OASP Organismos Antiseismikou Sxediasmou & Prostasias (Earthquake Planning & Protection Organization - EPPO)

EUR-OPA MAJOR HAZARDS AGREEMENT
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ECILS/ECPFE Workshop

"Seismic Assessment and Retrofitting of Masonry and Preserved Structures"

Skopje 2024

PROCEEDINGS

ECILS/ECPFE Workshop

“Seismic Assessment and Retrofitting of Masonry and Preserved Structures”

PROCEEDINGS

Skopje, 23rd May 2024

Introductory Note

EUR-OPA Major Hazards Agreement is a platform for co-operation in the field of major natural and technological disasters. Its field of competence covers disaster risk reduction, in particular; knowledge, prevention, preparedness, risk management and post-crisis analysis.

The main objectives of the EUR-OPA Major Hazards Agreement are to reinforce and to promote co-operation between member States in a multi-disciplinary context to ensure better prevention, protection against risks and better preparation in the event of major natural or technological disasters. In Greece, It was ratified by the Greek Law, 2031/92.

The 'Specialized Centers' operate within the framework of EUR-OPA, with specific role to develop projects, both at the national and regional level, that aim to improve the awareness and resilience to major risks within the population.

The European Center on Prevention of Earthquakes(ECPFE), was inaugurated in 1987 and it is part of the Network of the 21 Specialized Centers of the Agreement. It is supported administratively and financially by Earthquake Planning and Protection Organization(OASP).

The axis of policy are: Earthquake Protection of Monuments & Historical Centers, Earthquake-Development of Informative Material for individuals with disabilities, Reduction of the Vulnerability of Structures, Accessibility Assessment. In 2023, ECPFE and OASP organized a Workshop in Athens on "Seismic Assessment and Retrofitting of Masonry and Preserved Structures" where the new Greek Code for the Assessment and Structural Interventions of Masonry Structures (KADET) was presented. The European Centre on the Vulnerability of Industrial and Lifeline Systems,(ECILS), from North Macedonia participated as a partner in the Workshop, held in Athens. KADET is the third level pre-earthquake assessment for masonry buildings.

KADET, the new Greek Code for the assessment and structural interventions of masonry structures, was issued in Greece in 2022, responding to a long term need for a regulatory framework, relevant to seismic intervention of existing masonry structures.

As a follow up, ECILS, organized a workshop on the “Seismic Assessment and Retrofitting of Masonry and Preserved Structures” on 23 May 2024, in Skopje. The workshop constituted another milestone of a joint project implemented in cooperation with the European Centre on Prevention and Forecasting of Earthquakes, from Athens, Greece. In addition to the exchange of know-how at this workshop, both Centres working together under the aegis of the EUR-OPA Network of Scientific Centres, collected preliminary data from masonry and preserved structures in North Macedonia and discussed the lessons learned from the implementation of the new Greek Code on Seismic assessment and retrofitting of masonry structures (KADET).

During the workshop, distinguished Professors and also colleagues of ECPFE from Greece, Dritsos, Vintzilaiou, Miltiadou and Pandazopoulou, presented the separate chapters of the Code.

Relevant methodologies and experiences in the field of preserved masonry structures,will also be presented, commented and compared by ECILS, N.Macedonia and Serbia as well.

This Workshop, was a great opportunity to bring together distinguished scientists from different countries, to exchange ideas, to collaborate in the future and to improve measures to cope with. Specifically as the two countries and the Balkan area as a whole, share a common past in the field of cultural heritage, KADET is a very important tool that can be implemented in this field.

To conclude, I would also like to thank once again our colleagues, from both Centers, for the initiation to organise this event.

Dr Evangelia-Linda Pelli
Dir of Earthquake Planning Div. of OASP &
Dir of ECPFE

Maria Panoutsopoulou
Head of Planning Dep. of OASP &
Dep. Dir of ECPFE


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ECPFE
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AND FORECASTING OF EARTHQUAKES
75
ИЗИИС


IZNS
ECILS/ECPFE Workshop


Workshop


FINAL DISCUSSION / CLOSING


ECILS/ECPF


Protection of heritage structures from earthquake effects: status of regulations and practice in the Republic of Serbia
Dr. Svetlana Brzev
Adjunct Professor, Department of Civil Engineering, University of British Columbia, Canada
President, Serbian Association for Earthquake Engineering (SUZI-SAEE)
SU SA
ZI EE


FINAL DISCUSSION / CLOSING

ECILS/ECPFE Workshop Program

"Seismic Assessment and Retrofitting of Masonry and Preserved Structures"

Skopje 23rd May 2024, IZIIS Premises

WELCOME ADDRESS		
9:30 – 9:45	**Kristof Zyman** (online)	Executive Secretary, EUR-OPA
	Vlatko Sesov	EUR-OPA Permanent Correspondent for North Macedonia/ IZIIS director
	Zoran Pavlov	Director, Directorate for Protection of Cultural Heritage, North Macedonia
	Linda Pelli (online)	ECPFE/EPPO
	Veronika Shendova	ECILS/IZIIS
Presentation of the new Greek Code for the Assessment and Structural Interventions of Masonry Structures (KADET)		
	speaker	**presentation title**
9:45 – 10:15	**S. Dritsos** Professor Emeritus, University of Patras Deputy President of ECPFE	**THE GREEK CODE FOR ASSESSMENT AND STRUCTURAL INTERVENTIONS OF MASONRY STRUCTURES (KADET) AND THE SEISMIC CLASSES OF BUILDINGS**
10:15 – 10:45	**A. Miltiadou** Associate Professor, National Technical University of Athens	**INVESTIGATION AND DOCUMENTATION IN KADET**
10:45 – 11:00	**COFFEE BREAK**	
11:00 – 11:30	**E. Vintzileou** Professor Emeritus, National Technical University of Athens	**BASIC BEHAVIOUR MODELS, REPAIR and STRENGTHENING TECHNIQUES OF MASONRY STRUCTURES**
11:30 – 12:00	**S. Pantazopoulou** (online) Professor, Lassonde School of Engineering, York University, Canada	**PERFORMANCE LIMITS AND VERIFICATION CHECKS IN KADET**
12:00 – 12:30	**QUESTIONS/ROUND TABLE**	
12:30 – 13:30	LUNCH BREAK	
Presentation of the experience in the field of preserved masonry structures in Serbia and North Macedonia		
	speaker	**presentation title**
13:30 – 14:00	**Svetlana Brzev** Adjunct Professor University of British Columbia, Canada	**PROTECTION OF HERITAGE STRUCTURES FROM EARTHQUAKE EFFECTS: STATUS OF REGULATIONS AND PRACTICE IN SERBIA**
14:00 – 14:30	**Veronika Shendova** Professor, UKIM-IZIIS, Skopje North Macedonia	**HISTORIC BUILDINGS AND MONUMENTS IN NORTH MACEDONIA: TREATMENT AND RETROFITTING ASPECTS**
14:30 – 15:00	**FINAL DISCUSSION and CLOSING**	

CONTENTS

ECILS/ECPFE Workshop

"Seismic Assessment and Retrofitting of Masonry and Preserved Structures"

Opening address: Krzysztof Zyman,

Executive Secretary

European and Mediterranean Major Hazards Agreement (EUR-OPA)

23 May 2024, Skopje,

North Macedonia

Dear prof. Roberta Apostolska, deputy director of the Institute of Earthquake Engineering and Engineering Seismology, IZIIS-Skopje

Dear prof. Veronika Shendova, director of European Centre on the Vulnerability of Industrial and Lifeline Systems, ECILS, North Macedonia

thank you for your invitation to address this important gathering in my capacity of the Executive Secretary of the European and Mediterranean Major Hazards Agreement (EUR-OPA). I am grateful for this invitation and I warmly welcome other Seakers and Participants: Mr Vlatko Sestov, Mr Zoran Pavlov and Ms Linda Pelli (online).

Ladies and Gentlemen,

On 13 September 2023, I had the privilege of opening online the “Seismic Assessment and Retrofitting of Masonry and Preserved Structures” workshop held in Athens, that many of you participated in. I am equally honoured to be addressing you today, as you are gathered in Skopje, North Macedonia.

I am particularly grateful to be given the floor at the Workshop that gathers academics specialising in a variety of technical fields, working in an interdisciplinary manner, identifying problem areas, examining data, proposing solutions and making cases for policies to be implemented to increase resilience to earthquakes. I note with satisfaction the international aspect of your workshop, notably the presence of Professors Dritsos, Miltiadou, Vintzeliou and Pantazopulou from Greece and Ms Svetlana Brzev from Canada.

Today’s workshop constitutes another milestone of a joint project between the European Centre on the Vulnerability of Industrial and Lifeline Systems, from North Macedonia and the European Centre on Prevention and Forecasting of Earthquakes, Athens, Greece implemented under the aegis of the EUR-OPA Network of Scientific Centres.

In addition to the exchange of know-how at this workshop, both centres are collecting preliminary data from masonry and preserved structures in North Macedonia and discussing the lessons learned from the implementation of the new Greek Code on Seismic assessment and retrofitting of masonry structures (ΚΑΔΕΤ). This is exactly the type of cooperation that the EUR-OPA Network of Scientific Centres was create for. I am very satisfied to see it applied in practice.

Dear Participants,

Fighting against environmental degradation and climate change is one of the key priorities of the Strategic Framework for the Council of Europe. At the 4th Summit of the Heads of State and Government of the Council of Europe held in mid-May 2023 in Reykjavik, member States adopted a Declaration "United Around Our Values" in which they underlined the urgency of taking co-ordinated action to protect the environment by countering the triple planetary crisis of pollution, climate change, and loss of biodiversity. The Declaration, which provides guidance for future priorities of the Council of Europe affirms that human rights and the environment are intertwined and that a clean, healthy and sustainable environment is integral to the full enjoyment of human rights by present and future generations.

These priorities, that are currently being implemented by the Council of Europe, are directly relevant for the topic of your workshop today, as climate change increases the hazard of occurring disastrous events being more frequent and occurring with greater force. Higher sea surface temperatures increase evaporation and add additional moisture to the atmosphere over the oceans. This extra water vapor boosts the precipitation dumped by rainstorms and blizzards on coastal areas and inland locations.

While wetter areas will experience more precipitation, dry regions of the world will likely become drier due to the changes that ocean warming causes to the water cycle. Devastating fires over the dry land and unusually violent precipitation and flooding weaken structurally buildings and other structures by undermining the foundations as underground water levels drop due to drought or when land is eroded due to flooding. In consequence buildings and other structures are more vulnerable to earthquakes.

I wish you all interesting discussions and many insightful ideas. I am also looking forward to continued co-operation - and schedule permitting - meeting and greeting you all in person next time.

Thank you for your attention!

ΟΡΓΑΝΙΣΜΟΣ ΑΝΤΙΣΕΙΣΜΙΚΟΥ ΣΧΕΔΙΑΣΜΟΥ & ΠΡΟΣΤΑΣΙΑΣ (ΟΑΣΠ)
EARTHQUAKE PLANNING AND PROTECTION ORGANIZATION (EPPO)

ΕΥΡΩΠΑΪΚΟ ΚΕΝΤΡΟ ΠΡΟΛΗΨΗΣ ΚΑΙ ΠΡΟΓΝΩΣΗΣ ΤΩΝ ΣΕΙΣΜΩΝ (ΕΚΠΠΣ)
EUROPEAN CENTER ON PREVENTION AND FORECASTING OF EARTHQUAKES (ECPFE)

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ECILS/ECPFE Workshop

Seismic Assessment and Retrofitting of Masonry and Preserved Structures

The Greek Code for Assessment and Structural Interventions of Masonry Structures (KADET) and Seismic Classes of Buildings

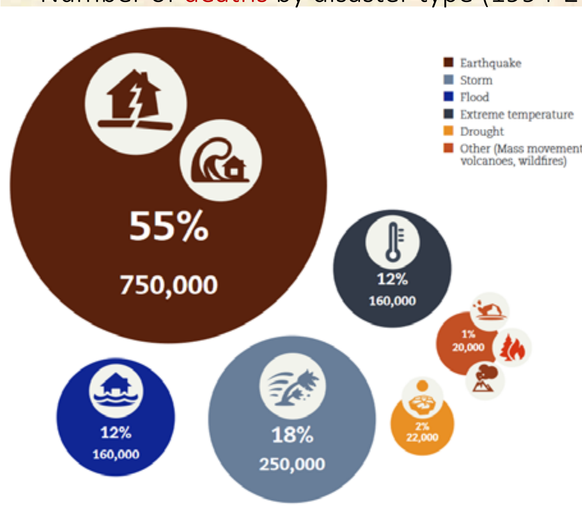
Stephanos E. Dritsos,
Prof. EmeritusDepartment of Civil Engineering

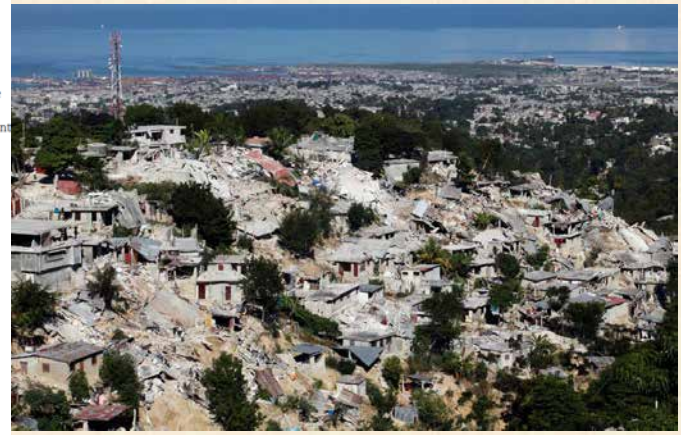
UNIVERSITY OF PATRAS
ΠΑΝΕΠΙΣΤΗΜΙΟ ΠΑΤΡΩΝ

Scopje, May 23rd 2024

Earthquakes represent one of the most destructive natural hazards

Number of deaths by disaster type (1994-2013)





http://www.boston.com/bigpicture/2010/01/earthquake_in_haiti.html

Ref: The Human Cost of Natural Disasters, CRE of Disasters, 2015

Assessment and retrofitting is a much more complicated issue, than the design of new structures

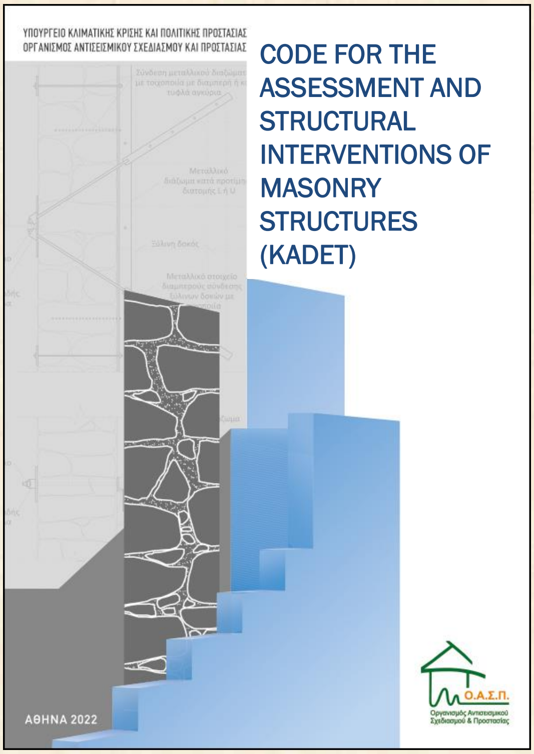
- *Limited knowledge, poorly documented for the subject*
- *Lack of codes or other regulations*
- *The configuration of the structural system of an existing structure may not be permitted according to the new code provisions. However, it exists.*
- *High uncertainty in the basic data of the initial phase of documentation. Hidden errors or faults.*
- Use of new (retrofitting) materials, which are still under investigation!
- Usually, low (or negative) qualifications or experience of workmanship in retrofitting applications

KADET: the new Greek Code for the Assessment and Structural Interventions of Masonry Structures

- KADET first issued in Greece in 2022: long term need for a regulatory framework
- Challenging task
  - ✓ inherent complexity of the problems associated with the seismic performance of masonry and the inevitable lack of scientific consensus on many open research topics.
  - ✓ need for simple, yet rigorous solutions and calculations for the practicing engineers in the framework of a legislative document.
  - ✓ vast majority of the existing masonry structures in Greece and beyond, usually is not compliant to any code for new structures.
  - ✓ need for good understanding of the load bearing mechanisms of both the existing (as built) and the retrofitted structures.

KADET: the history

- 2011: Appointment of the first drafting Committee for the Code development by the Directing Board of OASP, after the enforcement of the Greek Code for Seismic Interventions for RC Structures – KANEPE (used as a guide in terms of structure and context).
- April 2017: The first draft of KADET reviewed by 13 independent experts and 17 well established design offices acted as consultants that worked pro-bono to perform pilot studies on a set archetype structures to demonstrate and ultimately improve the applicability of the Code.
- March 2019: All comments were addressed by the Committee and were taken on board leading to the next draft version of the KADET.
- September 2019: The code draft was open to public consultation.
- March 2021: The new draft of the code was presented.
- 2022: KADET was finalized following a second round of public consultation by a finalization and publication committee.
- 2023: Enforcement of KADET as legislative document



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KADET: Objectives

- The main objective of the present code KADET is the introduction and enforcement of criteria for the assessment of the bearing capacity of existing masonry structures to resist seismic forces. The Code sets rules for the re-design of these structures following potential interventions (repair or strengthening), as well as for the interventions themselves.
- More specific aims are to:
  - offer a set of specific criteria for assessing the seismic response of masonry structures,
  - describe the appropriate approach for select the appropriate measures of intervention (repair, strengthening or addition of new elements)
  - set criteria for the re-design of the retrofitted structure, including the design of the strengthened or new structural elements and their connections, either between new and existing ones or among the new elements themselves.

KADET - Field of Application

- It covers all masonry structures, *formed by m*asonry units (*stones, bricks etc.) connected* ***with mortar***, however, it is evident that the underlying main principles of mechanics are of general use.
- ***Dry-stone*** *masonry structures are* ***not included***
- ***Preserved buildings****, monumental structures and monuments* → **Applied**
  But often under additional provisions and restrictions (provided by the responsible Public Authority) depending on the particularity of each building
- *Structures made of* ***timber-frame masonry*** *and Structures with a* ***composite bearing body*** *(vertical elements from masonry and RC)*
  → **Applied**
  In these cases, the Code can be used by the designer in combination with other Regulations (indicative: KAN.EPE., EC 3-1-1, EC 4-1-1, EC 5-1-1), with reasonable assumptions in favor of safety for the entire structure.

Obligation of the code provisions

- *Depending on the expression, such as: must, applies, may, proposed, alternatively*
- *Comments: Same force as main text (formative)*

Is partial satisfaction of the requirements of the Code allowed?

YES *under certain conditions*

- *Either with an explicit reference to the Code*
- *Either by a relevant decision of a Public Authority*

Obligation of the code provisions

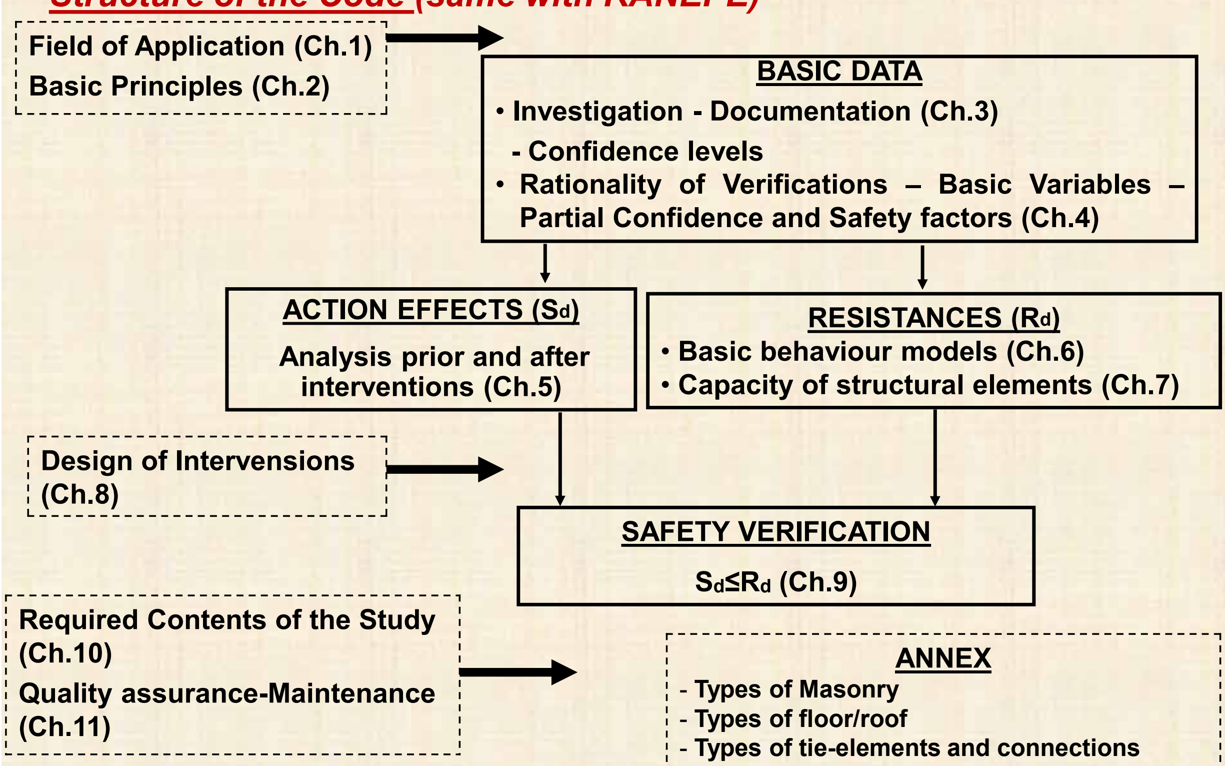
Is it allowed to use other evaluation methods besides those of the Code?

YES *under certain conditions*

- *Scientifically documented*
- *They provide at least the same level of safety*
- *They have been approved by the responsible Public Authority*

✓ *In buildings assessed or redesigned with this Code, **modifications of load-bearing or non-load-bearing structural elements (e.g., timber framed partition walls) are not allowed** without a prior study of the consequences of the changes.*

Structure of the Code (same with KANEPE)



KADET vs Eurocode

KADET and Eurocode share the same concept, adopting a similar framework for the assessment and retrofitting of existing structures. However:

- KADET:
  - ✓ is deemed as a major advancement in relation to the current version of Eurocode 8 – Part 3 (CEN, 2004) and the provisions referring to masonry structures as outlined in its respective Appendix C for dealing with seismic assessment and retrofitting of buildings.
  - ✓ is also more detailed covering approximately 350 pages compared to the new draft of the new generation Eurocode 8-Part 3 (CEN, version 16-12-2022) and specifically to the provisions of Chapter 11, which is dedicated to masonry (40 pages).

KADET and Eurocode Concept

What is failure? ➡ **Action effects > Resistance**

In the design of a new building this could never be accepted
However, in an existing building this is very possible to occur

Questions: What level of damage will there be?
What are the consequences?
Is this acceptable?

Damage Levels - **Performance Levels** or Limit States (LS)

in relation to the acceptable (tolerable) degree of damage of the building

Performance Level A
Damage Limitation (DL) or
Immediate Occupancy (IO)
➡ Minimal damage, elements have not substantially yielded

Performance Level B
Significant Damage (SD)
or Life Safety (LS)
➡ Significant damage is accepted in the building, as usually it happens in the ductility design of new buildings.

Performance Level C
Near Collapse (NC) or
Collapse Prevention (CP)
➡ Extensive and serious or severe damage is accepted. The building is very close to collapse

Damage Levels - **Performance Levels** or Limit States (LS)

in relation to the acceptable (tolerable) degree of damage of the building

Performance Level A ➡
Damage Limitation (DL)

the structure has only experienced light damage.
Its structural members retain a high degree of their capacity and stiffness. Residual relative displacements between storeys are negligible.

