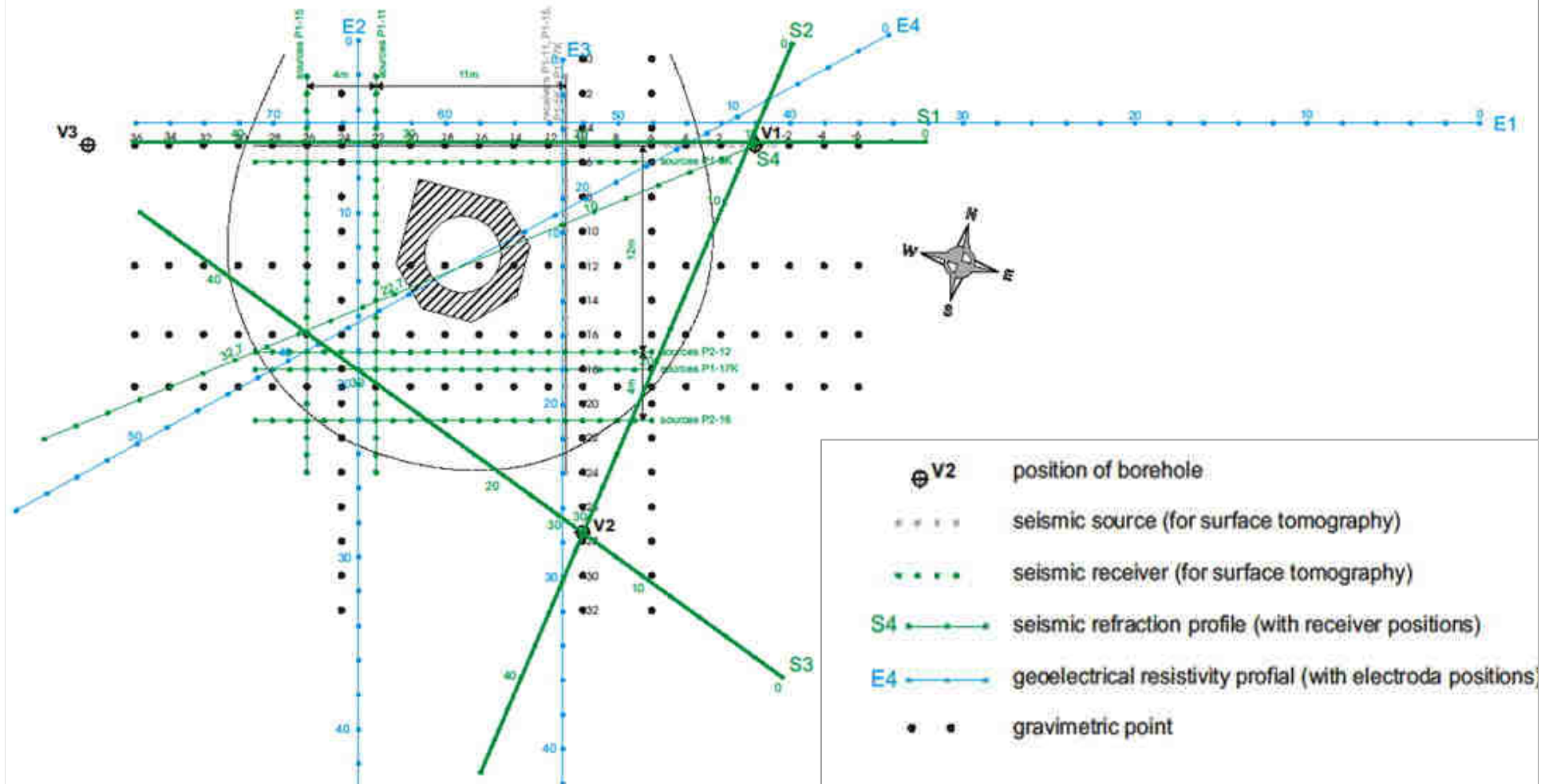
Methods used for determination of possible causes of minaret destruction and subsequent inclination

- **Shallow refractive seismology**
- **Seismic 3D/2D tomography**
- **Micro-gravimetry in rectangular system with the running step of 1 – 2 m**
- **Conductivity measurements**

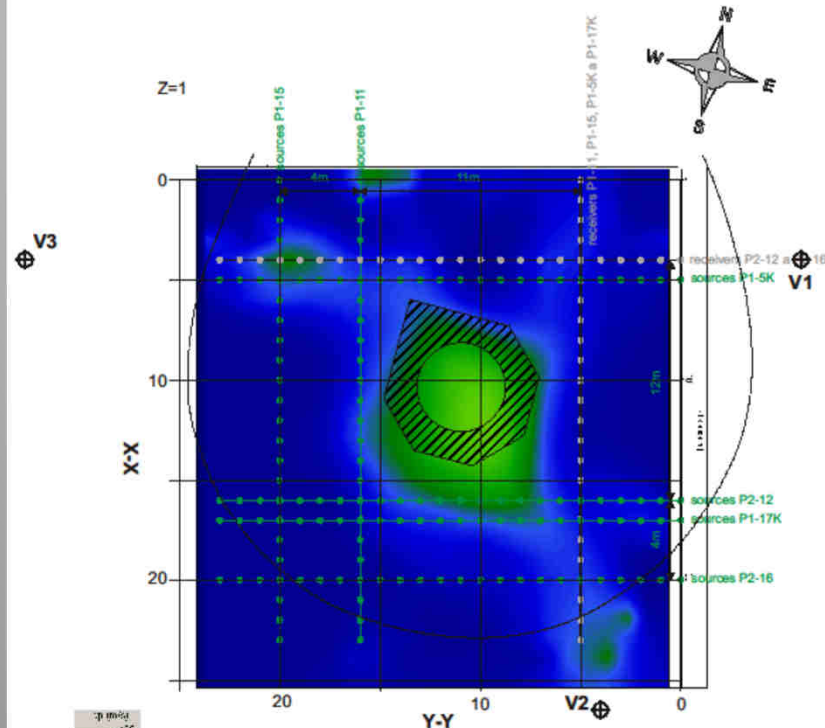
3 boreholes around the minaret (10 – 12,5 m deep each) to make cross section of the geological situation

- **Soil classification**
- **Particle size distribution**
- **Chemical tests**
- **Bulk density**
- **Salt content**

Geophysical Measuring Profiles and Points

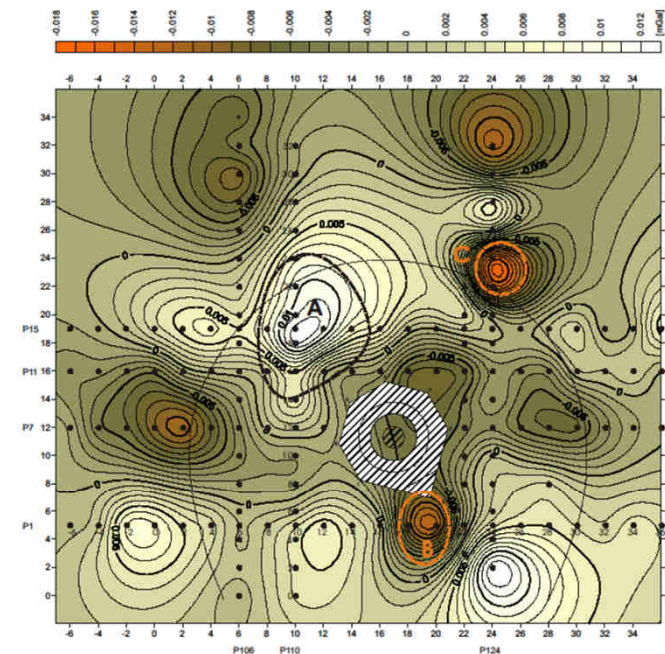


Seismic tomography, results of 3D processing



GEOPHYSICIST: Mgr. T. Chahr	PREPARED BY: Mgr. T. Chahr	DESIGNED BY: Mgr. T. Chahr	INSPECTED BY: RNDr. O. Levy
The Customer: Gema Art Group a.s.			
Minaret Choli, Erbil			
Kurdistan, Northern Iraq			
Geophysical Survey			
Seismic tomography, results of 3D processing velocity section in X-Y plane for Z(depth)=1		SCALE: 1 : 200	SUPPLEMENT No: 4f

Gravity survey

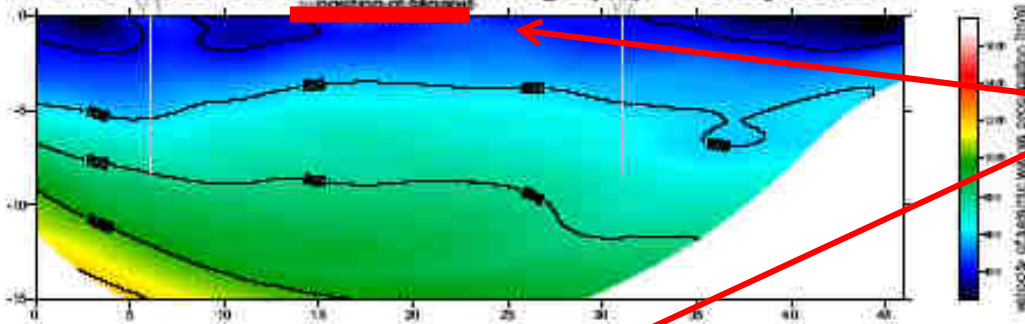


- gravimetric point
- positive gravity anomaly (e.g. remains of walls)
- negative gravity anomaly (mass deficit)

GEOPHYSICIST: Mgr. T. Chahr	PREPARED BY: Mgr. O. Filipczyk	DESIGNED BY: Mgr. O. Filipczyk	INSPECTED BY: RNDr. O. Levy
The Customer: Gema Art Group a.s.			
Minaret Choli, Erbil			
Kurdistan, Northern Iraq			
Geophysical Survey			
Gravity survey, map of residual Bouguer gravity anomalies corrected about effect of above-ground part of minaret and mass of interpreted foundation		SCALE: 1 : 200	SUPPLEMENT No: 2c

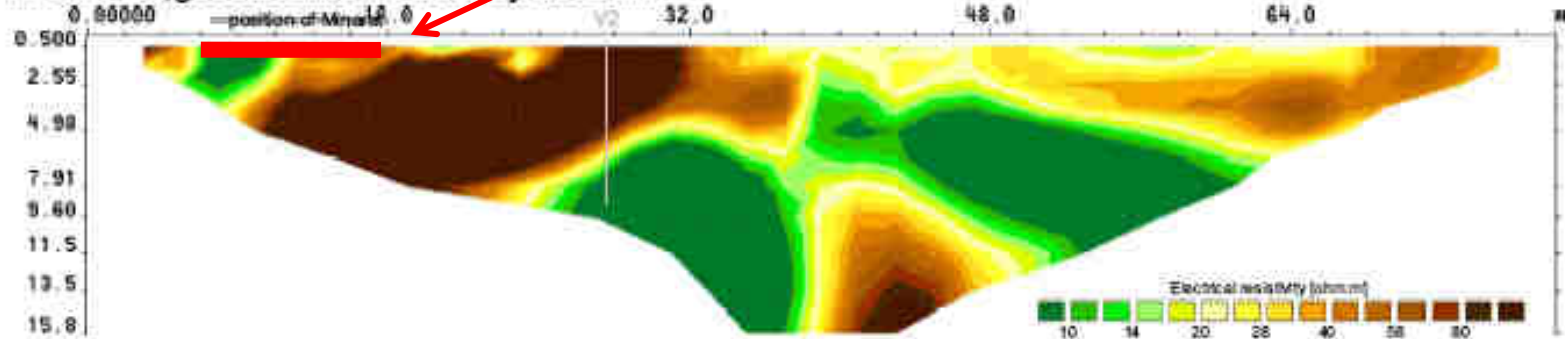
Seismic refraction tomography vs. geoelectrical resistivity profiles S 2 –E 3

