Challenges for the structural engineer on renovation of ancient buildings

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Main particularities and difficulties of monuments

- These particularities are of two kinds.
- Monuments constitute constructions which have been conceived and designed according to the so-called **rules of art.** They have a n wide **variety of mechanical properties** in the same structure or even in the same element. Basic assumptions like isotropy homogeneity and elastic behavior do not apply. Many different phases, not so clear geometry, badly known connections , unknown dynamic behavior and dumping mechanisms. So **mathematical simulation** is very difficult.

- the restrictions imposed by the need to respect the **architectural form and the structural identity** of the monument, normally **contradicts** with the interventions which would be necessary to make the construction **conform to the current levels of safety.** Monuments can not follow the standards of current Regulations if we make an analysis according to the **current scientific knowledge** on the behavior of buildings and their expected seismic respond.

Scope of my presentation

- First I will remind which is our main Regulatory status on Monuments interventions both on Codes and Guidelines.
- Then I will try to present these problems and particularities through the experience gained by my professional engagement in some minaret restoration projects, namely the minaret of Splantzia in Chania, the minaret of the Suleiman mosque in Rhodes, the Metzitie minaret in Chios and the Neratze and Valide minarets in Rethymnon.
- In the same time I will try to follow the evolution of my structural approach, that is the evolution of structural ideas in the practice of a small engineers office.

Uncertainty is the main motto when dealing with existing historic structures

- It has taken many years to realize that existing structures must have a completely different approach than the new ones.
- Here we do not design an ideal structure with ideal materials which we will try, by quality control methods, to realize during construction. Here we have to deal with an existing structure with a variety but existing properties. The only bad known factor is the anticipated loads. So the statistical approach of safety has to be reviewed.
- In the stonemasonry of the monument itself, we often find stones with differences in resistance rising to 1/10, as well as mortars with various compositions and corresponding differences in resistance of the wall.
- Connections of the different structural elements are also badly known.
- The sampling and the laboratory tests are impossible to be done in the extent that would allow us to deduce reliable values for the whole structure.
- So mathematical modeling is very difficult.

Main Regulatory texts about monuments from structural point of view

- **ICOMOS ISCARSAH RECOMMENDATIONS FOR THE ANALYSIS, CONSERVATION AND STRUCTURAL RESTORATION OF ARCHITECTURAL HERITAGE 2003**
- Eurocode 8 part 3 of EN1998
  Assessment and retrofitting of buildings 2006
- Linee Guida per la valutazione e riduzione del riscio sismico del patrimonio culturale con riferimento alle norme tecnice per le construzioni 2010

Iscarsah

International Scientific Committee on the Analysis and Restoration of Structures of Architectural Heritage

- **RECOMMENDATIONS FOR THE ANALYSIS, CONSERVATION AND STRUCTURAL RESTORATION OF ARCHITECTURAL HERITAGE 2003**
- Structures of architectural heritage, by their very nature and history (material and assembly), present a number of challenges in diagnosis and restoration that **limit the application of modern legal codes** and building standards. Recommendations are desirable and necessary to both ensure rational methods of analysis and repair methods appropriate to the cultural context.
- The safety evaluation, which is the last step in the diagnosis, where the need for treatment measures is determined, should reconcile **qualitative with quantitative analysis**: direct observation, historical research, structural analysis and, if it is the case, experiments and tests.
- Often the application of the same safety levels as in the design of new buildings requires excessive, if not impossible, measures. In these cases specific analyses and appropriate considerations may justify different approaches to safety.

ISCARSAH GUIDELINES

- A combination of both scientific and cultural knowledge and experience is indispensable for the study of all architectural heritage.
- Any planning for structural conservation requires both qualitative data, based on the direct observation of material decay and structural damage, historical research etc., and quantitative data based on specific tests and mathematical models of the kind used in modern engineering. This combination of approaches makes it very difficult to establish rules and codes.
- The subjective aspects involved in the study and safety assessment of an historic building, the uncertainties in the data assumed and the difficulties of a precise evaluation of the phenomena, may lead to **conclusions of uncertain reliability**. It is important, therefore, to show clearly all these aspects, in particular the care taken in the development of the study and the reliability of the results, in an **EXPLANATORY REPORT.**

Legal aspects, professional liability

- ISCARSAH Recommendations
- It must be clear therefore that the architect or engineer charged with the safety evaluation of an historic building **should not be legally obliged** to base his decisions solely on the results of calculations because, as already noted, they can be unreliable and inappropriate.
- Unfortunately this very important statement is just a recommendation and has not the status of a regulatory text.

Eurocode 8 part 3 of EN1998
Assessment and retrofitting of buildings

- Part 3 of Eurocode8 (EN1998-3, 2005) is a modern document, fully aligned with the recent trends regarding performance requirements and check of compliance in terms of displacements, providing also a degree of flexibility to cover the large variety of situations arising in practice.
- Seismic assessment of an existing, non conforming structure, however, is a difficult art, one for which the normal engineer is ill-prepared and was, until recently, without much assistance in the form of normative or pre-normative documents.

Eurocode 8 part 3

- Due to the recognized inadequate knowledge on the post-elastic behavior of generally poorly detailed structural members, the normative part of EN 1998-3 covers only material-independent concepts and rules.

- Existing buildings actually represent a very inhomogeneous population, in terms of age and criteria used for their design, and with unknown weaknesses, such that their overall inelastic behavior can hardly be represented by a single parameter established *a priori, such as the q-factor, even if* differentiated for necessarily broad categories.

Eurocode 8 part 3 of EN1998
PERFORMANCE REQUIREMENTS

- The performance requirements are formulated in terms of the three Limit States (LS), as reported below.
- LS of Near Collapse (NC). The structure is heavily damaged, with low residual lateral strength and stiffness although vertical elements are still capable of sustaining vertical loads.
- o LS of Significant Damage (SD). The structure is significantly damaged, with some residual strength and stiffness, and vertical elements are capable of sustaining vertical loads.
- o LS of Damage Limitation (DL). The structure is only lightly damaged, with structural elements prevented from significant yielding and retaining their strength and stiffness properties.

Displacement based analysis and criteria

- There is no more question among earthquake engineers that displacements/distortions are the quantities best suited for identifying the attainment of any of the above-defined limit states .
- The difficult part, however, comes with the obvious necessity of calculating the buildings' response in stages well beyond the elastic one and close to their actual inelastic deformation capacity.

SEISMIC EVALUATION AND RETROFIT OF CONCRETE BUILDINGS

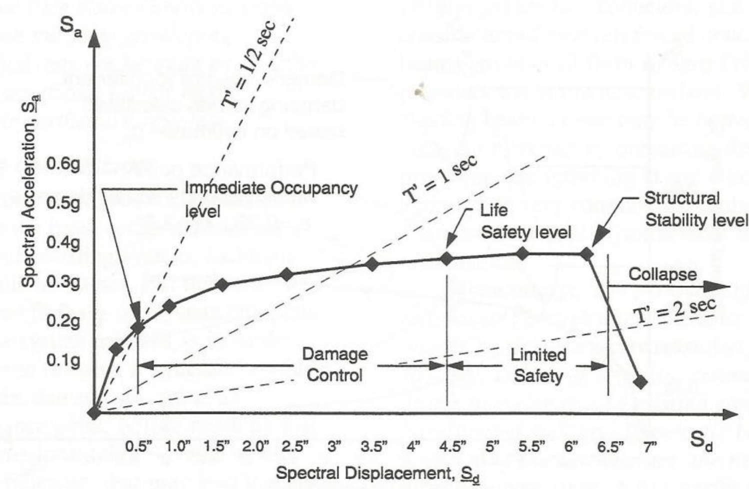


Figure 6-3. Typical Capacity Spectrum

Eurocode 8 part 3 of EN1998

KNOWLEDGE LEVELS CONFIDENCE FACTOR

- Amount and quality of the information usable for the assessment is discretized in EN 1998-3 into three "levels", called "Knowledge Levels" (KL), ordered by increasing completeness. The information refers to three aspects: **Geometry, Details and Materials.**
- Allowing a structural assessment to be carried out for different levels of knowledge requires that a proper account is taken of the corresponding different amounts of uncertainties, these latter clearly applying to all of the three quantities: Geometry, Details and Materials. The choice made by EN 1998-3 is to condense all types of uncertainties into a single factor, This factor, called **Confidence Factor (C**F**).**
- .

Eurocode 8 part 3 of EN1998
METHOD OF ANALYSIS

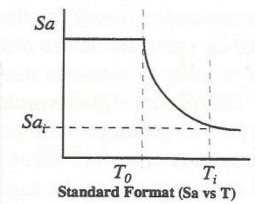
- In accordance with the displacement criterion adopted in EN 1998-3 for checking satisfaction of the various performance requirements, the seismic action to be used in conjunction with all allowed methods of analysis consists of the elastic response spectrum characterized by the appropriate value of its average return period.
- The allowed analysis methods are the same given in EN 1998-1:
- o Linear analysis, using statically applied lateral forces or modal response spectrum analysis
- o Non-linear analysis, either static (push-over) or dynamic using spectrum-compatible accelerograms.
- Use of linear static analysis is permitted under the same conditions given in EN 1998-1, i.e., geometrical regularity in elevation, and values of the fundamental period less than or equal to 2.0s and to 4TC,

Demand response spectra and capacity curves are plotted in spectral acceleration vs displacement domain

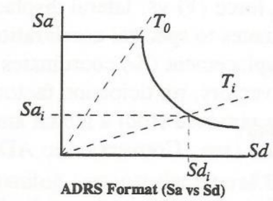
Conversion to ADRS Spectra

Application of the Capacity-Spectrum technique requires that both the demand response spectra and structural capacity (or pushover) curves be plotted in the spectral acceleration vs. spectral displacement domain. Spectra plotted in this format are known as Acceleration-Displacement Response Spectra (ADRS) after Mahaney et al., 1993.

Response Spectrum Conversion



Standard Format (Sa vs T)



ADRS Format (Sa vs Sd)

Every point on a response spectrum curve has associated with it a unique spectral acceleration, S_a, spectral velocity, S_v, spectral displacement, S_d and period, T. To convert a spectrum from the standard S_a vs T format found in the building code to ADRS format, it is necessary to determine the value of S_{di} for each point on the curve, S_{ai}, T_i. This can be done with the equation:

$$S_{d_i} = \frac{T_i^2}{4\pi^2} S_{a_i} g$$

Standard demand response spectra contain a range of constant spectral acceleration and a second range of constant spectral velocity. Spectral acceleration and displacement at period T_i are given by:

$$S_{ai}g = \frac{2\pi}{T_i} S_v \qquad S_{di} = \frac{T_i}{2\pi} S_v$$

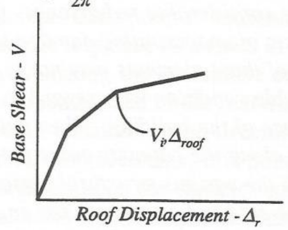
Capacity Spectrum Conversion

In order to develop the capacity spectrum from the capacity (or pushover) curve, it is necessary to do a point by point conversion to first mode spectral coordinates. Any point V_i, Δ_{roof} on the capacity curve is converted to the corresponding point S_{ai}, S_{di} on the capacity spectrum using the equations:

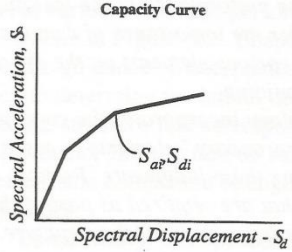
$$S_{ai} = \frac{V_i / W}{\alpha_1}$$

$$S_{di} = \frac{\Delta_{roof}}{(PF_1 \times \phi_{1,roof})}$$

where α_1 and PF_1 are respectively the modal mass coefficient and participation factors for the first natural mode of the structure and $\phi_{1,roof}$ is the roof level amplitude of the first mode. See also Section 8.5, Basics of Structural Dynamics.



Capacity Curve



Capacity Spectrum

Eurocode 8 part 3 of EN1998
METHOD OF ANALYSIS MASONRY

- For masonry structures, applicability of linear methods, both static and multi-modal, is subject to the following restrictive conditions:
- The lateral load resisting walls are *regularly arranged in both horizontal directions*.
- *Walls are continuous along their height*.
- The floors possess enough in-plane stiffness and are sufficiently connected to the perimeter walls to assume that they can distribute the inertia forces among the vertical elements as *rigid diaphragm*.
- *Floors on opposite sides of a common wall are at the same height*
- At each floor, the ratio between the lateral in-plane stiffness of the stiffest wall and the weakest
- primary seismic wall, evaluated accounting for the presence of openings, does not exceed 2.5.
- **With restrictions like these it can be anticipated that linear analysis will not be frequently used for masonry structures**.

Eurocodes8, previous edition of part1-4 and part 3 of EN1998 in force now.

- Previous Eurocode8 part 1-4 had an Appendix C dealing with monumental structures , which had summarized all the existing experience and formulated in a very legally useful way the appropriate approach for monuments.

- The final EN1998 which is in force has just the following comment. **"Although the provisions of this Standard are applicable to all categories of buildings, the seismic assessment and retrofitting of monuments and historical buildings often requires different types of provisions and approaches, depending on the nature of monuments."**

Important points of part 1-4 (1995)

- *4.4.2: In the cases where a conflict is created between the structural safety and the architectural/ artistic integrity, a* ***"cost and benefit"*** *analysis should be realized, where the benefit will be the increase of safety and the cost will be the loss of architectural integrity. In these cases, the issue should be discussed between two corresponding teams of experts and a common decision must be taken.*

- *In the cases of strengthening and repairing, the qualitative controls for the determination and the obliteration of important static faults can be very important; thus, they shouldn't be deterred by the more quantitative approach for which the present Part of Eurocode 8 was developed. Even though this is not the object of the present Part, it is anticipated that, on some occasions,* ***it will be possible to introduce specific proposals regarding the new planning, in which will dominate the qualitative aspect****.*

« Linee Guida per la valutazione e riduzione del riscio sismico del patrimonio culturale con riferimento alle norme tecnice per le construzioni» 2010

- Maybe the most elaborated guideline document.
- It gives clear definitions between monuments and historical buildings, between the evaluation of seismic risk for a whole region and a specific monument. It demands from the ministry of Culture to establish a scale of evaluation of the artistic importance of historic structures.
- It defines different levels of analysis and accepts various levels of seismic risk depending on the importance, the use and the life time given to the intervention. After that time new evaluation and possible measures must be taken.
- It recommends simplified analytical methods based on known types of failure

Seismic factors in relation to importance and use for the two limit

Tabella 2.1 – Probabilità di eccedenza in 50 anni dell'azione sismica (P) e fattori di importanza γ_I per la verifica allo SLU dei beni culturali tutelati

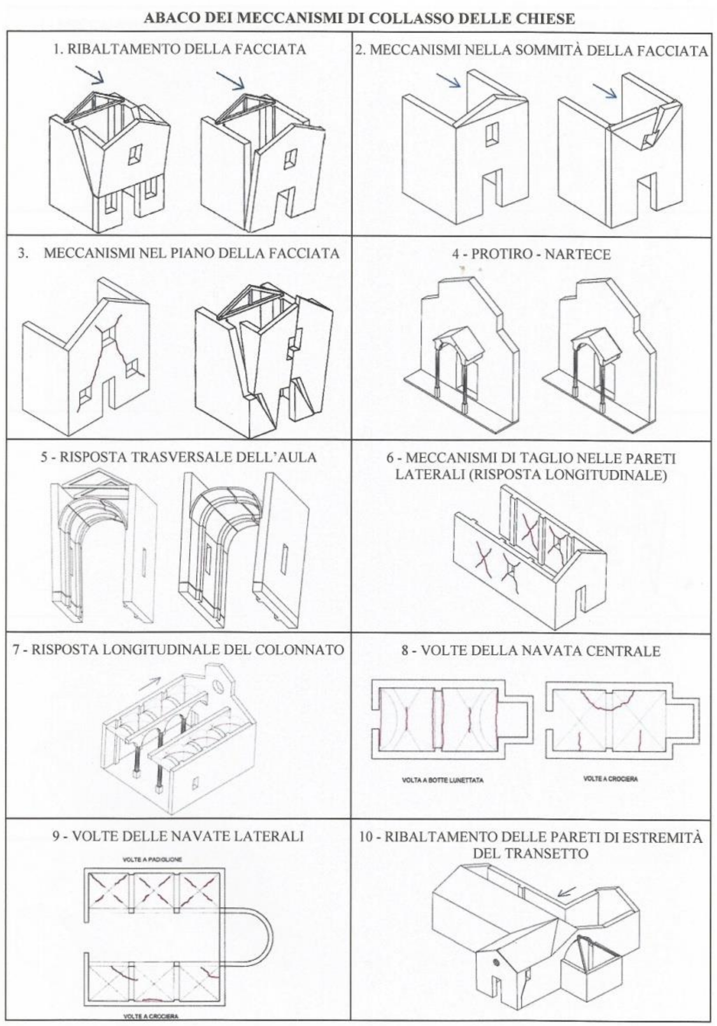
Categoria d'uso	Categoria di rilevanza					
	Limitata		Media		Elevata	
	P eccedenza	γ_I	P eccedenza	γ_I	P eccedenza	γ_I
Saltuario o non utilizzato	40%	0.50	25%	0.65	17%	0.80
Frequente	25%	0.65	17%	0.80	10%	1.00
Molto frequente	17%	0.80	10%	1.00	6,5%	1.20