Performance Level B ➡
Significant Damage (SD)

the structure has suffered major damage, some of which may be severe, without local collapses. However, it has retained residual bearing capacity and stiffness. The vertical structural members are able to bear permanent (gravity) and live loads. Some moderate residual relative displacements do exist among storeys, that can be large locally. The load-bearing structural system can resist moderate future earthquakes.

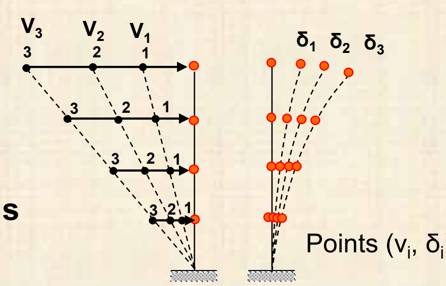
*Damage Levels - **Performance Levels** or Limit States (LS)*
in relation to the acceptable (tolerable) degree of damage of the building

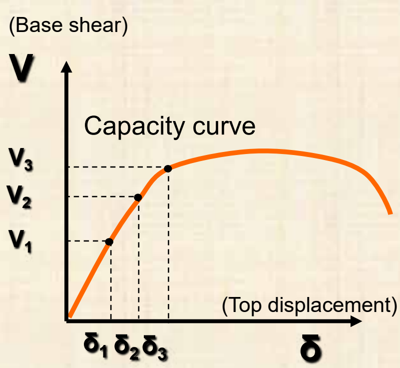
Performance Level C
Near Collapse (NC)

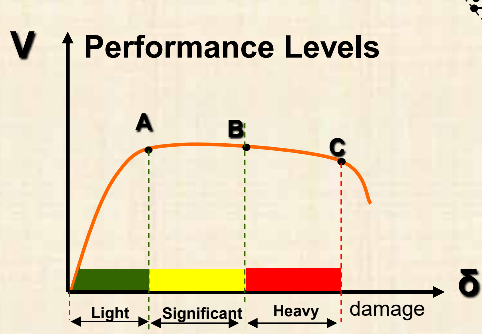
➡ *the structure has experienced severe damage, the majority of which is not repairable. Its residual capacity and stiffness are low; however, the vertical structural members are still able to bear permanent and live loads. Large residual relative displacements among storeys are observed. The load-bearing system does not possess adequate safety factor against collapse, and it is likely that it will not be able to resist future earthquakes even of moderate intensity.*

Performance Levels' Illustration

Gradual pushing (static horizontal loading) of structure up to failure







- The capacity curve of the building is represented by a base shear versus top displacement graph, which can be defined using pushover analysis.
- The performance levels A, B and C could be illustrated in the capacity curve as shown in this slide.
- The yield point of the curve represents yielding of the structural elements and defines the end of Performance Level A which is the level of damage limitation.
- C represents the enter of the near collapse level, while B is the threshold (of performance level B) and is depicted in this curve between B and C.

Seismic Actions

- Which is the design earthquake in assessment pro or after retrofitting?
- Which return period should be selected for the seismic action?
- Should this be the same as for new structures?

- Generally, assessment can be performed for a seismic action with any possible probability of occurrence (during the design life of the building) for any desired performance level.

- It is up to the owner to select the design seismic action and the desired Performance Level. However, in case of high importance structures there are specific limits for the minimum seismic actions and Performance Levels, which are defined by the national authorities.

Performance Objectives

KADET: Nine design earthquakes combined with three performance levels = 27 ***Performance Objectives***

Seismic Action	Occurrence probability in 50 years	$\alpha_g / \alpha_{g,ref}$	Performance Levels		
			Level A Damage Limitation (DL)	Level B Significant Damage (SD)	Level C Near Collapse (NC)
E_0	2%	1.80	A0	B0	C0
E_1^+	5%	1.30	A1+	B1+	C1+
E_1	10%	1.00	A1	B1	C1
E_2^+	20%	0.75	A2+	B2+	C2+
E_2	30%	0.60	A2	B2	C2
E_3^+	50%	0.45	A3+	B3+	C3+
E_3	70%	0.35	A3	B3	C3
E_4^+	90%	0.25	A4+	B4+	C4+
E_4	>90%	<0.25	A4	B4	C4

$\alpha_{g,ref}$ is the reference horizontal ground acceleration defined with a 10% probability to be exceeded in 50 years (as in the design of new structures) and
α_g is the seismic acceleration adopted in the assessment and redesign.
$\alpha_g / \alpha_{g,ref}$: seismic design index

Seismic Classes of Buildings

Which is the maximum seismic action that leads to failure of the building? (Owner or public authority question)

- For an acceptable level of damage (e.g., for a pre-selected performance level)
- Which is the higher performance objective that could be achieved?

➡ Seismic class of building

- For each Performance Level, the maximum seismic action a building can resist defines its seismic class. Classes of performance level B, are considered as basic classes.

max $\alpha_g / \alpha_{g,ref}$	Performance Level of the load-bearing structural system		
	A Limited Damage	B Significant Damage	C Near Collapse
1.80	A0	B0	C0
1.30	A1+	B1+	C1+
1.00	A1	B1	C1
0.75	A2+	B2+	C2+
0.60	A2	B2	C2
0.45	A3+	B3+	C3+
0.35	A3	B3	C3
0.25	A4+	B4+	C4+
<0.25	A4	B4	C4

max $\alpha_g / \alpha_{g,ref}$: capacity index

KADET: Social – Economic Aspects

KADET promotes a strategic decision to serve social-economic needs and yield redesign of masonry structures financially viable, hence, more attractive.

The minimum mandatory requirements for seismic capacity that must be met by existing structures may, under conditions, be reduced in relation to the provisions of the current design regulations that apply (at the time of the assessment) for new structures.

- The **minimum acceptable** assessment or redesign objectives are defined according to the importance class of the building. The owner can choose higher than the above minimum objective.

Minimum acceptable assessment or redesign objectives

Importance Class	Minimum Acceptable Objectives
I	C2
II	C1
III	B1
IV	B1 and A2 (both to be fullfilled)

KADET: Social – Economic Aspects

A breadth of options are provided to the designer in order to meet the specific needs of the respective owner or stakeholder that is assessed with the aim to be strengthened. It is deemed that the above flexible scheme will encourage pre-earthquake assessment and seismic upgrade of the existing stock of masonry structures and upscale the application of this new regulatory framework across the country.

Alternative Minima for the Redesign of Buildings of Importance Class I and II

In private buildings, any restoration or change of use and possibly addition of new floors, may be allowed under the condition that the building is finally upgraded (by retrofitting it) one basic seismic class at least and from those of Table below.
The higher seismic class is achieved, the higher financial support can be received by the State.

Table.1 Minimum (prior to be upgraded) basic seismic classes of existing buildings of importance I and II

Construction period and respective applied design code	Minimum basic seismic class of existing buildings
…<1985	B3
1985≤…≤1995	B3+
1995≤…	B2+

Assessment Procedure

1st stage:

Documentation of the existing structure

2st stage:

Assessment of the (seismic) capacity of the structure

3rd stage:

Design the structural intervention

Documentation of an Existing Structure

- Data on the strength of materials
- Reinforcement (quantity and detailing)
- Geometry (including foundation)
- Actual loads
- Past damage or "wear and tear" or defects

Extend of documentation ➡ Knowledge Levels (KL)

Code for the assessment and structural interventions of masonry structures – KADET

Documentation: Knowledge Levels (KL)

Geometry (KLG), Strength of Materials (KLM), Details (KLD)

- High Knowledge (Comprehensive Survey) ➡ KL3
- Average Knowledge (Extended Survey) ➡ KL2
- Minimum Knowledge (Limited Survey) ➡ KL1
- Inadequate: May allowed only for secondary elements

➡ Confidence factors = Safety factors for assessment of existing structures

Materials

Determination of masonry's compressive strength (empirical calculation)

$$f_{wc} = \xi[\{\tfrac{2}{3}\sqrt{f_{bc}} - f_0\} + f_{mc}]$$

Determination of mortar's tensile strength

The fragments method is recommended

Reference values for the strength of materials under specific conditions

- *In small-sized buildings of minor importance that are free from damage (area up to approx. 100 m^2 and maximum 2 floors above the basement)*
- *In cases when mortar is particularly friable, so samples for mechanical tests cannot be obtained*
- *Not in monumental or preserved buildings*

Methods of Analysis before and after the Intervention

- *Lateral Force (Static) Method of Analysis – Basic Reference Method*
- *Modal Response Spectrum Analysis (Elastic Dynamic)*
- *Non linear Static Analysis*
- *Non linear Dynamic Analysis (Time History Analysis) – Not recommended in general*
- *Approximated Analysis*

Linear Analysis by using:

- ✓ *Global behavior factors **q** (q-factor approach) or local factors **m** ($m = \delta_{lim}/\delta_y$) through force control*
- ✓ $R = V_{el}/V_y$ *through deformation control*

q-factor approach

Table 2: Reference values of the behavior factor q for performance level B (Significant Damage)

Masonry Type	Existing damage in primary structural elements	
	YES	NO
Unreinforced masonry	1,20	1,50
Masonry with horizontal ring beams	1,50	2,00
Masonry with horizontal and vertical tie elements (confined masonry)	2,00	2,50

A modified behaviour factor q^* is prescribed in KADET to account for different performance levels adopted for assessment or redesign, as opposed to the fixed value of q<1.5 prescribed in current version of Eurocode 8 – Part 3 (CEN, 2004). The values of ratio q^*/q are summarized in the following table:

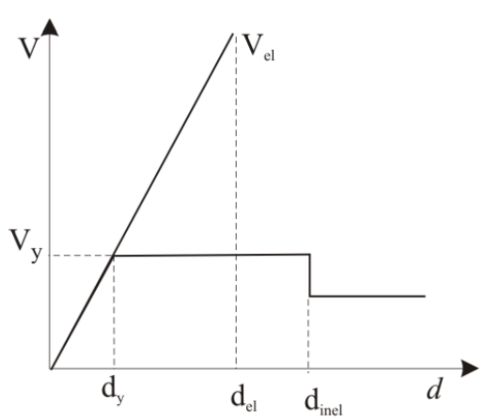
Table 3:Values of the ratio q/q*

Performance Level		
Damage Limitation (A)	Significant Damage (B)	Near Collapse (C)
0,60 in any case 1,0<q*<1,2	1,0	1,4

q* refers to values of any performance level, q refers to values of performance level B (Table 1)

Elastic Analysis

Application with control in terms of deformations



Corellation between elastic and inelastic deformations

$$\frac{d_{inel}}{d_{el}} = 1 \text{ για } T \geq Tc$$

$$\frac{d_{inel}}{d_{el}} = \frac{1.0+(R-1)\frac{T_C}{T}}{R} \geq 1 \text{ για } T < T_c$$

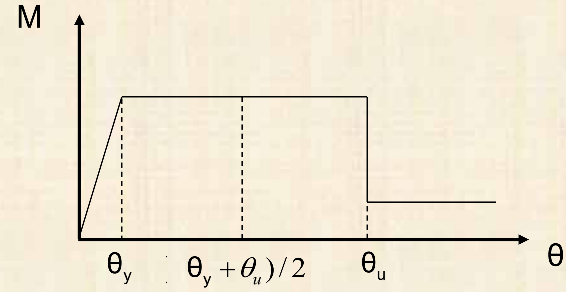
$R = V_{el}/V_y$

V_{el} Obtained from the eleastic spectrum

V_y Base shear at the yield point of the structure

Safety Checks

Verification criteria for performance levels A, B or C are defined in terms of forces or deformations depending on the analysis method



$$S_d \le R_d$$

S_d is the design action effect

R_d is the design resistance

For brittle components/mechanisms (e.g., shear) S_d, R_d **concern forces**

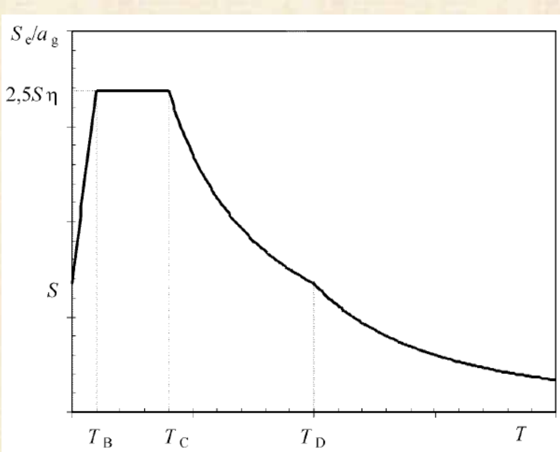
For ductile components/mechanisms (e.g., flexural) S_d, R_d **concern deformations**

A Level (IO) $\theta_{Rd}=\theta_y$

B Level (LS) $\theta_{Rd}=\dfrac{1}{\gamma_{Rd}}\dfrac{\theta_y+\theta_u}{2}$ "primary" elements; $\theta_{Rd}=\dfrac{\theta_u}{\gamma_{Rd}}$ "secondary" elements; $\gamma_{Rd}=1,8$

C Level (NC) $\theta_{Rd}=\dfrac{\theta_u}{\gamma_{Rd}}$ $\gamma_{Rd}=1,8$ for "primary" elements; $\gamma_{Rd}=1,0$ for "secondary" elements

Elastic Acceleration Response Spectrum according to EC8 (EN 1998-1)



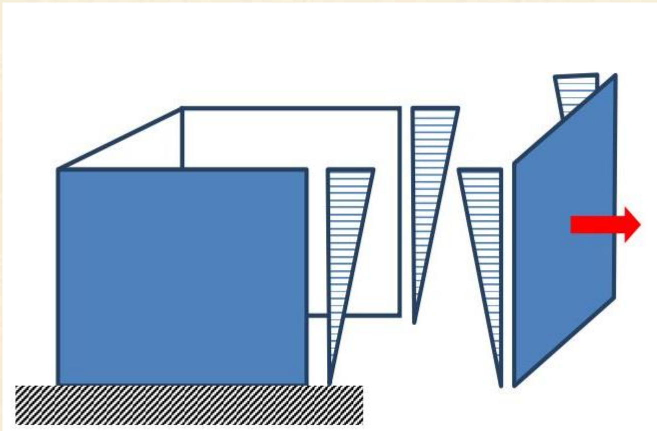
$$0\le T\le T_B:\ S_e(T)=a_g\cdot S\cdot\left[1+\frac{T}{T_B}\cdot(\eta\cdot 2{,}5-1)\right]$$

$$T_B\le T\le T_C:\ S_e(T)=a_g\cdot S\cdot\eta\cdot 2{,}5$$

$$T_C\le T\le T_D:\ S_e(T)=a_g\cdot S\cdot\eta\cdot 2{,}5\left[\frac{T_C}{T}\right]$$

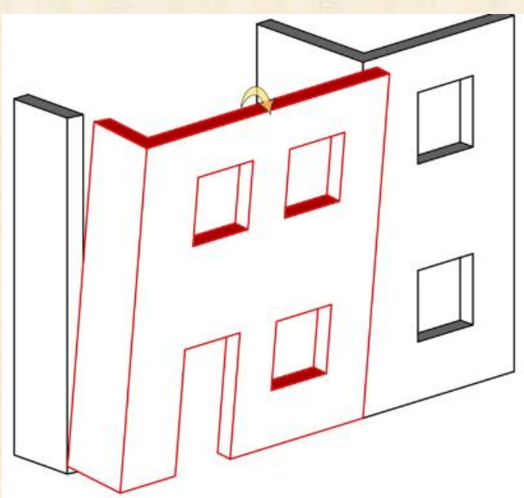
$$T_D\le T\le 4s:\ S_e(T)=a_g\cdot S\cdot\eta\cdot 2{,}5\left[\frac{T_C T_D}{T^2}\right]$$

Out-of-Plane Action



Code for the assessment and structural interventions of masonry structures – KADET

Out-of-Plane Action



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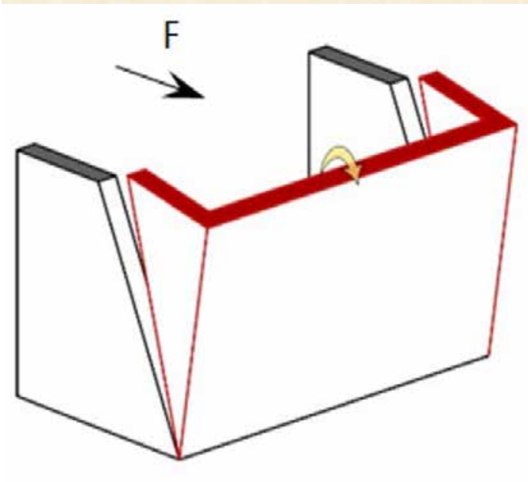
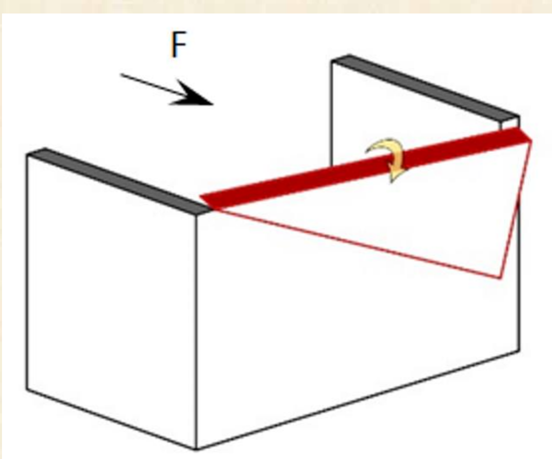
Out-of-Plane Action

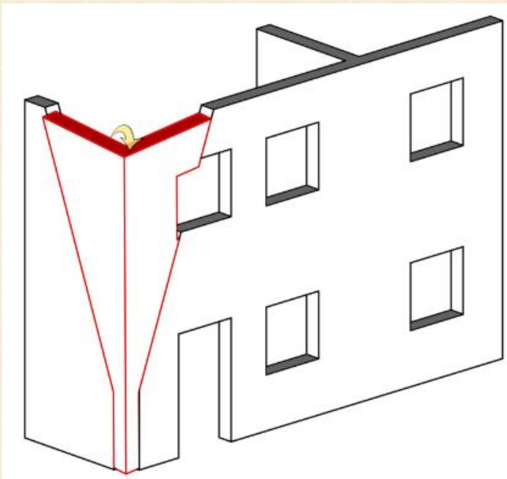


Code for the assessment and structural interventions of masonry structures – KADET

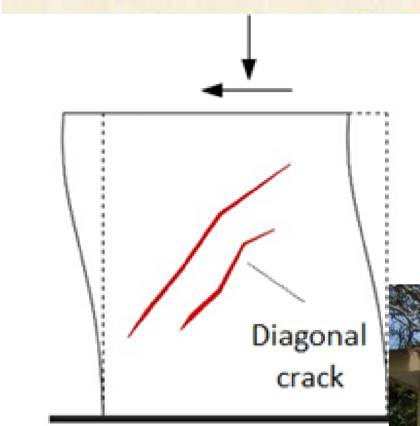
Out-of-Plane Action



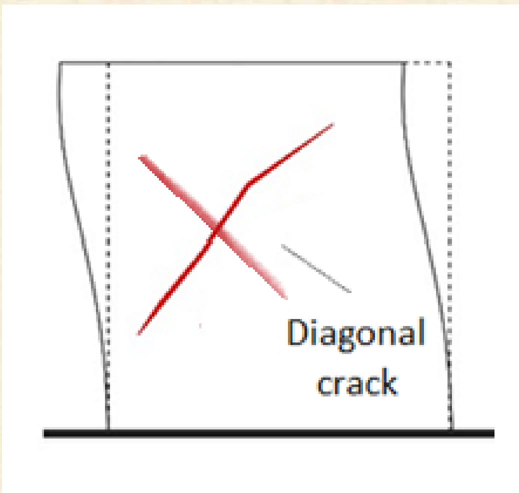
Corner Failure



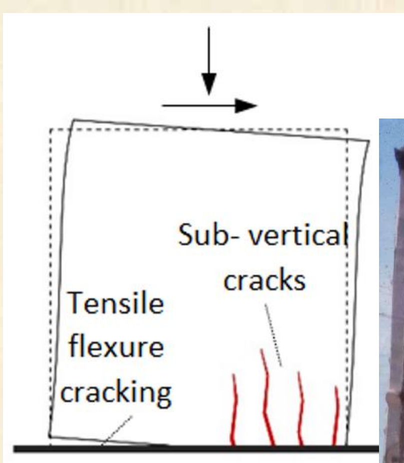
In-Plane Action



In-Plane Action



In-Plane Action



In-Plane Action

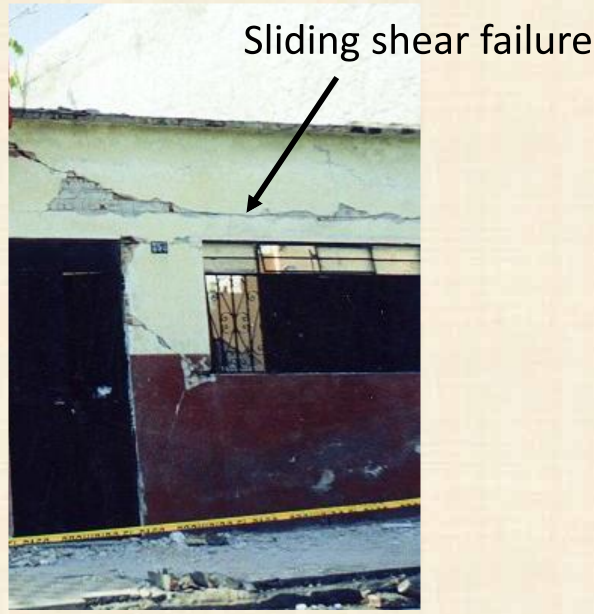
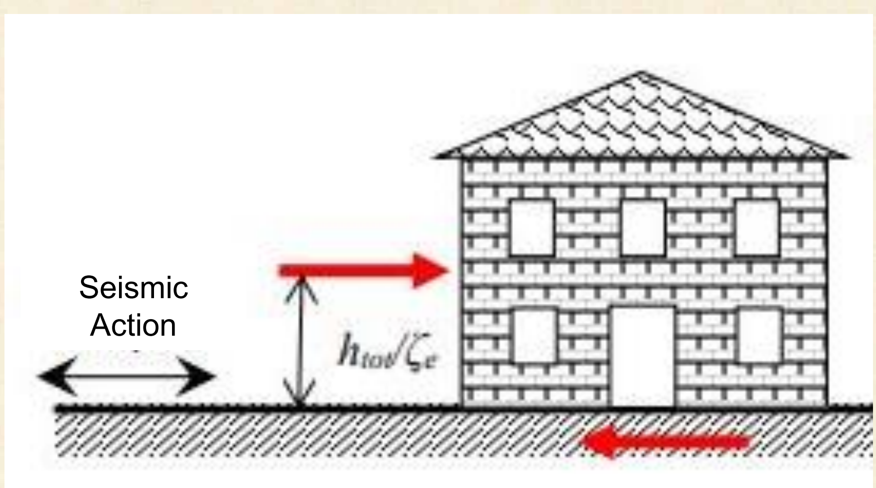
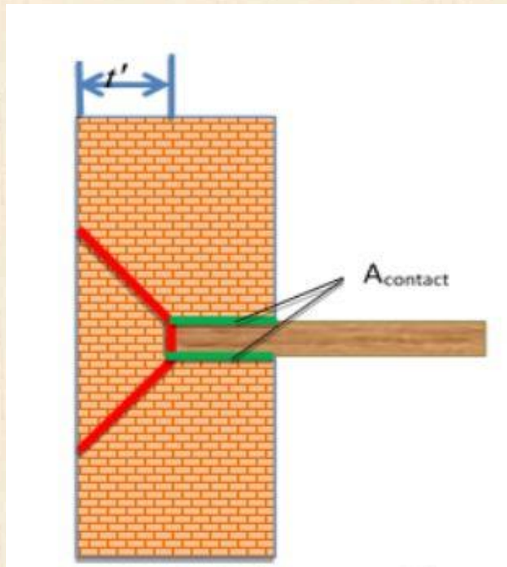


photo by J. Jara

Safety Verification against Overturning

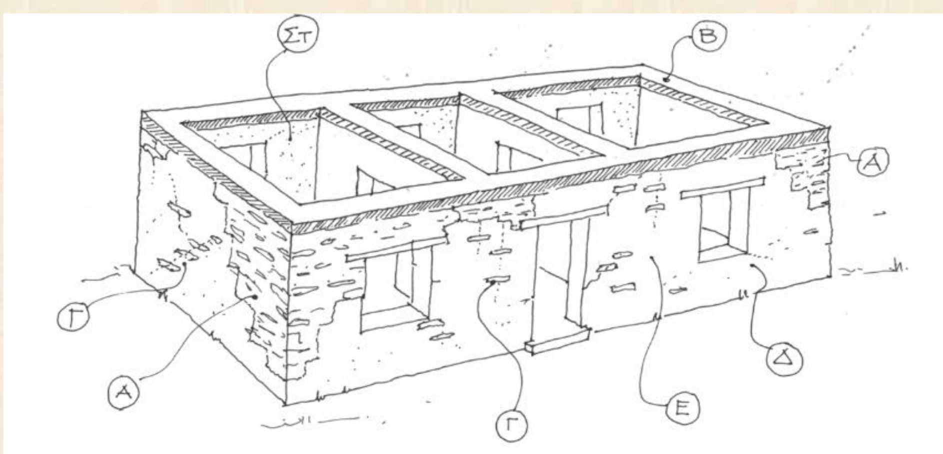


Local Checks



Punching control at the floor support

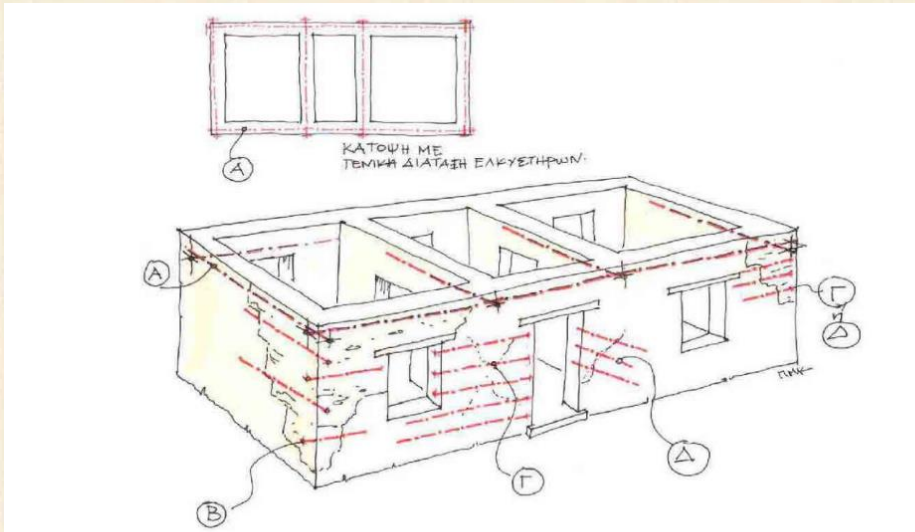
Interventions in Masonry with conventional techniques