Profile S2, seismic refraction tomography, velocity section



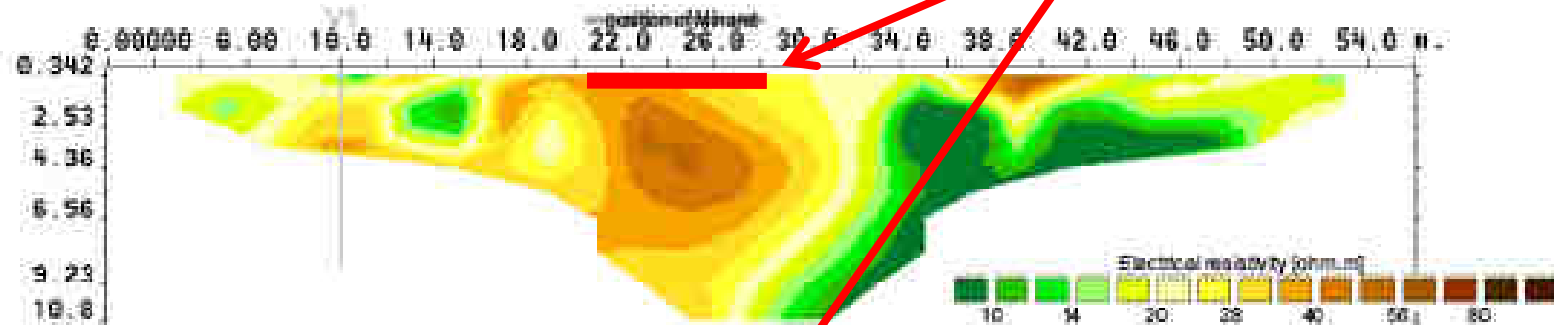
Position of minaret

Profile E3, geoelectrical resistivity section

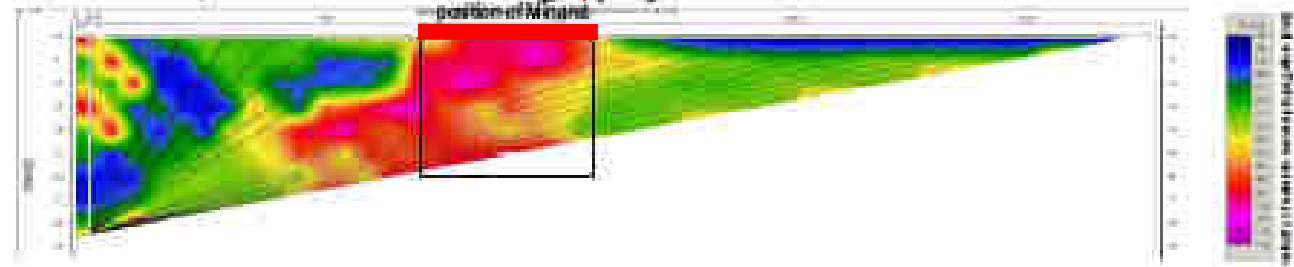


Seismic refraction tomography vs. geoelectrical resistivity profiles S 4 –E 4

Profile E4, geoelectrical resistivity section



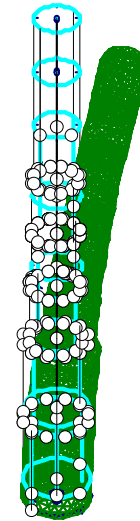
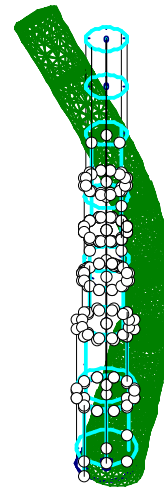
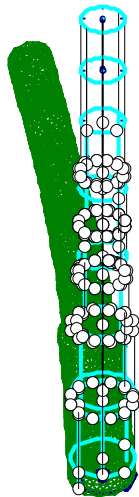
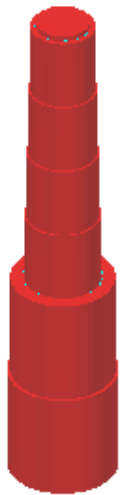
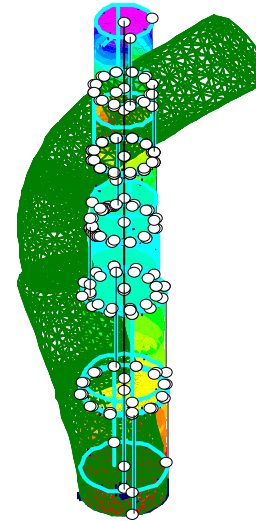
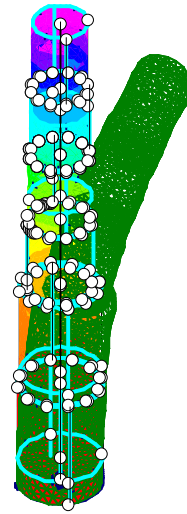
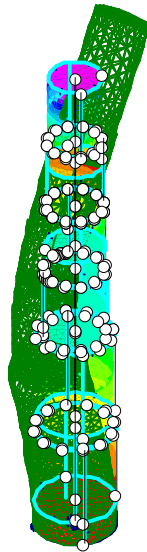
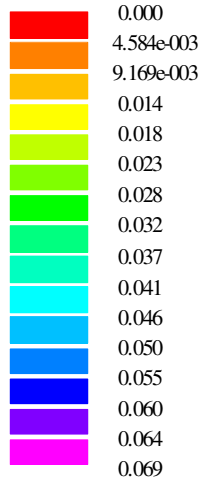
Profile S4, 2D seismic tomography section



Seismic models of Minaret Choli

quantity axes local
total displacement [m]

Total def[m]



CONCLUSIONS FROM GEOPHYSICAL RESEARCH

- Loss of the upper part of minaret was due to the sudden impact during an earthquake in the past.
- The depth of foundation is approx. 5 – 7 m with the ground plan overlapping the base by not more than 0.5 m.
- Underground situation is stable if dry, the environment becomes more consolidated with growing depth
- **Any increase of MOISTURE in the ground environment will deteriorate the geo-mechanical parameters of highly clay soil and can considerably influence the stability of minaret**

Analysis of Building Materials

Sample M6

Left upper part of the decorative relief in the niche on the north-east tower section; on the surface of the sample is also a surface finish layer (enamel ?)

Sampling place



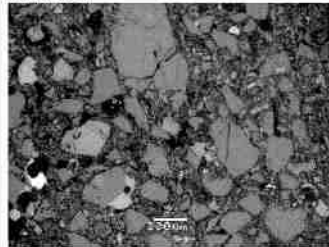
Microphotograph of cross-section in white reflected light



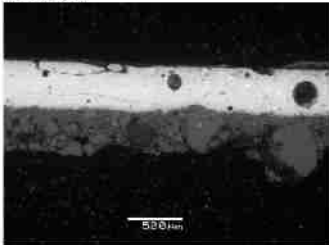
Microphotograph of cross-section in white reflected light



REM-BEI



REM-BEI



REM-EDX results:

The matrix is composed from silicate-compounds. The single grains of filler are mainly quartz and aluminosilicates, rarely small particles of iron oxides and Fe-Ti compounds.

The coloured layer with a glassy structure contains mainly silicon and lead, than lower content of calcium, aluminium, sodium, tin, chlorine and a few amount copper and iron. Some particles in the basic matrix are containing higher amounts of Pb and Sn.

Mineral phases identified by XRD:

Main: Quartz
Adjacent: Plagioclase
Accessory: K-Feldspar

Sample M2

Joint mortar from deeper part of the joint; same place as M1

Sampling place



Microphotograph of cross-section in white reflected light



REM-EDX results:

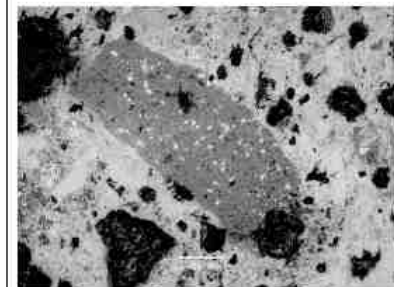
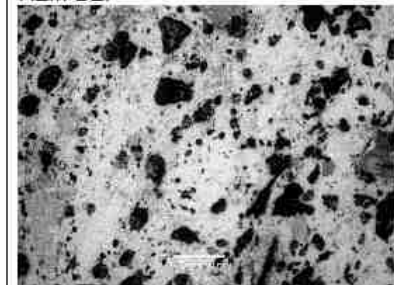
The matrix is composed mainly by calcium sulphate. It has a very high porosity with quite large pores (up to 300-400 µm), which are often typical for gypsum based mortars. Matrix contains a very low amount of calcium carbonate (max. 2-3 %). Single grains of calcium sulphate are also present in the mortar. Similarly to sample M1 are the edges of a part these grains again well interconnected with the matrix and a reaction rim is visible.

There were found also low quantities of strontium sulphate (natural common impurity of gypsum), iron compounds (probably oxides), calcium carbonate, quartz particles and particles of aluminosilicates and small particles of titanium compounds.