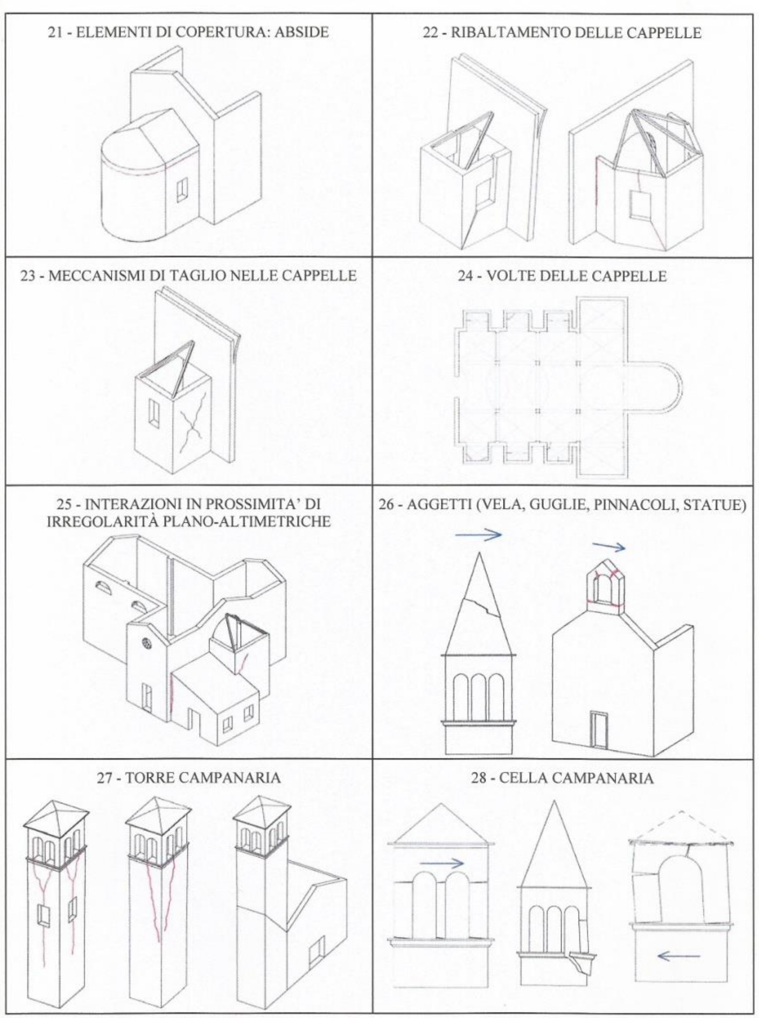
Tabella 2.2 – Probabilità di eccedenza in 50 anni dell'azione sismica (P) e fattori di importanza γ_I per la verifica allo SLD dei beni culturali tutelati

Categoria d'uso	Categoria di rilevanza					
	Limitata		Media		Elevata	
	P eccedenza	γ_I	P eccedenza	γ_I	P eccedenza	γ_I
Saltuario o non utilizzato	90%	0.50	80%	0.65	65%	0.80
Frequente	80%	0.65	65%	0.80	50%	1.00
Molto frequente	65%	0.80	50%	1.00	40%	1.20

In any case it is accepted even the simple **amelioration of the seismic response** of the monument and not its compliance to a certain safety standard. In that case an explanatory document must justify the seismic safety index , the possible monitoring and restriction of use measures, and the time limit for a new assessment and intervention

Simplified models based on rigid body equilibrium and cinematic methods upon common failure types





Some important points need for reliable data

- We believe that in order to improve the reliability of the assessment of the existing monumental constructions, we need to build a broad base of experimental data for the different types of masonry and building techniques that were developed according to the local conditions and the historical periods in each country. The need for a data base of reliable mechanical characteristics from real masonry works from all over our countries is, in our view, compelling.

- **The issues that are related to the actual mechanisms of the dynamic behavior that is damping and the gradual degradation of the rigidity of the stone structures are very little known to give reliable dynamic analyses.**

Some countries develop such a database

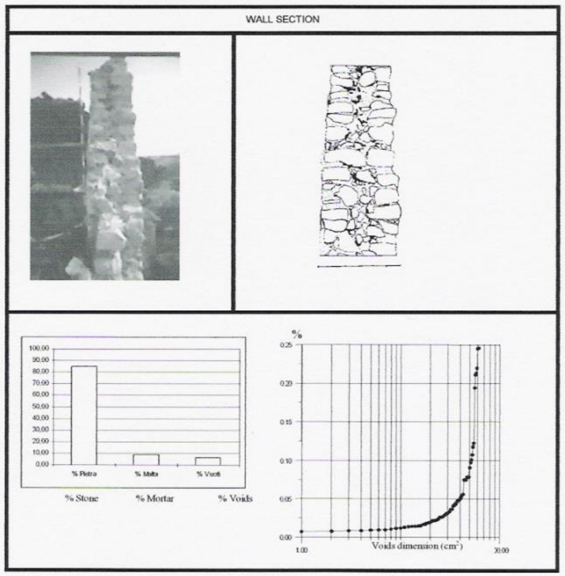


Fig. 7. Form representing the wall section and the void calculation [Binda. 1999].

is study allowed the verify of simplified structural models.

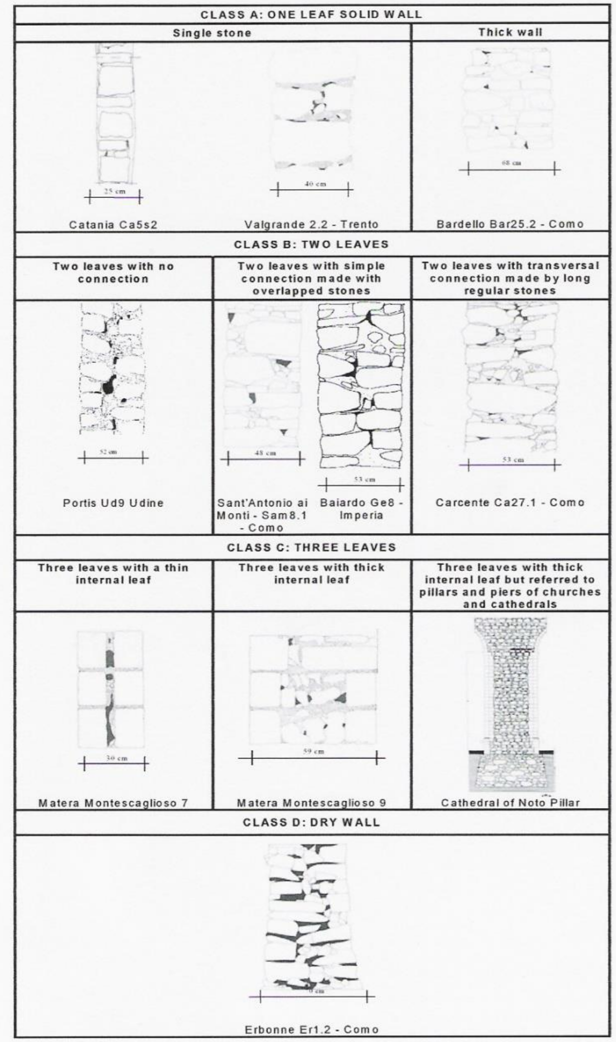


Fig. 16. Example of the stonework sections catalogue. [Binda, 2001].

APPENDIX 11.D – MASONRY TYPOLOGIES AND RELATIVE MECHNICAL PARAMETERS

Table 11.D.1: Reference values of the mechanical parameters (maxima and minima) and average specific weights for different types of masonry related to the following conditions: poor quality mortar, absence of courses (coursed masonry at regular intervals), wall leaves merely placed together or badly connected, unconsolidated masonry.

Masonry typology	f_m (N/cm^2)	τ_0 (N/cm^2)	E (N/mm^2)	G (N/mm^2)	W (kN/m^3)
	min-max	min-max	min-max	min-max	
Irregular stone masonry (pebbles, erratic and irregular stone)	60 90	2.0 3.2	690 1050	115 175	19
Uncut stone masonry with facing walls of limited thickness and infill core	110 155	3.5 5.1	1020 1440	170 240	20
Cut stone masonry with good bonding	150 200	5.6 7.4	1500 1980	250 330	21
Soft stone masonry (tuff, limestone, etc.)	80 120	2.8 4.2	900 1260	150 210	16
Dressed rectangular stone masonry	300 400	7.8 9.8	2340 2820	390 470	22
Full brick masonry with lime mortar	180 280	6.0 9.2	1800 2400	300 400	18
Masonry in half-filled brick blocks with cement mortar (e.g. double UNI)	380 500	24.0 32.0	2800 3600	560 720	15
Hollow brick masonry (percentage of perforations < 45%)	460 600	30.0 40.0	3400 4400	680 880	12
Hollow brick masonry with dry perpend joints (percentage of perforations < 45%)	300 400	10.0 13.0	2580 3300	430 550	11
Concrete block masonry (percentage of perforations between 45% and 65%)	150 200	9.5 12.5	2200 2800	440 560	12
Masonry in half-filled concrete blocks	300 440	18.0 24.0	2700 3500	540 700	14

f_m = average compressive strength of masonry
τ_0 = average shear strength of masonry
E = average value of the normal elastic modulus
G = average value of the shear modulus
w = average specific weight of the masonry

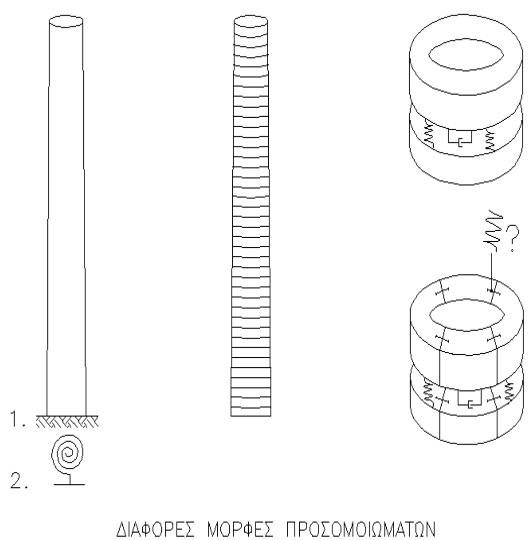
Table 11.D.2: Correction coefficients of the mechanical parameters (indicated in Table 11.D.1) to be applied in the presence of good or very good quality of mortar; presence of courses (or regular layering); systematic presence of transverse connections; Strengthening with injection mortars; Strengthening with reinforced plaster

Masonry typology	Good mortar	Courses or borders	Transverse connections	Mortar injections	Reinforced plaster
Irregular stone masonry (pebbles, erratic and irregular stone)	1.5	1.3	1.5	2.0	2.5
Uncut stone masonry with facing walls of limited thickness and infill core	1.4	1.2	1.5	1.7	2.0
Cut stone masonry with good bonding	1.3	1.1	1.3	1.5	1.5
Soft stone masonry (tuff, limestone, etc.)	1.5	-	1.5	1.7	2.0
Dressed rectangular stone masonry	1.2	-	1.2	1.2	1.2
Full brick masonry with lime mortar	1.5	-	1.3	1.5	1.5
Masonry in half-filled brick blocks with cement mortar (e.g. double UNI)	1.3	-	-	-	1.3
Hollow brick masonry (percentage of perforations < 45%)	1.3	-	-	-	1.3
Hollow brick masonry with dry perpend joints (percentage of perforations < 45%)	1.3	-	-	-	1.3
Concrete block masonry (percentage of perforations between 45% and 65%)	1.3	-	-	-	1.3
Masonry in half-filled concrete blocks	1.3	-	-	-	1.3

Some personal remarks from my experience

- It is very reasonable that the recently adopted Eurocode 8-3 dealing with the Assessment and retrofitting of existing buildings, states that the method of analysis must correspond to the data-knowledge level, the type and the importance of the structure. (Eurocode 8, part 3)
- An attempt for a detailed analytical simulation in the plastic region of monuments response, will meet the lack of reliable data on the mechanical properties of the fasteners and the damping characteristics of the structure.
- Entering the plastic region in historic stonemasonry is like being left to the hands of god. A method developed for steel structures is not so reasonable for a material where friction mechanisms and large scale particles friction can prevail.

Mathematical modeling needs reliable data



- Determining the real dynamic response of a historic structure is, at a certain point, a non realistic requirement within the frame of a professional occupation with these subjects.

- We often feel that we perform sophisticated calculations with wrong numbers

At the end of calculations engineering judgment will be waiting for you

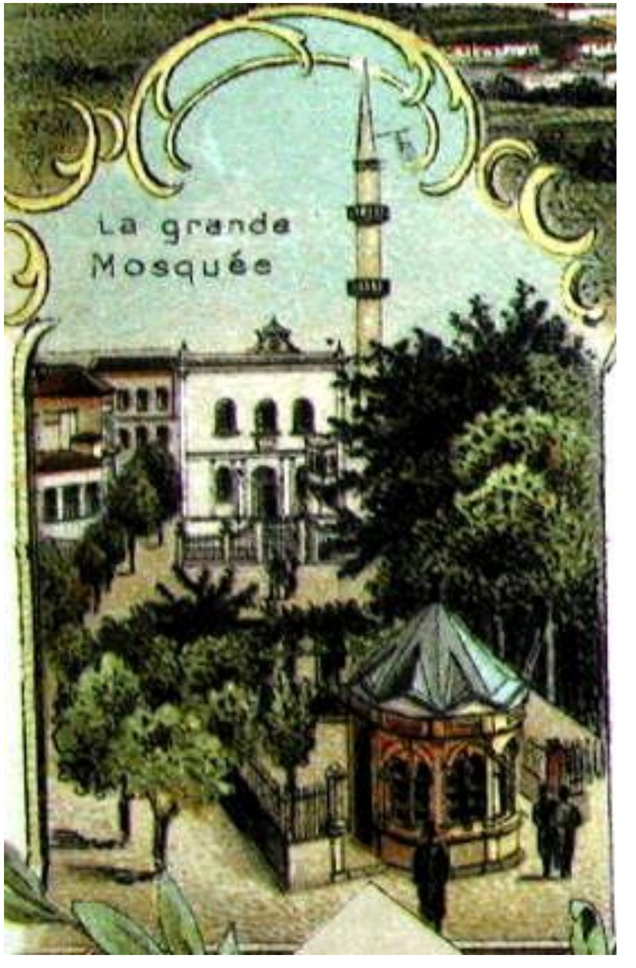
- Before getting in to the analysis part lets try to understand the monument and learn from the old masters. We must define what we will accept as failure of our interventions design. Collapse in tall structures is depending on dynamic characteristics .
- Analysis must begin with the question of what do you expect of it. Is the structure so complicated that you are not sure if there are considerable stress regions that you can not foresee. Or you know the structures behavior and you need numbers. What surprises could hide a simple cantilever whatever type of analysis you do?
- So the output of analysis must be read from both qualitative and quantitative point of view.
- For me it is obvious that behind any surviving historic structure there is a successful theory or simple rules of design.

Concluding

- So as we have to do with a very demanding environment with restricted options of intervention, **even the simple improvement of the response** of a monument, rather than the conformity with one of the levels of performance (whether or not reduced), should be considered as an accepted solution after **joint decision** of all the authorities involved.
- As it appears in the examples of the minarets that we present below, the proposed solutions and the approved interventions were based more on qualitative observations and the so-called rules of art than the results of the structural analysis calculations.

The Splandzia minaret af Chania

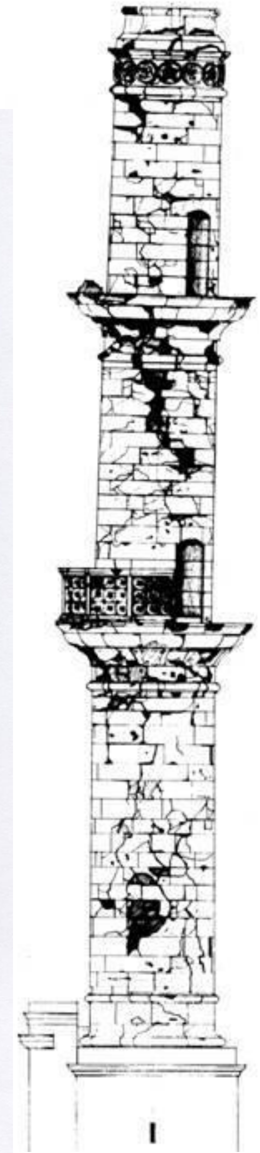
- Constructed during the beginning of the Ottoman rule in Crete, in 1645, the minaret was dangerously unstable during these last years. The top presented a 40 cm deviation from the perpendicular line and in some areas there was a great disarrangement of the stonework. The monument had been built as an imperial cylindrical minaret with two balconies, with big stones of good quality. Its 13-meter base is contiguous to the neighboring church. From that point above, begins the stone-made cylindrical part of the minaret, whose height is 21 m.