A. Reconstruction, B. Introduction of a RC ring tie beam, Γ. Stone stitching, Δ. Re-pointing,
B. E. Grout injection, ΣΤ. Covering with fiber reinforced mortar

P. Koufopoulos, “Theoretical and practical issues for strengthening of monumental structures by steel elements”, 21ο Student Conference, University of Patras, 2015

Interventions in Masonry with steel elements or other modern materials



A. Introduction of steel ties along the walls, B. Steel bars for corner stitching, Γ. Array of prestressed or unstressed steel bars, Δ. Crack stitching with small mismatched steel rods

P. Koufopoulos, “Theoretical and practical issues for strengthening of monumental structures by steel elements”, 21ο Student Conference, University of Patras, 2015

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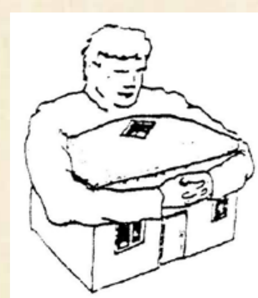
Interventions in masonry with steel ties or other modern materials



P. Koufopoulos, “Theoretical and practical issues for strengthening of monumental structures by steel elements”, 21ο Student Conference, University of Patras, 2015

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Addition of a new internal structural system

- *With **stiffness** at least equal to the stiffness of the existing structure*
- *Crucial for the application of the technique: **Connections** to the existing building should be verified*
- *There should be **at least two** non-coplanar and stable new elements in two mutually perpendicular directions (e.g. the main ones), depending on the size, geometry and regularity of the structure*
- *Eurocodes should be used for the design of the new system*
- In the application of the **q factor approach**, when the ratio V_R / V_E is at least equal to 0.75 on each floor and in each direction, q is taken as in new constructions

  V_R is the total resisting shear force of the new elements and

  V_E is the active shear force

  In cases where $0.60 \leq V_R / V_E \leq 0.75$, q´= 4/5q can be obtained

The Greek Myth

- The ancient Greeks had impersonated earthquake as the chief of the Giants named Egelados, who was attacking and punishing the people. The myth says that goddess Athena bit Egelados in a battle and imprisoned him in Mountain Etna, in Sicily. This is the reason why Etna erupts from time to time, as Egelados tries to escape.
- As Athena was the goddess of wisdom and knowledge, the myth's message is that people shouldn't be afraid. Knowledge and wisdom will win the battle with the earthquake.

References

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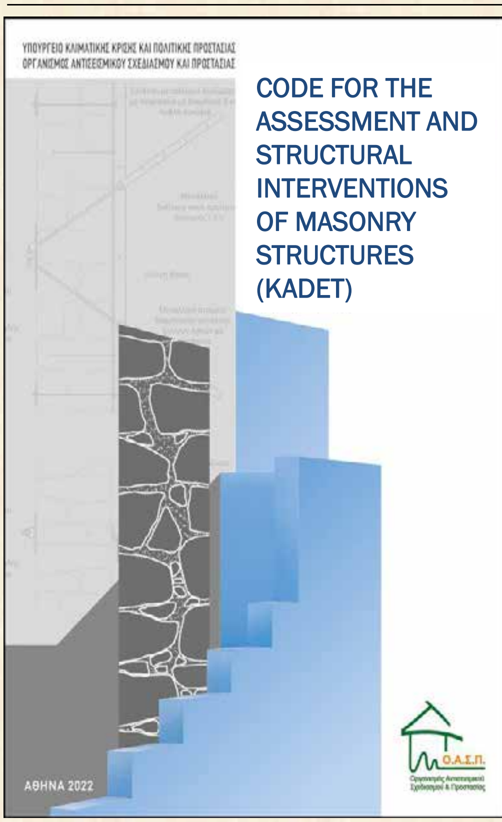
- Code for Seismic Interventions of Concrete Structures, KAN.EPE. (2022), 3rd amendment (in Greek): https://tinyurl.com/4dre57u3
- Code for Seismic Interventions of Concrete Structures, KAN.EPE. (2012), 1st Draft (in English): https://ecpfe.oasp.gr/sites/default/files/files/%CE%9A%CE%91%CE%9D%CE%95%CE%A0%CE%95_EN2013_FINAL(1).pdf
- CEN. (2004). European Standard EN 1998-3. Eurocode 8: Design of structures for earthquake resistance - Part 3: Assessment and retrofitting of buildings", Committee for Standarization.
- CEN/TC 250. (Draft 2023). Eurocode 8 - Design of structures for earthquake resistance-Part 3: Assessment and retrofitting of buildings and bridges, Committee for Standarization.

Code for the assessment and structural interventions of masonry structures – KADET



https://oasp.gr

https://ecpfe.oasp.gr/

www.episkeves.civil.upatras.gr

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ECILS/ECPFE Workshop

“Seismic Assessment and Retrofitting of Masonry and Preserved Structures”

Investigation and Documentation in KADET

Androniki Miltiadou-Fezans

Dr Civil Engineer,

Associate Professor (r.), School of Architecture,

National Technical University of Athens

Skopje, 23rd May 2024, IZIIS Premises

Introduction

Existing masonry structures, differ from ordinary new structures built under controlled conditions of conception and construction, as they are old “non engineered” structures, which:

a) have been constructed without prior calculation and dimensioning

We need to discover their secrets

Androniki Miltiadou-Fezans, Associate Professor (r), National Technical University of Athens

Introduction

β) are based on empirical knowledge gained through trial and error. usually reflected in local earthquake resistant structural systems developed over the centuries to protect human life and prevent collapse and severe damage

PLOMARI LESVOS ISLAND

Local structural system, comprising a wooden reinforcement system on the inner side of the masonry, systematically connected to the outer side with metallic ties well anchored to the façade

Androniki Miltiadou-Fezans, Associate Professor (r), National Technical University of Athens

Introduction

γ) have suffered damage and interventions that need to be identified.

Past interventions, often contributed, if not caused collapse and heavy damage

Introduction

Vrisa, Lesvos island

Insertion of R.C. Ring beams of various dimensions without strengthening the low quality masonry and without taking measures for their connection with masonry
Result: Collapse of ring beams and/or masonry

Introduction

Amatrice

(Source: E. Vintzileou)

Rieti, 2016

Illica

The importance of documentation - Especially before earthquake

The traditional buildings of rural architecture that exist in most of the villages of our countries, give them a special local character, which we should preserve. Otherwise there is the danger, after an earthquake to replace them with neo-traditional constructions, …

The load bearing systems of such structures are composed by masonry and wood. These systems have to be preserved, that is why they should be investigated, documented and assessed, in order to:

- Identify their internal vulnerabilities and their advantages
- Make it possible to design adequate interventions to mitigate (in whole or in part) the internal vulnerabilities of the system, without altering it radically.

BUT, WHY WE NEED TO INVESTIGATE EACH BUILDING??

The importance of documentation - Especially before earthquake

… The mechanical characteristics of masonry depends on the mechanical characteristics of constituent materials and the way of construction …








For the analysis of the structural behaviour, the Engineer makes the hypothesis (even in the most precise ones) that the masonry has the same properties through its entire width..

But, the problems emerge with the earthquake and then the operation is more difficult and requires a lot of resources and time!!!

KADET CHAPTER 3

Before any design study or intervention, it is necessary to investigate and document the existing structure to a sufficient extent and depth, with detailed surveys, observations, in situ and lab investigations and records in order to map the condition of the structure and the history of its construction and maintenance, which may differ from structure to structure or even from one part to the other of the same structure. Necessary, either there are or there are no damages!!





Aiming at the structural documentation of the existing building in sufficient extent and depth → so as to make the **data** on which the assessment and/or redesign study will be based **as reliable as possible**.

KADET CHAPTER 3

The required in each case level of reliability of the above data depends on many factors, and affects

- ✓ **the calculations of actions and resistances**
- ✓ **The decisions for the interventions**

Some of the factors that affect the reliability of the data are:
- the availability of the historical records of the building
- the adequacy of the investigated load-bearing system and its material characteristics
- The difficulties to investigate on-site invisible elements, connections, and to assess material properties.

KADET CHAPTER 3

For the assessment of the condition of the existing structure, data will be collected, where necessary and feasible,

- ✓ **from available public or private records,**
- ✓ **from relevant responsible and reliable information,**
- ✓ **from on-site and laboratory tests and investigations.**

Inspection procedures, on-site and laboratory tests and investigations, and other data collection procedures, shall follow professional or public organization specifications, and shall be compatible with available means for inspection, investigation, and repair/strengthneing measures. [see and § 1.2.1.(g)].

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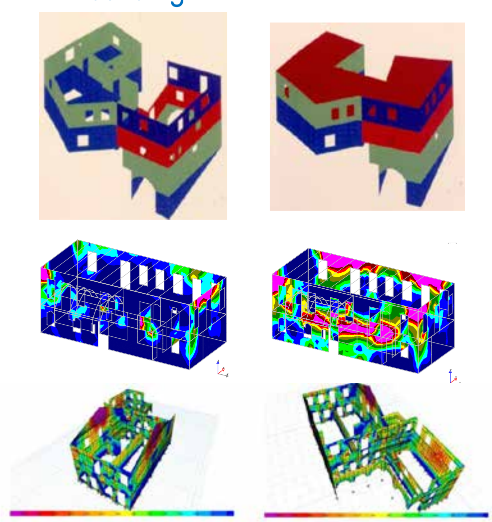
KADET CHAPTER 3

It is advised to carry out a preliminary analysis of the building, after collecting the necessary data, in order to identify:

(a) the most vulnerable sections of the structure

(b) the expected failure modes of the building.



- The drafting of the investigation work program is facilitated and its optimum efficiency is achieved.
- The areas are identified where the characteristics of materials and structural members, which are expected to play a significant role for the assessment of the building's condition, should be assessed as a matter of prioritv

There is relevant literature on the preliminary sensitivity analysis that could be performed by the designers.

CONTENTS OF KADET CHAPTER 3

3.1 General (Introduction)

3.2 Survey and mapping of the load-bearing system

3.3 Historical survey

3.4 Survey of decay and damage (pathology)

Elements to be documented

3.5 Investigations (in situ and laboratory).

3.6 In situ measurement of materials strength

3.7 Monitoring of the behaviour of the struvture

3.8 Laboratoty tests

3.9 Tests on scaled models of buildings

Methos of documentation

3.10 Data reliability level (D.R.L.)

Level of documentation

Annex 3.1 Contains elements to assist the Designer for the selection of default strength values of the materials

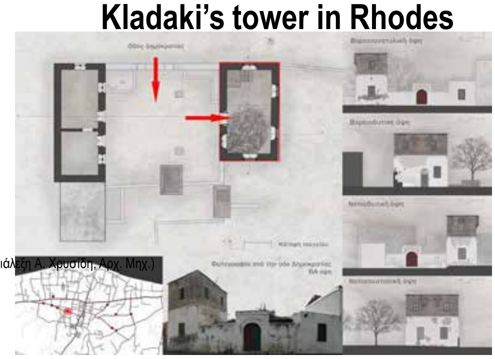
3.2. Survey and mapping of the load bearing system

Knowledge of the geometry of the structure, which includes both load-bearing and non-load-bearing structural members, is a prerequisite for assessment and redesign.

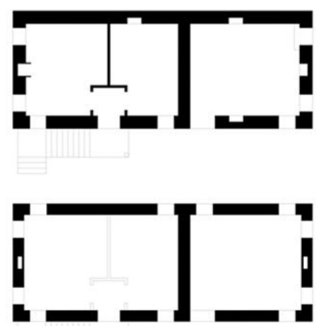
- General construction plans of the deformed structure: describe the geometry of the load-bearing system, allow the determination of structural members and their dimensions, and of the load-bearing system that resists the vertical and lateral actions (earthquake, wind pressure, etc.). They are based on:
  - Architectural surveys of the building
  - Already existing drawings after checking their accuracy
  - Investigations for the invisible elements.

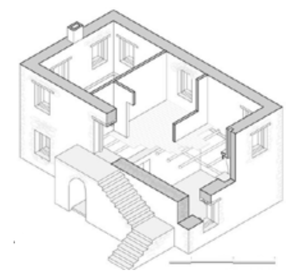
Source: Raptis and Mitrousis,

Kladaki's tower in Rhodes



(Διάλεξη Α. Χρυσίδη, Αρχ. Μηχ.)



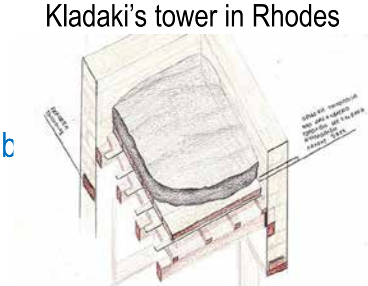


3.2. Αποτύπωση Φ. Ο. (φερόντων + μή φερόντων στοιχείων

Detailed construction drawings : in plan or elevation or section describe the way of connection between the members and the construction detailing in all places where this is deemed necessary.

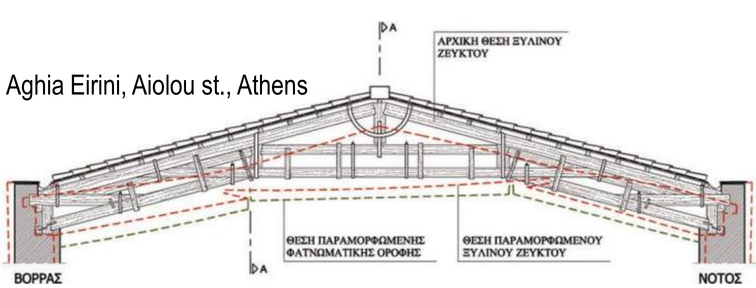
(a) Roof drawings,
(b) Floor drawings,
(c) Drawings of curved entities acting as roofs or floors
(d) Connection of roof and floors to the vertical load-bearing memb
(e) Connections between the various roof and floor elements
(f) Foundation drawings.
(g) Plans of construction phases and past interventions

Kladaki's tower in Rhodes



Τομή στέγης - δώματος, κλίμακα 1:20

Aghia Eirini, Aiolou st., Athens



Source: A. Chryside, Arch. Eng.

Aim: full understanding of the materials and the way of construction and connection of each member with other members and the structural system of the entire construction

3.3 Historical record

- **Gathering of information relevant to:**
- **Its construction time, as well as its construction phases.**
- **Subsequent additions, interventions, changes of use or loads, etc.**
- **Presence of damage or wear in the past and how they have been restored**
- **Accidental actions (earthquakes, fire, pounding, construction of a large neighbouring project, etc.).**

The required adequacy and completeness of the historical record is proportional to the importance of the structure.

In private buildings of small scale and limited importance,

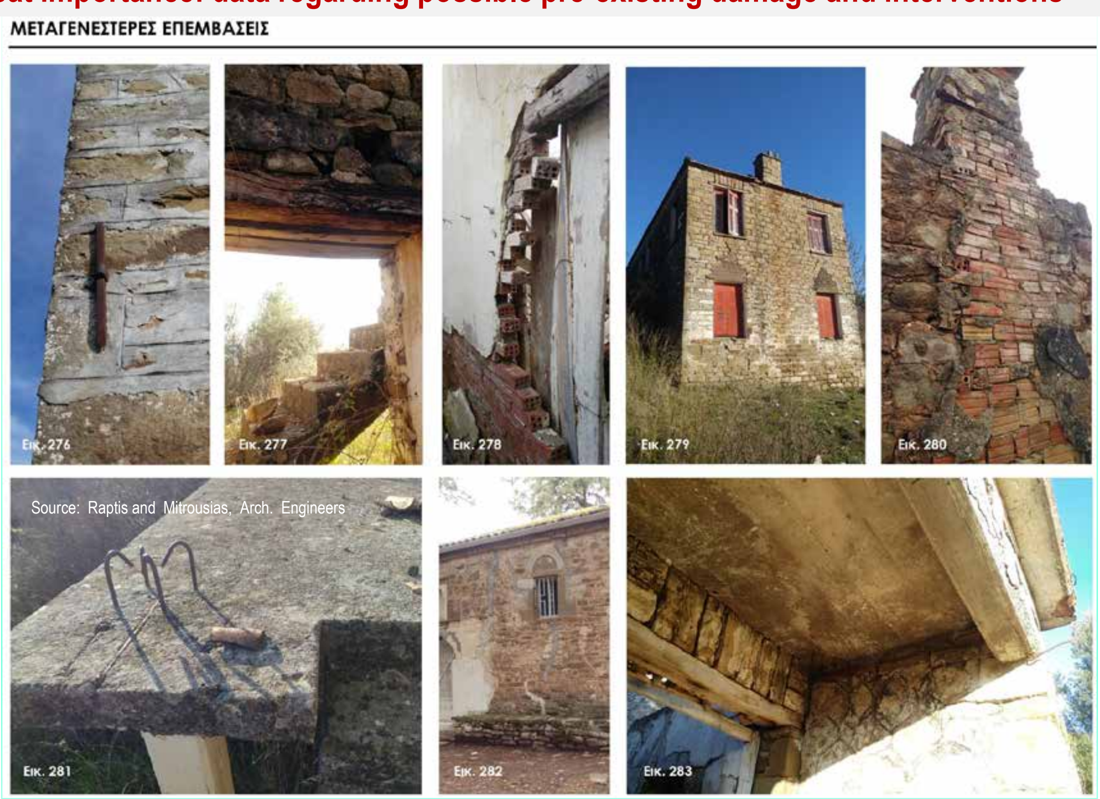
The history may be a simple record of facts, data, etc. or information, which is given by the Project Owner.

In buildings with historical/architectural/artistic value, an archive research and a review of the relevant literature is required

The Historical Record can be based on relevant studies of other disciplines (Architects, Archaeologists, Historians, Art Historians, etc.)

3.3 Historical record

Great importance: data regarding possible pre-existing damage and interventions



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3.3 Historical record

In case that a building is located in a historic settlement, the collection of information can also be done in neighbouring or other buildings of the settlement, which have been constructed with the same structural system and have experienced similar actions.

Especially in terms of seismic response, the comparison of the structure under consideration with other neighbouring ones is a piece of information that must be duly taken into account as an overall physical test of the building.

Vrisa, Lesvos island

Anavatos, Chios island

3.4 Recording of damage and decay (pathology)

Damage: any alteration or deterioration of the geometry, or of the continuity or the mechanical characteristics of the load-bearing or non-load-bearing elements (e.g. partition walls constructed in-dry).

Decay: due to aging of the materials, due to physicochemical actions, etc.

Examples of damage:

- **Deformations** of structural members and/or **their deviations from the vertical or horizontal axes.**
- **Cracks or detachments** between structural members.
- **Local failures, cracks or fractures** of stone bodies.
- **Deformations, fractures, disorganization** of wooden or metal elements.
- **Extensive exfoliation** of stone bodies.

.

Both damage and Decay shall be recorded and mapped on the drawings in plan, elevation and cross sections

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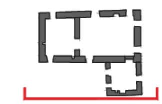
3.4 Recording of damage and decay (pathology)

The detailed record of decay and damage "Pathology", repaired or no and their evolution in time since the beginning of the study, complements the mapping of the load-bearing.

All data regarding damage and decay are recorded on the survey drawings together with the necessary explanations and relevant photos.

Selection of adequate means and in situ works, in order to survey the deformed geometry of the building.



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ΓΟΥΓΟΥΛΑ Κ. | ΚΑΛΥΦΟΜΜΑΤΟΣ Π. | ΡΟΒΗΛΟΣ Π. | ΡΟΖΑΝΗ Γ.

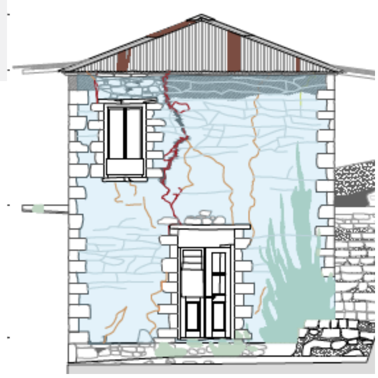
Άσκηση Δ.Π.Μ.Σ. Προστασία Μνημείων, ΕΜΠ

3.4 Recording of damage and decay (pathology)

Cracks are recorded in detail by location and size. Other issues are also recorded such as:

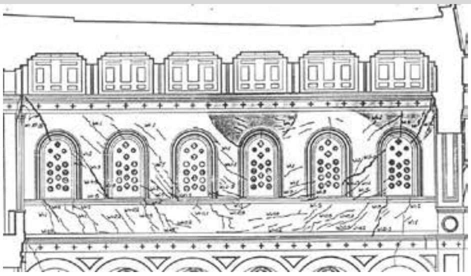
- ✓ whether the cracks are new or preceding
- ✓ whether their opening is constant or varies significantly along the length of each crack.,
- ✓ if out-of-plane displacement of the crack edges is observed.,
- ✓ if slip is observed along the cracks (between blocks or arch stones, …)
- ✓ whether the cracks are constant over time or a change in their width (or their length) has been observed since the initiation of the study
- ✓ if the cracks occur along joints or they cross through the stones.