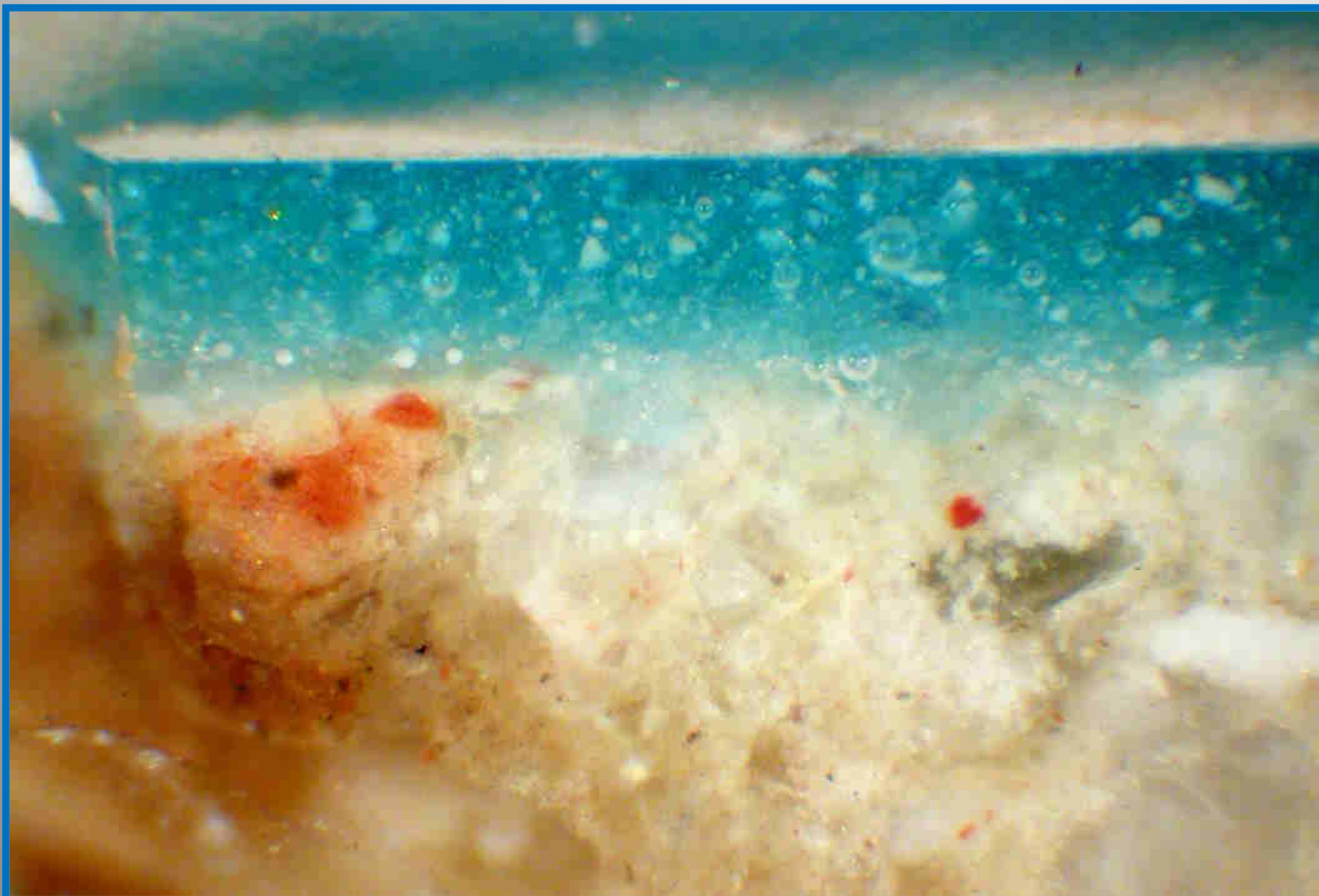
Mineral phases identified by XRD:

Main: Gypsum
Adjacent: Quartz, Calcite, Plagioclase
Accessory: Hematite, Anhydrite

REM-BEI



Analysis of blue ceramic tiles

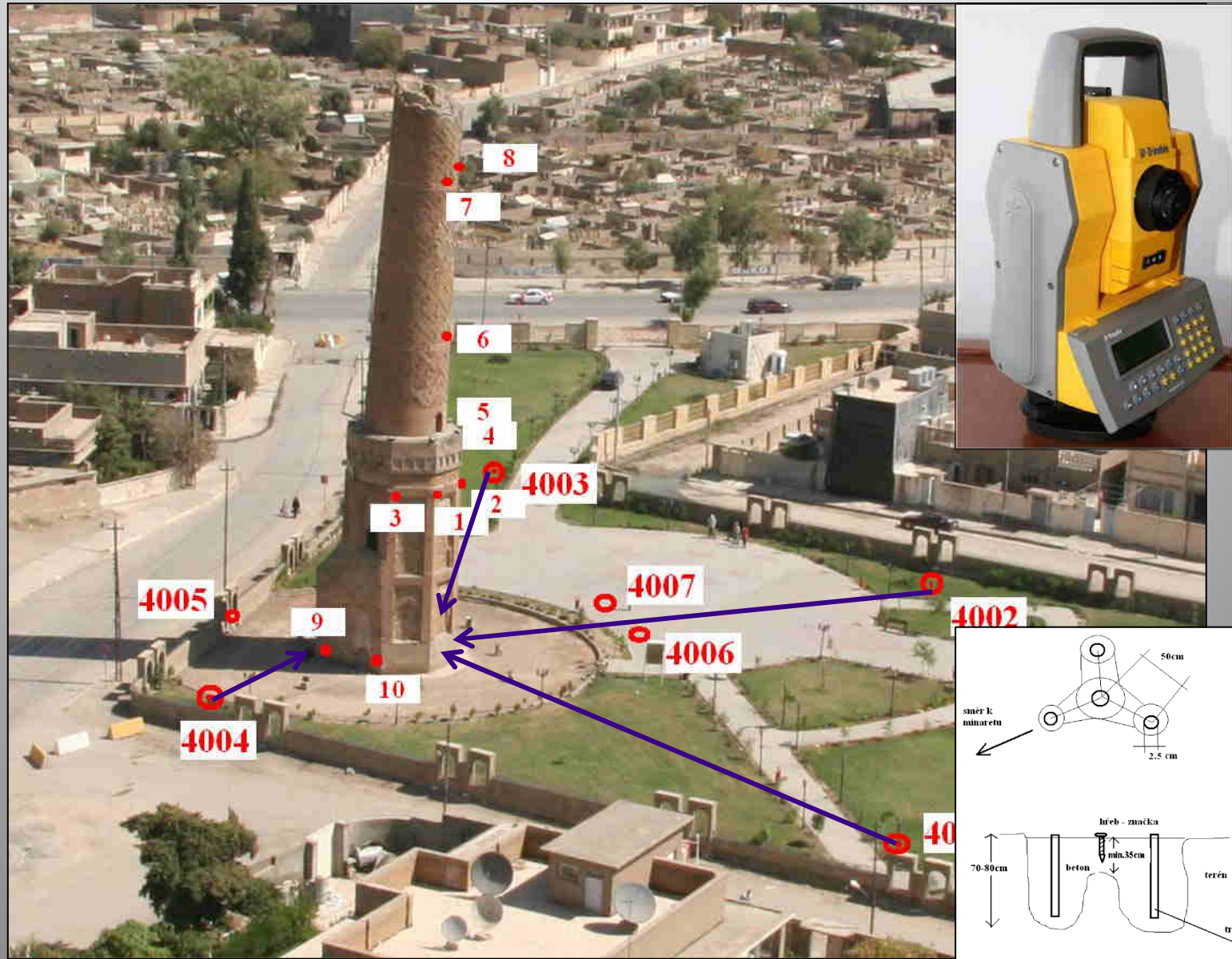


Blue enamel on the
basis of Egyptian
Blue with addition of
tin and lead,
0,22 mm

White vitreous
substance of silica,
0.4 mm

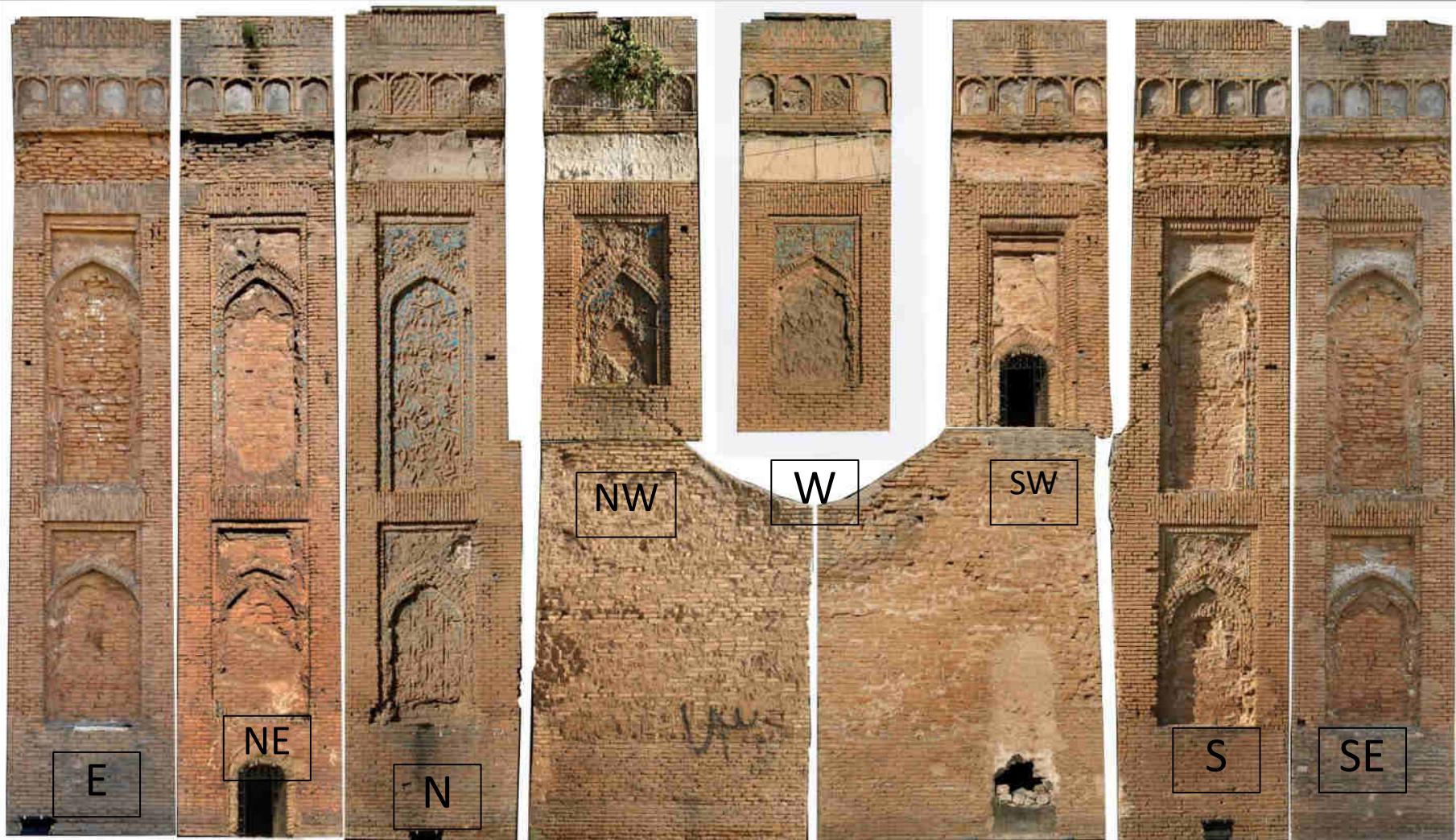
brown –burnt clay
with oxides of
silicon, iron,
aluminium with
additions of
magnesium and
sodium