The Splandzia minaret before restoration works

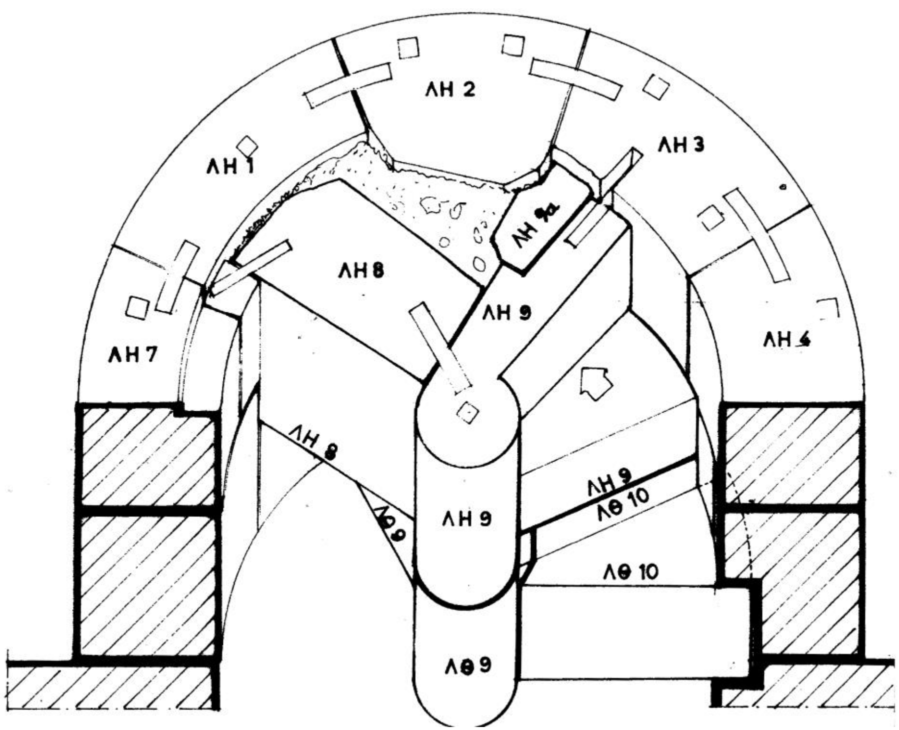
- Very severe damage and dangerous inclination but yet not collapse

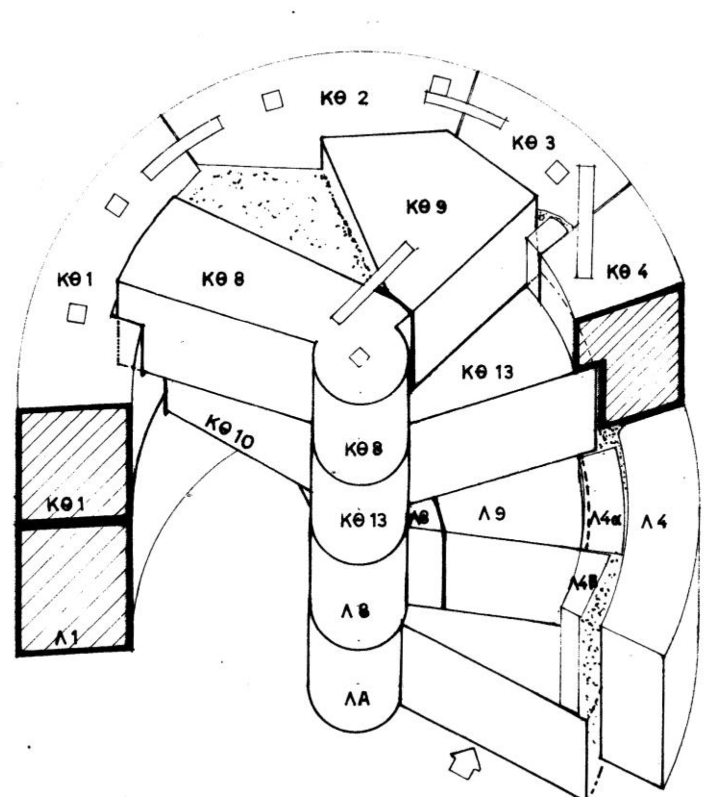
Εργασίες άμεσης άρσης της επικινδυνότητας
μετά τον κεραυνό της 17/3/98



The retaining and working scaffolding

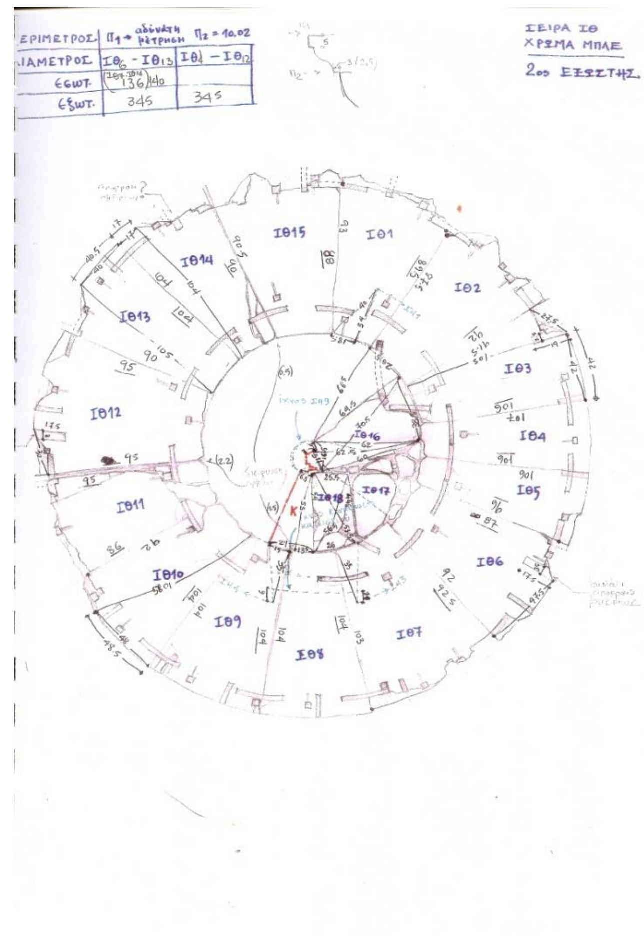
The construction of the staircase was at first approach incomprehensible. There was no geometric reason for such a complexity. Was it by existing rules of art conceived as an energy dissipating devise.?



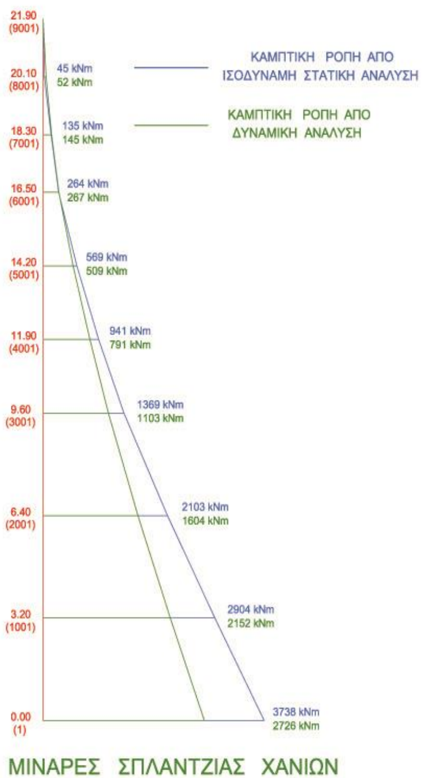


There has been a very detailed sketch of each layer and of each stone within it.

- The diameter of the cylinder's base was 2.50 meters; the width of the stones was 40 cm; the average arched length was 105 cm and the height of the layers was 30 cm. These large horizontal layers of stone were connected with horizontally lead-cast iron bifurcate hooks (*tzinetia*) which worked like rings, as well as with vertical wedges, which were also lead-cast layer by layer. The helical stairway, whose construction was complex in each step that occupied roughly the area of a quadrant, is also very interesting from a structural and a static point of view.



Analysis data and a very uncertain decision of intervention method



- The seismic analysis of the minaret as a monolithic cylindrical cantilever cannot prove its sufficiency or even its stability according to the current earthquake regulations.
- However, the minaret is in fact a non-monolithic structure, with numerous constitutive elements which are not strongly attached to each other and whose total rigidity is difficult to measure – however, it is certain that it’s low. Flexibility is essential for the monument’s resistance, since it implies a long natural period of the minaret and, hence, very low rates at the accelerations design spectrum.

Structural and decision concerns , a rather qualitative approach

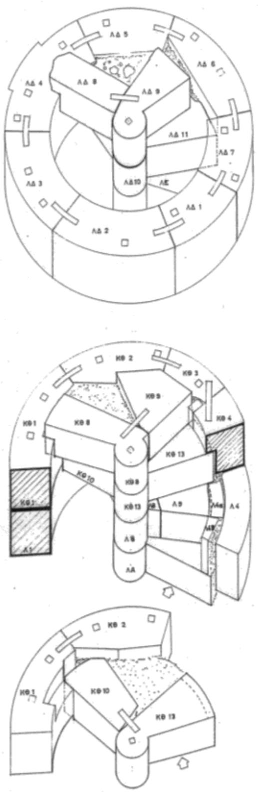
- The view that we finally adopted is the following: the minaret's capability to bear stressing which initially seems destructive is due precisely to its "laxity", that leads to decreased forces of inertia during the earthquake, but also to the possibility to consume the decreased seismic stressing through frictions and minor displacements that lead to the continuous adaptation of the static system to the forced oscillation, aiming at the maintenance of balance.
- During our initial reflections, we also examined the constriction of the minaret by an armor cage, which could be achieved by the actual perforation of the stones throughout their height.
- The application of methods that would tend to make the minaret inflexible or to "secure" its joints could have unwanted consequences for the monument.

When you are desperate you are looking for good news. At that time it came from a disaster.

- The opinion that we adopted was that we should proceed with a light static intervention on the monument, trying to restore his initial characteristics, reversing the degradations caused by time, and healing the weaknesses of the initial materials mainly as far as their durability is concerned.

The construction site was organized on the scaffolding and to its base.

We have respected the construction technology that was revealed to us. Filing with plumb all iron fastenings was essential for the protection and the ductillity of connections which allow energy dissipation through plastic deformations

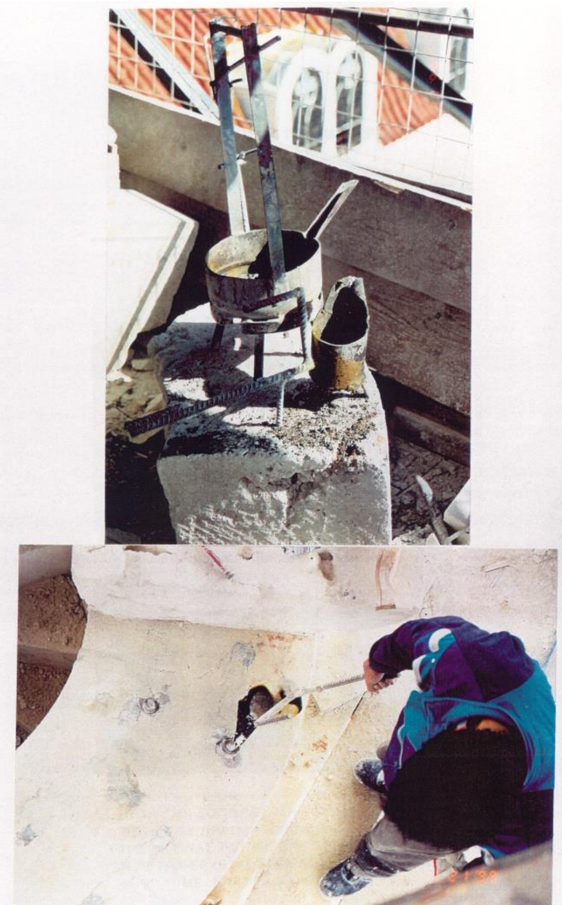


i. ΤΟ ΣΚΑΛΙ ΚΑΝΕΙ 'ΔΟΝΤΙ, ΚΑΙ ΠΑΤΑΕΙ ΠΑΝΩ ΣΕ ΔΟΜΟ ΤΟΥ ΜΙΝΑΡΕ. (π.χ. ΛΔ 8)

ii. Ο ΔΟΜΟΣ ΣΧΗΜΑΤΙΖΕΙ 'ΔΟΝΤΙ, ΓΙΑ ΝΑ ΠΑΤΗΣΕΙ ΟΛΟΚΛΗΡΟ ΤΟ ΣΚΑΛΙ ΕΠΑΝΩ Σ'ΑΥΤΟΝ. (π.χ. ΚΘ 8)

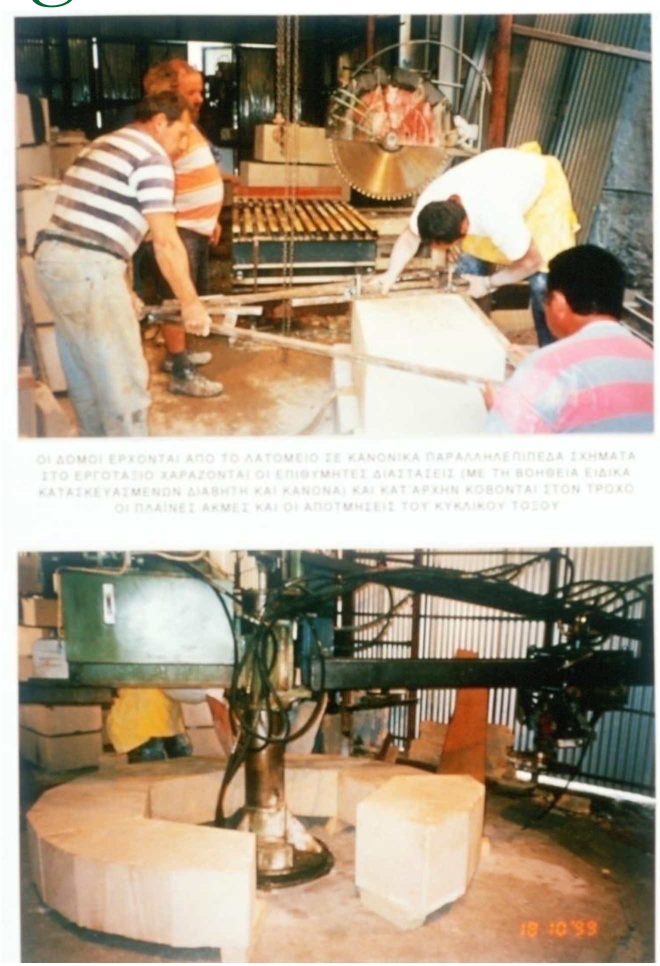
iii. Ο ΔΟΜΟΣ ΣΧΗΜΑΤΙΖΕΙ ΔΙΠΛΟ 'ΔΟΝΤΙ, ΓΙΑ ΝΑ ΔΕΧΤΕΙ ΔΥΟ ΣΚΑΛΙΑ. (π.χ. ΚΘ1 - ΚΘ 8, ΚΘ 10)
ΣΕ ΟΡΙΣΜΕΝΕΣ ΠΕΡΙΠΤΩΣΕΙΣ ΟΠΟΥ ΣΥΜΠΙΠΤΕΙ Η ΕΠΙΦΑΝΕΙΑ ΤΟΥ ΣΚΑΛΙΟΥ ΜΕ ΚΑΠΟΙΑ ΕΠΙΦΑΝΕΙΑ ΤΟΥ ΔΟΜΟΥ ΥΠΑΡΧΕΙ ΜΕΤΑΛΛΙΚΟΣ ΣΥΝΔΕΣΜΟΣ (π.χ. ΛΗ 8 - ΛΗ1)

iv. Ο ΔΟΜΟΣ ΣΧΗΜΑΤΙΖΕΙ ΑΝΑΠΟΔΟ 'ΔΟΝΤΙ, ΚΑΙ ΣΚΕΠΑΖΕΙ ΤΟ ΣΚΑΛΙ. (π.χ. ΚΘ4 - ΚΘ 13)



Μολυβδοχύηση συνδέσμων, οριζόντιων τζινετιών και κατακόρυφων γόμφων.

The stonecutting working shop was organized at the base of the scaffolding.

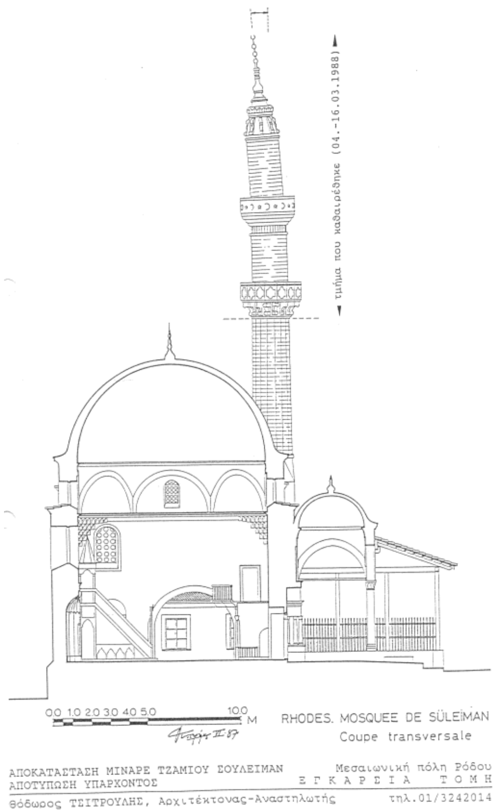


- It was essential that the stone was cut at millimeter precision and tested again for its fitting to its place.
- There have been some clever transformations to ordinary tools so that they adopt to curve cutting.