Special attention should be paid to the identification of any horizontal cracks in horizontal joints or vertical cracks in vertical joints and/or stone



Πηγή: Καραγιαννακίδου, Μέρου, Κρεκούκια, ΔΠΜΣ ΠΡΟΣΤΑΣΙΑ ΜΝΗΜΕΙΩΝ, ΕΜΠ

3.4 Recording of damage and decay (pathology)



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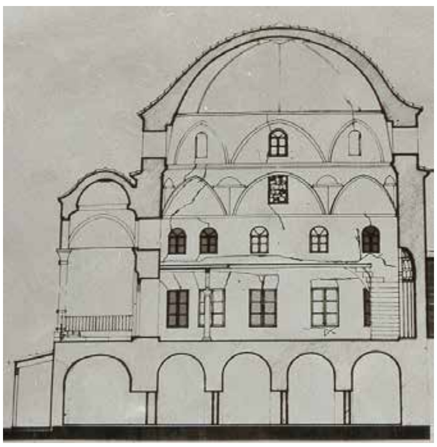
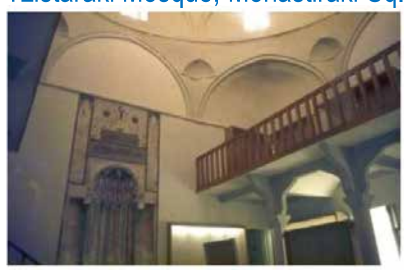
Μελέτη: , Μιλτιάδου-Fezans, Θωμοπούλου, Κωνσταντίνου



Μελέτη: Παπαστύρου, Μιλτιάδου, Δεληνικόλα

Tzistaraki Mosque, Monastiraki Sq. Athens



3.4 Recording of damage and decay (pathology)

Many times it is necessary to draw up special plans or axometric drawings in order to render the damage in a more visual way.

West part of Aghia Eirini Church in Aiolou Str., in Athens

Μελέτη: Μιλτιάδου-Fezans, Θωμοπούλου, Κωνσταντίνου

Σχεδίαση: Β. Σιδεράκη, Αρχ, Μηχ

Παραμόρφωση ξύλινης φατνωματικής οροφής και των φερόντων αυτήν δίδυμων ζευκτών

The piers of the drum of the dome of the Katholikon of Daphni Monastery, in Athens

Μελέτη: Μιλτιάδου-Fezans, Δεληνικόλας, Χωραφά, Ζαρογιάννη, ΔΑΒΜΜ &1η ΕΒΑ - ΥΠΠΟ

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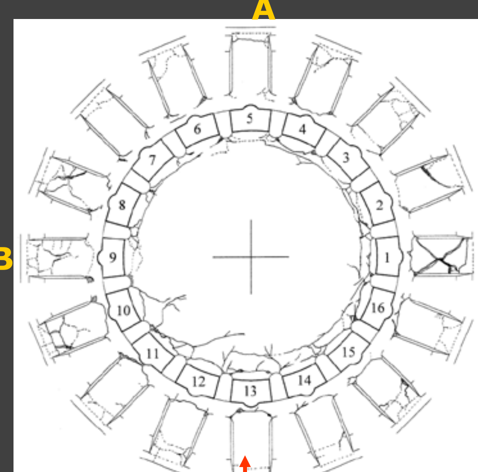


Ν

Δ

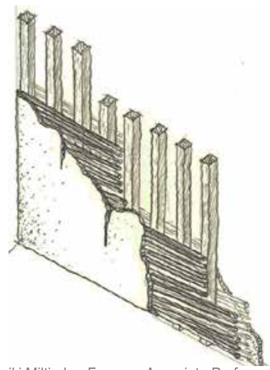
Κάτοψη στάθμης παραθύρων-πεσσών τρούλου. Προβολή ρωγμών ημισφαιρικού κελύφους. Κατάκλιση εσωτερικών όψεων πεσσών.

3.4 Recording of damage and decay (pathology)

Possible poor workmanship or construction errors, which cause a change in the characteristics of the load-bearing system and may have lead to a reduction of the bearing capacity, functionality and/or durability of the building, are reported and duly taken into account.

Source: Raptis and Mitrousias, Arch. Engineers

Potential damage to non-load-bearing structural members (such as, for example, partition walls) is also recorded and evaluated appropriately.



Source: Raptis and Mitrousias, Arch. Engineers

ΠΑΛΑΙΟΣ ΔΙΑΧΩΡΙΣΤΙΚΟΣ ΤΟΙΧΟΣ (ΜΠΑΓΔΑΤΙ)
1. ΚΑΔΡΟΝΙΑ
2. ΚΑΛΑΜΙΑ
3. ΕΠΙΧΡΙΣΜΑ

Androniki Miltiadou-Fezans, Associate Professor (r), National Technical University of Athens

3.4 Recording of damage and decay (pathology)

At this stage, depending on the extent and intensity of the damage, taking into account the importance of the building, the need to take immediate (emergency) intervention measures is considered.

In the case of buildings classified as listed or monuments, the relevant works must have been previously approved by the competent public authority

The choice of temporary emergency measures depends on several factors, including the:

- ✓ type and use of the building, in relation to its size and importance (according to the meaning of the applicable Seismic Code and/or the applicable relevant legislation)
- ✓ type of damage
- ✓ available resources (personnel, equipment, etc.)
- ✓ degree of risk
- ✓ probable evolution of damage
- ✓ expected seismic response
- ✓ the cost of interventions

Such immediate intervention measures can be:

- ✓ Immediate demolition of unstable sections
- ✓ Removal of loose or hanging elements
- ✓ Reduction or removal of large loads
- ✓ Temporary support against vertical loads
- ✓ Lateral support against horizontal loads
- ✓ Prohibition of use of the building (in part or as a whole)

Androniki Miltiadou-Fezans, Associate Professor (r), National Technical University of Athens

3.5.1 Investigation works - General

The investigation works are aimed at gathering data, which are necessary for assessing the capacity of the building.

The exploratory works carried out are divided into several groups, depending on the data obtained through them:

- **Locating and mapping invisible elements**
- **Material characteristics and method of construction**
- **Foundation soil, etc.**
- **Other factors**

Appropriate measurements and tests can be performed on site and/or in a Laboratory.
The choice of measurements and appropriate tests, should be made on a case-by-case basis, at the discretion of the Designer. However, to minimize uncertainties, it is recommended to cross-check the results of the measurements or tests.

When drawing up the program of investigation works, the Designer takes into account
- the importance of the building,
- its pathology,
- the type and methods of calculation that will be applied during the assessment and redesign.

Based on the results of the exploratory works, the Designer must justify the assumptions made, on the basis of which, the assessment and redesign will be performed, in accordance with Chapters 2 and 4 of this Code

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3.5.1 Investigation works - General

The Designer draws up the program of the investigation works, which are carried out by him/her, either under his/her supervision, or by laboratories recognized for this purpose. The supervision of the execution of the program and the evaluation of the results, is carried out by the Designer or another Engineer with the required qualifications.

Criteria for the selection of the sample size and the respective locations:
- **The intended level of data reliability.**
- **The representativeness of the samples or sampling locations.**
- **Local damage and potential decay**

The determination of the minimum number of sampling tests must be made in such a way, so that statistical processing and calibration are possible (see Ch. 3.10).

The importance of each structural member on the seismic capacity of the building should also be taken into account

Monuments and listed buildings:
- the sampling program must take into account the limitations that result from the historical/architectural value of the building.
- the sampling program should have the approval of the competent Authorities.

See in relevance "primary" and "secondary" members, according to §2.5.3.

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3.5.2 Documentation of materials and method of construction

It includes Technical Reports, Drawings and evaluation of results of on-site and/or laboratory investigations, which contain data on the following:

a) the construction materials of all structural members and their physical and mechanical characteristics, as well as the method of construction.

Specifically for masonry elements, the following are indicated:

(i) the type, shape, dimensions, way of carving and the way of arrangement and interlocking of the stones, as well as the degree of any erosion.

3.5.2 Documentation of materials and method of construction

(ii) the type and quality of the bed construction mortar and the mortar used for jointing (if applicable), the thickness of the mortar joints, as well as the state of preservation of the mortar (in terms of strength, hardness, disintegration, presence of decay, cracks or possible large internal voids, etc.),

(iii) the way of construction of the masonry along the thickness, the existence or not of transverse connections in two-leaf or three-leaf masonry and the characteristics of the filling material (percentage of mortar and small pieces of stones, cohesion of material, existence of voids and discontinuities, etc.).

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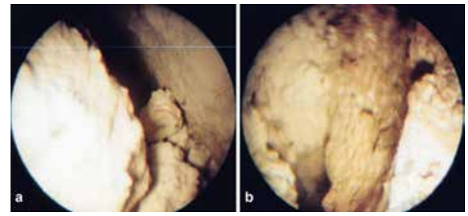
3.5.2 Documentation of materials and method of construction

(iv) the minimum nominal width of cracks-voids-discontinuities (W_{nom}), which characterizes the masonry and is necessary for the design of an adequate strengthening hydraulic grout and the percentage of voids and cracks to be filled.

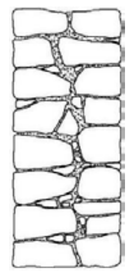
Coexistence of cracks and discontinuities of various widths: both large and very fine cracks are present



An estimation of the minimum nominal width of discontinuities W_{nom} is needed

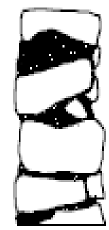
Three-leaf

Two-leaf



Πηγή: Ε. Τσακανίκα

One-leaf



Πηγή: Ε. Τσακανίκα

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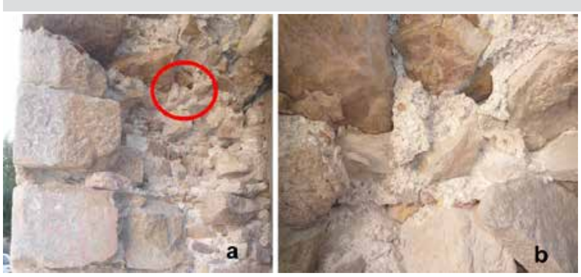
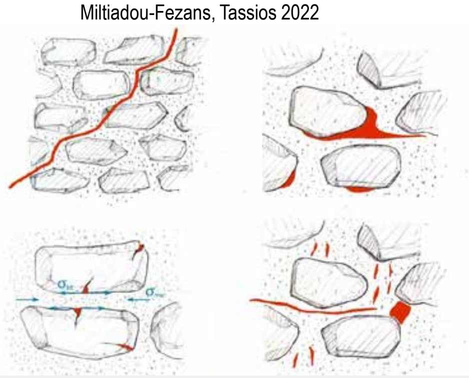
The importance of Wnom (minimum nominal width of voids)



Miltiadou-Fezans, Tassios 2022



There is many fine cracks and voids in the interior of masonry and **it is proved that** :

- **It is not necessary to fill "all" voids of masonry**
- **A considerable increase of the strength of masonry elements may be achieved after filling voids of a nominal minimum width of the order of 0,1-0,3 mm.**
- **Thus, strengthening of masonry is achieved, without preventing the masonry to breath**

- Moreover, through such fine cracks larger internal ones may be reached

The "minimum nominal width" of the cracks-voids-discontinuities of a masonry is estimated by the Engineer by using the results of the investigations, to be used in the design of the appropriate grout composition: the grout should be able to penetrate cracks and voids having a width greater than or equal to this width (see § 8.9.5, where a default value is also proposed =~ **0.25mm**).

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3.5.2 Documentation of materials and method of construction

(α)

(v) The elements used for masonry reinforcement, if existing (wooden or metal reinforcement, etc.)




(α)

(vi) the existence of horizontal or vertical tie beams of reinforced concrete, wood, steel, etc.



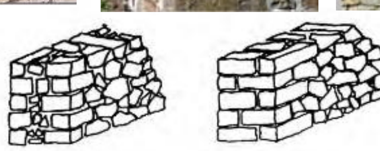

Πηγή: Ε. Δεληνικόλα

3.5.2 Documentation of materials and method of construction

(α)

(vii) the way the walls are connected and the condition of the connections (at the corners of the building in case of external walls, as well as at the point of contact of external with internal load-bearing walls etc.)



Τυπική διαμόρφωση αργολιθοδομής

Διαμόρφωση διασταυρώσεων αργολιθοδομών

Πηγή: Στυλιανίδης - Ιγνατάκης

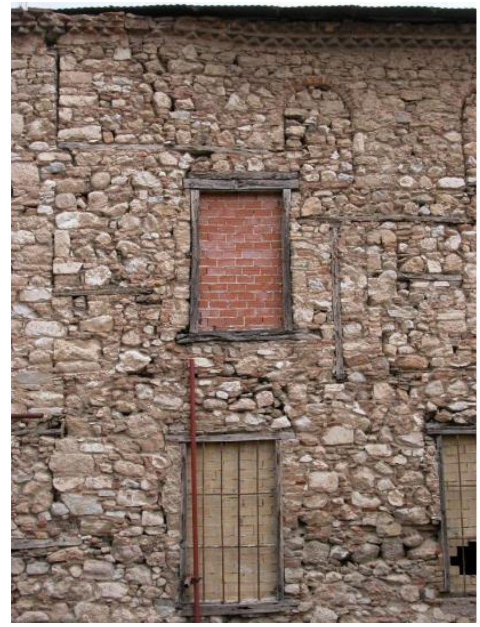


3.5.2 Documentation of materials and method of construction

(α)

(viii) the discontinuities in the vertical walls (walled openings, joints of different construction phases, etc.).

Πηγή: Καραγιαννακίδου, Μέρου, Κρεκούκια, άσκηση Βίνιανη Δ.Π.Μ.Σ. Προστασία Μνημείων, ΕΜΠ



Πηγή: Ε. Τσακανίκα

Πηγή: Στρατηγάκης, Διπλωματική, ΔΠΜΣ, Προστασία Μνημείων, ΕΜΠ

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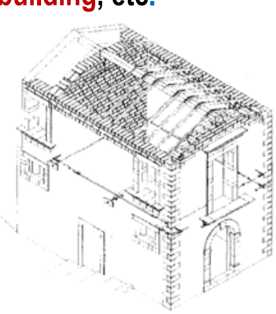
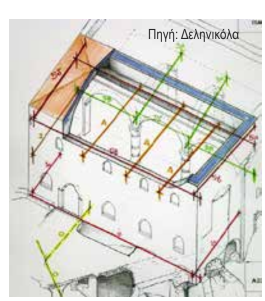
3.5.2 Documentation of materials and method of construction

(b) the location and size of the openings as well as the configuration of the lintel (material, dimensions, support on either side of the piers) as well as the rest of their framing (lintel, arch, pilars, etc.).

(c) other elements, such as steel ties at the origin of arches, at the level of the floors or at the corners of the building, etc.





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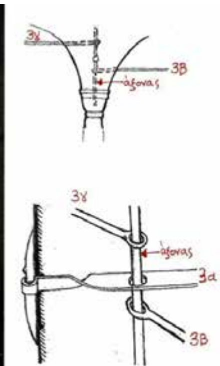
3.5.2 Documentation of materials and method of construction

(c) other elements, such as **steel ties** at the origin of arches, at the level of the floors or at the corners of the building, etc.

Πηγή: Δεληνικόλα



Λεπτομέρεια διασταύρωσης των ελκυστήρων των σταθμών 3α, 3β και 3γ.

3.5.2 Documentation of materials and method of construction

(d) **the type and characteristics of the floors and roof** and **their connections** to any existing horizontal tie beams and vertical elements, as well as **their state of preservation**.

Πηγή: Βερικάκη, Μπαρμπουνάκη, Τσιρώνη , Άσκηση Δ.Π.Μ.Σ. Προστασία Μνημείων, ΕΜΠ

Εικ. 75: Στέγη εσωτερική άποψη

Εικ. 77: Έδραση της στέγης στην ξυλοδεσιά

Εικ. 79: Λεπτομέρεια σύνδεσης ψαλιδιού με οριζόντια δοκό

Πηγή: Καραγιαννακίδου, Μέρου, Κρεκούκια, Άσκηση Δ.Π.Μ.Σ. Προστασία Μνημείων, ΕΜΠ

3.5.2 Documentation of materials and method of construction

e) the type and depth of **the foundation.**
(f) the type and characteristics of **the foundation soil.**

(g) invisible elements, such as steel ties, wooden ties or other tie beams, ducts, chimneys, etc....

Εικόνα Β66 Θέση συμβολής τόξων

Εικόνα Β67 Αγκύριο ελκυστήρα στη θέση συμβολής τα

Εικόνα Β65 Μη εμφανής ξυλοδεσιά σε σήψη

Πηγή: Π. Στρατηγάκης, Διπλωματική εργασία, Δ.Π.Μ.Σ. Προστασία Μνημείων ΕΜΠ

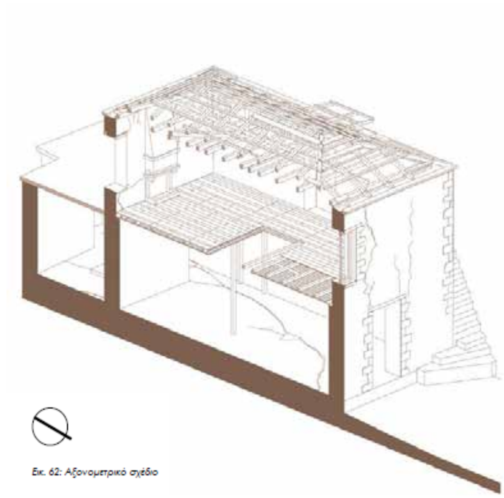
3.5.2 Documentation of materials and method of construction

(h) possible **previous interventions** in the building and the **estimated time of their implementation.**

(i) evidence of the **behaviour of the materials** in the past or that of **structural members**, the possible **failure mechanisms** and the **potential evolution of their current properties over time**.

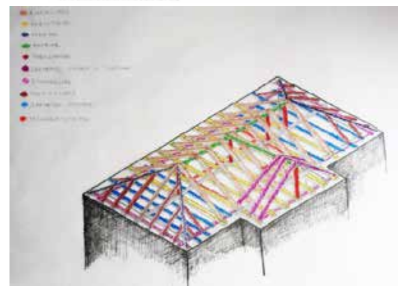
3.5.2 Documentation of materials and method of construction

All elements are drawn to a suitable scale depending on the detail required for the presentation of the data. 3D representations may be very useful



Πηγή: Καραγιαννακίδου, Μέρου, Κρεκούκια, Άσκηση Βίνιανη Δ.Π.Μ.Σ. Προστασία Μνημείων ΕΜΠ

Πηγή: Καραγιαννακίδου, Μέρου, Κρεκούκια, Άσκηση Βίνιανη Δ.Π.Μ.Σ. προστασία Μνημείων ΕΜΠ



Πηγή: Βερικάκη, Μπαρμπουνάκη, Τσιρώνη, Άσκηση Βίνιανη Δ.Π.Μ.Σ. Προστασία Μνημείων ΕΜΠ

The Technical Reports also include all the necessary supporting material (sketches, photographs, diagrams, etc.), which are used for the evaluation the documentation elements.

3.5.3 Documentation methods

The mapping of the load-bearing structural system, of the type and characteristics of the materials, as well as the behaviour of the building, result from on-site observation and measurements (either on-site or in the Laboratory), as is indicatively described in the following.

Usually a combination of simple and more sophisticated methods may be necessary, depending on the structure and its pathology

3.5.3.1 INSPECTION-VISUAL INVESTIGATION

3.5.3.2 IN SITU MEASUREMENTS BY USUAL MEANS

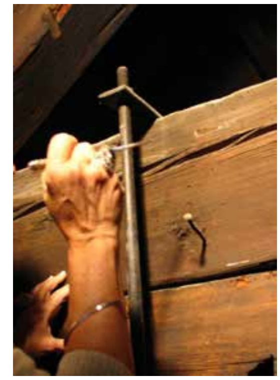
3.5.3.3 IN SITU MEASUREMENTS USING INSTRUMENT

3.5.3.4 LABORATORY MEASUREMENTS

3.5.3.1 Inspection-visual investigation

The inspection consists of the systematic observation and recording of information about the documentation of the load-bearing system, including its behaviour.

The inspection, repeated as many times as necessary to complete the information, is required regardless of the application of on-site and/or laboratory measurements.



3.5.3.2 In situ measurements by usual means

The mapping of the geometry, damage and wear, as well as the monitoring of their evolution over time, is carried out in principle or even exclusively through systematic measurements using a tape measure, spirit level and level thread.


5^A Κάτω Βίτσα ΖΑΓΟΡΙ 2018
Πηγή: Τσακανίκα

Androniki Miltiadou-Fezans, Associate Professor (r), National Technical University of Athens

3.5.3.3 In situ measurements using instruments

Depending on the size, importance and/or criticality of a building's condition, measurement methods are selected and applied using appropriate equipment.

Methods such as: topographic, photogrammetric, laser scanning, etc.

When visual inspection of hidden elements is not possible or when it is not allowed to reveal certain invisible areas of the building, one should:
(a) either apply on-site survey methods using appropriate equipment,
(b) or search for relevant information in other similar buildings (of the same area and period of construction), or in the literature
(c) ensure that the drawings clearly indicate either the lack of information, or the source of the data that are assumed within reason.

This is a fairly common case, when e.g.

(i) the building under consideration is declared as listed or monument,,

(ii) the identification of the required information would result into local or complete destruction of items, such as ceiling paintings, etc.,

(iii) the building is in use.

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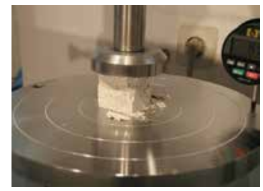
3.5.3.4 Laboratory measurements

Depending on the size, importance, use and condition of the building, laboratory measurements can include

- **simple measurements of physical, chemical and mechanical characteristics of materials**



- **testing models of a structural member, of a part or even of the entire building**


3.5.4 In situ investigation works

Depending on the size, importance and/or the criticality of the condition of the building, and depending on the objective of the investigation, one or more of the following on-site investigation techniques may be applied (listed below, ranked by the investigation objective:

3.5.4.1 IDENTIFICATION OF MASONRY WAY OF CONSTRUCTION ON ITS FAÇADES

3.5.4.2 IDENTIFICATION OF MASONRY WAY OF CONSTRUCTION ALONG ITS WIDTH

3.5.4.3 LOCATION OF HORIZONTAL TIE BEAMS IN MASONRY

3.5.4.4 IDENTIFICATION OF HOW THE WALLS ARE CONNECTED BETWEEN THEM

3.5.4.5 IDENTIFICATION OF CONSTRUCTION PHASES, DISCONTINUITIES, ETC.

3.5.4.6 IN SITU MEASUREMENT OF COMPRESSIVE STRESS IN CRITICAL REGIONS

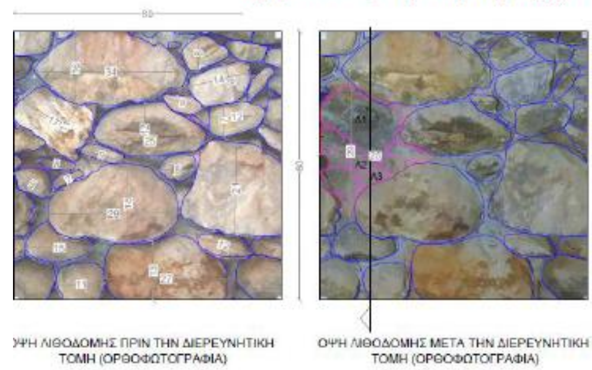
3.5.4.7 FOUNDATION SOIL

3.5.4.8 OTHER FACTORS

3.5.4.1 Identification of masonry way of construction on its façades

Local removal of the renderings in characteristic positions, observation and recording of the necessary data

Σχήμα Β8 Θέση διερευνητικής τομής Ι



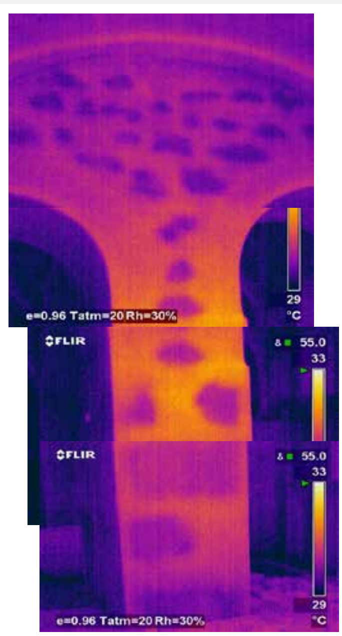
Σχήμα Β9 Όψη λιθοδομής πριν και μετά την διερευνητική τομή Ι

Πηγή: Π. Στρατηγάκης, Διπλωματική εργασία, Δ.Π.Μ.Σ. Προστασία Μνημείων ΕΜΠ

Map the outline of the stones on a representative surface (approximately 1X1m2), and estimate the average width of the horizontal mortar joints and the average height of the stones and the average volume of the mortar as a percentage of the volume of masonry in this location.