Geodetic measurement of Minaret Photogrammetry



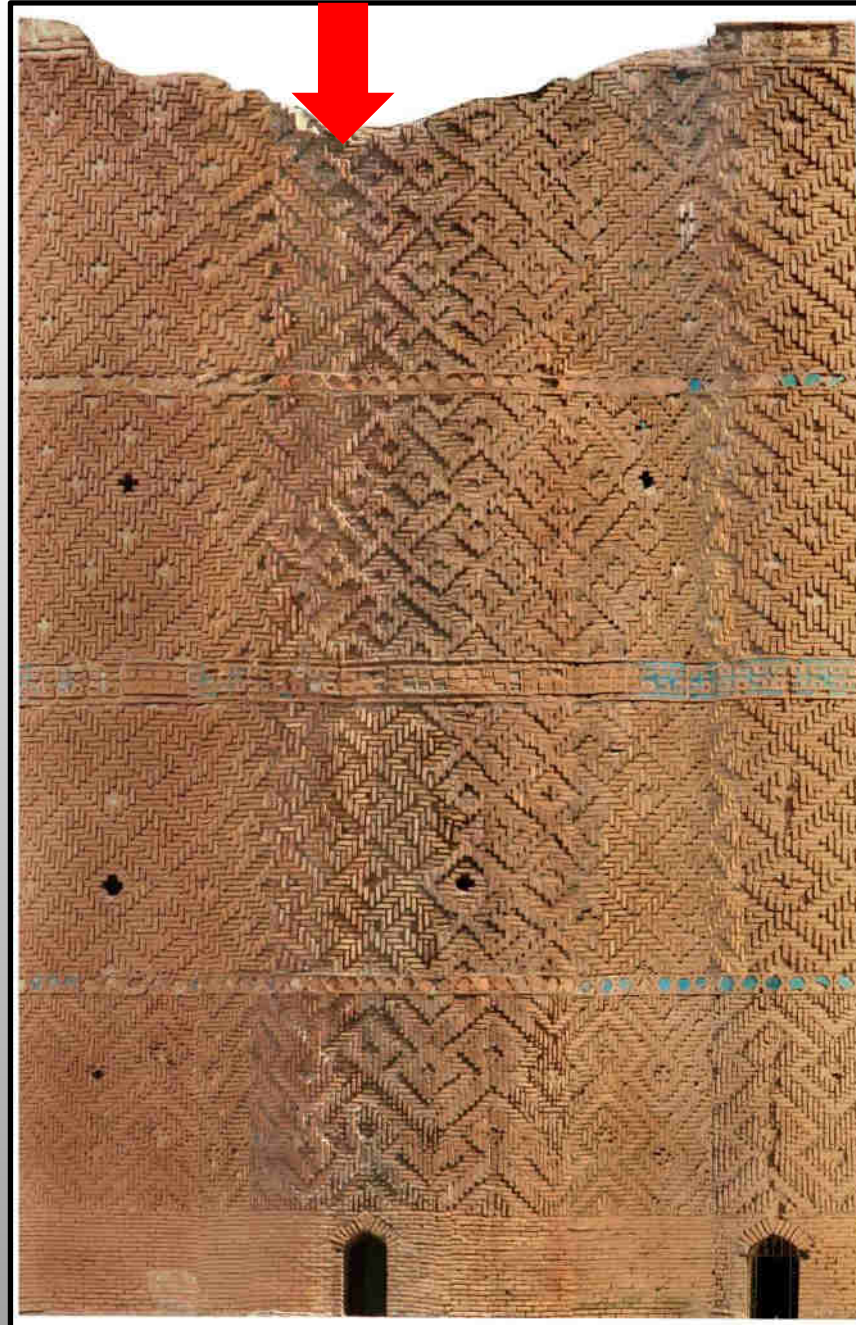
PHOTOGRAMMETRY

All lower parts of minaret

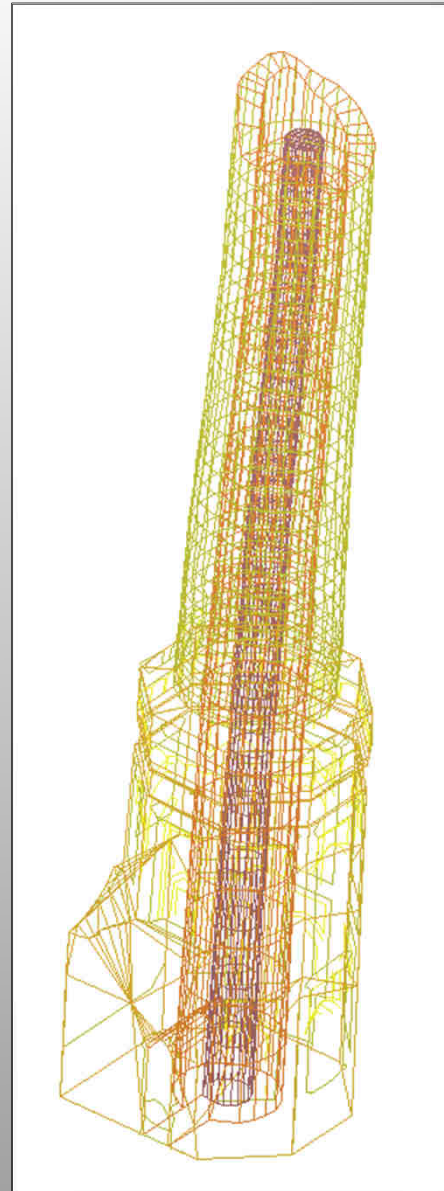
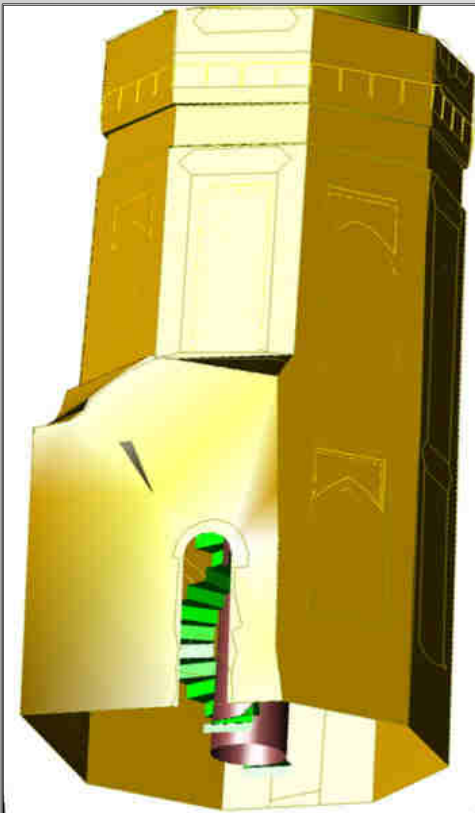
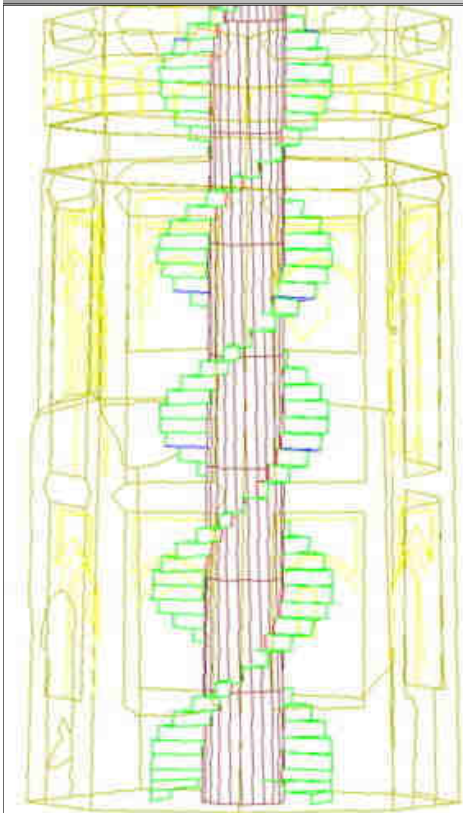


PHOTOGRAMMETRY Rollout

Southern part of the minaret is
highlighted with arrow



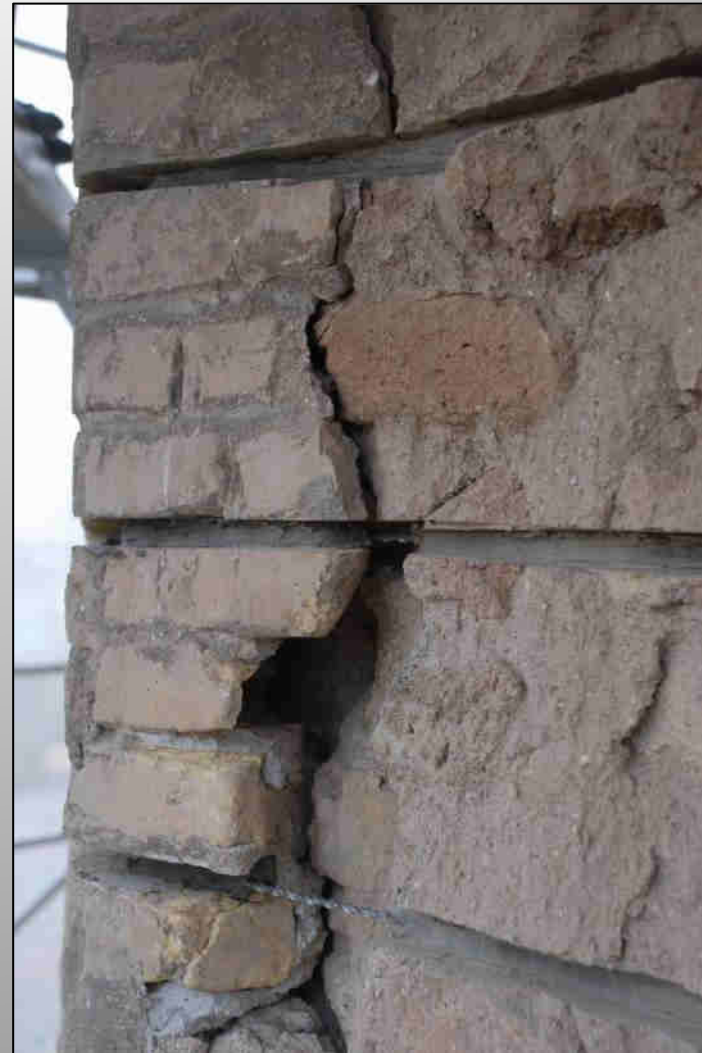
CAD construction 3D modelling



Virtual modelling in AutoCAD



II. STABILIZATION



Scaffolding





Detachment of the outer wall from the core

Outer wall

Core structure

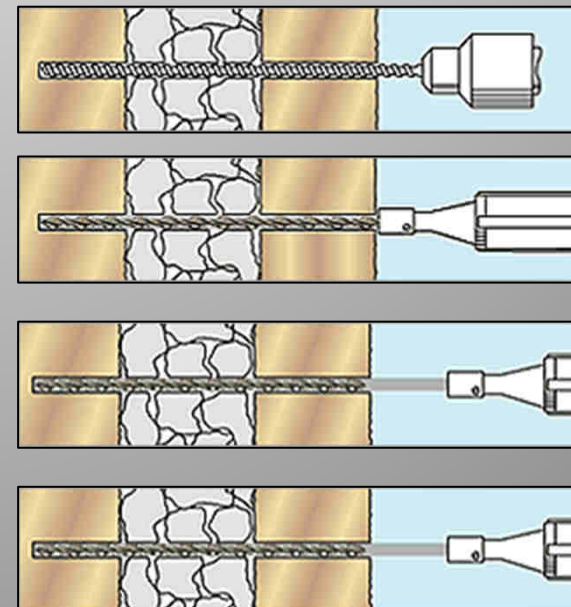
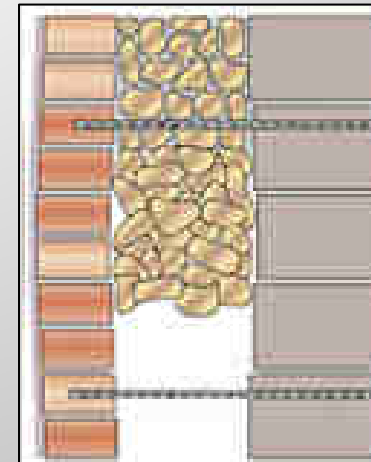