Splandzias Minaret after restoration works

The Suleiman minaret at Rhodes

Tsitroulis study

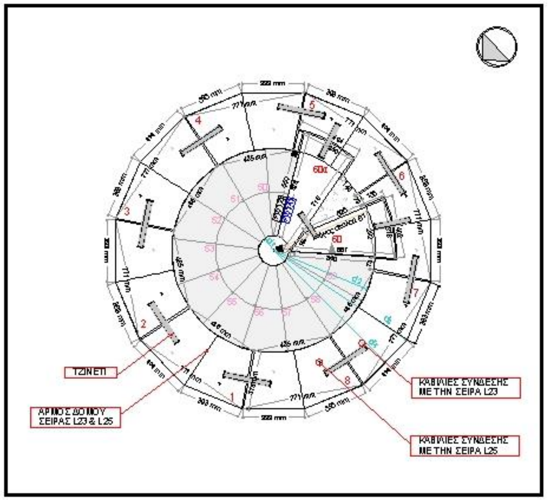


- The part of the minaret which is preserved until today was saved thanks to its reconstruction in 1890. After the earthquake of 1923, the Italians once more realized extensive restoration works on the minaret.
- During the last years, it was in an extremely tottery condition. Thus, in 1988, it was partly removed and only 9.60 m. of its trunk remained above the roof of the mosque.
- In the form that it was preserved until nowadays, the minaret had two balconies and a total height of 21.23 m. above the roof of the mosque in which it is found, without its aciculate ending.

Basic structural and historical remarks for the monument

- . The size of the stones is small in general –from 30 to 40 cm– and the height of the successive rings is approximately 20 cm. Horizontal metal joints (*tzinetia*) were found between every two layers, according to the documentation of a study made by Mr. Tsitroulis.
- The mechanical resistance of the stones is very small and presents great dissemination, according to the laboratorial tests of the Chronopoulos' study. In general, its way of construction could be characterized **"poor"** and the history of the monument shows that the minaret should be now considered badly designed (under dimensioned), since after every important earthquake, it presented serious damage.

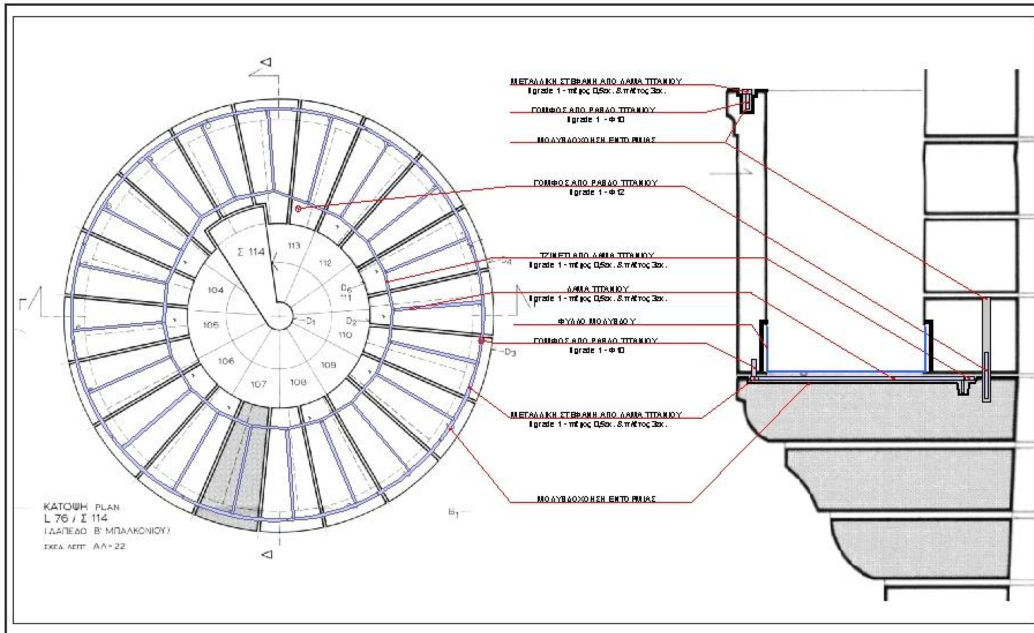
Our proposals were qualitative in nature and adapted to the experience of Chania.



ΑΝΑΚΑΤΑΣΚΕΥΗ ΜΙΝΑΡΕ				
ΣΕΙΡΑ L24 - ΣΚΑΛΟΠΑΤΙ Σ 60 (Σ 60α) - υψόμετρο σειράς +103,43				
ΤΜΗΜΑ Β - ΠΟΛΥΓΩΝΙΚΗΣ ΔΙΑΤΟΜΗΣ ΚΑΝΟΝΙΚΟΥ ΔΕΚΑΕΞΑΠΛΕΥΡΟΥ				
ΠΑΧΟΣ ΤΟΙΧΩΜΑΤΟΣ = 37,5 εκ.			ΠΛΑΤΟΣ ΣΚΑΛΑΣ = 55 εκ.	
ΑΡΙΘΜΟΣ ΔΟΜΩΝ = 8		ΥΨΟΣ ΣΤΡΩΣΗΣ = 18,5εκ.	ΟΡΙΖ. ΑΡΜΟΣ = 1εκ.	ΚΑΤΑΚ. ΑΡΜΟΣ = 1εκ.
ΚΛΙΜΑΚΑ 1 : 20				
ΣΧΕΔΙΑ ΑΝΑΦΟΡΑΣ :				
ΔΙΑΜΕΤΡΟΙ		ΤΖΙΝΕΤΙΑ : λάμα τιτανίου πάχους 5χλστ και πλάτους 30χλστ.		
d1	19 cm	1 - 2 30 εκ.	5 - 6 30 εκ.	5 - 60α 23 εκ.
d2	129 cm	2 - 3 30 εκ.	6 - 7 30 εκ.	6 - 60 23 εκ.
d3	204 cm	3 - 4 30 εκ.	7 - 8 30 εκ.	60 - 60α 17 εκ.
d4	198 cm	4 - 5 30 εκ.	8 - 1 30 εκ.	ΣΥΝΟΛΟ τεμάχια 11
		ΚΑΒΙΛΙΕΣ : ράβδοι τιτανίου Φ14 μήκους 15εκ. / διάτρημα Φ24		
Η σκάλας = 202 cm		L24 - L23 τεμάχια 9	L24 - L25 τεμάχια 9	

ΑΠΟΚΑΤΑΣΤΑΣΗ ΤΕΜΕΝΟΥΣ ΣΟΥΛΕΪΜΑΝ ΣΤΗ ΜΕΣΑΙΩΝΙΚΗ ΠΟΛΗ ΡΟΔΟΥ
ΜΕΛΕΤΗ ΕΦΑΡΜΟΓΗΣ - ΔΕΚΕΜΒΡΙΟΣ 2002

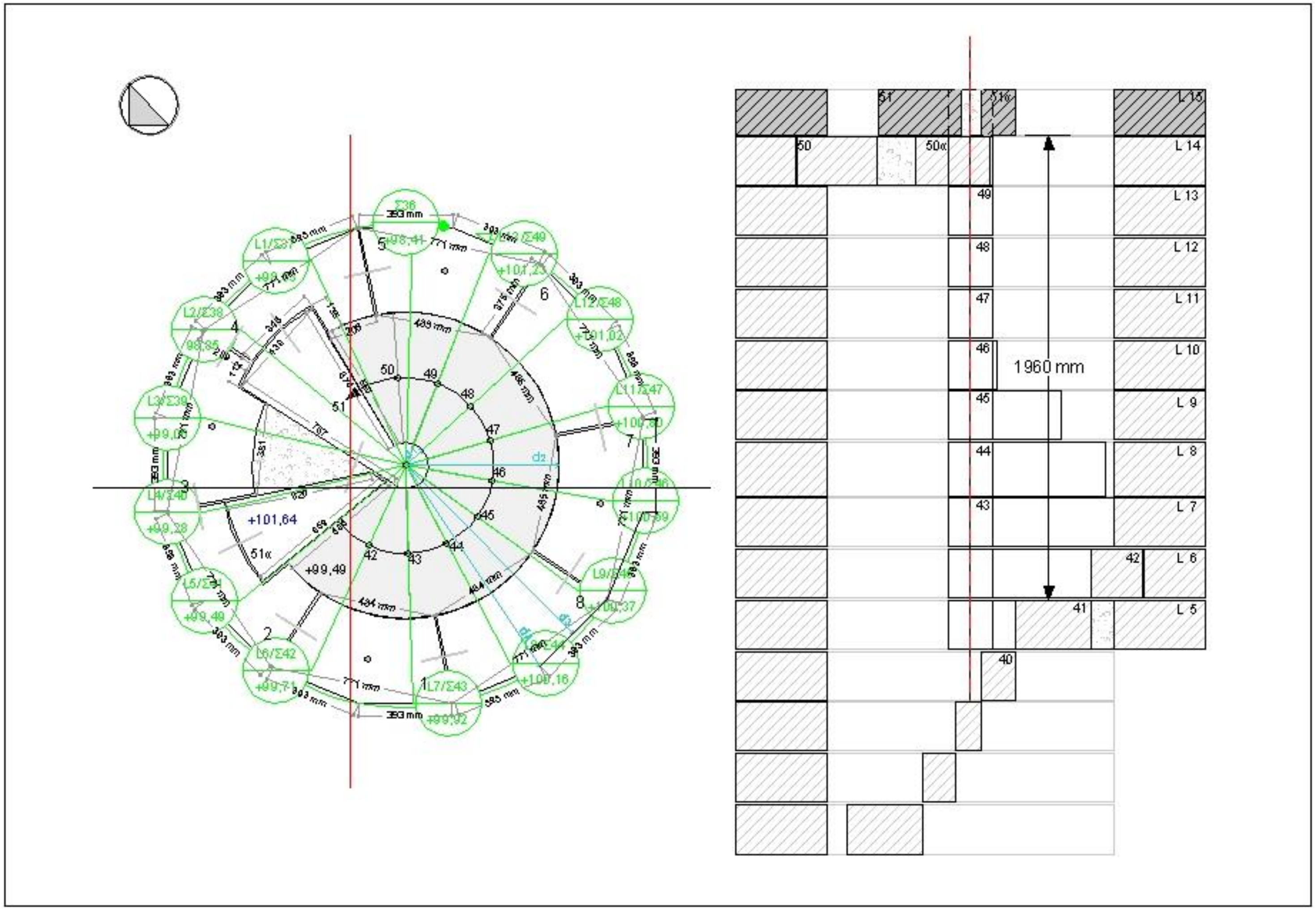
24



ΑΠΟΚΑΤΑΣΤΑΣΗ ΤΕΜΕΝΟΥΣ ΣΟΥΛΕΪΜΑΝ ΣΤΗΝ ΜΕΣΑΙΩΝΙΚΗ ΠΟΛΗ ΤΗΣ ΡΟΔΟΥ

ΣΤΑΤΙΚΗ ΜΕΛΕΤΗ - ΦΑΣΗ ΜΕΛΕΤΗΣ : ΜΕΛΕΤΗ ΕΦΑΡΜΟΓΗΣ ΔΙΑΤΑΞΗ ΕΝΙΣΧΥΤΙΚΟΥ ΟΠΛΙΣΜΟΥ ΕΞΩΣΤΩΝ ΜΙΝΑΡΕ

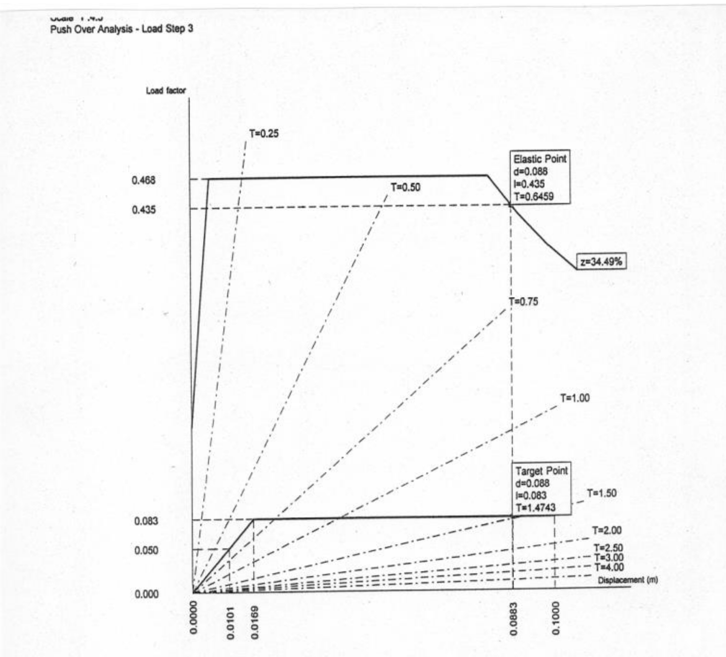
We gave geometric rules for the stonecutting of the complex staircase



Finally we designed by the rules of art, geometry and selective use of modern materials.

The Suleiman minaret after reconstruction

Structural investigations 2002

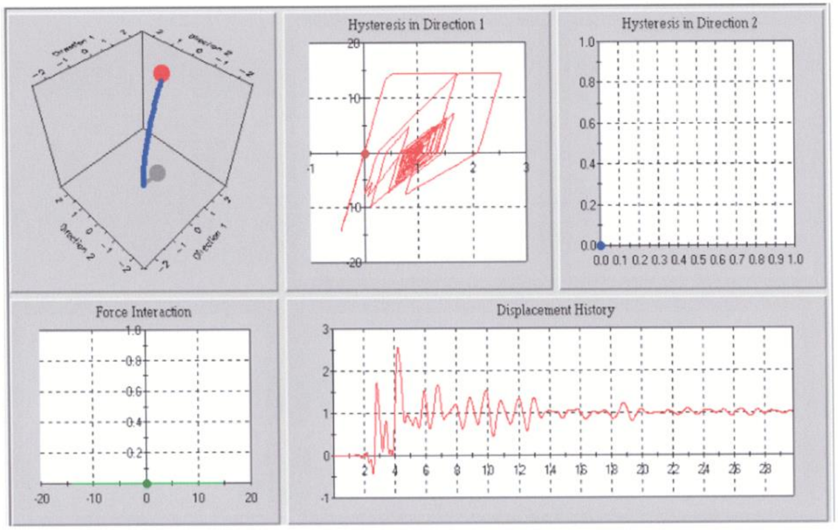


ΔΙΑΓΡΑΜΜΑ PUSH OVER

- Our static analysis was made using the push-over method. The minaret was initially considered tenacious on his cylindrical-conical base (which constitutes the critical cross-section) and it was simulated by 24 successive rings that correspond to its real geometry and masses.
- The picture of the minarets behavior to increasing lateral forces that resulted from the analysis is that we will have at first an elastic branch up to a force corresponding to 0,083G and then cracking will begin. At the target point of displacement we will have inert areas between the joints and non-flexible shortenings at an altitude of 3.0 m. approximately from the base of minaret.
- At this point, the secant natural period of the minaret would be 1.47 sec., while the elastic one would be 0.57, and the assumption of the seismic force would correspond to 9% of the weight.

Investigation of dynamic response

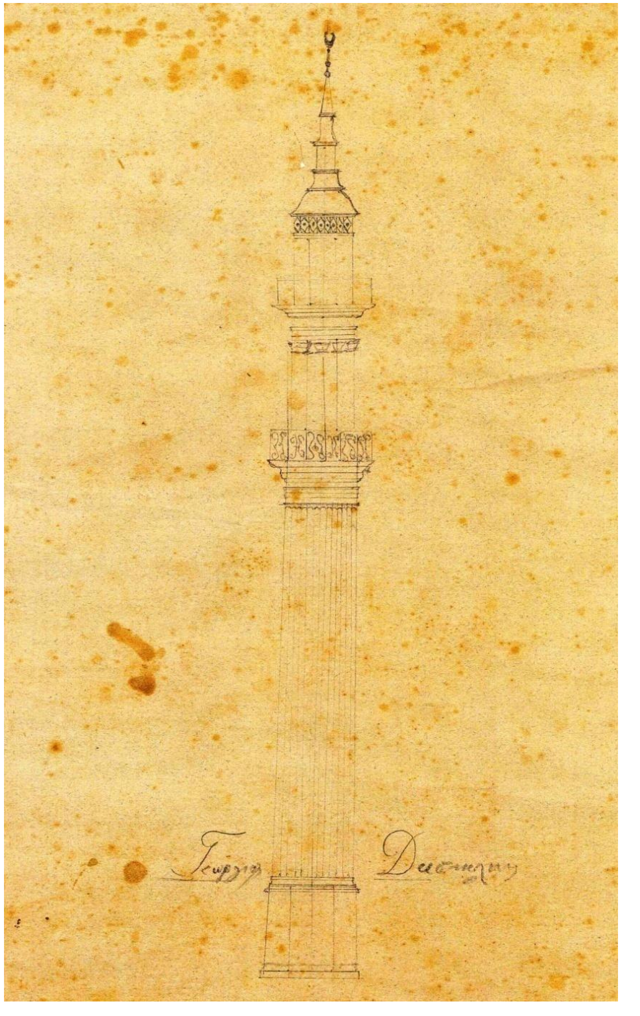
- After this charge, the minaret would start rocking, without necessarily collapsing. The collapse or not of the minaret depends on the total of the vibration's characteristics, and not only from its biggest value, as well as from the real and changeable characteristics of the damping capacity and rigidity of the minaret.
- However, due to the lack of relative experimental data, a further parametrical investigation of the problem is required.