3.5.4.1 Identification of masonry way of construction on its façades

When the masonry is plastered but local removal of the plaster is not permitted, the thermography technique can contribute to clarify the way in which the masonry is structured along its faces



In the case of monuments or listed historic buildings the renders and plasters may have decorative elements to be preserved; the application of thermography and/or other non-destructive techniques is needed.

3.5.4.2 Identification of masonry way of construction along its thickness

With careful visual observation :

(a) In parts with local collapsed or damaged areas.

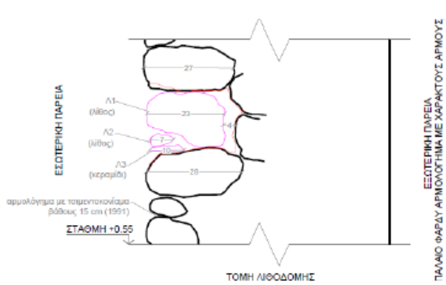
(b) After local removal of the casements around some openings of the building

(γ) After careful removal of a small number of stones or bricks on the one face of the masonry, observation of its interior and mapping of the way of construction along its thickness. Subsequently, the removed stones are carefully restored back to their initial position. The same procedure is repeated from the other face of the masonry

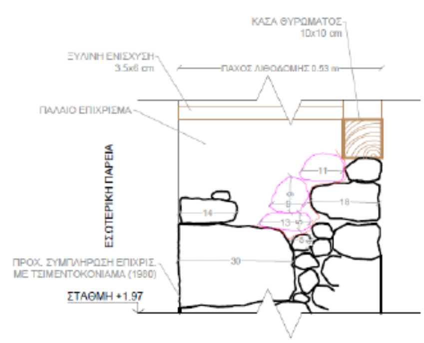
Documentation is sought of the number of leaves and their respective thicknesses, the existence of stones that fully or partially cross through the thickness of the wall, the existence or not of filling material, etc. The materials that compose the filling material and the existence of voids and discontinuities are also recorded.

3.5.4.2 Identification of masonry way of construction along its thickness

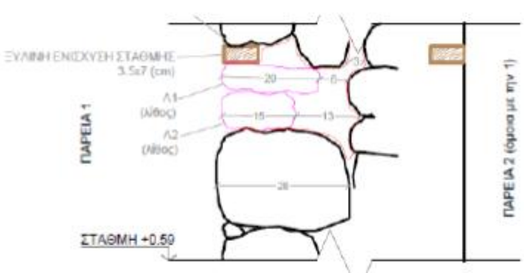
Example of careful removal of a small number of stones or bricks on the one face of the masonry, observation of its interior and mapping of the way of construction along its thickness



Πηγή: Π. Στρατηγάκης, Διπλωματική εργασία, Δ.Π.Μ.Σ. Προστασία Μνημείων ΕΜΠ



Σχήμα Β15 Αποτύπωση λιθοδομής διερευνητικής τομής ΙΙΙ



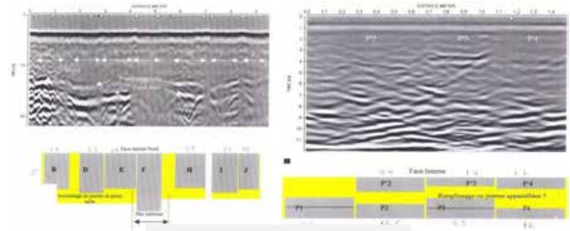
Σχήμα Β13 Αποτύπωση λιθοδομής διερευνητικής τομής ΙΙ

CHECK: the number of leaves and their respective thicknesses, the existence of stones that fully or partially cross through the thickness of the wall, the existence and quality of filling material, etc.

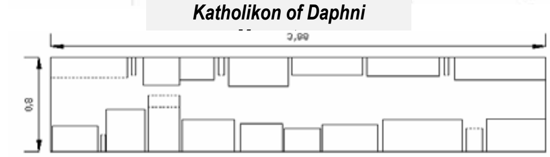
3.5.4.2 Identification of masonry way of construction along its thickness

(d) Alternatively, cores are taken at representative locations and the way of construction is observed along their length.

(e) In case that it is not possible to apply (a) to (d), then the determination of the way of construction along the thickness is complemented by means of radar and endoscopies, as well as by sound-based methods, especially sound tomography.



Katholikon of Daphni



These techniques are usually applied to buildings of great historical/architectural value

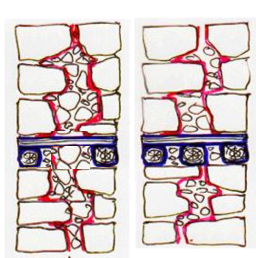
(f) In addition to cases (a) to (d), in case that the building belongs to a historical settlement with practically uniform construction, then data from other neighboring buildings can be used.

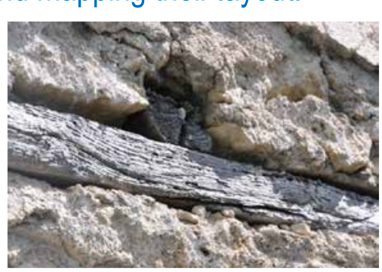
Tower of Pisa

ΠSource: Prof. Macchi

3.5.4.3 Location of horizontal tie beams in masonry

(a) When timber or metal tie beams are placed on the faces of the masonry and the masonry is uncoated, the tie beams are visible along the length of the masonry elements, together with the transverse wooden or metal elements: limited investigation is only required for measuring the dimensions of the horizontal tie beams and mapping their layout.



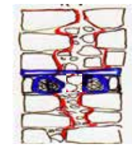


If the masonry is coated, local plaster removal is required to collect the necessary data.

In case it is not possible to partially remove the coating (e.g., in a building that is in use or in a building classified as a monument or listed), an investigation with the methods mentioned in § (b) is required. στην παράγραφο (β).

3.5.4.3 Location of horizontal tie beams in masonry

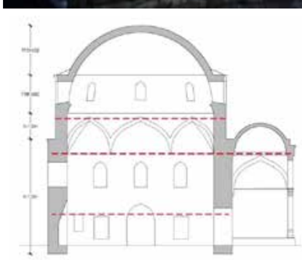
(b) **Invisible reinforcements**: the presence of tie beams cannot be identified on the faces of the masonry, then an investigation is required for finding the possible location of horizontal tie beams within the masonry body and identifying their dimensions (Observations through scaffolding holes, behind layers of small stones or bricks ,...).



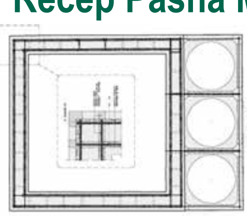
Source: Bureau of structural studies Epilysi Papathanasiou

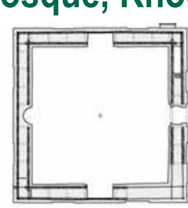
3.5.4.3 Location of horizontal tie beams in masonry

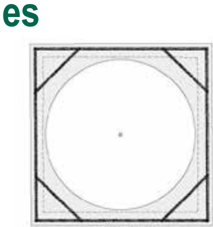
(i) With local removal of some stones of the external and internal leaf of masonry, if this is permitted by the way of construction .



Recep Pasha Mosque, Rhodes



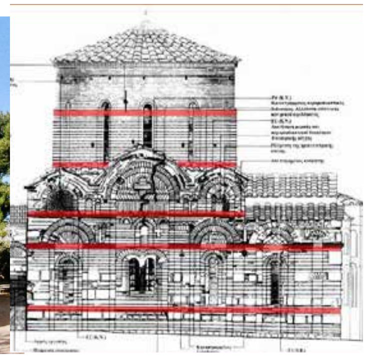


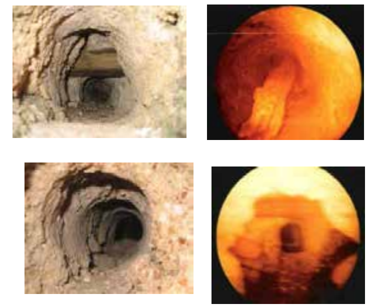


Επιστημονική Επιτροπή για την αποκατάσταση των Μνημείων της Ρόδου, ΥΠΠΟΑ.
Ομάδα Μελέτης: Γ. Κίζης, Γ. Ντέλλας, Ε. Παπαγεωργίου, Α. Παπαθανασίου, Α. Ζαγκότσης, Α. Μιλτιάδου-Fezans, Α. Καλαγρή

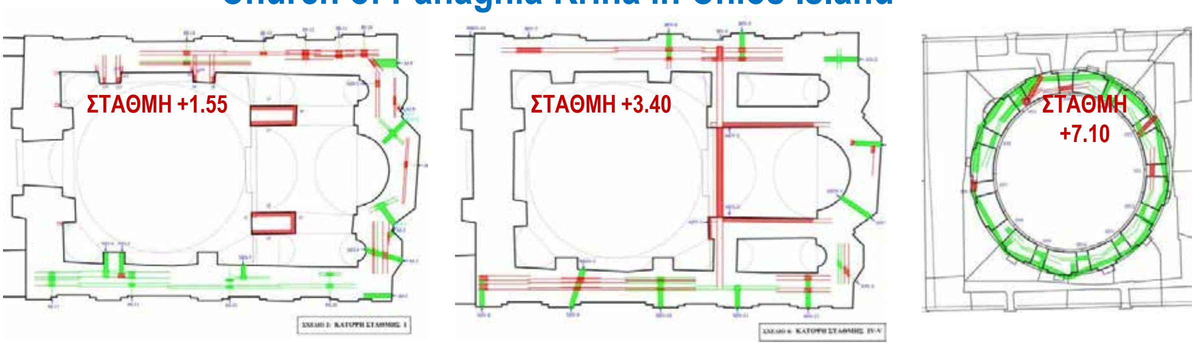
3.5.4.3 Location of horizontal tie beams in masonry

(ii) In some cases by means of radar or endoscopy.





Church of Panaghia Krina in Chios Island



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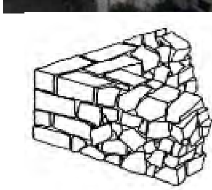
3.5.4.4 Identification of how the walls are connected between them

After the local removal of the render across a suitable surface area, both at the internal and the external face of the walls, a plan is drawn up for structuring the examined areas, based on the visible dimensions of the stones and given the thickness of the intersecting walls.

In cases where it is deemed by the process that there is no connection between intersecting walls by means of interlocking stones, the way of structuring should be identified in the ways described in § 3.5.4.2

In many cases, the connection areas of vertical elements of three-leaf masonry have a core with filling material. This is probable in case of walls with a large thickness (>0.60m approximately).



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3.5.4.4 Identification of how the walls are connected between them

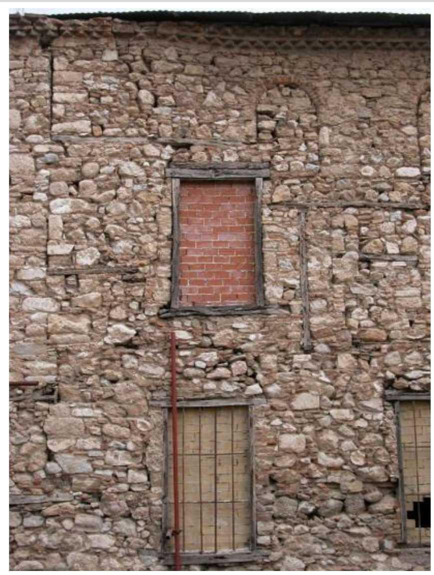
In the case of buildings, in which local removal of coating is not possible, the following can be applied:

(a) The geometry of the stones on the faces of the masonry is identified through thermography, and then the procedure of the previous paragraph is followed.

(b) If it appears from such an investigation that the construction is not solid, then the provisions in § 3.5.4.2 are followed.

3.5.4.5 Identification of construction phases, discontinuities, etc.

In the case renders are not present or when it is possible to remove the renders, careful visual observation is sufficient to locate these elements.



Source E. Tsakanika

When the masonry is rendered and it is not possible to remove the renders, the identification of the construction phases or discontinuities, etc. can be assisted by the application of thermography.

In any case, the effective and economical application of thermography presupposes that the history of the building has been studied and there will be evidence for the few positions in which the investigation should focus

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3.5.4.6 In situ measurement of compressive stress in critical regions

In cases of critical or important for the capacity of the building regions or structural members, it is possible to measure the compressive stress under which the area or member is located, through the method of flat jacks.

The method can only be trusted under certain conditions and is applied based on the following relevant RILEM recommendations:
(a) RILEM Recommendation MDT. D. 4: In-situ stress tests based on the flat jack, and
(b) RILEM Recommendation MDT. D.5: In-situ stress-strain behavior tests based on the flat jack..

ISMES, Restauro edilizio e monumentale, 1990

ATTENTION! Information only regarding the external leaves

Source: E. Vintzileou

3.5.4.7 Foundation soil

If a previous geotechnical investigation is available and there is no evidence of foundation failure, no new investigation is required.

Special attention is required in cases where there is a suspicion of failure of the existing building foundation

Σε κάθε άλλη περίπτωση, ακολουθούνται οι απαιτήσεις του Πίνακα 3.1

Preexisitng Geotechnical Investigation	Previous foundation behaviour	Intervention that causes additional actions on the soil (1)	Need for new geotechnical investigation
Available	Poor		Yes
Not available	Good	No	No
		Yes	Yes
	Poor		Yes

(1) When soil stresses are increased by more than 20% in at least one foundation element.

With reference to the type of the Geotechnical Investigation, the applicable regulatory provisions concerning the design of new constructions apply.

3.5.4.7 Foundation soil

When, during the assessment or redesign, soil-structure interaction is taken into account, according to the provisions of Chapter 5, and as long as there is no sufficient Geotechnical Investigation (GI) available, a GI is performed (either new or complementary) as per Engineer's judgment.

This provision applies regardless of whether the intervention causes additional actions on the soil.

The values of the design soil parameters, for building of importance I and II (γ_I=0,80 ή 1,00) according to EC8-1, Van be taken by the literature, on the basis of the description of soil layers which influence the foundation

The wider knowledge of the soil conditions is necessary for its classification according to EC 8-1.

In cases where soil characteristics are not known from Geotechnical Investigation, parametric analyses are recommended, using reasonable maximum (upper bound) values of deformability.
The cases of buildings with a basement along its entire footprint without signs of problems are excluded.

The supporting conditions of the building consist an important factor of rigor for the analysis of the superstructure.

3.5.4.8 Other factors

In special cases, other factors may affect the capacity of the building, such as:

- The natural environment
- The vicinity to other structures or underground works
- The operation of machinery, etc.,

These factors need to be evaluated.

3.6 In situ measurement of strength of materials

In addition to the measurement of the strength of materials by means of laboratory tests on specimens, the following can be complementary applied to estimate the material strength on site.

However, due to lack of calibration data, the application of these techniques in situ cannot replace the sampling to form specimens and the measurement of the mechanical characteristics in the laboratory.

In this way, it is possible to perform measurements in more places and hence increase the degree of reliability of the acquired data, provided that the on site measurements are properly calibrated.

3.6.1 COMPRESSIVE STRENGTH OF STONES

3.6.2 COMPRESSIVE STRENGTH OF BRICKS

3.6.3 COMPRESSIVE STRENGTH OF MORTAR

3.6.4 STRENGTH OF TIMBER

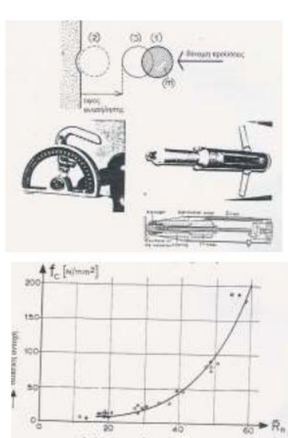
3.6.5 STRENGTH OF METAL

3.6.6 MECHANICAL CHARACTERISTICS OF MASONRY

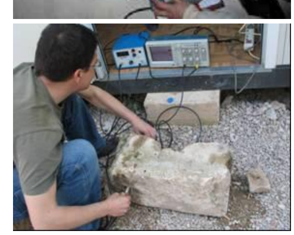
3.6.1 Compressive strength of stones

The compressive strength of the stones can be estimated by applying the impact test using Schmidt hammer, as well as the ultrasonic and sonic methods in general.

In order for Schmidt hammer impact tests to be useful, data calibration should be available (by means of laboratory tests), which are obtained through (i) application of Schmidt hammer impact tests to stone samples in the laboratory and (ii) loading of the samples until fracture. Thus, there is a correlation between the measurements resulting from the indirect and the direct method.
The use of respective correlation curves from the literature is not recommended.
The above also applies to the case of sound methods in general.



Tassios, Mamillan (1985)



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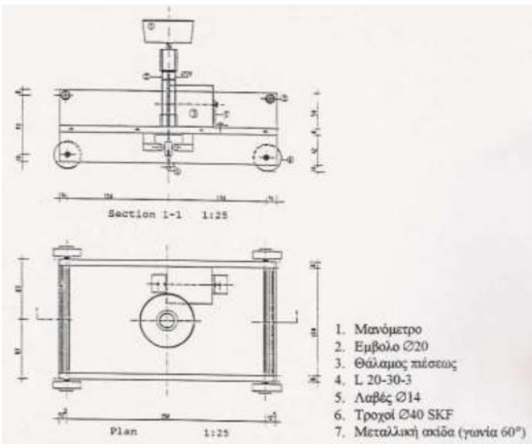
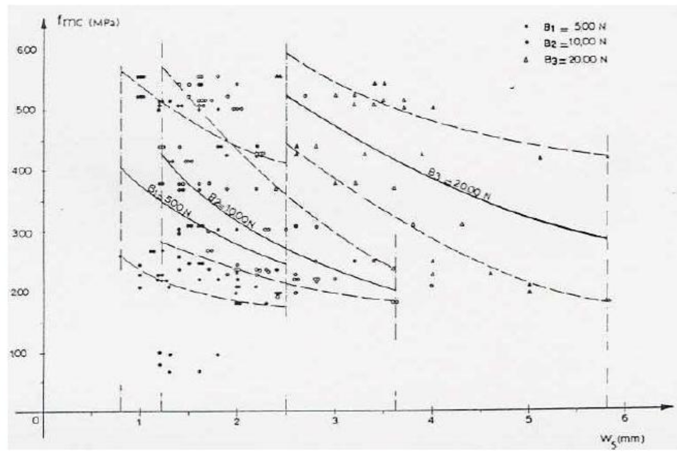
3.6.2 Compressive strength of bricks

In the case of stones with low strength or in the case of bricks, the engraving or scratch method can be applied..

The description of the method should be sought in the peer-reviewed literature.





Tassios, Vachliotis, Spanos

3.6.3 Compressive strength of bricks

The compressive strength of the mortar can be measured in situ by scratch or penetration techniques

The description of the methods should be sought in the peer-reviewed literature
. In both cases, it is necessary to have laboratory calibration data available, as indicatively described in the commentary of § 3.6.1.

A relevant recommendation for the penetration test has been drafted by the Technical Committee of RILEM TC177MDT: The penetration test with a special drill.

The following two recommendations of the Technical Committee of RILEM TC127MS Tests for masonry materials and structures are also mentioned:

(a) MS-D.7: Determination of pointing hardness by pendulum hammer,

to estimate the hardness of mortar used in stone working, and

(b) MS-D.9: Determination of mortar strength by the screw (helix) pull-out method, to estimate the quality of the mortar and its strength after appropriate calibration.

3.6.4 Strength of timber

The strength of wooden members is assessed for each member separately, after detailed on-site observation and visual grading based on physical defects and pathology.

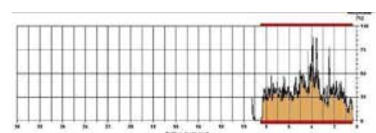
Strengths vary according to the stress state of the member in the building (bending members, members in compression or tension in parallel or perpendicularly to the fibers etc).

Where required, the above classification in terms of resistances is supplemented by the application of non-destructive or minor destructive methods (such as measurements with a resistograph, ultrasound, etc.).

The process and the on-site methods are described in documents prepared by the RILEM Technical Committee AST 215 "STAR 215 AST, In-situ assessment of structural timber", as well as in other peer-reviewed literature..

Roof of Aghia Paraskevi Chalkidas. Research Program of Hellenic Ministry of Culture –National Tecnical University of Athens –Politecnino de Torino



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3.6.5 Strength of metal

The on-site measurement of the hardness of the metal permits the approximate estimation of its strength.

For this purpose, calibration data is needed along with knowledge of the characteristics of the metals used during the period the building was constructed.

An important element that needs to be additionally considered in situ is the weldability of the old metal elements.

Androniki Miltiadou-Fezans, Associate Professor (r), National Technical University of Athens

3.6.6 Mechanical characteristics of masonry

On-site measurement of the mechanical characteristics of masonry can be performed through the following methods

(a) By the method of flat jacks. This method can only be trusted conditionally and therefore the decision to apply, as well as the evaluation of its results, must be made by a qualified Civil Engineer.

The description of the method should be sought in the peer-reviewed literature. The relevant recommendations of RILEM MDT are mentioned.
D. 4: In-situ stress tests based on the flat jack and RILEM Recommendation MDT.
D.5: In-situ stress-strain behavior tests based on the flat jack. Conditionally, this test can also provide information on the modulus of elasticity as well as the transverse expansion ratio of the masonry.

When the flat jack method is applied to three-leaf masonry, it provides data solely for the masonry wall faces.

((b) By cutting out masonry "specimens" and subjecting them to compression or diagonal compression in the laboratory, upon suitable instrumentation.

This method cannot be used in the case of constructions which are declared as monuments or listed buildings, due to its highly destructive nature..

3.7 Monitoring the behaviour of the structure

When the aim is to establish that the damage observed in a building do not evolve in time, or when there are indications that they deteriorate in time, then appropriate instruments shall be placed on the structure and/or in its immediate environment (e.g. on the ground), in order to monitor its behavior for an appropriate period of time.