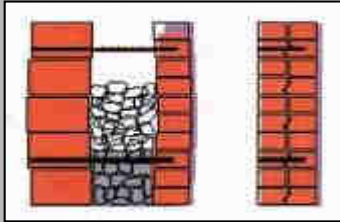
**Vertical detachment (window) and
horizontal destruction (wall)
statical cracks highlighted with red arrows**



CemTies for reconnecting separated internal and external building walls

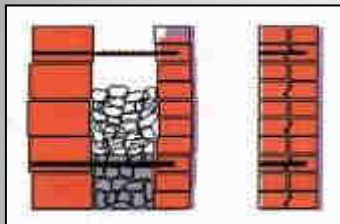
CemTies and HeliBond (by HELIFIX) grout were installed into clearance holes drilled through the near leaf and at least 100 mm into the far leaf. The density of the ties was 2,5 connecting points per square meter in average





Repair of sandwich construction – radial reinforcement drilling and high pressure cleaning

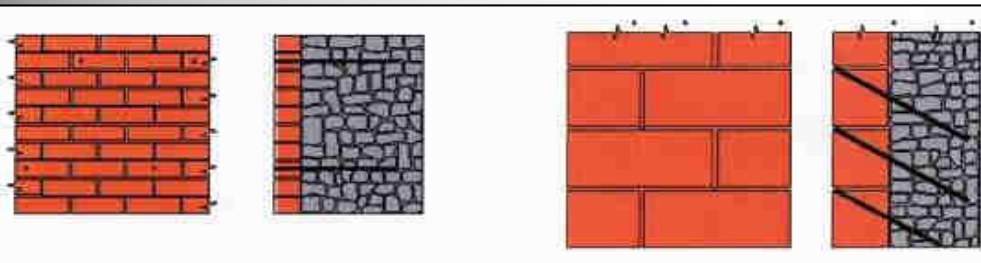




Repair of sandwich construction – radial reinforcement

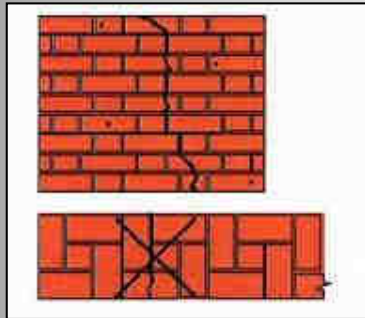
Inserting stainless steel spiral rods and the grout



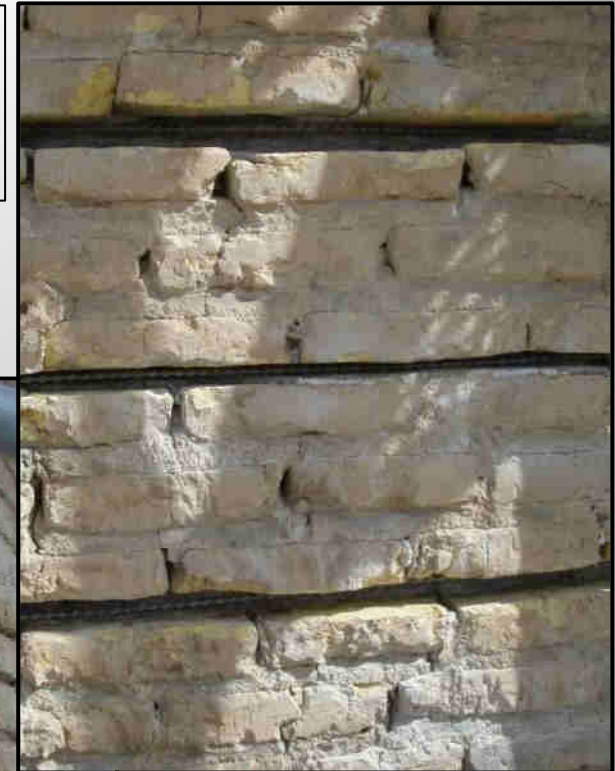


**Repair of sandwich constructions,
connecting the outer and inner wall
- detail of rods in upper part**





Horizontal reinforcement

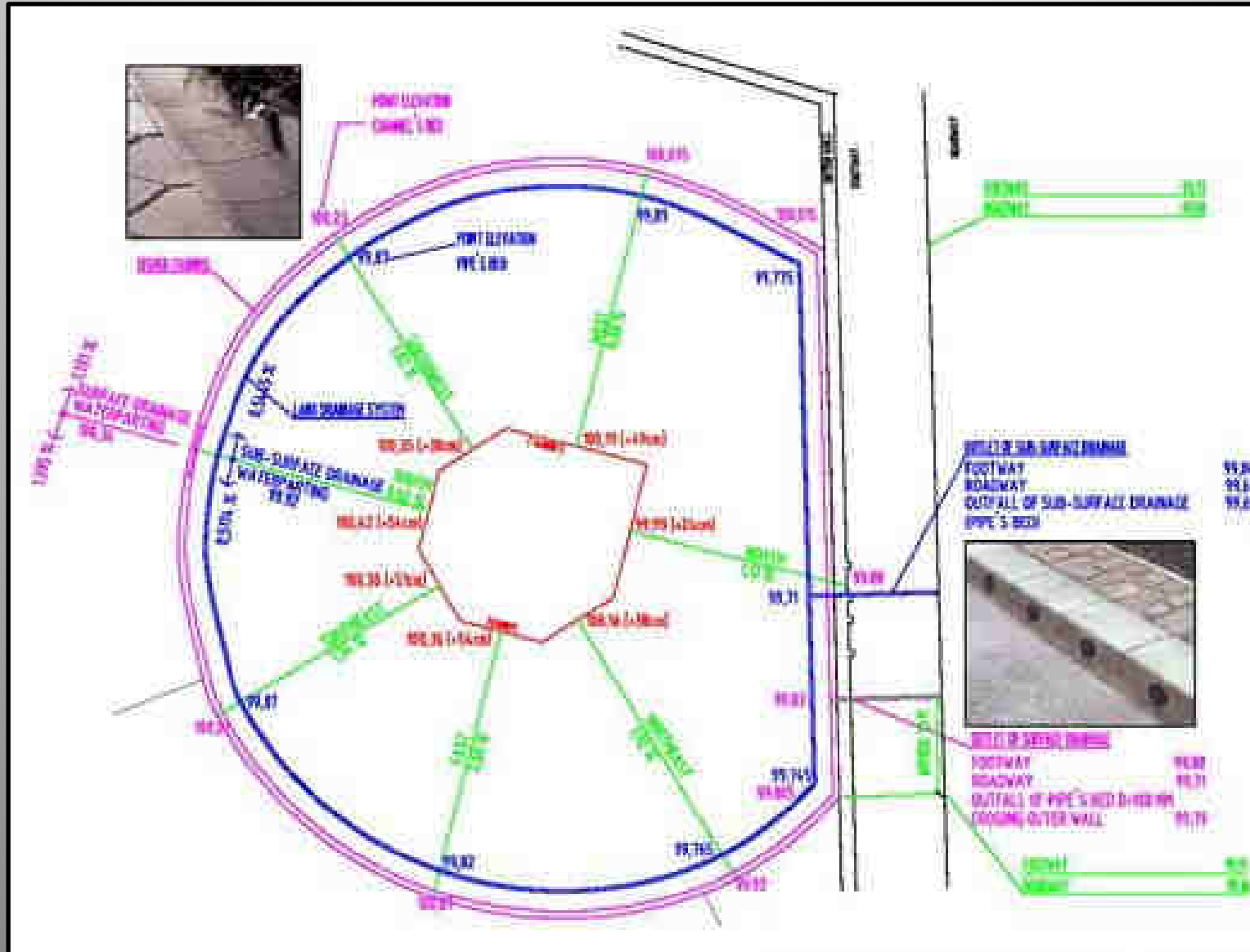




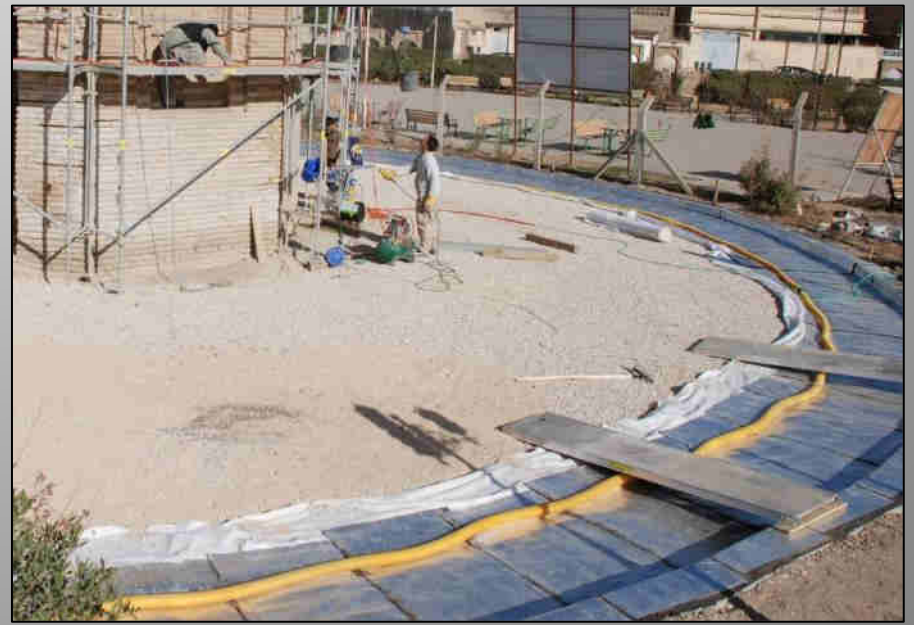
**Inside reinforcement of the
stairs and walls**



Drainage project for surrounding area -plan



Hydroizolation of surrounding area



Drainage system



1. farshi tile
2. silica sand
3. non-woven textile
4. limestone gravel
5. non-woven textile
6. round gravel
7. plastic sheet
(non permeable)
8. non-woven textile
9. limestone gravel
10. soil