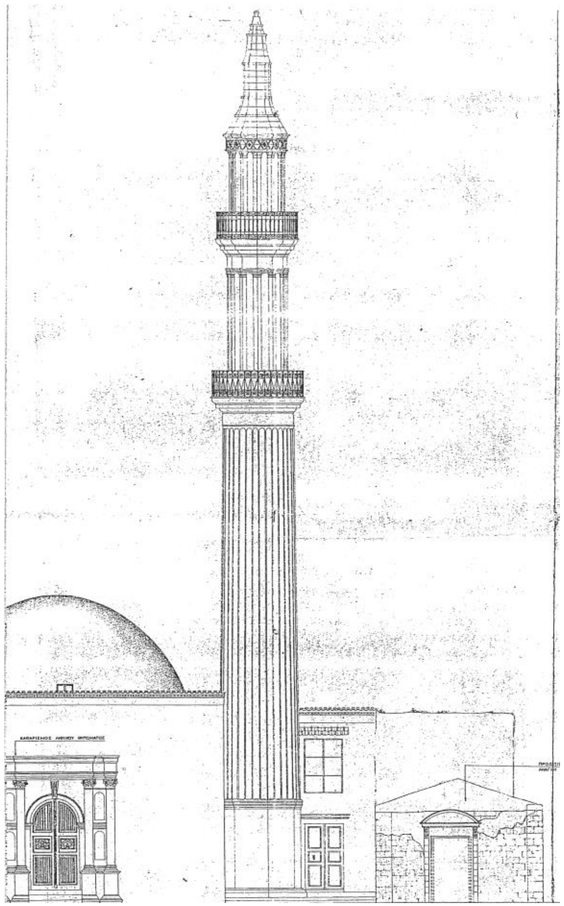
ΣΕΙΣΜΟΣ ΚΑΛΑΜΑΤΑΣ ΑΠΟΣΒΕΣΗ 10% ΜΕ ΥΠΟΒΑΘΜΙΣΗ ΑΚΑΜΨΙΑΣ

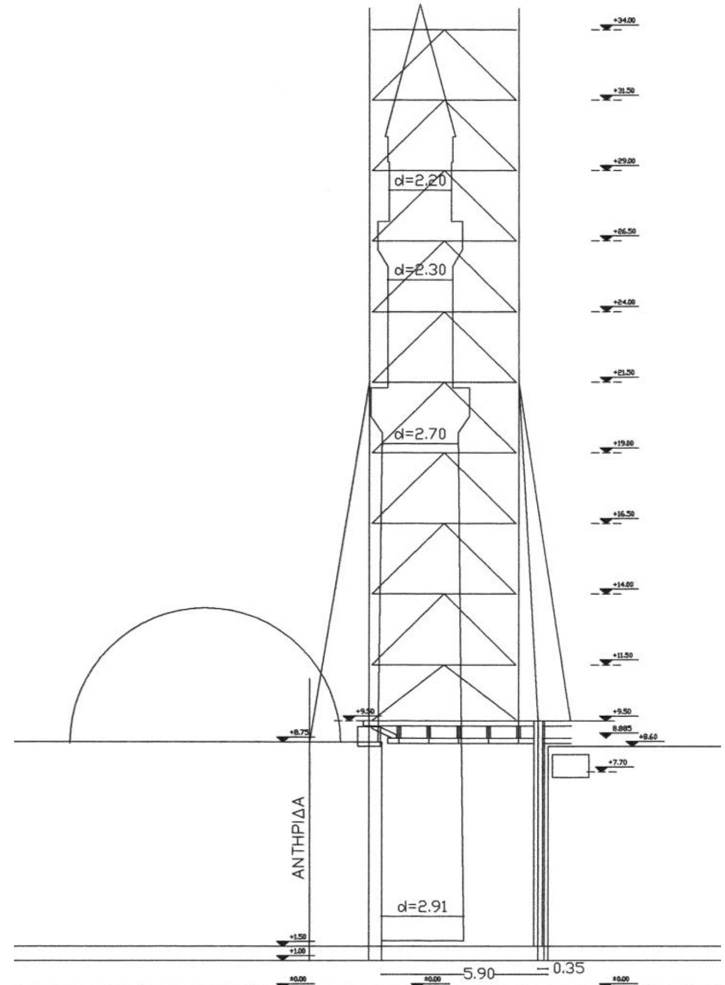
The Neratze minaret at Rethymnon

- The Neratze Mosque was built by the Christian craftsman George Daskalakis from Roussospiti and the Turkish artisan Ibrahim Alisakadaki.
- It is said that they were sent to Turkey in order to study the way minarets were built. Another story talks about the plan of the project that was sent to Crete from Turkey.
- In the draft that was saved from that time, we see the signature of the craftsman that advocates the opinion that he had actually participated in the minarets design.
- Let us note here that the same craftsman designed and built the tower of the Cathedral of Rethymno in the period 1892-1894.

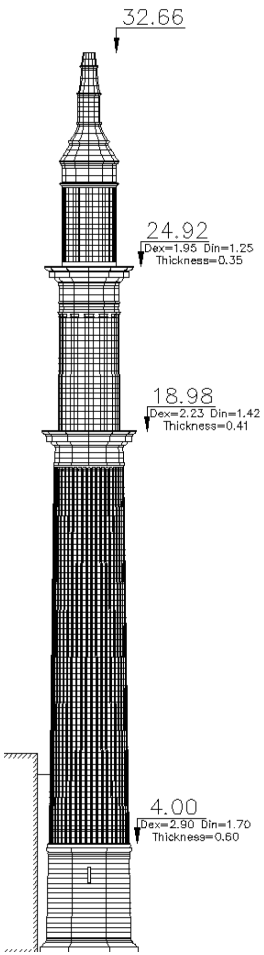


The urgent retaining scaffolding is also the working platform



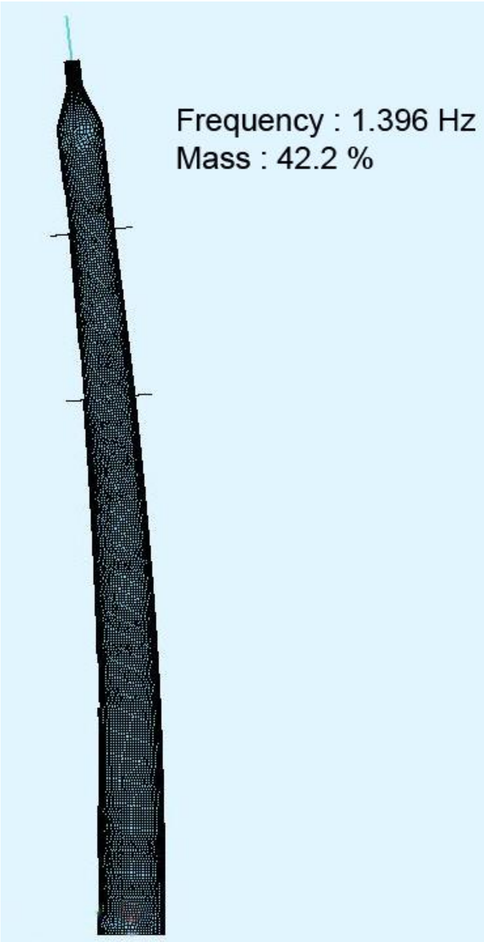


Basic geometry data



- The minaret, has two balconies and a total height of 32.66 m, without the barbed tip. The octagonal base has a height of 3.44 m. At this height, where the cylindrical-conical part begins, the external diameter is 2.9 m, the inner diameter is 1.69 m and the thickness of the “ring” is 0.605 m.
- The first balcony of the minaret is 14.96m high from the beginning of cylindrical-conical part. At this point the external diameter is 2.23 m, the internal diameter is 1.42 m and the thickness of the “ring” is 0.405 m.
- The second balcony is 5.95 m above the first one. At this point the external diameter is 1.95 m, the internal diameter is 1.25 m and the thickness of the “ring” is 0,35 m.

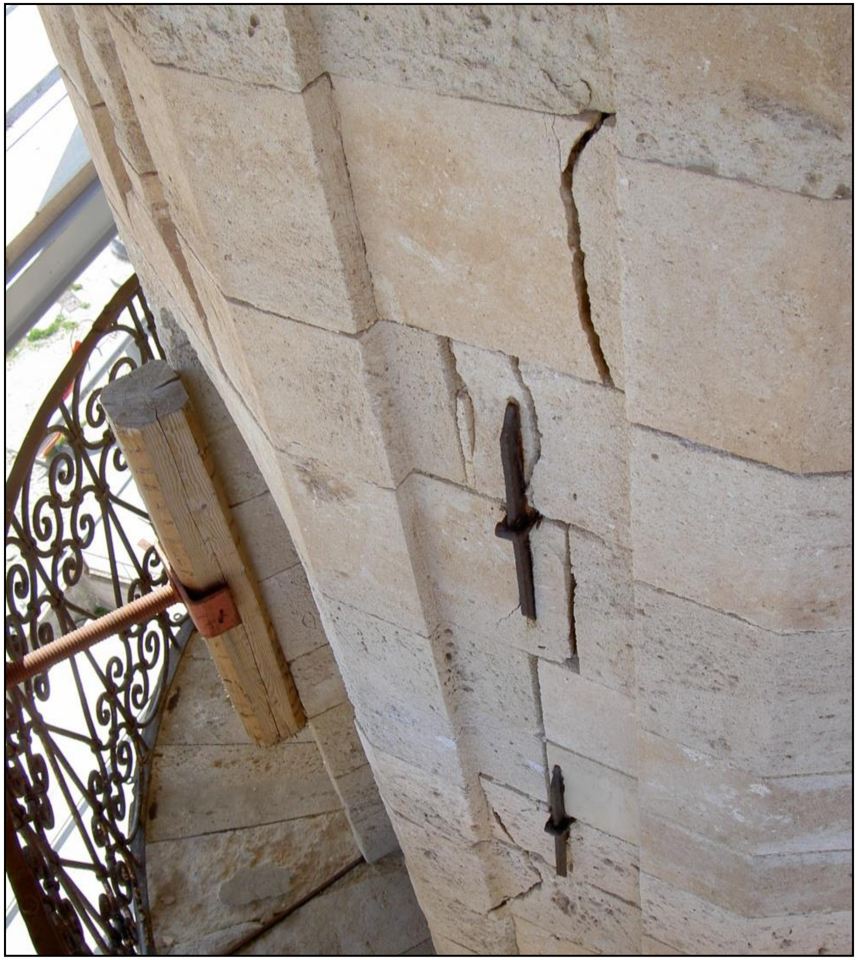
Structural analysis



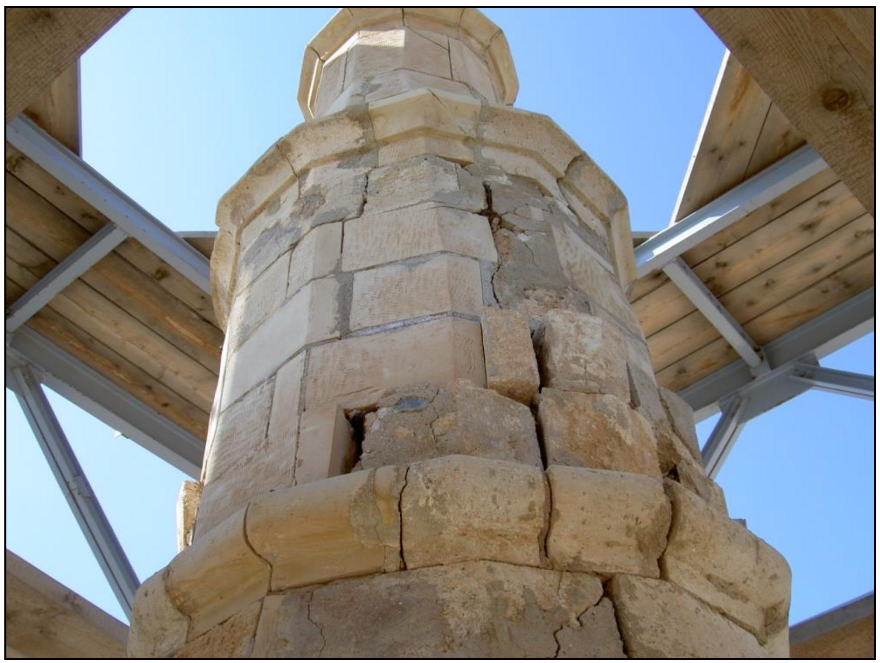
- For earthquake ε=0,40
- Maximum compressive stress -5.50 Mpa
- Maximum tensile stress +2.12 Mpa
- Measurements at the bottom level of the free section of the minaret, for a combination that includes seismic charge as well.
- Maximum displacement at the top 106,5 mm
- For the stonemasonry we consider maximum allowable Compressive stress fwc ≈ 3,5 MPa and
- Tensile stress fwt ≈ 0,35 MPa
- In order to have compressive stress below the allowable the earthquake should be ε = 3,5/5,5 x 0,40 ≈ 0,25.
- Accordingly the maximum tensile stress would be 0,25/0,40 x 2,12 = 1,33 MPa.
- In this case the maximum displacement at the top would be 0,25/0,40 x 106,5 ≈ 66,6 mm
- In order to have tensile stress below the maximum allowable we should experience an earthquake ε = 0,35/2,12 x 0,40 ≈ **0,07**

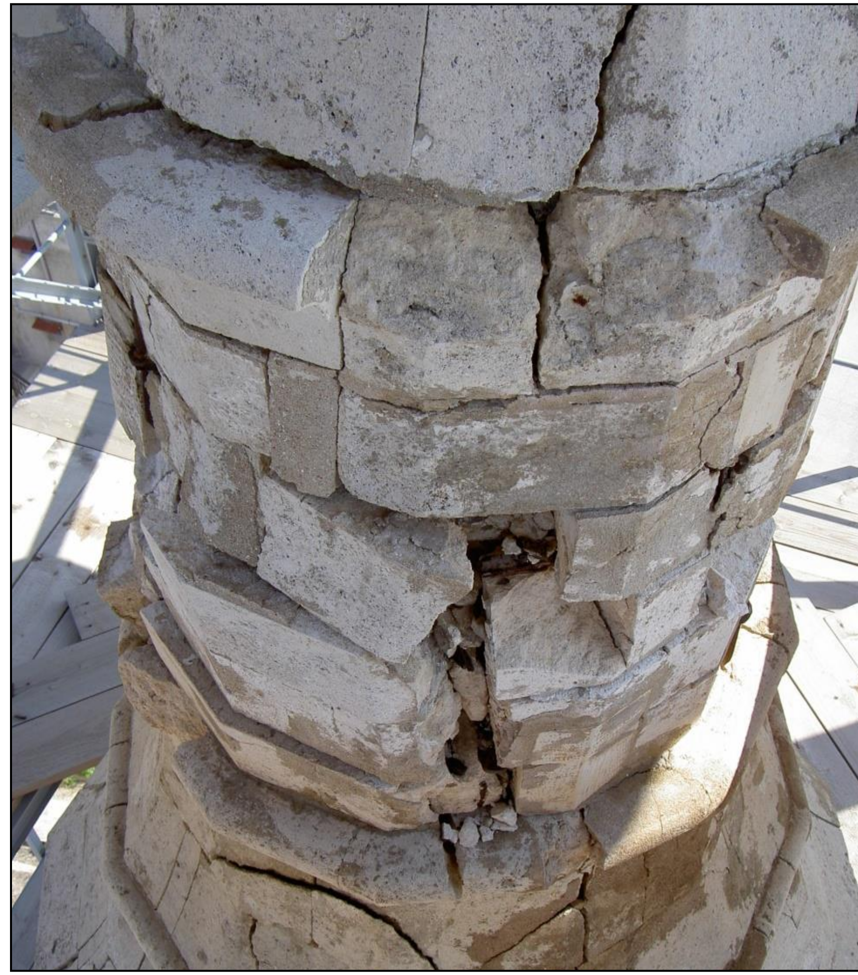
The scaffolding after construction was used for the study of the monument, and the urgent works of demolition of dangerous parts