Evolution of the technology regarding the instrumentation.
May solutions in the market

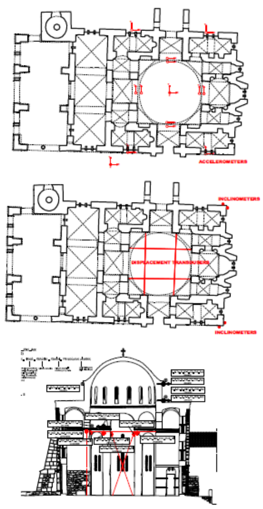
The decision on the measurement locations, the type of measurements to be made (crack width, deviation from the vertical, etc.), as well as the duration of the monitoring scheme is made by the Civil Engineer.

The selection of these data is based on the knowledge about the building, as well as on the qualitative (at least) interpretation of the observed damage

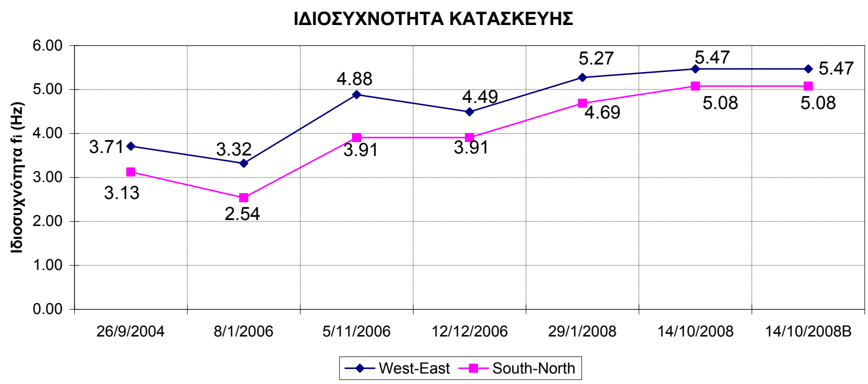
3.7 Monitoring the behaviour of the structure

In case of important buildings (from an architectural/historical point of view), as well as in case of complex structural systems, it may be necessary to install a comprehensive instrumentation system for monitoring the building over a long period of time. In case of important monuments, this system is recommended to remain in operation even after the completion of the interventions, in order to collect data that allows to evaluate the effectiveness of the interventions and to take - if necessary - corrective measures.

Katholikon of Daphni Monastery



Research program with the collaboration of Hellenic Ministry of Culture and the National Technical University of Athens



3.8 Laboratory tests

Laboratory tests can include a wide variety of measurements of physical, chemical and mechanical properties at a material level, or at a member level, part of the structure or even at the level of a scaled model of the entire building.

The type and number of tests, as well as the size and complexity of the specimens depend on the importance, the condition of the building, its size, its use, etc.

The tests related to the mechanical behavior of the structures are the following:.

3.8.1 MEASUREMENT OF THE MECHANICAL PROPERTIES OF BLOCKS

3.8.2 MEASUREMENT OF THE MECHANICAL PROPERTIES OF MORTARS

3.8.3 MEASUREMENT OF THE MECHANICAL PROPERTIES OF TIMBER, METAL, ETC.

3.8.4 MEASUREMENT OF THE MECHANICAL PROPERTIES OF MASONRY

3.8.5 TESTS OF STRUCTURAL COMPONENTS, CONNECTIONS BETWEEN STRUCTURAL MEMBERS ETC..

Androniki Miltiadou-Fezans, Associate Professor (r), National Technical University of Athens

3.8 Laboratory tests

The chemical and mineralogical properties of materials affect the behavior of buildings over time and, therefore, the development of damage. On the other hand, the determination of the chemical properties of the materials in question is useful (or even necessary) for the design of intervention materials, so that they are compatible, from a physicochemical point of view, with the existing ones.

For the characterization of old mortars, the recommendations of RILEM TC COM 167 "Characterization of Old Mortars with Respect to their Repair: State-of-the-Art Report" are deemed useful.

3.8.1 Measurement of the mechanical properties of blocks

The measurement of the compressive strength, the tensile strength, the flexural strength, as well as the modulus of elasticity of the stones and bricks is carried out through corresponding laboratory tests on samples which are formed

- ✓ **either from stones taken from the building,**
- ✓ **or from the products of cores taken,**
- ✓ **or from stones of the same origin, which may be found in the surrounding area of the building.**

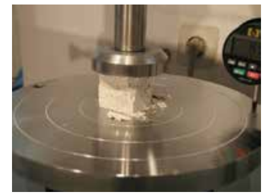
As a result, these specimens are either cylindrical or prismatic in shape and of varying dimensions..

In some cases, if the quarry of origin of the stones of the monument is known, additional testing of stones from that quarry is possible.

3.8.2 Measurement of the mechanical properties of mortars

Where possible, test specimens are formed to measure the compressive strength.

Care is taken so that the mortar used in construction that will be detached from the building for the experimental investigation are taken from the interior of the structural members and are not weathered.



In any case, however, the pieces of mortar that are taken from the building are irregular and of small dimensions. For this reason, as well as due to the low strength of mortar in many buildings, it is not possible to form prismatic or cubic specimens in the laboratory, in order to measure the compressive strength of the mortar.

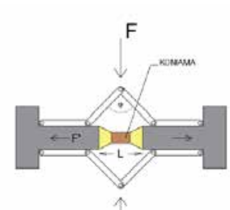
In the case of joints with small thickness, the following recommendation is applied: RILEM Technical Committee TC 167 COM.2: Compression tests on sampled joints.

3.8.2 Measurement of the mechanical properties of mortars

To measure the tensile strength of the mortar, it is recommended to apply the fragment method..

The method is described in the peer-reviewed literature.

Εικόνα Γ3 Δείγματα κονιαμάτων θέσης Ι



Πηγή: Π. Στρατηγάκης, Διπλωματική, Δ.Π.Μ.Σ. Προστασία Μνημείων ΕΜΠ

Εικόνα Γ7 Τοποθέτηση στη μηχανή θλίψης

Two additional tests are proposed by RILEM to measure the tensile strength of mortar:

(a) in case of 30-40mm thick joints "Indirect tensile strength" as drafted by the RILEM TC 76 LUMA.3 for bricks with holes and

(b) in case of thin joints "Splitting test for new and on site sampled old mortars", issued by RILEM TC 167 COM.

The use of the point load test method is also suggested in the literature for irregularly shaped specimens. The test gives a measure of tensile strength. The results can also be related to the compressive strength. It is noted, however, that in order for the measurements obtained through point loading to be usable, calibration data should be available for low-strength materials, such as old mortars.

Androniki Miltiadou-Fezans, Associate Professor (r), National Technical University of Athens

3.8.2 Measurement of the mechanical properties of mortars

The tensile strength of the mortar allows a rough estimate, based on the literature, of its compressive strength

Besides, to be able to estimate the compressive strength of the mortar based on its measured tensile strength, the composition of the mortar should be known. In particular, it is useful to approximately determine, by means of chemical analysis, the type of binder powder, as well as its ratio to the aggregates

However, the reduced reliability when estimating the compressive strength of the mortar does not significantly affect the results of the load-bearing capacity tests, as the participation of the strength of the mortar in shaping the mechanical characteristics of the masonry is limited, and it manifests itself more in terms of tensile rather than compressive strength.

In the event that the mortar is particularly fragile and therefore it is not possible to form a specimen to measure its tensile strength, the Design Engineer may adopt a very low compressive strength value, as defined in § 3.10.5.1(d1) (vi) and in the Annex of Chapter 3

3.8.3 Measurement of the mechanical properties of timber, metal, etc.

The measurement of the mechanical characteristics (compressive strength, tensile strength, modulus of elasticity, etc., as the case may be) is carried out on samples taken from the respective materials on site.

In case of timber, material anisotropy, the direction of the fibers, presence of defects, moisture etc. should be considered during sampling. Also, the sampling must be representative and taken from appropriate locations based on on-site observations and the assessment of the existing situation. It should be noted that, in any case, the results of strength measurements of wood samples are complementary data of the visual grading, which, as mentioned above in § 3.6.4, takes into account the factors that primarily define the strength of timber (natural defects, pathology etc). The methodology is described in peer-reviewed literature.

3.8.4 Measurement of the mechanical properties of masonry

If this is deemed necessary, and if all the required data is available, masonry specimens are constructed in the laboratory, from the testing of which the strength and deformability characteristics of masonry are derived.

The construction materials of the specimens are of the same or similar characteristics as those of the in situ materials. During construction, the method of construction (in terms of faces and in terms of thickness) which has been established on site is followed precisely.

The responsibility of designing the tests, as well as evaluating the results, rests with the Design Civil Engineer.

3.8.5 Tests of structural components, connections between structural members

Laboratory tests may be performed, where appropriate, to study the behavior of connections in wooden or metal roofs, or connecting walls to each other, to floors or the roof, etc..

As these tests cannot be standardized, their design (as well as the evaluation of their results) must be performed by the Designe

3.9 Tests on scaled models of buildings

In cases of buildings listed as monuments, it is possible to build models and carry out tests (e.g. in a shaking table), with the aim to assess the monument, as well as to study the influence of various methods of intervention.

Tests on structural models are also recommended in the case of buildings that have suffered partial collapse and for which it is requested to establish whether they can remain intact or require additions

3.10.1 Data Reliability Level (DRL) - General

In existing structures, the numerical values of the data that are considered in the assessment and redesign may be associated with more significant errors than in the case of new structures

In case of buildings that are declared monuments or listed, the restrictions on the implementation of on-site investigative work and tests may lead to increased deviations of the estimated values from the actual mechanical characteristics in place..

The Data Reliability Level (D.R.L.) concerning actions or resistances, expresses the adequacy of the information about the existing building, and is taken into account during the assessment and redesign.

The D.R.L. it is not defined based on the dispersion of the results of the exploratory works. This dispersion is already taken into account during the evaluation phase and affects the "representative" value of each size.

D.R.L. it is not necessarily uniform for the entire building. Partial D.R.Ls. are determined for the various parts of the building. For the selection of the analysis methods of Chapter 5, the most unfavorable of the individual D.R.Ls.

The concept of D.R.L. is also applied for the completeness of the mapping of the load bearing structural system, especially in case of invisible structural members. The effects of uncertainty may be considered in actions or resistances as appropriate

3.10.2 Categories of Data Reliability Level (DRL)

Three categories of data reliability levels are distinguished:

A. "High"

B. "Satisfactory"

C. "Tolerable"

D.R.Ls. correspond to Knowledge Levels (KL) 1 to 3 (Limited, Normal, Full) as per new generation EC8-3 (§ 3.3)

For the case of monuments and listed buildings, the D.R.L. is defined by the relevant Public Authority.

In special cases the selection of the minimum D.R.L. is made in collaboration between the Engineer and the Authority.

3.10.3 Implications of D.R.L. On the assessment and redesign

Depending on the Data Reliability Level:

(a) Suitable safety factors γ_f are selected for some actions with uncertain values, in conjunction with appropriate factors γ_{Ed} (see §4.5),(α)

b) The appropriate safety factors γ_m are selected for the existing materials along with the suitable factors γ_{Rd} (see. § 4.5).

Such may be the case of representative values of certain indirect actions (i.e., active or passive pressures), as well as the weight of hard-to-reach overlays (such as fill materials over the domes' exterior).

In certain cases of increased uncertainty (and when it is estimated that the influence of the amplitude of the respective action is significant), the consideration of two "reasonable extreme" representative values ($E_{k,min}$ and $E_{k,max}$) is recommended.

Material data imply the thickness of the elements, the mechanical characteristics of the stones, mortars, wooden and metal elements (if they exist), as well as the way of construction of the masonry in three dimensions (along its length, width and height), the way the elements are connected to each other, and other factors that control the resistances.

3.10.4 Criteria for determining the DRL

The consequence of the established D.R.L. for each piece of data will be treated with corresponding handling provisions in the design of the relevant structural member.

The D.R.L. for the mechanical characteristics of the materials is determined in the subsections of 3.10.5

3.10.5 Minimum investigation requirements - Evaluation of results – Definition of DRL

3.10.5.1 Tolerable Data Reliability Level

(a) Mapping of the structural system.

General construction drawings are required to be available, as well as sketches of:

(i) the way of construction of the masonry along its faces and its thickness, including the possible existence of horizontal tie beams,

(ii) the configuration of vertical connections at the corners and wall intersections,

(iii) the way of construction at the framing of openings and lintels,

(iv) the basic elements that form the roof and floors of the building, so that their in-plane stiffness can be roughly estimated,

(v) how the horizontal elements are connected to the vertical ones, so that the effectiveness of the connections can be assessed.

3.10.5.1 Tolerable Data Reliability Level

(b) Construction history.

Simple documentation of data and information, provided by the Project Owner, as well as brief reference to any modifications that took place during the life cycle of the project (according to § 3.3), are deemed to meet the requirements for this D.R.L.

(c) Documentation of decay and damage.

An approximate documentation of decay and damage is deemed sufficient: on the general drawings of the load bearing system body and on special sketches of the Engineer's choice, accompanied by characteristic photographs.

The approximate documentation of damage is the sketching of cracks (by location), as well as the rough estimate of their width. With persistent visual observation, the existence of any cracks in joints (horizontal and vertical) will be sought and will be noted on the sketches. Next, an assessment will be made (without any detailed mapping) of any deviations of load-bearing elements from the vertical, etc., by rough measurements with simple means, in the context of the general mapping of the building.

3.10.5.1 Tolerable Data Reliability Level

d) Documentation of materials and way of masonry construction

d_1) Documentation of materials

In cases of buildings of low importance [importance category I or II] that have small size (with a total floor area up to approximately 100 sq.m). and with a maximum of two storeys above the basement, and provided that there are no issues of poor workmanship, decay or damage etc., reliable results of previous quality control processes may be used to document the strength of the materials. When these are not available, as an exception, it is possible to use “default” representative strength values of materials in accordance with the Annex of Chapter 3, on the basis of thorough visual inspection as per the type of stones and mortar as well as their condition in the various areas of the building (see Commentary of [d1 (i)].

The possibility of using default values does not apply whatsoever, in case of a building declared as a monument or listed, irrespectively of its size or use.

The «default» values are **conservative.**
Therefore, in case where they lead to the need for extensive interventions, which are not justified based on the pathology of the building, the provisions of paragraphs 3.10.5.1 d1(i, ii, iii, iv) apply instead.

3.10.5.1 Tolerable Data Reliability Level

d) Documentation of materials and way of masonry construction

d_1) Documentation of materials

i. **A detailed visual inspection of the stones and the mortar is necessary to facilitate the initial determination of their type and condition of preservation in the various areas of the building.**

For natural blocks (stones), their geological type shall be assessed macroscopically, by examining whether (and how) the stone is fractured using a geological hammer and whether it is engraved with a knife (see Table P3.1 of the Appendix of Chapter 3). Any areas where the stones are not healthy and are discolored, decomposed or fractured will also be identified so that the Engineer shall include such stones in the sampling or take reduced values for the strength of stones compared to those that will have resulted from the tests or, exceptionally, from the use of the default values (see Table T3.2 of the Appendix of Chapter 3).

For the artificial blocks, the Engineer should identify category in which they belong, among those that are usually met in old existing masonry (as they are presented in more detail in the Appendix of Chapter 3) i.e., clay bricks or the cement blocks

For modern artificial blocks, one can also make use of the classification scheme mentioned in EC6.

Based on these observations and his/her own experience, the Engineer will determine the sampling locations to be used for the tests of the artificial stones or, exceptionally, will obtain the appropriate default values (see Table T3.3 of the Appendix of Chapter 3).

3.10.5.1 Tolerable Data Reliability Level

Bed mortars and jointing mortars, examine :

- **Vissually the general category in which they belong will be identified (clay mortars, lime mortars, lime-clay mortars, lime-pozzolan mortars, lime-cement mortars, cement mortars)**
- **By means of contact, friction, and compression with the hand or scratching with a sharp object, the Engineer will assess if they are hard, moderately hard, friable or crushed.**
- **Using simple means their permeability will also be examined (almost impermeable, moderately permeable, permeable).**

All of these information and data will be taken into account by the Engineer to characterize the mortar as very strong, strong, moderately strong and weak.
Their preservation condition across the structure will also be examined in terms of the presence of different colors and moisture, corrosion, cracks or any internal voids, etc.

Based on these observations and his/her experience, the Engineer will determine the sampling locations for the tests or, exceptionally, obtain the appropriate default values (see Table T3.4 of the Appendix of Chapter 3).

3.10.5.1 Tolerable Data Reliability Level

ii. It is deemed sufficient to take three stones and three pieces of mortar from the prevailing type of masonry and from suitable representative locations, in order to form specimens and measure their mechanical characteristics in the Laboratory.

Alternatively, respective specimens may be obtained by taking three cores at suitable representative locations..

Η διάμετρος των πυρήνων: από 15-20 cm ή κατ΄ ελάχιστον 10 cm.

Iii When it is seen that many types of masonry are contributing in large percentages to the formation of the load-bearing system, the sampling and relevant verification checks must be repeated for all types

iv. If the construction is large, the number of samples should be such that 15% of the vertical elements (piers - walls) and 8% of the lintels are checked.

iv. If metal or wooden or reinforced concrete elements exist in the construction, it is deemed sufficient to assess the condition of these elements through careful visual inspection.

3.10.5.1 Tolerable Data Reliability Level

d_2) Documentation of masonry way of construction.

i. Along to the faces of the masonry (after removal of renderings if necessary)

- At least three places on both sides: check the way of construction of the prevailing type or for each essentially contributing type: visual documentation on surface of (~1m^2) on different structural members

- At least three places on both sides: check the way of construction of the corners of the building, the connections of the walls and the framing of the openings, the configuration of the lintel (material, dimensions, adequacy of support)

- At least three places : visually inspect the existence of horizontal tie beams at the level of the floors, at the stem of the walls as well as above and below the openings, from both sides

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3.10.5.1 Ανεκτή Στάθμη Αξιοπιστίας Δεδομένων

ii. Along to the thickness of the masonry

- **In the case that cores have been taken, the construction of the masonry can be roughly established by observing the core, in combination with the appreciation of the hole in the position from which it was taken.**

- **If cores have not been taken or the information of the cores is not sufficient : stones are removed from both sides at three places for the prevailing masonry type or for each essentially contributing one** § **3.5.4.2γ.**

- **In case it is not possible to remove stones from one (usually, from the inner) side of the masonry, then the provisions of § d2(i) apply, under the same restrictions.**

3.10.5.1 Tolerable Data Reliability Level

d_3) Documentation of foundation and foundation soil.

Provided that no building damage is identified that are attributed to the role of the foundation soil or to a deficiency of the foundations, it is acceptable to omit the relevant investigations

In the event that damage is observed and it is attributed to the foundation or the soil, then the provisions for satisfactory D.R.L. should apply.

3.10.5.1 Tolerable Data Reliability Level

(d$_4$) Documentation of horizontal floors or chambers, vaulted structures and roofs.

- By visual observation and/or exploratory cross-sections and on-site measurements are determined:
-
  α) at least one location per type of floor or roof or vault : the material and way of construction
  β) the distances of the load bearing beams of floors and roofs,
  γ) the section of at least one one rafter and one tie of a typical roof truss
  δ)) the section of at least one beam of a floor, or the thickness of a R.C. slab

- To determine the connections of the floors and roofs with the vertical walls, at least one investigation section is made on each floor together with one on the roof at the level of its support on the walls.

- For a large structure, the geometry, materials and construction method of 15% of the floors, domes and roofs shall be determined.

It is imperative to collect all the necessary data to assess the in-plane stiffness of the horizontal floors and roofs, as well as to identify the effectiveness of their connections with any tie beams and vertical elements..

3.10.5.2 Satisfactory Data Reliability Level

Additional data is needed apart from those included in Tolerable DRL:

- ✓ Detailed geometry of all visible elements
- ✓ Pathology on general drawing and sketches for details and photos
- ✓ Data for materials and way of construction, after checking in 30% of piers and 15% of spandrels, 30% of connections, lintels, tie beams, elements of roof, floor and vaults, etc..

Based on a rational combination of laboratory and in situ minor destructive methods.

3.10.5.2 High Data Reliability Level

Additional data is needed apart from to those included in Tolerable DRL:

- ✓ Detailed geometry of all visible and invisible elements
- ✓ Pathology on general drawing and detailed drawings and complete photographic survey.
- ✓ Data for materials and way of construction, after checking in 50% of piers and 25% of spandrels, 50% of connections, lintels, tie beams, elements of roof, floor and vaults, etc..

Based on a rational combination of laboratory and in situ minor destructive methods.

ANNEX ASSISTING THE ENGINEER FOR SELECTING DEFAULT VALUES FOR MATERIALS STRENGTH

TABLE WITH THE CHARACTERISASION OF THE INTACT ROCK IN THE FIEKD

Use of the Table of ISRM: International Society for Rock Mechanics

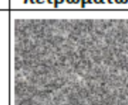
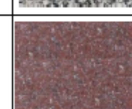
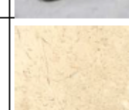
Table T3.1: Characterization of Intact Rock in the Field and Estimation of Compressive Strength (by ISRM 1981, reprinted from Tsiampaos, 2009, see footnote 1).

Characterization	Uniaxial Compressive strength (MPa)	In situ assessment of strength	Examples
Extremely strong	> 250	It does not break with a geological hammer	Healthy basalt, quartzite, diabase, gneiss, granite, flint
Very strong	100–250	It breaks after several blows with a geological hammer	Amphibolite, sandstone, basalt, gabbro, gneiss, granodiorite, peridotite, rhyolite, tuff
Strong	50–100	It breaks with more than one blow with a geological hammer	Limestone, marble, phyllite, sandstone, slate
Moderately strong	25–50	Cannot be craved with a knife. It breaks with only one blow with a geological hammer	Concrete, phyllite, slate, siltstone*
Weak	5–25	It is difficult to carve with a knife	Chalk, claystone, potash, marl, slate, mineral salt **
Very weak	1–5	Shatters with strong blows with a geological hammer. It is carved with a knife	Intensely defaced or weathered rock
Extremely weak	0,25–1	It can be carved with the fingernail	Rigid crack filler

Notes by the Drafting Committee of the present code
* Travertine is also classified in this category
** Porous sandstones, such as bioclastic limestones (biocalcarenites) and calcareous margaic/margaic sandstones found in Greece, such as e.g. the porous sandstone of Rhodes, Crete, Kefalonia. In the same category are the fossiliferous Margaic limestones, such as the shell stone.

TABLE WITH THE CHARACTERISTICS OF THE MOST COOMON GEOLOGICAL TYPES AND DEFAULT VALUES FOR OF STONES

Πίνακας Π3.2: Ενδεικτικές τιμές μηχανικών χαρακτηριστικών συνηθέστερων πετρωμάτων και ερήμην τιμές λιθοσωμάτων με βάση την επί τόπου οπτική παρατήρηση, εξέταση και κατάταξη του λιθοσώματος στις κατηγορίες του Πίνακα Π3.1 από τον Μηχανικό.

ΠΕΤΡΩΜΑ	Φαινόμενη πυκνότητα ρ (gr/cm³)	Αντοχή σε θλίψη (MPα)	Αντοχή σε εφελκυσμό (MPα)	Μέτρο ελαστικότητας E, (GPα)	Ενδεικτικές υφές πετρωμάτων	Ερήμην τιμή αντοχής σε θλίψη (MPα)
Γρανίτης	2,60 – 2,82	16 – 434	3 - 40	10 -77		Ισχυρό: 50 Μετρ. Ισχυρό: 25
Διορίτης	2,50 – 3,03	64 – 333	5 - 50	29 – 107		Ισχυρό: 50 Μετρ. Ισχυρό: 25
Πορφυρίτης	2,50 – 2,80	173 – 250	12 - 13	65 – 76		Ισχυρό: 50 Μετρ. Ισχυρό: 25
Ηφαιστειακός τόφφος	1,80 – 2,11	6– 300	1 - 40	2 – 55		Ισχυρό: 50 Μετρ. Ισχυρό: 25 Ασθενές: 5
Αργιλικός σχιστόλιθος	1,60 – 2,90	34 – 503	0,7 - 23	2 – 90		Ισχυρό: 50 Μετρ. Ισχυρό: 25
Δολομίτης	2,40 – 2,87	45 – 410	3 - 13	23 – 90		Ισχυρό: 50 Μετρ. Ισχυρό: 25

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ΑΝΑΓΝΩΡΙΣΗ ΦΥΣΙΚΩΝ ΛΙΘΟΣΩΜΑΤΩΝ ΚΑΙ ΠΡΟΤΑΣΗ ΕΡΗΜΗΝ ΤΙΜΩΝ ΘΛΙΠΤΙΚΗΣ ΑΝΤΟΧΗΣ

Πίνακας Π3.2: Ενδεικτικές τιμές μηχανικών χαρακτηριστικών συνηθέστερων πετρωμάτων και ερήμην τιμές λιθοσωμάτων με βάση την επί τόπου οπτική παρατήρηση, εξέταση και κατάταξη του λιθοσώματος στις κατηγορίες του Πίνακα Π3.1 από τον Μηχανικό.