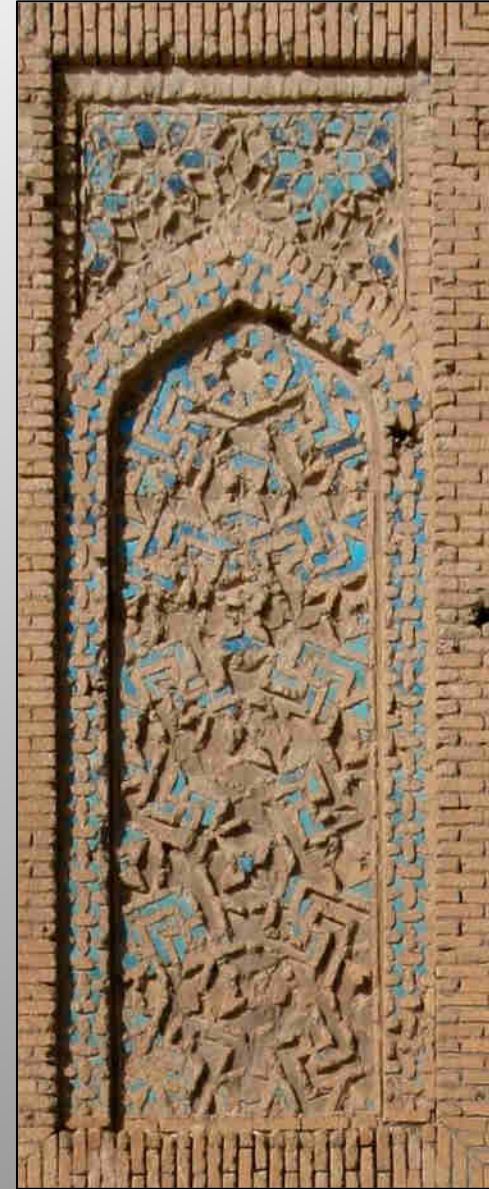
Paving and consolidation of surrounding area



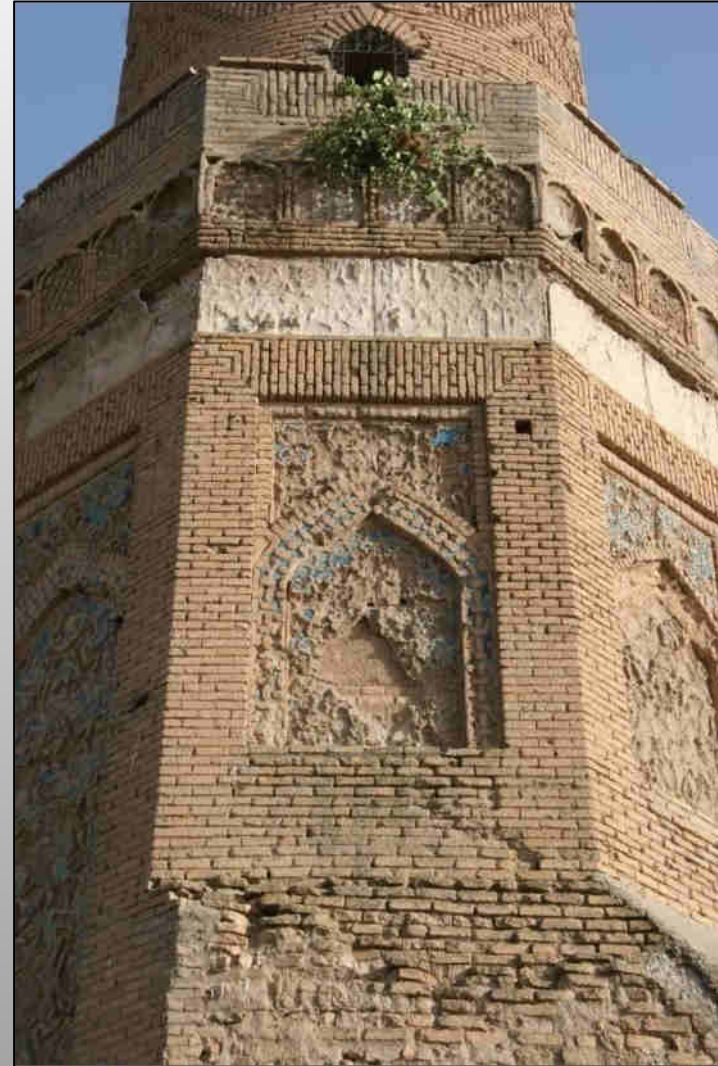
III. CONSERVATION



Lower large niches before treatment



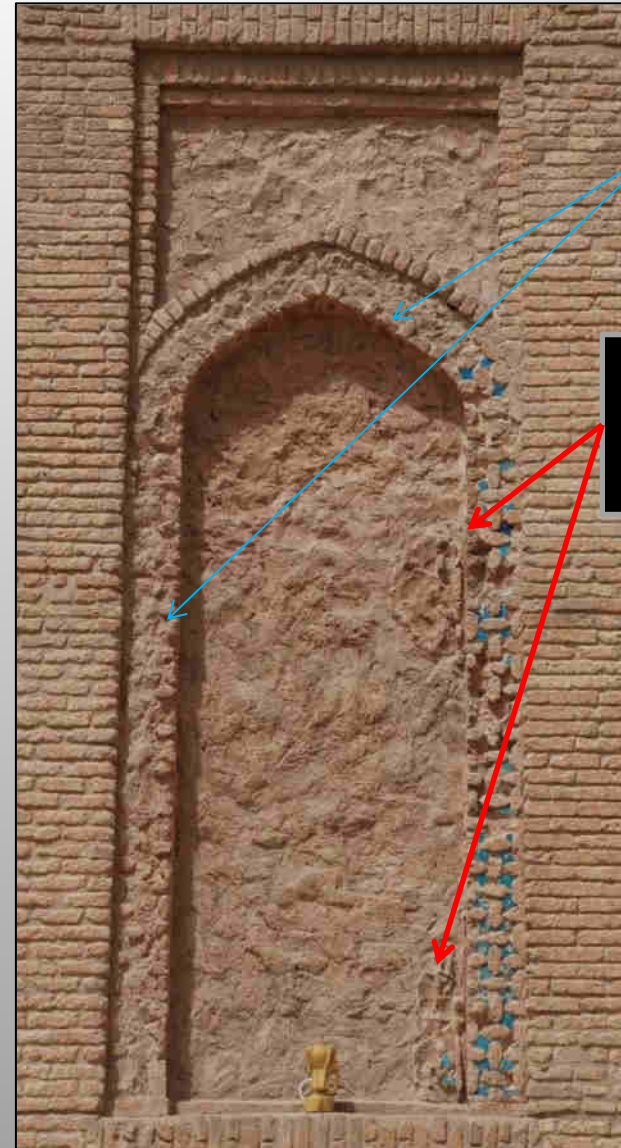
NW small upper niches before intervention



SW large niche in course of treatment



SW large niche after intervention



Reconstruction
of architectural
shape

Conservation of
original
fragments

Mortar for joints and gap filling

- Modified gypsum system based on alpha gypsum (calcium sulfate hemihydrate) ANHYMENT FE 20 (product of TBG Maltý, Prague, Czech Republic).
- Gypsum was mixed with local basic gypsum in ratios from 1:1 to 1:4 according to the individual needs.
- Different fractions of aggregates, namely silica sand have been added depending on the use and desired texture. Iron oxides were used as pigments.
- Hydrophobic admixture Wacker IBS was added as water repellent additive.



Brick production



Brick production

- Hand made bricks have been produced in the local brick manufacture according to the historical recipe
- Made from clay, straw and sheep waste
- Bricks were fired close to the original firing temp. (hopefully around 750°C).



Running **gypsum belt** under small niches – before treatment



Stabilization and reconstruction of the gypsum belt



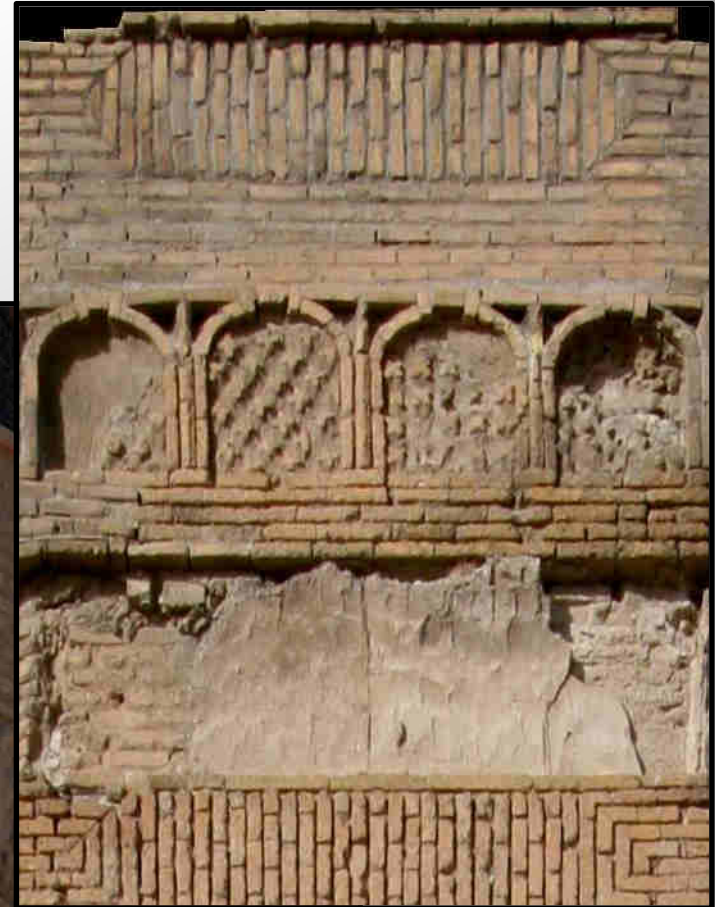
**Gypsum running belt after conservation
and partly reconstruction (right)**