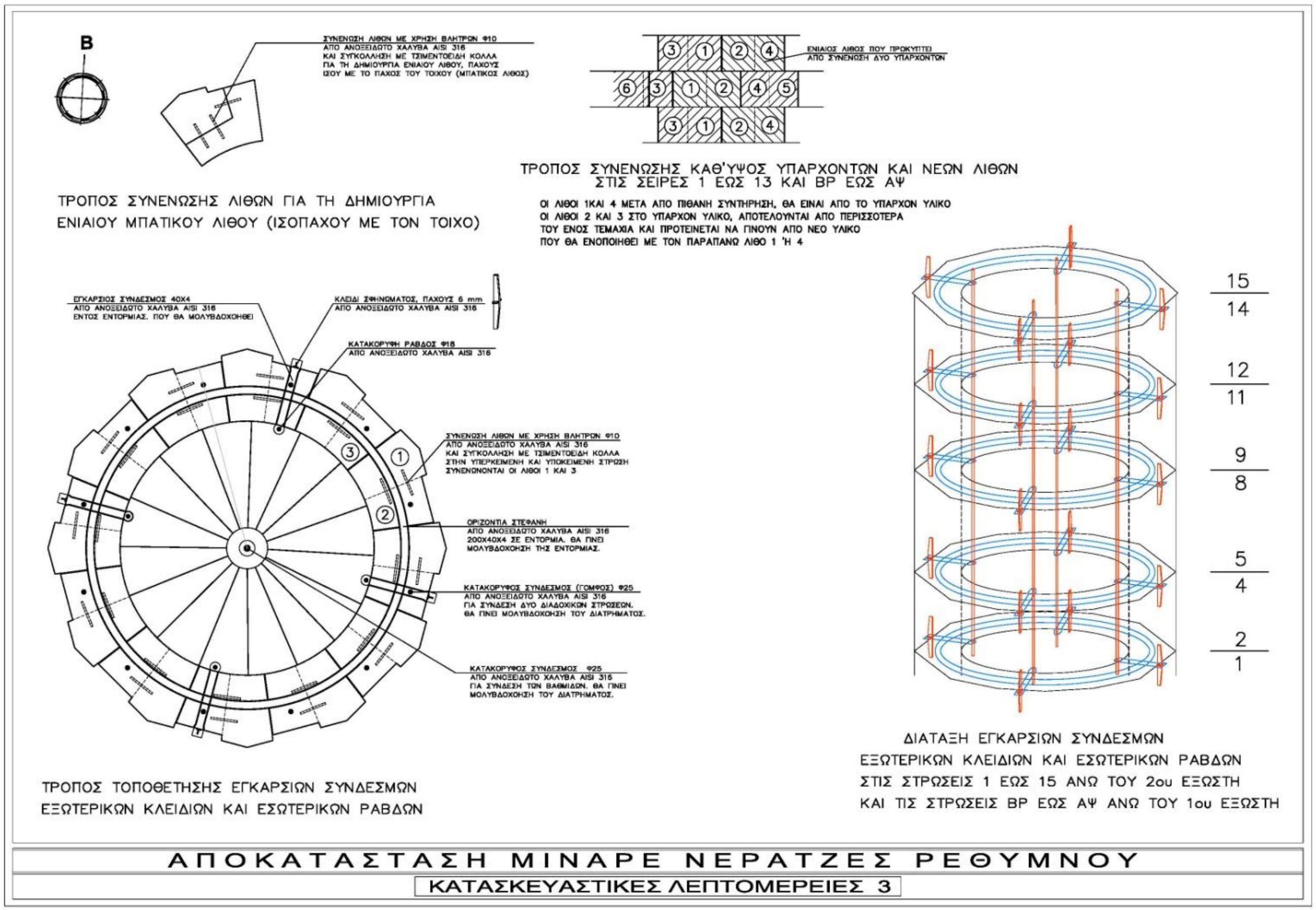
Staircase and iron reinforcement fastenings



Damage is limitated mainly in the upper parts after the first balcony






B
ΣΥΝΕΝΩΣΗ ΛΙΘΩΝ ΜΕ ΧΡΗΣΗ ΒΛΗΤΡΩΝ Φ10
ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
ΚΑΙ ΣΥΓΚΟΛΛΗΣΗ ΜΕ ΤΣΙΜΕΝΤΟΕΙΔΗ ΚΟΛΛΑ
ΓΙΑ ΤΗ ΔΗΜΙΟΥΡΓΙΑ ΕΝΙΑΙΟΥ ΛΙΘΟΥ, ΠΑΧΟΥΣ
ΙΣΟΥ ΜΕ ΤΟ ΠΑΧΟΣ ΤΟΥ ΤΟΙΧΟΥ (ΜΠΑΤΙΚΟΣ ΛΙΘΟΣ)
ΤΡΟΠΟΣ ΣΥΝΕΝΩΣΗΣ ΛΙΘΩΝ ΓΙΑ ΤΗ ΔΗΜΙΟΥΡΓΙΑ
ΕΝΙΑΙΟΥ ΜΠΑΤΙΚΟΥ ΛΙΘΟΥ (ΙΣΟΠΑΧΟΥ ΜΕ ΤΟΝ ΤΟΙΧΟ)
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6 3 1 2 4 5
3 1 2 4
ΕΝΙΑΙΟΣ ΛΙΘΟΣ ΠΟΥ ΠΡΟΚΥΠΤΕΙ
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ΤΡΟΠΟΣ ΣΥΝΕΝΩΣΗΣ ΚΑΘ'ΥΨΟΣ ΥΠΑΡΧΟΝΤΩΝ ΚΑΙ ΝΕΩΝ ΛΙΘΩΝ
ΣΤΙΣ ΣΕΙΡΕΣ 1 ΕΩΣ 13 ΚΑΙ ΒΡ ΕΩΣ ΑΨ
ΟΙ ΛΙΘΟΙ 1ΚΑΙ 4 ΜΕΤΑ ΑΠΟ ΠΙΘΑΝΗ ΣΥΝΤΗΡΗΣΗ, ΘΑ ΕΙΝΑΙ ΑΠΟ ΤΟ ΥΠΑΡΧΟΝ ΥΛΙΚΟ
ΟΙ ΛΙΘΟΙ 2 ΚΑΙ 3 ΣΤΟ ΥΠΑΡΧΟΝ ΥΛΙΚΟ, ΑΠΟΤΕΛΟΥΝΤΑΙ ΑΠΟ ΠΕΡΙΣΣΟΤΕΡΑ
ΤΟΥ ΕΝΟΣ ΤΕΜΑΧΙΑ ΚΑΙ ΠΡΟΤΕΙΝΕΤΑΙ ΝΑ ΓΙΝΟΥΝ ΑΠΟ ΝΕΟ ΥΛΙΚΟ
ΠΟΥ ΘΑ ΕΝΟΠΟΙΗΘΕΙ ΜΕ ΤΟΝ ΠΑΡΑΠΑΝΩ ΛΙΘΟ 1 'Η 4
ΕΓΚΑΡΣΙΟΣ ΣΥΝΔΕΣΜΟΣ 40Χ4
ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
ΕΝΤΟΣ ΕΝΤΟΡΜΙΑΣ. ΠΟΥ ΘΑ ΜΟΛΥΒΔΟΧΟΗΘΕΙ
ΚΛΕΙΔΙ ΣΦΗΝΩΜΑΤΟΣ, ΠΑΧΟΥΣ 6 mm
ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
ΚΑΤΑΚΟΡΥΦΗ ΡΑΒΔΟΣ Φ18
ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
ΣΥΝΕΝΩΣΗ ΛΙΘΩΝ ΜΕ ΧΡΗΣΗ ΒΛΗΤΡΩΝ Φ10
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ΣΤΗΝ ΥΠΕΡΚΕΙΜΕΝΗ ΚΑΙ ΥΠΟΚΕΙΜΕΝΗ ΣΤΡΩΣΗ
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ΟΡΙΖΟΝΤΙΑ ΣΤΕΦΑΝΗ
ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
200Χ40Χ4 ΣΕ ΕΝΤΟΡΜΙΑ. ΘΑ ΓΙΝΕΙ
ΜΟΛΥΒΔΟΧΟΗΣΗ ΤΗΣ ΕΝΤΟΡΜΙΑΣ.
ΚΑΤΑΚΟΡΥΦΟΣ ΣΥΝΔΕΣΜΟΣ (ΓΟΜΦΟΣ) Φ25
ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
ΓΙΑ ΣΥΝΔΕΣΗ ΔΥΟ ΔΙΑΔΟΧΙΚΩΝ ΣΤΡΩΣΕΩΝ.
ΘΑ ΓΙΝΕΙ ΜΟΛΥΒΔΟΧΟΗΣΗ ΤΟΥ ΔΙΑΤΡΗΜΑΤΟΣ.
ΚΑΤΑΚΟΡΥΦΟΣ ΣΥΝΔΕΣΜΟΣ Φ25
ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
ΓΙΑ ΣΥΝΔΕΣΗ ΤΩΝ ΒΑΘΜΙΔΩΝ. ΘΑ ΓΙΝΕΙ
ΜΟΛΥΒΔΟΧΟΗΣΗ ΤΟΥ ΔΙΑΤΡΗΜΑΤΟΣ.
ΤΡΟΠΟΣ ΤΟΠΟΘΕΤΗΣΗΣ ΕΓΚΑΡΣΙΩΝ ΣΥΝΔΕΣΜΩΝ
ΕΞΩΤΕΡΙΚΩΝ ΚΛΕΙΔΙΩΝ ΚΑΙ ΕΣΩΤΕΡΙΚΩΝ ΡΑΒΔΩΝ
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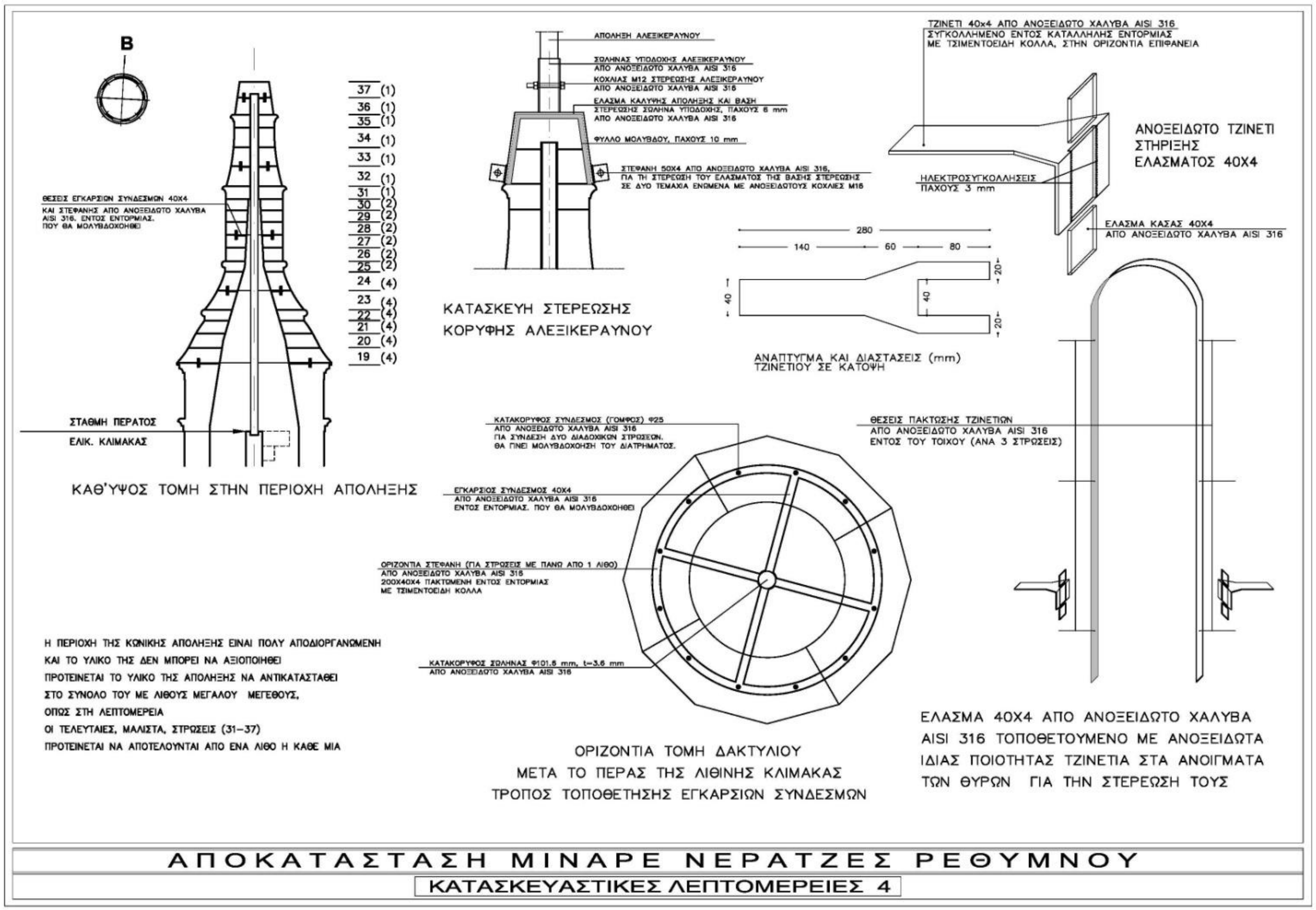
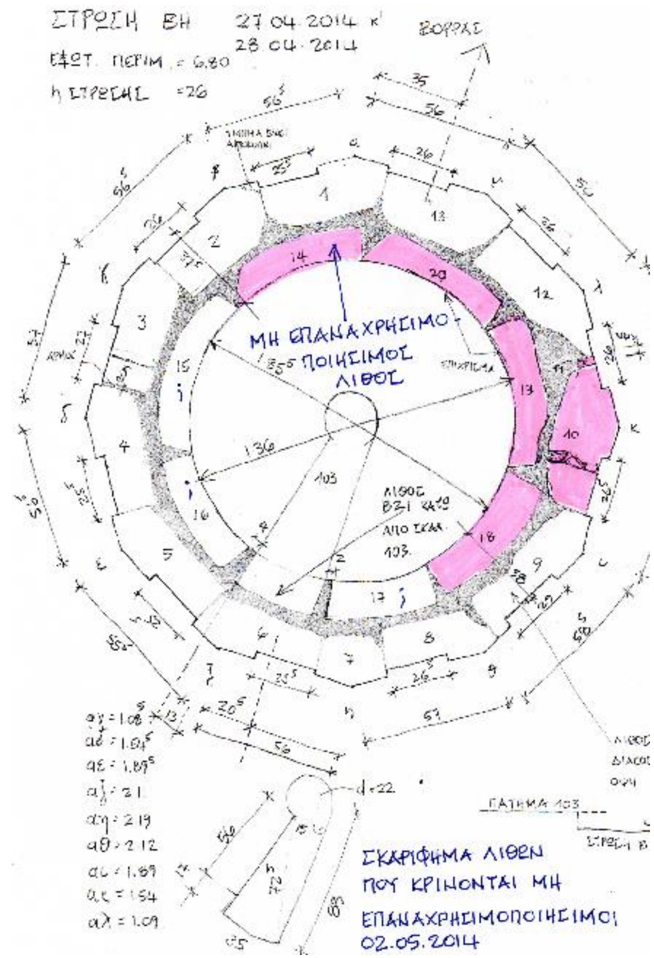
ΔΙΑΤΑΞΗ ΕΓΚΑΡΣΙΩΝ ΣΥΝΔΕΣΜΩΝ
ΕΞΩΤΕΡΙΚΩΝ ΚΛΕΙΔΙΩΝ ΚΑΙ ΕΣΩΤΕΡΙΚΩΝ ΡΑΒΔΩΝ
ΣΤΙΣ ΣΤΡΩΣΕΙΣ 1 ΕΩΣ 15 ΑΝΩ ΤΟΥ 2ου ΕΞΩΣΤΗ
ΚΑΙ ΤΙΣ ΣΤΡΩΣΕΙΣ ΒΡ ΕΩΣ ΑΨ ΑΝΩ ΤΟΥ 1ου ΕΞΩΣΤΗ
ΑΠΟΚΑΤΑΣΤΑΣΗ ΜΙΝΑΡΕ ΝΕΡΑΤΖΕΣ ΡΕΘΥΜΝΟΥ
ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΛΕΠΤΟΜΕΡΕΙΕΣ 3