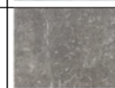
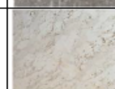
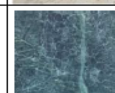
ΠΕΤΡΩΜΑ	Φαινόμενη πυκνότητα ρ (gr/cm³)	Αντοχή σε θλίψη (MPα)	Αντοχή σε εφελκυσμό (MPα)	Μέτρο ελαστικότητας E, (GPα)	Ενδεικτικές υφές πετρωμάτων	Ερήμην τιμή αντοχής σε θλίψη (MPα)
Μάρμαρο	2,64 – 3,02	38 – 280	2 - 29	24 – 103		Ισχυρό: 50 Μετρ. Ισχυρό: 25
Ασβεστόλιθοι	2,4– 2,70	18 -197	3,5 - 14	10.5-87.0		Ισχυρό: 50 Μετρ. Ισχυρό: 25 Ασθενές: 18
Τραβερτίνης	2,40 – 2,54	18 – 68	4 - 10	4 – 45		Ισχυρό: 50 Μετρ. Ισχυρό: 25 Ασθενές : 18
Σερπεντίνης	2,61 – 2,80	70 - 250	16 - 19	45 - 65		Ισχυρό: 50 Μετρ. Ισχυρό: 25
Ψαμμίτες (λ.χ. λιθαρενίτες)	2,50 – 2,80	35-140	5 - 16	13 - 54		Ισχυρό: 50 Μετρ. Ισχυρό: 25
Πωρόλιθοι (πορώ-δεις ψαμμίτες (π.χ. βιοκλαστικοί ασβε-στόλιθοι, ασβεστο-μαργαϊκοί ψαμμί-τες) ή απολιθωματο-φόροι μαργαϊκοί ασβεστόλιθοι, κλ.π.).	1,57 - 2,45	1-25	1,8 - 10	-		Ασθενές: 5 Πολύ Ασθενές: 1

TABLE WITH THE CHARACTERISTICS OF THE MOST COMMON TYPES OF BRICKS AND DEFAULT VALUES FOR OF STONES

Type of artificial stone	Default values of conressive strength (MPa)
Slab-shaped solid bricks	7,0
Solid bricks ~ 6/9/19 cm	10,0
Bricks with horizontal holes	3,0
Bricks with vertical holes	4,0
Cement blocks	2,0

TABLE WITH THE CHARACTERISTICS OF THE MOST COMMON TYPES OF MORTARS AND DEFAULT VALUES

Mortars used in construction	Range of variation of compressive strength (MPa)	Default values of compressive stength (MPa)
Clay mortars	0,1 – 0,5	0,2
Lime-clay mortars	0,2 – 0,7	0,3
Lime mortars	0,3 – 2,0	0,4
Lime mortars with pozzolana and clay	0,7 – 2,5	0,8
Lime-pozolanic mortars	0,9 – 4,0	1,0
Ασβεστοκονιάματα με θραυστό κεραμικό και πιθανή χρήση ποζολάνης (κουρασάνια) Lime mortars with brittle ceramics and possible use of pozzolan («κουρασάνια»)	1,0 – 5,0	1,5
Lime-cement mortars	2,0 – 10,0	2,0
Cement mortars	5,0 – 15,0	5,0

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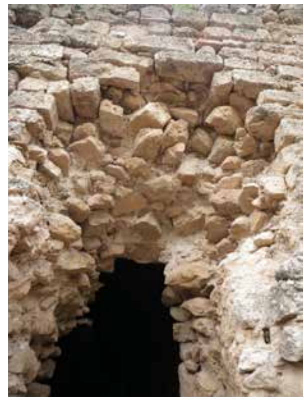
ECILS/ECPFE Workshop Program

"Seismic Assessment and Retrofitting of Masonry and Preserved Structures"

Basic Behaviour Models, Repair and Strengthening Techniques of Masonry Structures

E. Vintzileou

Skopje, 23rd May 2024



THE TOPIC

WHAT DO WE NEED TO KNOW?

Mechanics of masonry (of the construction typologies applied in old masonry constructions).

The major significance of documentation of the bearing system and the means to achieve it.

The typical weaknesses of masonry buildings, and their strong points.

To learn from their pathology and to detect the causes of the observed damage.

To adequately model the structures and to do the necessary verifications.

To choose adequate interventions (and materials) and to dimension them.

…………

The vast majority of Str. Engineers in many countries do not hear about all this, during the undergraduate studies.

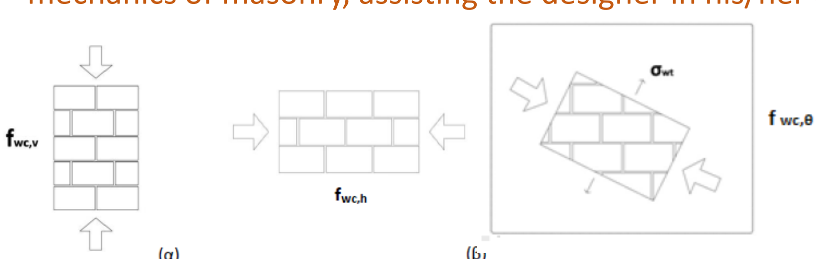
Furthermore, the available scrutinized knowledge is not at the desired level. This is proven also by the relatively poor “representation” of those topics in Codes (e.g., the revised EC8-3 includes *2 ½* pages to §11.6-Analysis and resistance models for retrofitting, as well as an Informative Annex E-of qualitative nature, providing also default values for the mechanical properties of masonry).

The recently approved Greek Code provides quantitative guidance-wherever the available knowledge allows. In several cases, the character of the document can be classified as “didactic”. Although this may not satisfy the concrete requirements of the designer, it is of value. Indeed, the structural engineer who is aware of the nature of the phenomena can seek for data contributing to the adoption of reasonable assumptions.

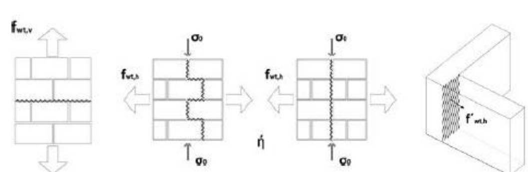
CHAPTER 6: BASIC BEHAVIOUR MODELS

Basic information on the mechanical behaviour of masonry (at material level), as well as on the behaviour of constructions-before and after interventions.

Although the data included in this Chapter are mostly qualitative, they introduce the designer to the next (more quantitative) chapters. They also function as a reminder of the mechanics of masonry, assisting the designer in his/her decision making.



The Code does not provide arithmetic values for this reduction, because (a) relevant data are not available, and (b) reduction factors strongly depend on the construction typology of masonry.



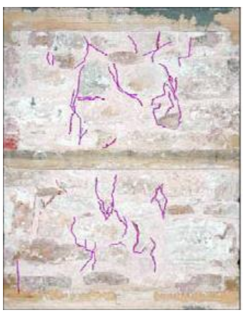
Example: Because of the anisotropy of masonry, its compressive strength depends on the angle of application of the compression. Thus, when verifying a masonry element subjected to in-plane shear, the bearing capacity of the inclined strut should be calculated based on the “inclined” compressive strength of masonry. Furthermore, there is a simultaneous transverse tension acting on the strut, leading to further reduction of the “vertical” compressive strength.

Similar to the compressive strength, the tensile strength of masonry depends on the angle of application of tension.

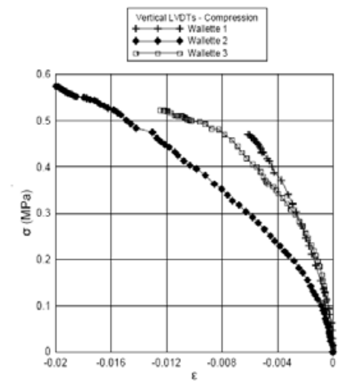
Reference to modification of the mechanical properties of masonry, at the level of the bearing element.

The typical example of timber laced masonry.
Due to the confinement offered by the laces, there is a moderate increase of the compressive strength of masonry, and...

0,47 MPa

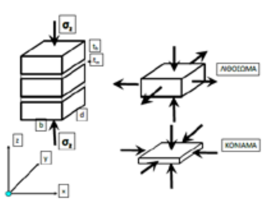


0,58MPa



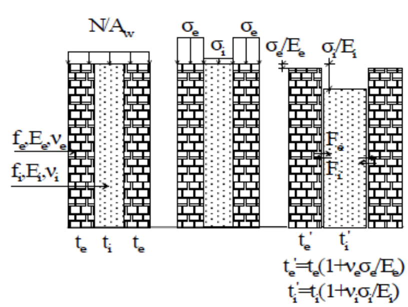
... Significant increase of its deformability!

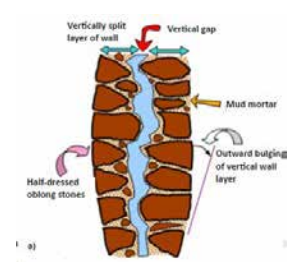
The basics of the mechanics of masonry (single-, double-, three-leaf) in compression, as well as of the (many) parameters on which this property depends.



The compressive strength of masonry is higher than that of the mortar and smaller than the strength of the masonry units

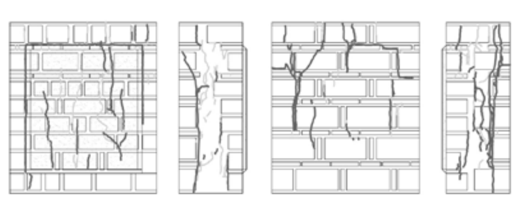
Interpretation of the limited contribution of mortar to the shaping of the compressive strength of masonry.





Bothara, Brzev, 2011

Σχ. Σ 6.18: Η Μηχανική της τρίστρωτης τοιχοποιίας υπό κεντρική θλίψη.

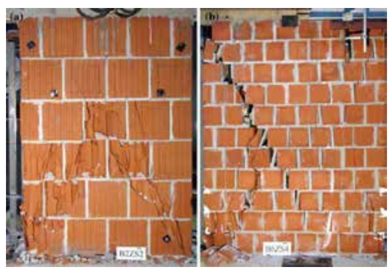


crack opening~1,0mm (faces) vs. ~5,0mm (within thickness)

(Empirical) equations are given, for the estimation of the compressive strength of masonries of various construction typologies.
Because the equations are empirical, they are given in the left hand side of the Code.

Information related to the tensile strength of masonry is also provided.
A highly uncertain property. Typically, it is not accounted for in the design.

Shear capacity of masonry (equations) and masonry elements and influencing parameters



CHAPTER 8: REPAIR/STRENGTHENING, VERIFICATIONS

The strategy of interventions: Introductory paragraph of significance

The scheme of interventions is chosen, based on (a) its target and on the difference between the current and the targeted behaviour, (b) on the future use of the building, (c) on the historical, architectural, artistic, social and economic value, (d) the geographic location and the available technical facilities, etc.

The optimum scheme of interventions (the Structural Engineer is expected to choose) is based on the overall behaviour of the building and it is not limited to measures improving the properties of each distinct structural element. E.g., when it is proven that the strengthening of some individual elements is not sufficient for the target to be reached, it is recommended to the engineer to examine “systemic” interventions, to alleviate the inherent weaknesses of the original structural system (for example, enhancement of the diaphragm action of floors and roof, the improvement of the connection among the bearing elements, the transformation of non-bearing elements to bearing ones, etc.).

Quite often, there is a need for more than one intervention techniques to be applied. **We cannot add the contribution of each distinct technique to the improvement of the bearing capacity, due to the lack of relevant data!**

The preliminary modelling and numerical analysis (before the documentation is completed) is highly recommended, as it can detect the more vulnerable regions, the type of inadequacy, as well as the difference between the assessed and the targeted behaviour. Thus, the structural engineer is guided towards the adoption of the most adequate scheme of interventions.
Recommended also by ISCARSAH/IICOMOS

The intervention techniques are distinguished in Repair and in Strengthening techniques.

Repair are those techniques that are meant to reinstate the pre-earthquake bearing capacity of the structure, although it is known that-at least-some of the repair techniques provide some enhancement of the bearing capacity.
E.g., re-pointing, plastering, filling or stitching of cracks, local reconstruction, reinstatement or improvement of connections and connectors.

Reinstatement or improvement of connections and connectors.

Strengthening techniques are assumed to be applied after repair of the structure.

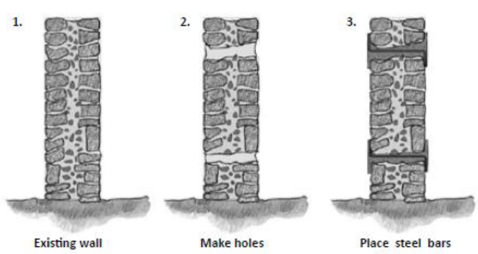
Transverse connection of masonry leaves

L'Aquila, 2009

Samos, 2020

Gaziantep, 2023

It is achieved through grouting **AND**, if so needed, using transverse connectors (the code provides guidance related to the durability, the diameter, the distribution, the minimum number of connectors, etc.)



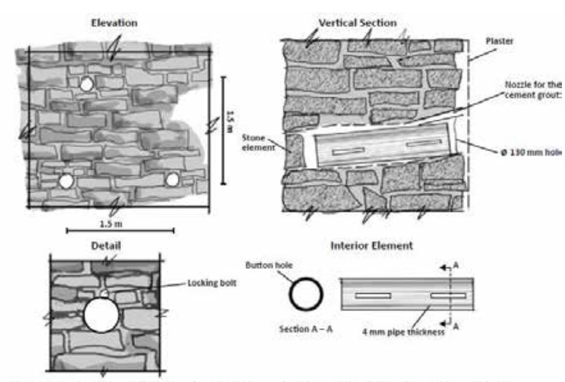


Figure 4.21 Installation of though-wall anchors in stone masonry walls after the 2002 Molise, Italy, earthquake (source: Maffei et al. 2006)

We do not recommend the use of connectors unless grouting precedes.

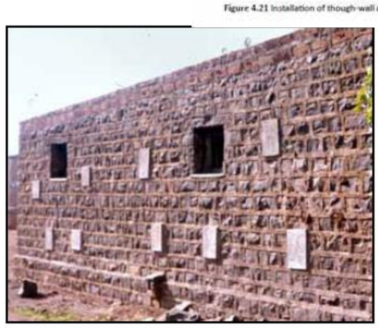
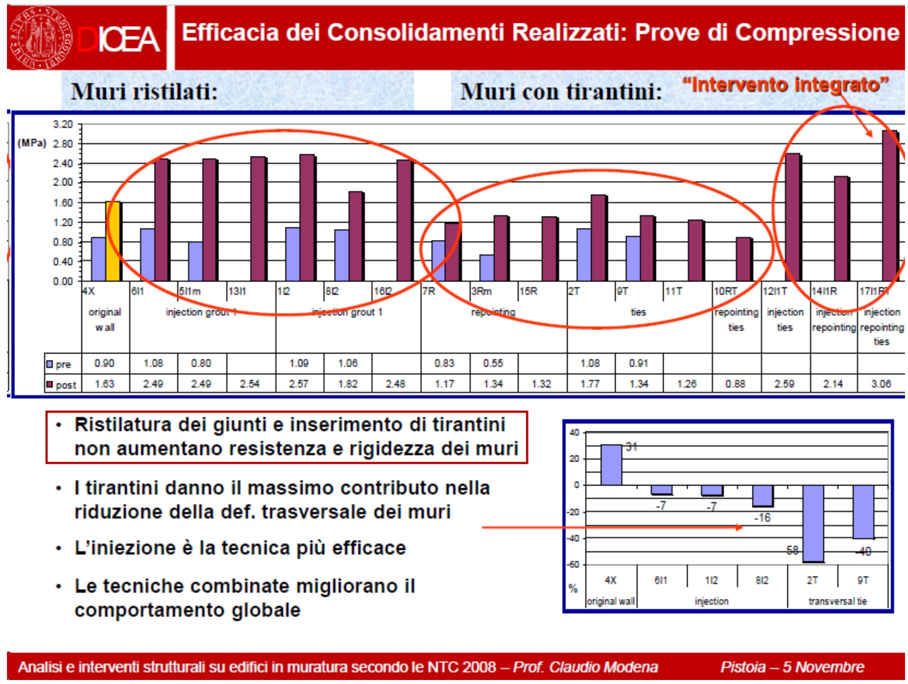


Figure 4.20: Examples of completed through-stone retrofit projects in Maharashtra, India (photos: S. Brzev)

Bothara, J., and Brzev, S. A Tutorial: Improving the Seismic Performance of Stone Masonry Buildings, EERI-First Edition 2011.



Modena C., 2012. *Analisi e interventi strutturali su edifici in muratura secondo le Norme Tecniche per le Costruzioni 2008,* Ordine degli Ingegneri della Provincia di Pistoia

Modena, 2012

Deep repointing/rejointing

Double-sided deep rejointing (using adequate new mortar) to elements of thickness limited to 0.60m and of relatively low original mechanical properties, can be considered as strengthening technique.
Pre-requisite! Homogenization of masonry.

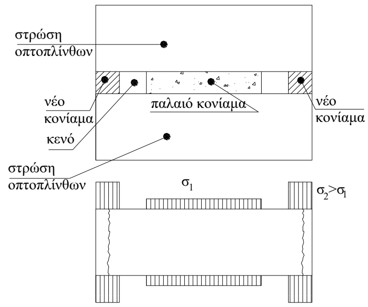
The percentage of the replaced mortar as a ratio of the total mortar volume is rather limited. Taking into account the small contribution of the mortar to the shaping of the mechanical properties of masonry, the benefit from this intervention is not expected to be significant.
The mechanical properties of the new mortar should not differ significantly from those of the original mortar.
The new mortar has to be compatible with the original one (to ensure durability)

The efficiency of the technique strongly depends on the quality of the workmanship (complete filling of the joints).

High cost with limited efficiency.

Rejointing: YES
Deep rejointing: ???

The use of mortar much stronger than the removed one, as well as the deficient filling of the joints, may cause spalling of the masonry units and, finally, reduction of the compressive strength of masonry!



Tests at NTUA: Compressive strength of bricks=50MPa, Compressive strength of original mortar~1.0MPa
compressive strength of rejointing mortar~6.0MPa

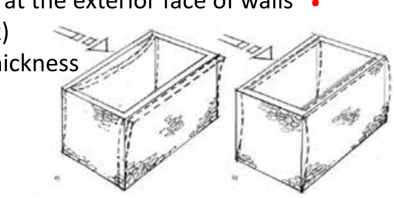
Original compressive strength of wall=6.50MPa, after rejointing=4.50-5.70MPa

Vintzileou E.: "The effect of deep rejointing on the compressive strength of brick masonry", Masonry International, Vol. 15, No 1, 2001, pp. 8-12.

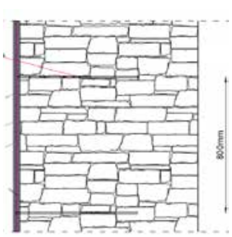
Reinforced Plaster

Reinforced plasters may contribute to the improvement of the in- and out-of-plane capacity of walls provided that

(a) Homogenization of masonry precedes (e.g., grouting)
(b) They are double-sided or, if one-sided, they are constructed at the exterior face of walls **!**
(c) The thickness of the walls is such that the (max. 40mm thick)
(d) Πlasters constitute a substantial percentage of the overall thickness of the element.



Adequate materials (durability), surface preparation, anchorage to masonry, etc.

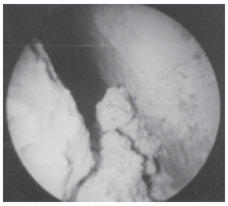


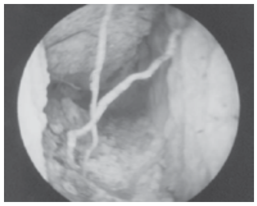
80cm thick masonry is assumed to be solid!

Quite often, in contrast to mechanics, single-sided reinforced plaster is located at the interior face of walls, the exterior one remaining unplastered. The Code allows for this application, stating though that the exterior face should also be adequately protected. No guidance on how to achieve this is provided.

Compare the thickness of the plaster to the overall thickness of the wall

Grouting-Homogenization of masonry (exclusive use of hydraulic grouts!)

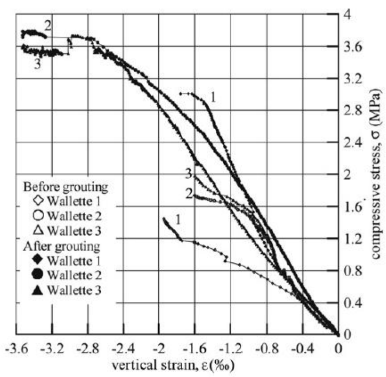


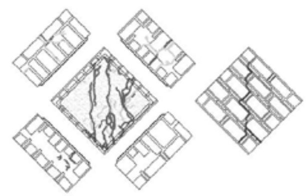


Grout introduced (at low pressure) to masonry elements, to fill all voids and cracks (to the order of the tenth of mm) and to bond together the leaves of masonry

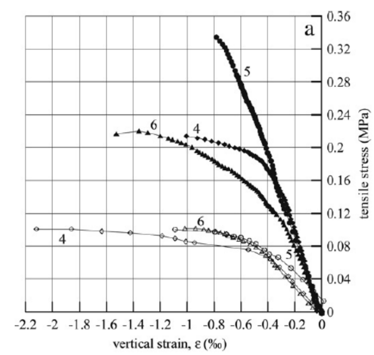
The technique is non-reversible and, hence, the requirements related to in-time behaviour of grouts are rather stringent.