Arrows locate original fragments



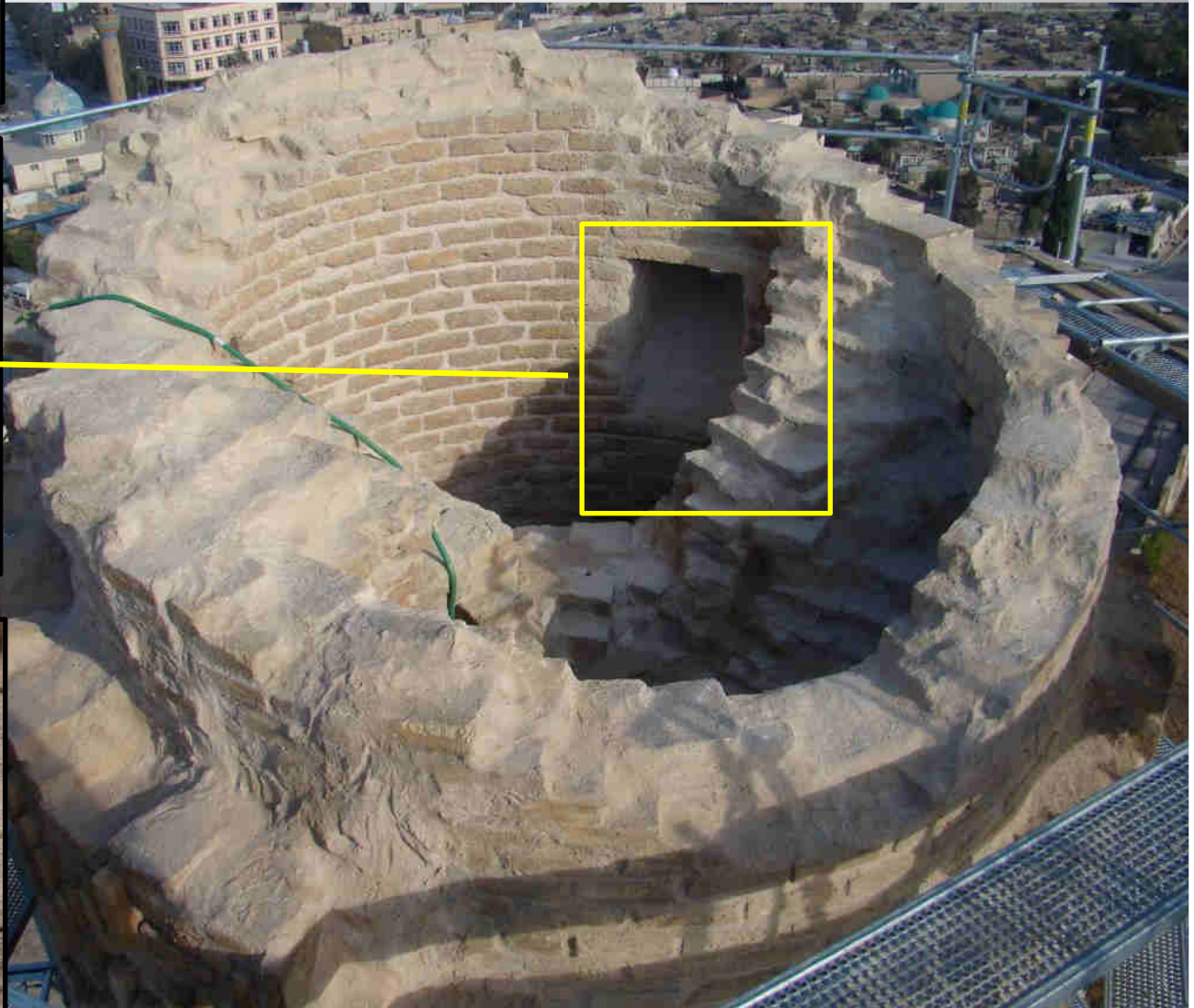
**Gypsum running belt during
reconstruction (above)**

NE part of the minaret, **small niches**
and **gypsum belt** after treatment

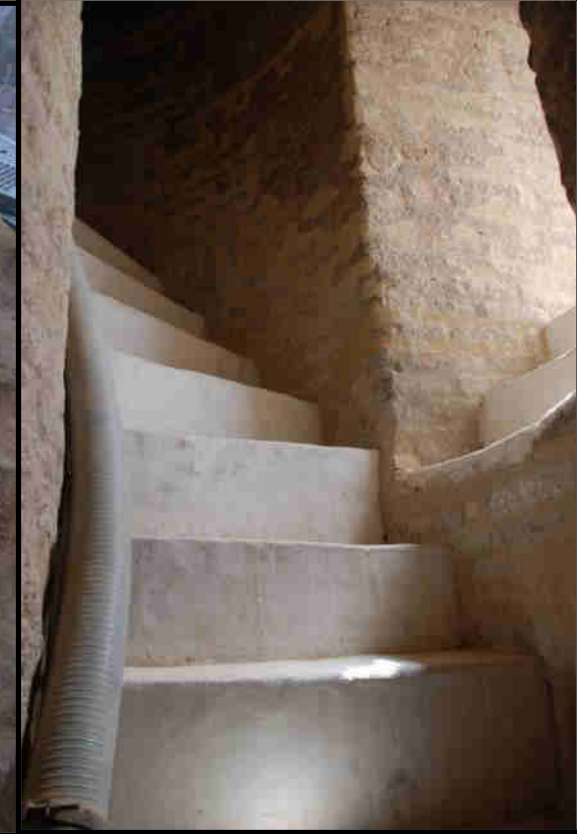


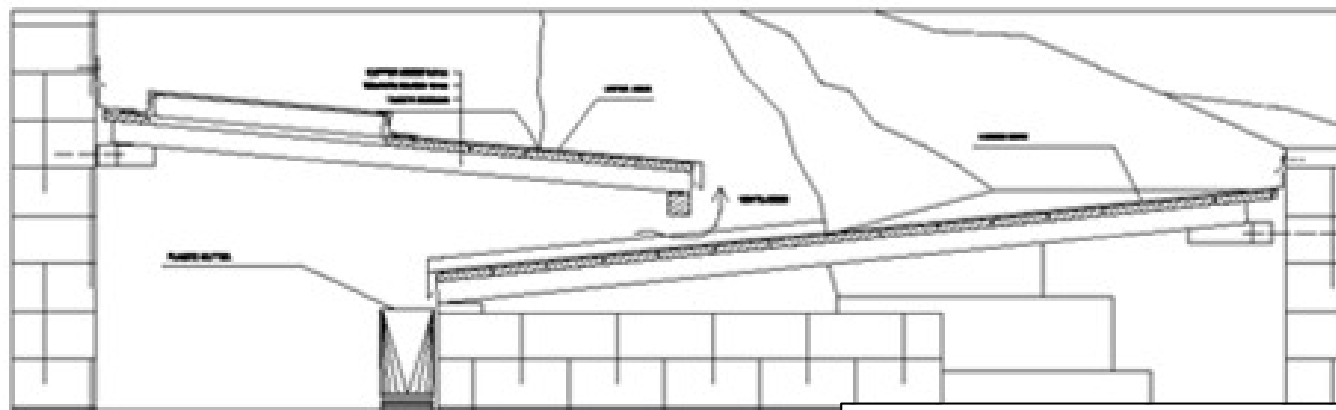


**The summit after conservation, before roofing (below)
reconstruction of northern window (left, see the arrow)**

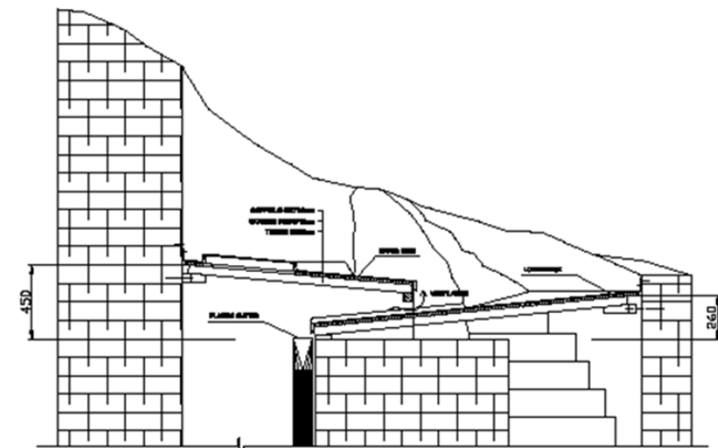


New **copper roof** protecting staircases from leakage of rain water
Non-invasive intervention to the original structure
Fully reversible

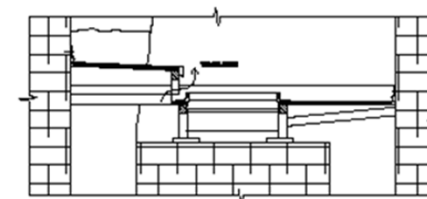




DETAIL: SECTION A - A' M 1:10



SECTION A - A'



SECTION B - B'

Copper roof in detail

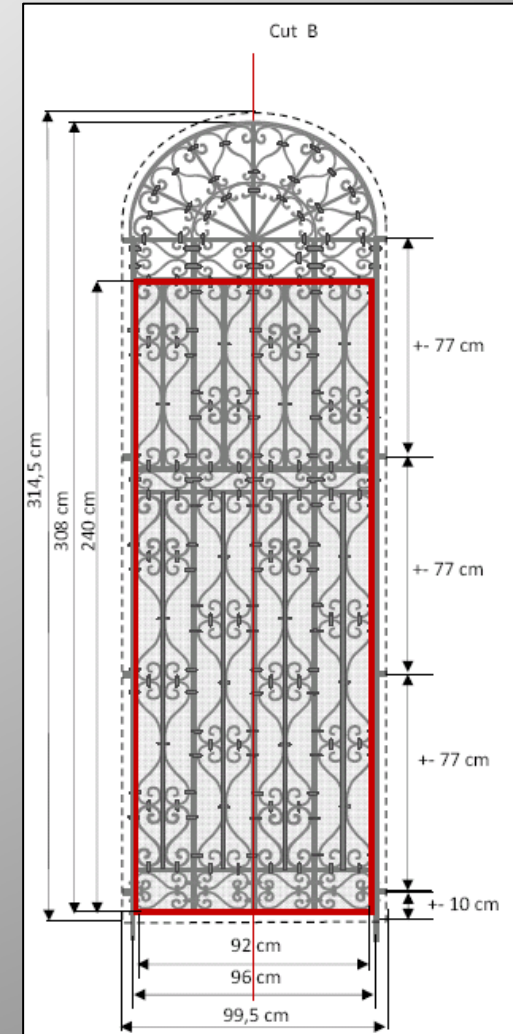
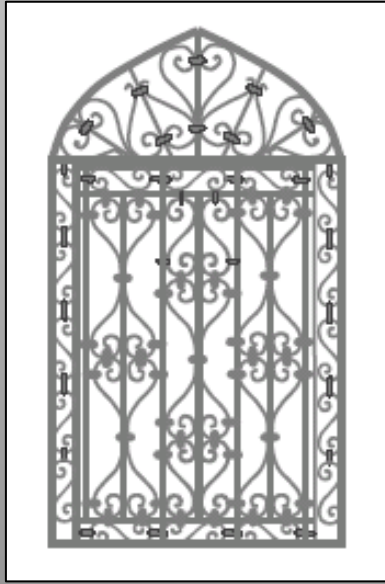
The procedure of **repointing** of joints