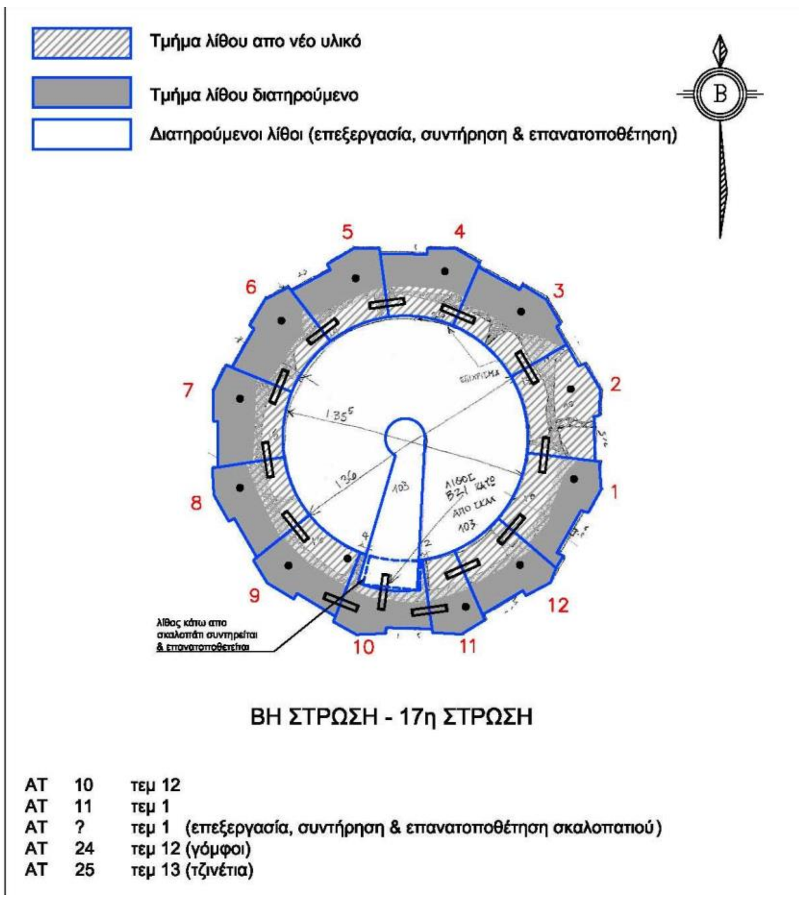

B
37 (1)
36 (1)
35 (1)
34 (1)
33 (1)
32 (1)
31 (1)
30 (2)
29 (2)
28 (2)
27 (2)
26 (2)
25 (2)
24 (4)
23 (4)
22 (4)
21 (4)
20 (4)
19 (4)
ΘΕΣΕΙΣ ΕΓΚΑΡΣΙΩΝ ΣΥΝΔΕΣΜΩΝ 40Χ4
ΚΑΙ ΣΤΕΦΑΝΗΣ ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ
AISI 316. ΕΝΤΟΣ ΕΝΤΟΡΜΙΑΣ.
ΠΟΥ ΘΑ ΜΟΛΥΒΔΟΧΟΗΘΕΙ
ΣΤΑΘΜΗ ΠΕΡΑΤΟΣ
ΕΛΙΚ. ΚΛΙΜΑΚΑΣ
ΚΑΘ'ΥΨΟΣ ΤΟΜΗ ΣΤΗΝ ΠΕΡΙΟΧΗ ΑΠΟΛΗΞΗΣ
ΑΠΟΛΗΞΗ ΑΛΕΞΙΚΕΡΑΥΝΟΥ
ΣΩΛΗΝΑΣ ΥΠΟΔΟΧΗΣ ΑΛΕΞΙΚΕΡΑΥΝΟΥ
ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
ΚΟΧΛΙΑΣ Μ12 ΣΤΕΡΕΩΣΗΣ ΑΛΕΞΙΚΕΡΑΥΝΟΥ
ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
ΕΛΑΣΜΑ ΚΑΛΥΨΗΣ ΑΠΟΛΗΞΗΣ ΚΑΙ ΒΑΣΗ
ΣΤΕΡΕΩΣΗΣ ΣΩΛΗΝΑ ΥΠΟΔΟΧΗΣ, ΠΑΧΟΥΣ 6 mm
ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
ΦΥΛΛΟ ΜΟΛΥΒΔΟΥ, ΠΑΧΟΥΣ 10 mm
ΣΤΕΦΑΝΗ 50Χ4 ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316,
ΓΙΑ ΤΗ ΣΤΕΡΕΩΣΗ ΤΟΥ ΕΛΑΣΜΑΤΟΣ ΤΗΣ ΒΑΣΗΣ ΣΤΕΡΕΩΣΗΣ
ΣΕ ΔΥΟ ΤΕΜΑΧΙΑ ΕΝΩΜΕΝΑ ΜΕ ΑΝΟΞΕΙΔΩΤΟΥΣ ΚΟΧΛΙΕΣ Μ16
ΚΑΤΑΣΚΕΥΗ ΣΤΕΡΕΩΣΗΣ
ΚΟΡΥΦΗΣ ΑΛΕΞΙΚΕΡΑΥΝΟΥ
ΤΖΙΝΕΤΙ 40x4 ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
ΣΥΓΚΟΛΛΗΜΕΝΟ ΕΝΤΟΣ ΚΑΤΑΛΛΗΛΗΣ ΕΝΤΟΡΜΙΑΣ
ΜΕ ΤΣΙΜΕΝΤΟΕΙΔΗ ΚΟΛΛΑ, ΣΤΗΝ ΟΡΙΖΟΝΤΙΑ ΕΠΙΦΑΝΕΙΑ
ΑΝΟΞΕΙΔΩΤΟ ΤΖΙΝΕΤΙ
ΣΤΗΡΙΞΗΣ
ΕΛΑΣΜΑΤΟΣ 40Χ4
ΗΛΕΚΤΡΟΣΥΓΚΟΛΛΗΣΕΙΣ
ΠΑΧΟΥΣ 3 mm
ΕΛΑΣΜΑ ΚΑΣΑΣ 40Χ4
ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
280
140
60
80
20
40
40
20
ΑΝΑΠΤΥΓΜΑ ΚΑΙ ΔΙΑΣΤΑΣΕΙΣ (mm)
ΤΖΙΝΕΤΙΟΥ ΣΕ ΚΑΤΟΨΗ
ΚΑΤΑΚΟΡΥΦΟΣ ΣΥΝΔΕΣΜΟΣ (ΓΟΜΦΟΣ) Φ25
ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
ΓΙΑ ΣΥΝΔΕΣΗ ΔΥΟ ΔΙΑΔΟΧΙΚΩΝ ΣΤΡΩΣΕΩΝ.
ΘΑ ΓΙΝΕΙ ΜΟΛΥΒΔΟΧΟΗΣΗ ΤΟΥ ΔΙΑΤΡΗΜΑΤΟΣ.
ΘΕΣΕΙΣ ΠΑΚΤΩΣΗΣ ΤΖΙΝΕΤΙΩΝ
ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
ΕΝΤΟΣ ΤΟΥ ΤΟΙΧΟΥ (ΑΝΑ 3 ΣΤΡΩΣΕΙΣ)
ΕΓΚΑΡΣΙΟΣ ΣΥΝΔΕΣΜΟΣ 40Χ4
ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
ΕΝΤΟΣ ΕΝΤΟΡΜΙΑΣ. ΠΟΥ ΘΑ ΜΟΛΥΒΔΟΧΟΗΘΕΙ
ΟΡΙΖΟΝΤΙΑ ΣΤΕΦΑΝΗ (ΓΙΑ ΣΤΡΩΣΕΙΣ ΜΕ ΠΑΝΩ ΑΠΟ 1 ΛΙΘΟ)
ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
200Χ40Χ4 ΠΑΚΤΩΜΕΝΗ ΕΝΤΟΣ ΕΝΤΟΡΜΙΑΣ
ΜΕ ΤΣΙΜΕΝΤΟΕΙΔΗ ΚΟΛΛΑ
Η ΠΕΡΙΟΧΗ ΤΗΣ ΚΩΝΙΚΗΣ ΑΠΟΛΗΞΗΣ ΕΙΝΑΙ ΠΟΛΥ ΑΠΟΔΙΟΡΓΑΝΩΜΕΝΗ
ΚΑΙ ΤΟ ΥΛΙΚΟ ΤΗΣ ΔΕΝ ΜΠΟΡΕΙ ΝΑ ΑΞΙΟΠΟΙΗΘΕΙ
ΠΡΟΤΕΙΝΕΤΑΙ ΤΟ ΥΛΙΚΟ ΤΗΣ ΑΠΟΛΗΞΗΣ ΝΑ ΑΝΤΙΚΑΤΑΣΤΑΘΕΙ
ΣΤΟ ΣΥΝΟΛΟ ΤΟΥ ΜΕ ΛΙΘΟΥΣ ΜΕΓΑΛΟΥ ΜΕΓΕΘΟΥΣ,
ΟΠΩΣ ΣΤΗ ΛΕΠΤΟΜΕΡΕΙΑ
ΟΙ ΤΕΛΕΥΤΑΙΕΣ, ΜΑΛΙΣΤΑ, ΣΤΡΩΣΕΙΣ (31–37)
ΠΡΟΤΕΙΝΕΤΑΙ ΝΑ ΑΠΟΤΕΛΟΥΝΤΑΙ ΑΠΟ ΕΝΑ ΛΙΘΟ Η ΚΑΘΕ ΜΙΑ
ΚΑΤΑΚΟΡΥΦΟΣ ΣΩΛΗΝΑΣ Φ101.6 mm, t=3.6 mm
ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ AISI 316
ΟΡΙΖΟΝΤΙΑ ΤΟΜΗ ΔΑΚΤΥΛΙΟΥ
ΜΕΤΑ ΤΟ ΠΕΡΑΣ ΤΗΣ ΛΙΘΙΝΗΣ ΚΛΙΜΑΚΑΣ
ΤΡΟΠΟΣ ΤΟΠΟΘΕΤΗΣΗΣ ΕΓΚΑΡΣΙΩΝ ΣΥΝΔΕΣΜΩΝ
ΕΛΑΣΜΑ 40Χ4 ΑΠΟ ΑΝΟΞΕΙΔΩΤΟ ΧΑΛΥΒΑ
AISI 316 ΤΟΠΟΘΕΤΟΥΜΕΝΟ ΜΕ ΑΝΟΞΕΙΔΩΤΑ
ΙΔΙΑΣ ΠΟΙΟΤΗΤΑΣ ΤΖΙΝΕΤΙΑ ΣΤΑ ΑΝΟΙΓΜΑΤΑ
ΤΩΝ ΘΥΡΩΝ ΓΙΑ ΤΗΝ ΣΤΕΡΕΩΣΗ ΤΟΥΣ
ΑΠΟΚΑΤΑΣΤΑΣΗ ΜΙΝΑΡΕ ΝΕΡΑΤΖΕΣ ΡΕΘΥΜΝΟΥ
ΚΑΤΑΣΚΕΥΑΣΤΙΚΕΣ ΛΕΠΤΟΜΕΡΕΙΕΣ 4

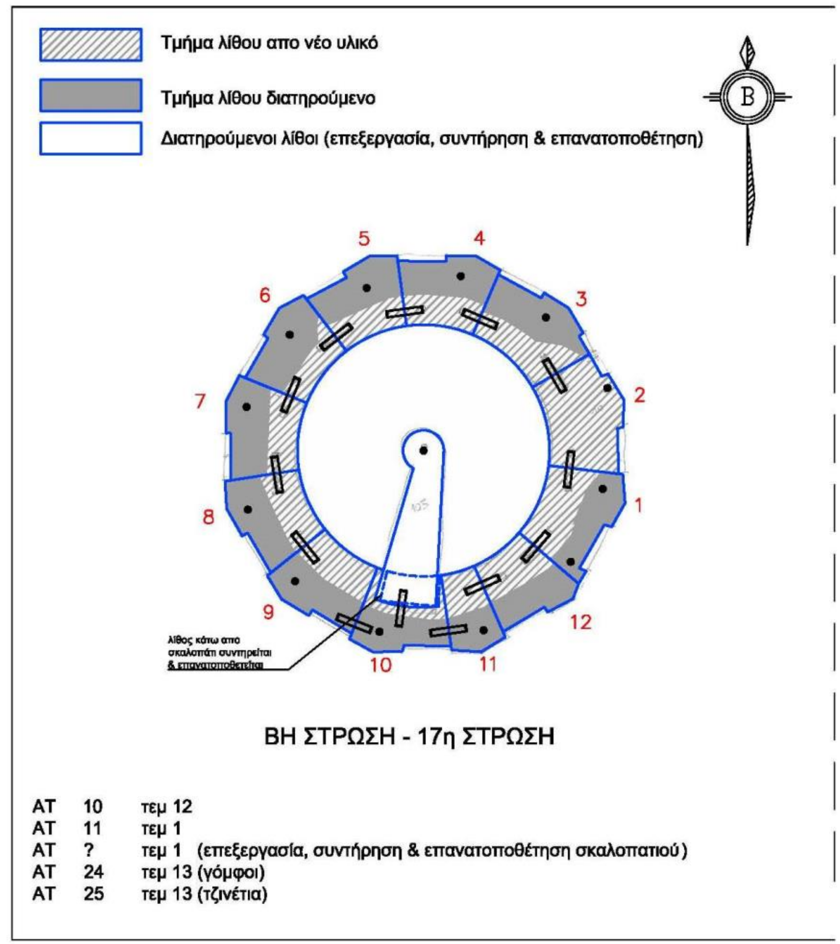
Reconstruction with composite stones and traditional techniques