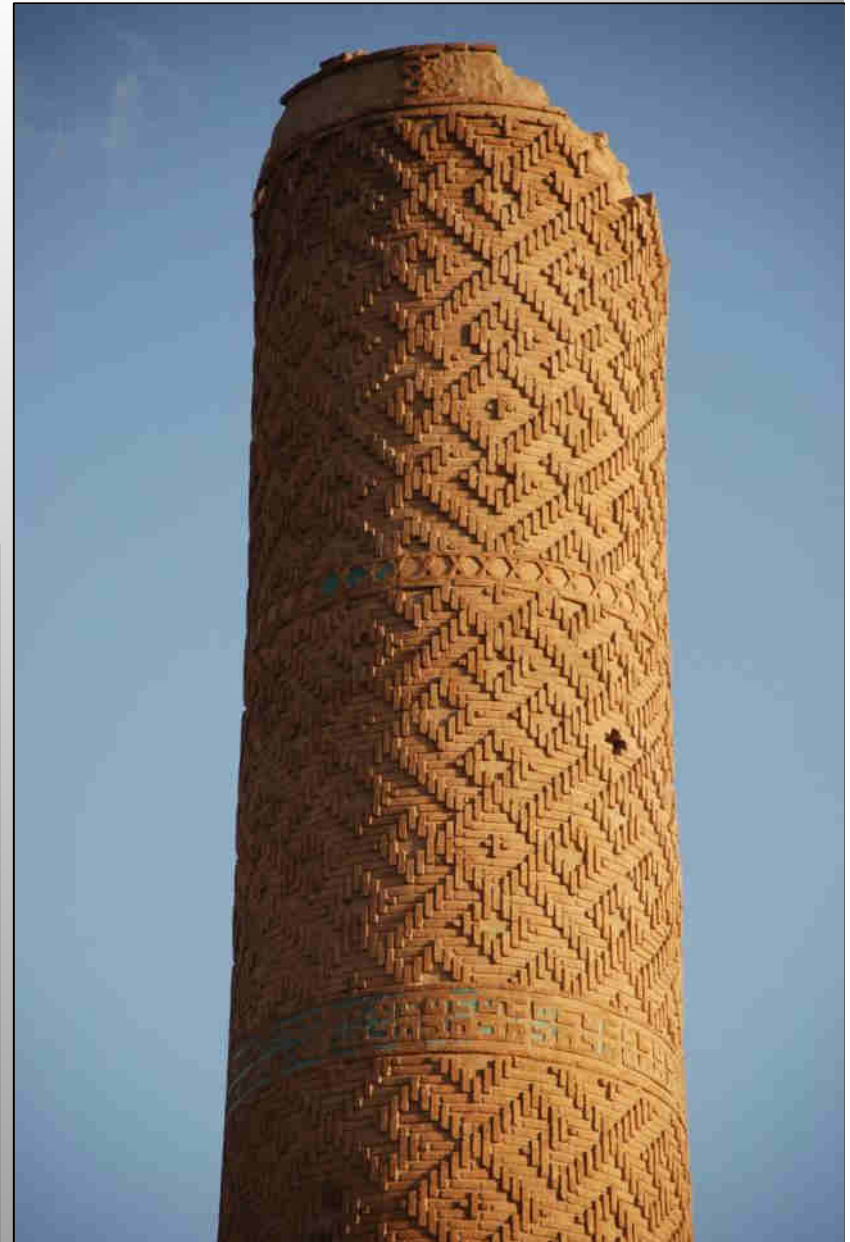
Repointing of joints after completion



New design for window and door grills



Minaret Choli after conservation



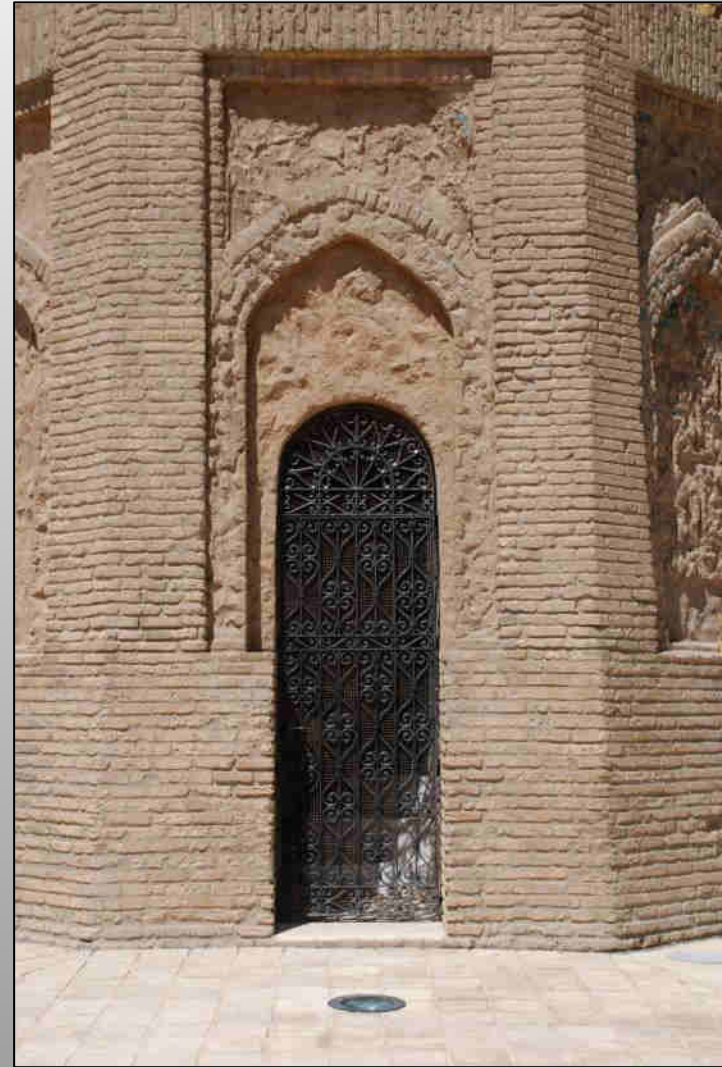
Minaret Choli after conservation



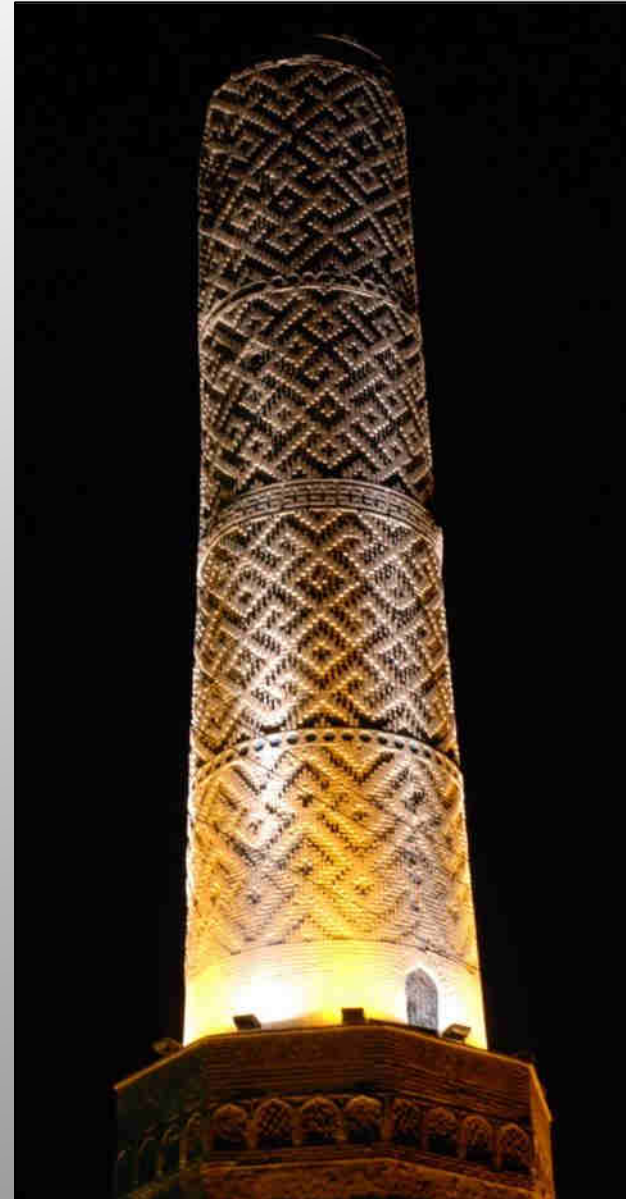
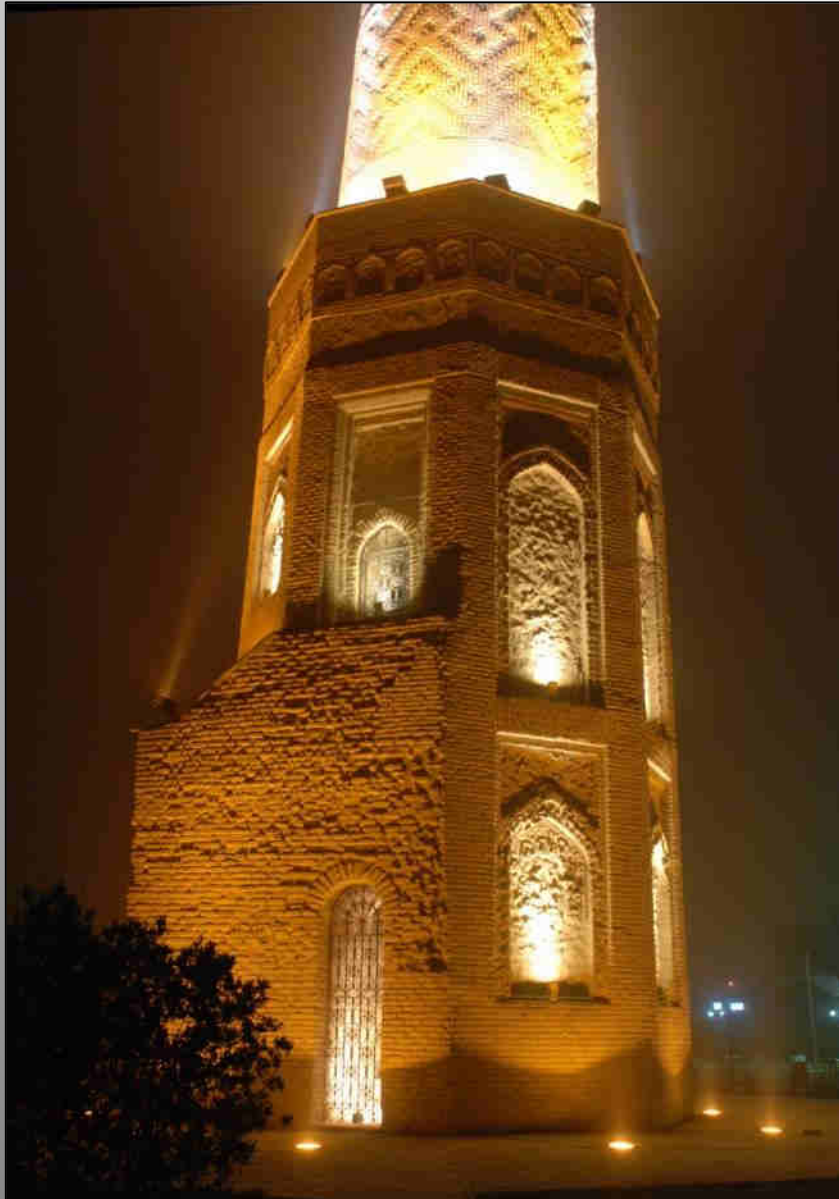
Southern upper niches after conservation



Detail of the eastern entrance with new grills before and after conservation



ILLUMINATION



Special thanks to

Mrs. Gouhar Shemdin

ADVISER TO THE MINISTER AND
ARCHITECT CONSULTANT FOR THE PROJECT



THANK YOU

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**Gema Art Group
2008-2009**