Layer after demolition and in situ sketch



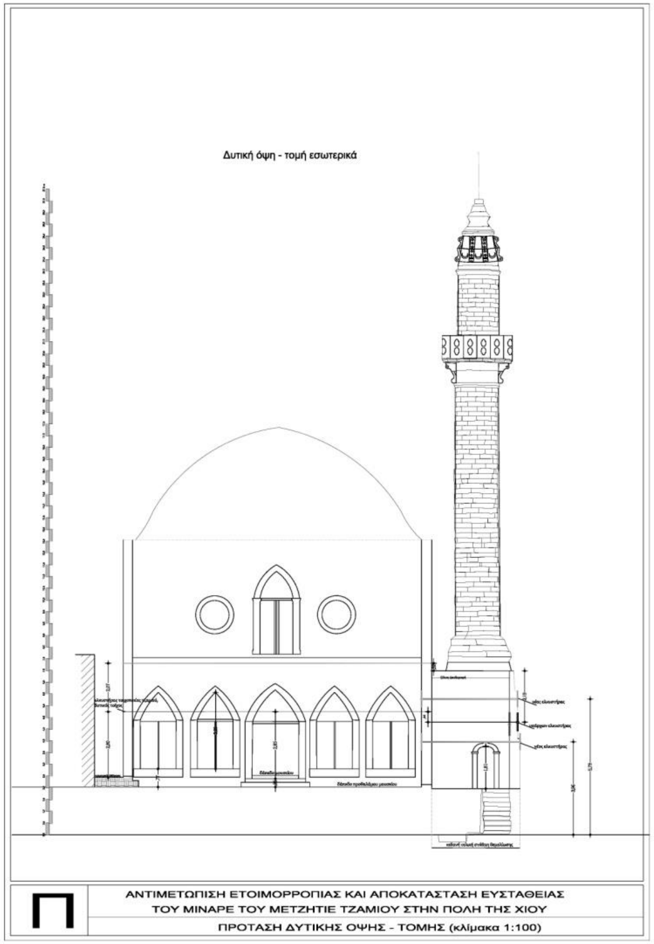
Proposal as built



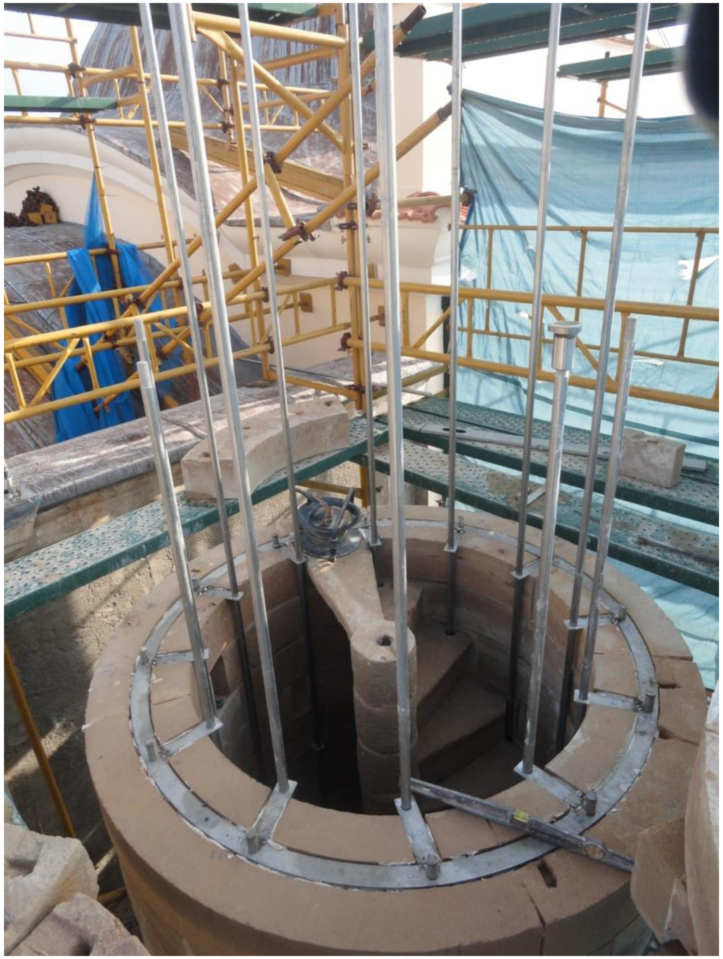


Layer and minaret after completion

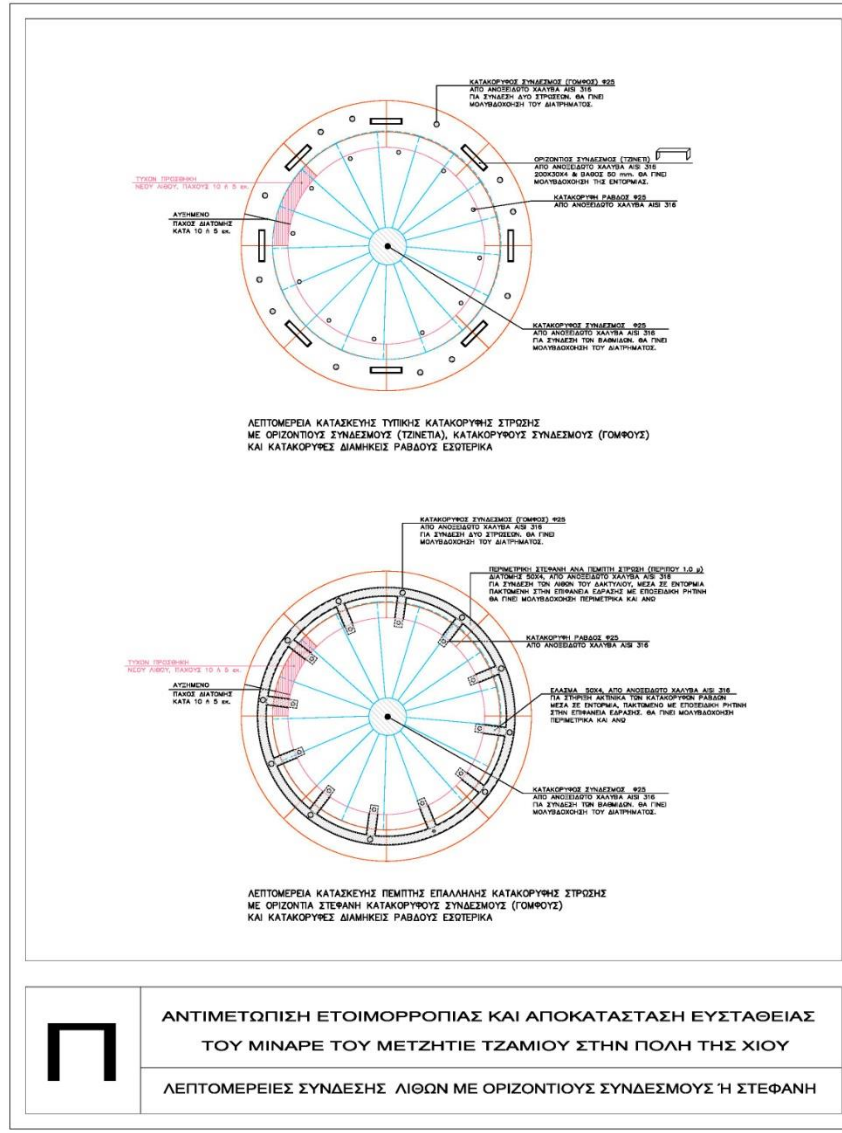
The Chios Minaret



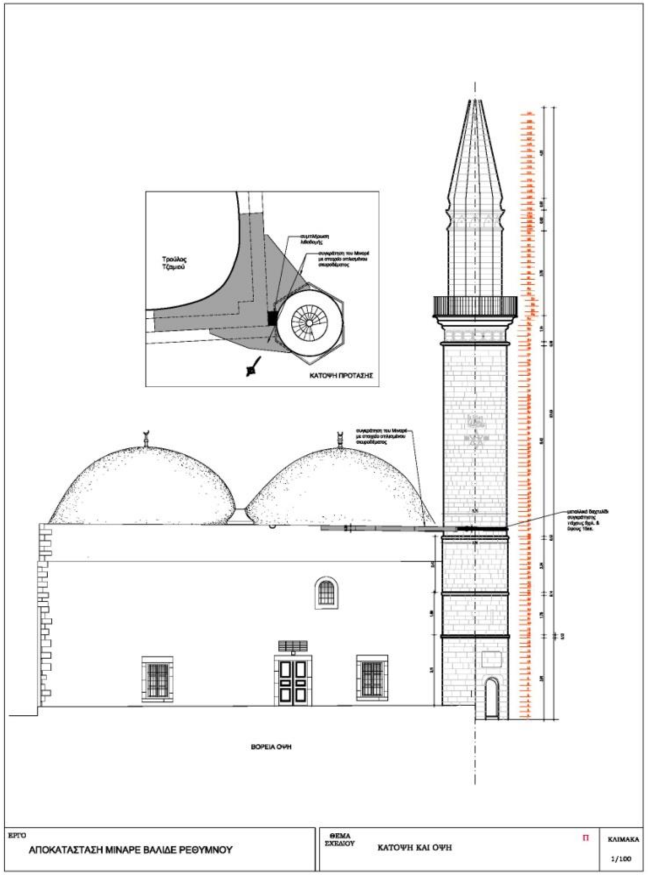
It was under dimensioned, it has fallen twice and we decided to strengthen it



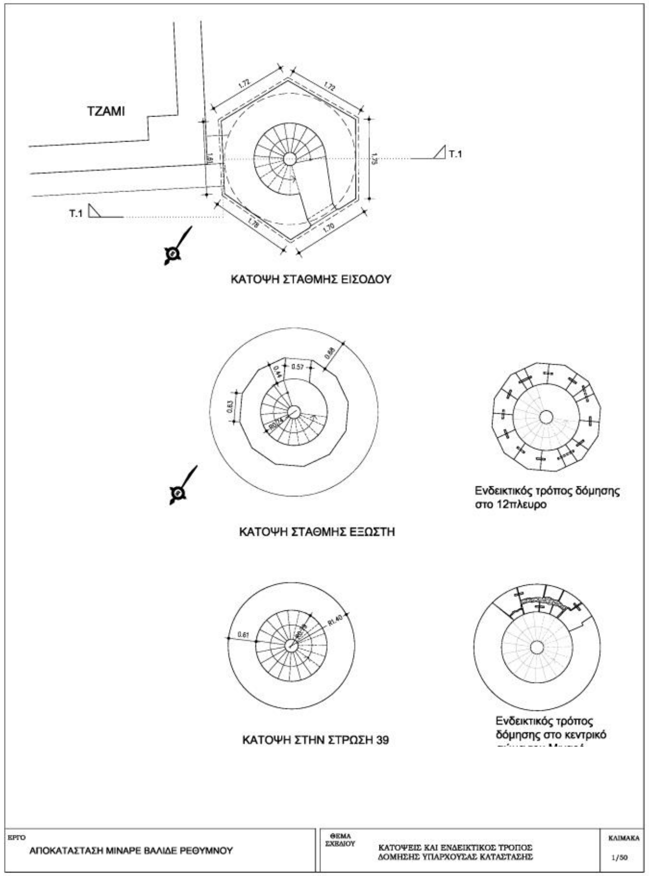
Thicker stones at the base and “loose” steel bars to help keep geometrical integrity in a strong motion



The Valide minaret , urgent protection measures

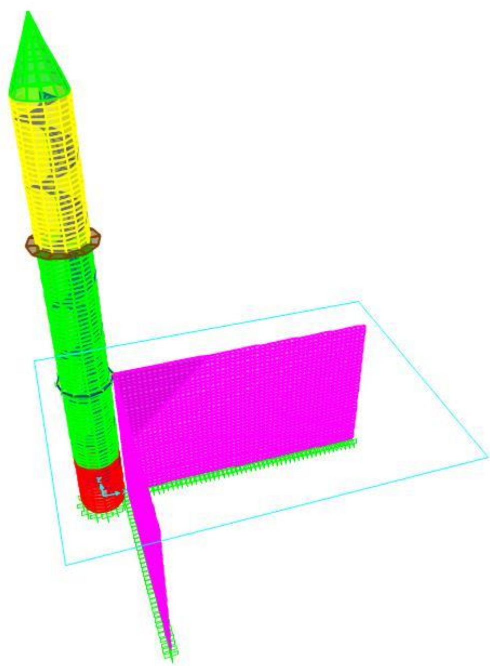


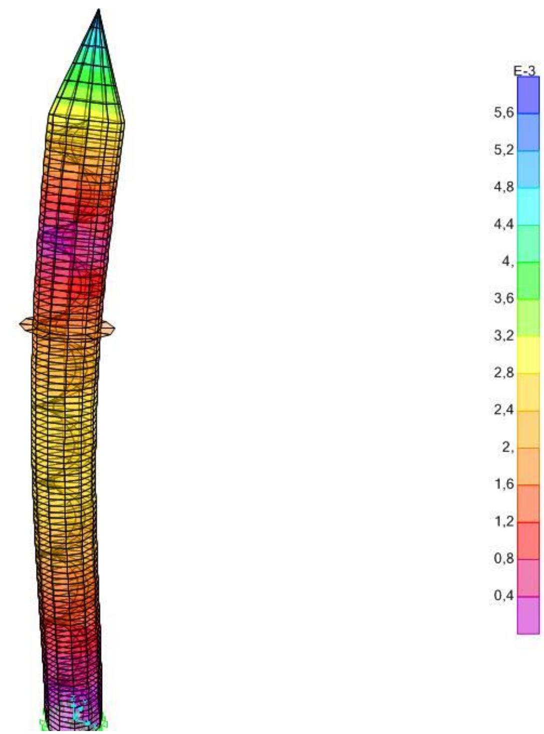
Τρούλος Τζαμιού
ΚΑΤΟΨΗ ΠΡΟΤΑΣΗΣ
ΒΟΡΕΙΑ ΟΨΗ
ΕΡΓΟ
ΑΠΟΚΑΤΑΣΤΑΣΗ ΜΙΝΑΡΕ ΒΑΛΙΔΕ ΡΕΘΥΜΝΟΥ
ΘΕΜΑ ΣΧΕΔΙΟΥ
ΚΑΤΟΨΗ ΚΑΙ ΟΨΗ
Π
ΚΛΙΜΑΚΑ
1/100



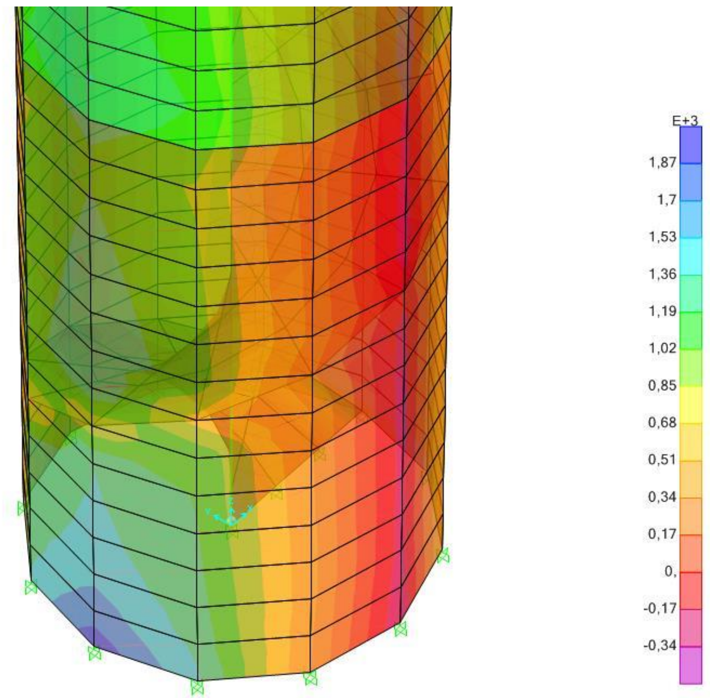
ΤΖΑΜΙ
T.1
ΚΑΤΟΨΗ ΣΤΑΘΜΗΣ ΕΙΣΟΔΟΥ
ΚΑΤΟΨΗ ΣΤΑΘΜΗΣ ΕΞΩΣΤΗ
Ενδεικτικός τρόπος δόμησης στο 12πλευρο
ΚΑΤΟΨΗ ΣΤΗΝ ΣΤΡΩΣΗ 39
Ενδεικτικός τρόπος δόμησης στο κεντρικό
ΕΡΓΟ
ΑΠΟΚΑΤΑΣΤΑΣΗ ΜΙΝΑΡΕ ΒΑΛΙΔΕ ΡΕΘΥΜΝΟΥ
ΘΕΜΑ ΣΧΕΔΙΟΥ
ΚΑΤΟΨΕΙΣ ΚΑΙ ΕΝΔΕΙΚΤΙΚΟΣ ΤΡΟΠΟΣ ΔΟΜΗΣΗΣ ΥΠΑΡΧΟΥΣΑΣ ΚΑΤΑΣΤΑΣΗΣ
ΚΛΙΜΑΚΑ
1/50

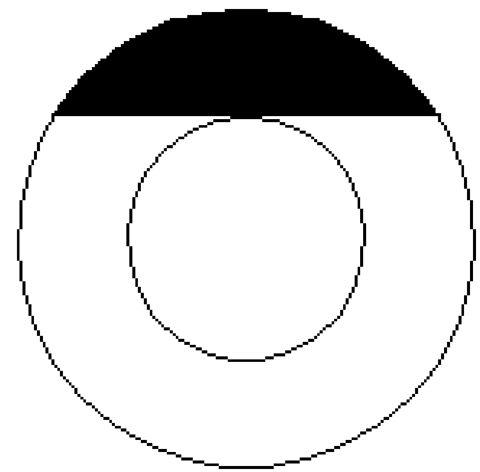
Structural analysis
Modeling as elastic system using FE



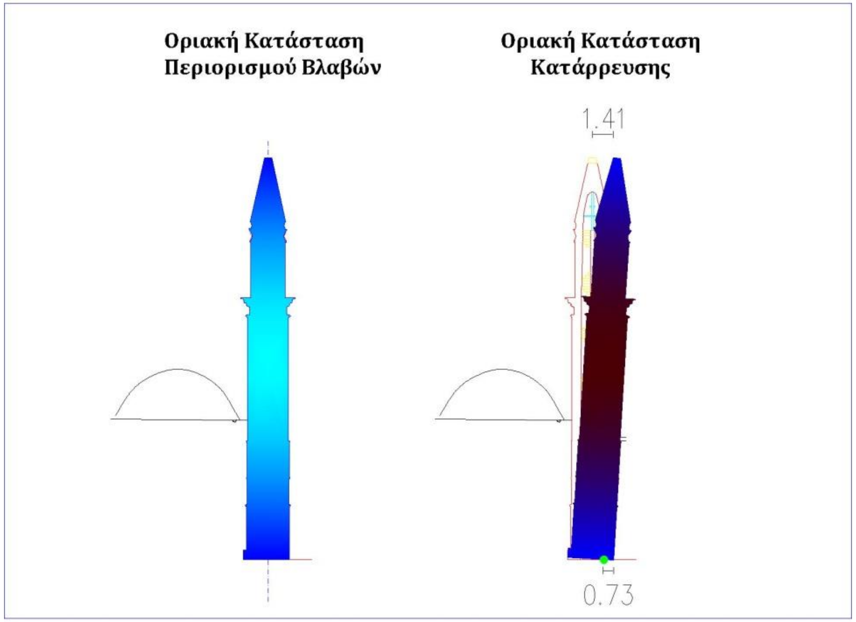


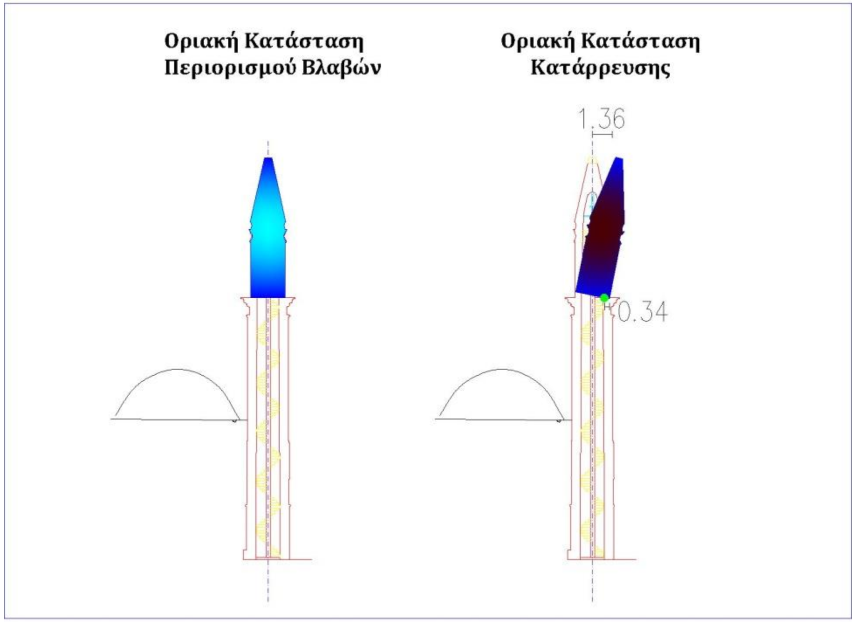
Moment is double from the strength capacity





The minaret seems to be safe on the two examined overturning mechanisms as a rigid body (kinematic analysis)





Acknowledgments

- This report has been written by a team of professional engineers and is largely based on the knowledge that has been obtained in the field of practice. This is not an academic text nor is based solely on theoretical facts. The projects that are presented here have been implemented within the last twenty years and this report refers to problems that have actually arisen during our work and solutions that have been applied in the frame of the practice of our profession.
- The main persons of my office are Eng Panagiotis Moshouris Eng Zervou Kyriaki and Architects Alki Nistikouli and Chrysoula Gagani. If we consider also all the engineers involved for the approval and the supervision of these projects from the ministry of Culture we can understand that it is really a team work

Some wishes for the end

- our common cultural heritage deserves our respect.
- engineers have a major role on that.
- Lets study the monuments.
- Lets learn from the old masters
- Make history of construction one essential part of engineers education.

- Thank you