PREREQUISITE FOR ANY EXTERNALLY APPLIED INTERVENTION



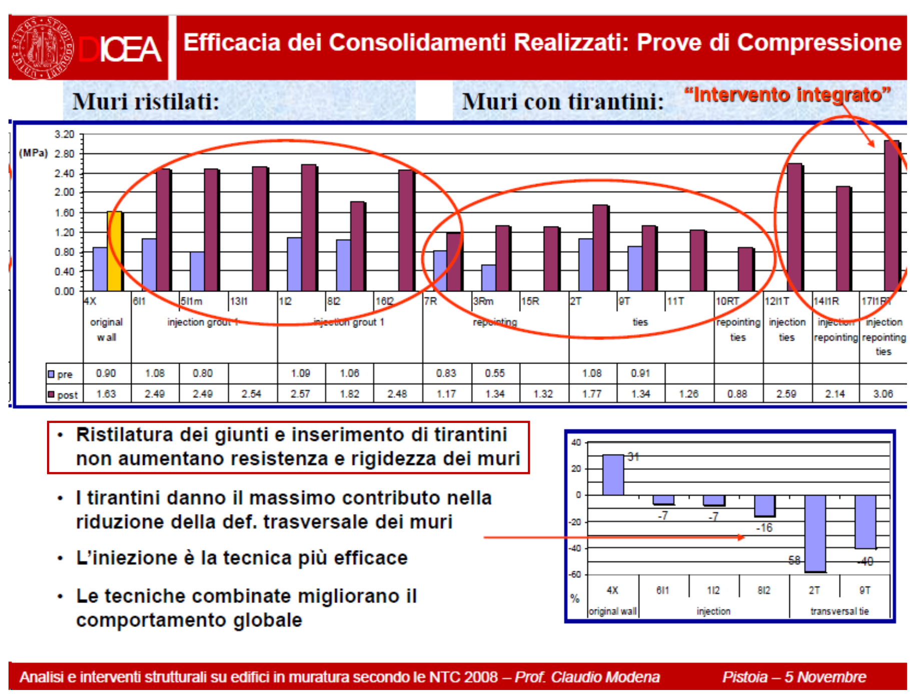


Vintzileou E., Miltiadou-Fezans A.: “Mechanical properties of three-leaf stone masonry grouted with ternary or hydraulic lime-based grouts”, Engineering Structures, Volume 30, Issue 8, August 2008, Pages 2265-2276



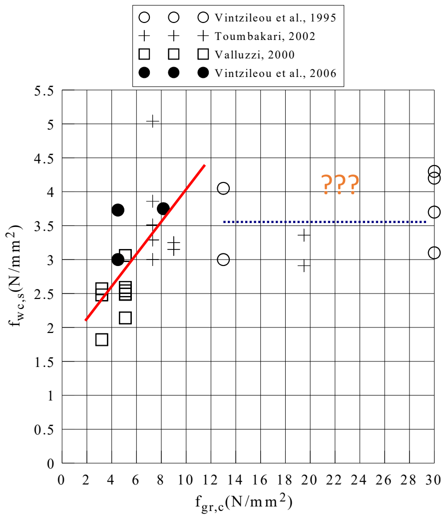
Modena C., 2012. *Analisi e interventi strutturali su edifici in muratura secondo le Norme Tecniche per le Costruzioni 2008*, Ordine degli Ingegneri della Provincia di Pistoia

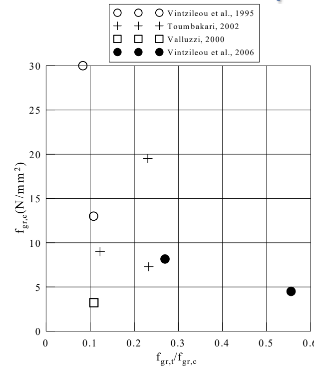
Modena, 2012

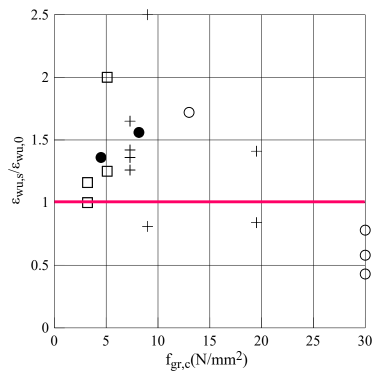


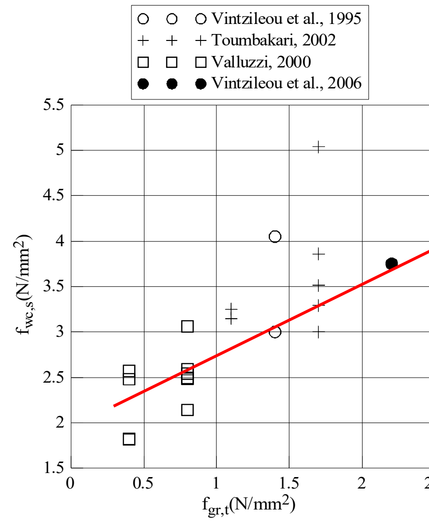
	4X	6I1	5I1m	13I1	1I2	8I2	16I2	7R	3Rm	15R	2T	9T	11T	10RT	12I1T	14I1R	17I1RT
pre	0.90	1.08	0.80		1.09	1.06		0.83	0.55		1.08	0.91					
post	1.63	2.49	2.49	2.54	2.57	1.82	2.48	1.17	1.34	1.32	1.77	1.34	1.26	0.88	2.59	2.14	3.06

Do we need cement-based grouts to increase the mechanical properties of masonry?









Reinforced Concrete Jackets

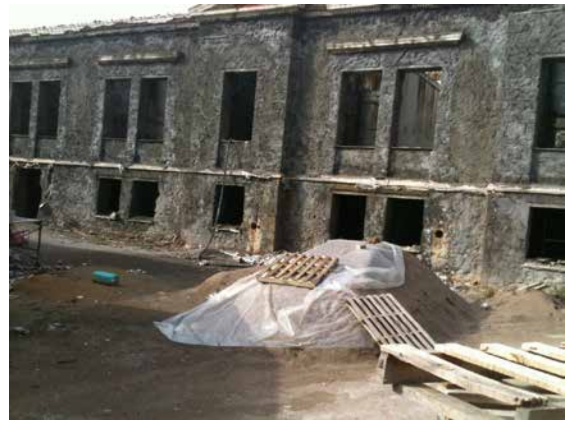
A very invasive technique applied when there is significant gap between the assessed and the target capacity of the building.

(a) Radical change of moisture and vapour movement within masonry, leading to durability problems
(b) Proper anchorage to floors, walls, perimeter of openings, etc., affects the geometry of spaces.
(c) Significant increase of mass and stiffness (hence, of conventional seismic loads.
(d) Effects on foundation (interventions?)
(e) To be applied to already homogenized masonry
(f) If single-sided, usually applied on the interior face of walls!

Intervention prohibited by the Hellenic Ministry of Culture to historical constructions and monuments.

The Code guide the Engineers to apply alternative systemic interventions (such as, enhancement of diaphragm action of floors and roof, improvement of all connections among structural members, construction of new bearing elements at the interior of the building, transforming non-bearing elements to bearing, etc.).

The Code discourages in any possible way the Engineers!

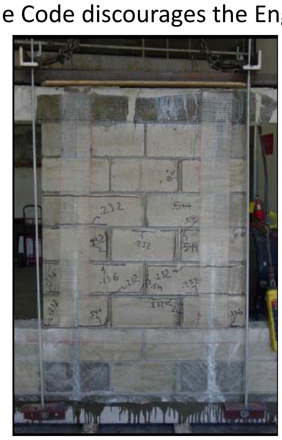


Plomari, Lesvos island, 2018

Pyrgos, Peloponnese, 2014

Composite materials

For durability reasons, as well as due to the (by orders of magnitude) difference in the mechanical properties between FRPs and masonries, the Code discourages the Engineers to use them in the form of “jackets”



The Code covers the technique of fiber reinforced composites in inorganic matrix (treated in a way similar to reinforced plasters).

Still, the masonry elements have to be consolidated before the application of the composites.

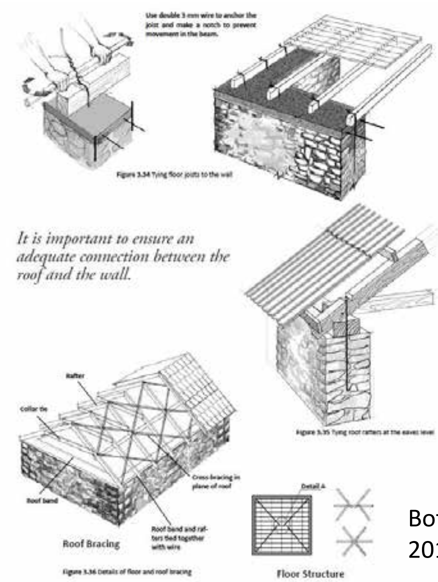
Tie- or bond-beams

Needed to ensure the connection between floors/roof and walls. Made of timber, steel, RC.

Connection between the roof and the walls (through the tie-beams). The friction between concrete and top of walls may not be sufficient! The vertical loads at that level are of very small value.

Width of tie-beams ~ thickness of walls and Prior consolidation of masonry

L'Aquila, 2009



Bothara, Brzev, 2011

As a rule, the tie-beams DO NOT provide diaphragm action to floors and roof!!!

Antakya, 2023

Christchurch, 2011




Illica, Rieti, 2016

Diaphragm action

Ensured, provided that (a) the masonry walls are adequately repaired and strengthened, (b) tie-beams are arranged, (c) adequate interventions are applied to enhance the in-plane stiffness of horizontal elements, and (d) diaphragms, tie-beams and walls are connected.

Hellenic Association of Earthquake Engineering, Report on the Arkalohori earthquake, 2021

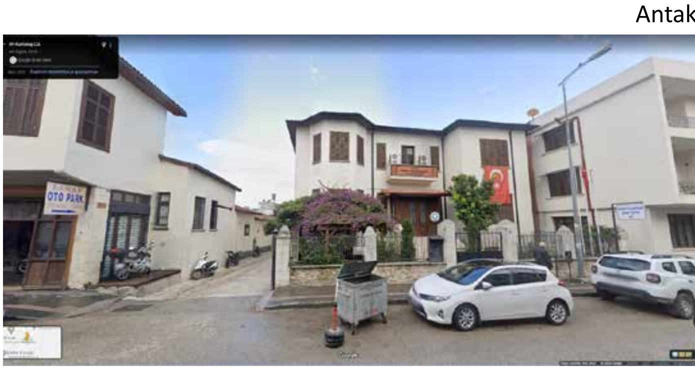
The Code does not promote the replacement of timber floors and roofs by RC slabs, due to the resulting significant increase of the mass of the building and to the difficulties related to the construction of RC tie-beams of sufficient width and to their connection with the walls.

Applications of RC slabs, without following the aforementioned provisions/conditions, are-in many cases-proven to be catastrophic.

Alternative techniques: Double-planking, arrangement (in-the-plane of diaphragms) of steel or FRP rods, etc.

Antakya, 2023

Antakya, 2023



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ECILS/ECPFE Workshop Program

"Seismic Assessment and Retrofitting ofMasonry and Preserved Structures"

Performance Limits and Verification Checks in KADET

S. J. Pantazopoulou
York University, the Lassonde Faculty of Engineering, Canada

Skopje, 23rd May 2024

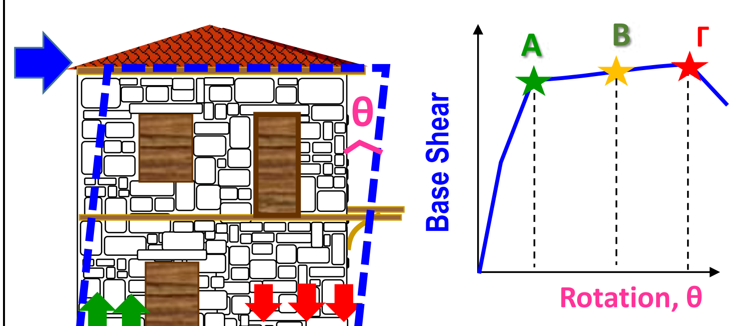
ΚΑΔΕΤ: A Code for Seismic Evaluation and Interventions in Load Bearing Masonry

Chapter 1	Objective, Field of Application, Role of the Engineer
Chapter 2	Fundamental Principles, Criteria and Procedures
Chapter 3	Investigation, Documentation
Chapter 4	Basic Data for the Seismic Evaluation and Retrofit
Chapter 5	**Analysis before and after the Intervention**
Chapter 6	Models of Material and Structural Behavior
Chapter 7	**Engineering Demand Parameters / Modelling Parameters**
Chapter 8	Dimensioning / Detailing of the Intervention
Chapter 9	**Acceptance Criteria**
Chapter 10	Contents of the Evaluation File

Intent: To Formulate Rules for:

- **Seismic Evaluation & Redesign ; Versatile Rules, for the broad range of "non – engineered" Construction. Dependable results that can be used to guide retrofit**

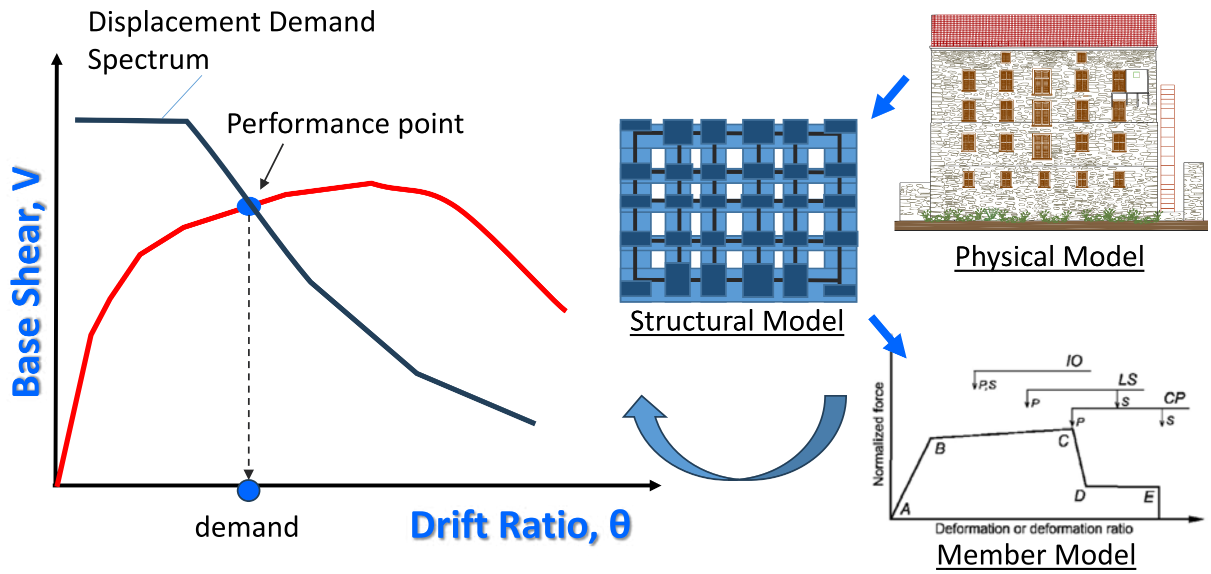
- **Intensity of effort commensurate with the level of uncertainty in the data and the magnitude of the future seismic hazard**



Important Decisions / Uncertainty:

- -Idealization of structure
- -Modelling material behavior
- -Method of Analysis
- -Loads

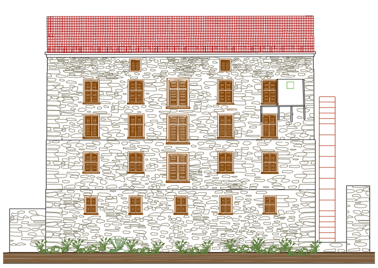
Scope of the Chapters: $S_d \leq R_d$

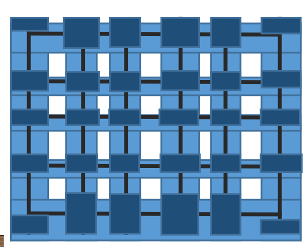


- **Chapter 7:** mechanistic models for calculating the member resistance
- **Chapter 9:** the performance criteria that are part of the design inequality

Lateral Resistance Curve (Case without Diaphragm Action):

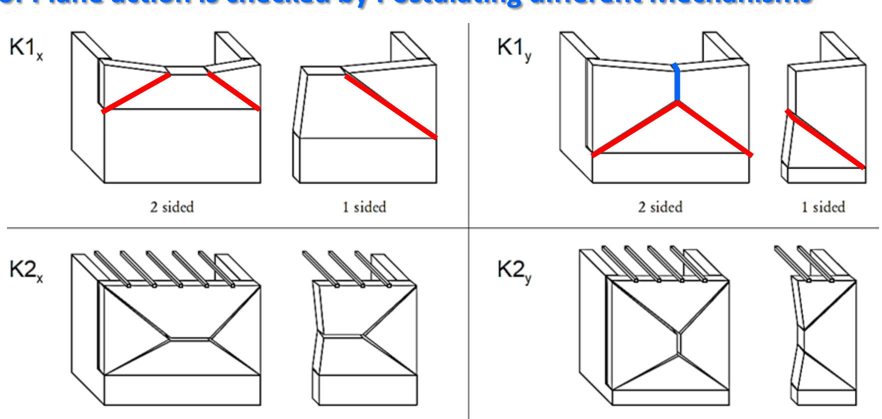
- **Equivalent Frame Analysis** / macroelements (inelastic, dynamic, or static pushover)



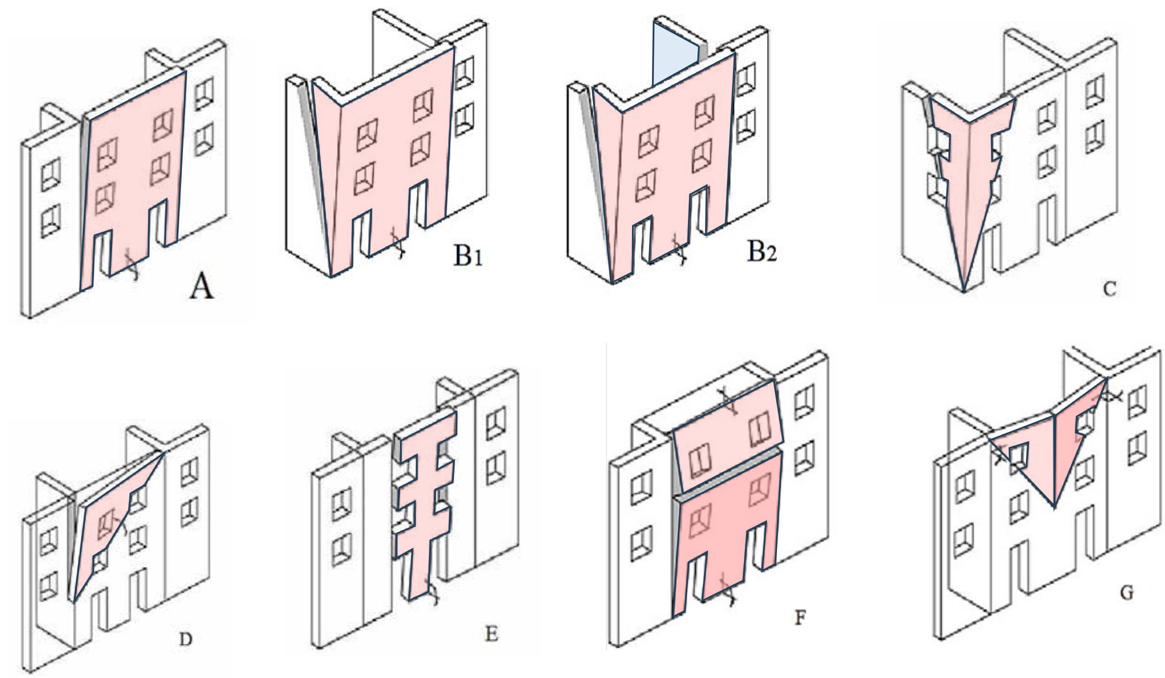


Modeling the 3-D structure, as a sequence of plane frames. After the lateral load analysis, the individual walls are checked against out-of-plane failure mechanisms

- **Out of Plane action is checked by Postulating different Mechanisms**

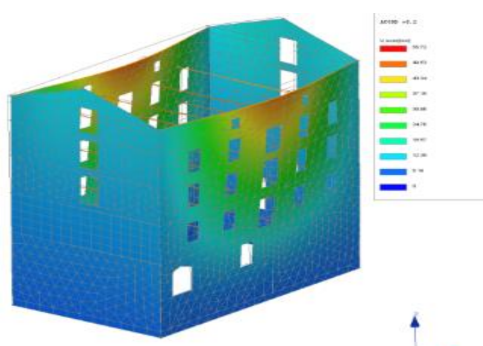


Yield Line Arrangement for Out-of-Plane Mechanism Assessment



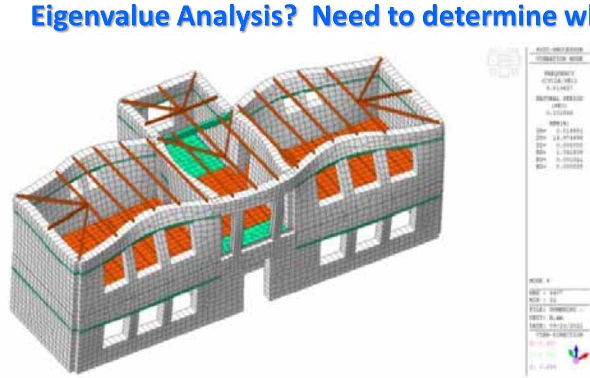
Lateral Resistance Curve (Case without Diaphragm Action):

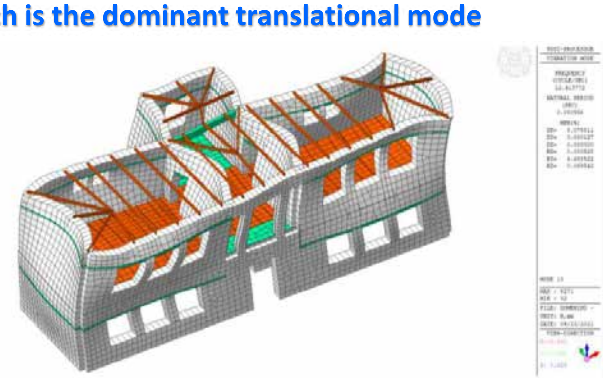
• **3-D Elastic Analysis** – shell elements / plate elements, or 3D solids (bricks) (If possible, combined with nonlinear springs for unidirectional contacts).



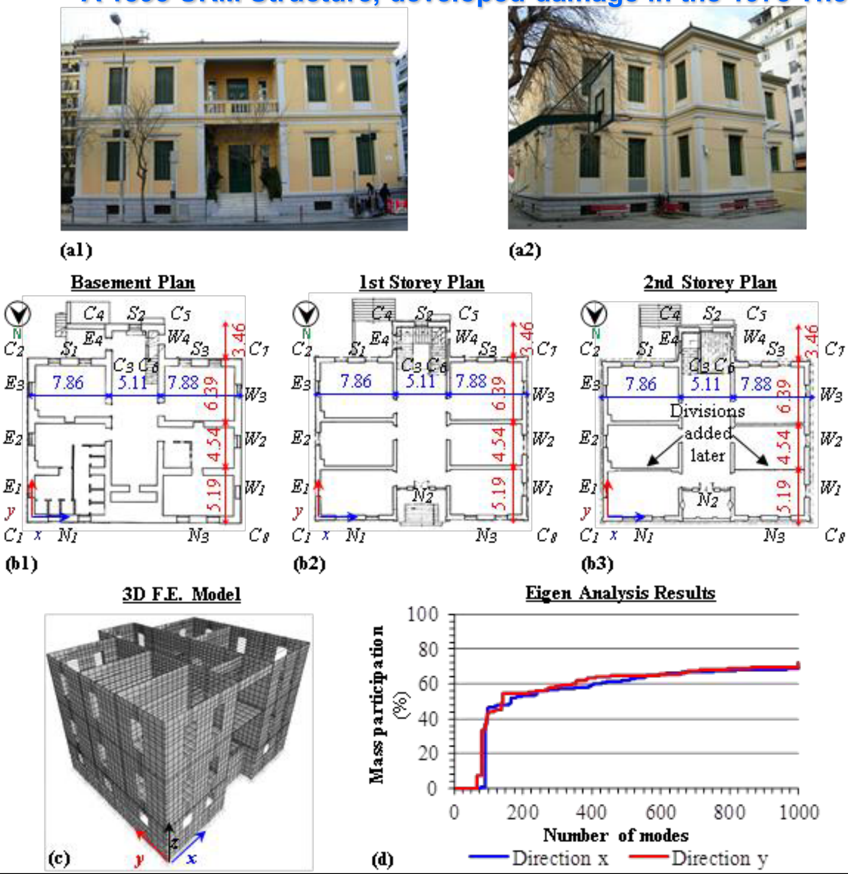
Specifically for Inelastic Analysis, the amount of required information is not necessarily compatible with the **level of documentation and data reliability** that we can have in common buildings: Therefore, this method is more appropriate for special structures of significant heritage value, or the structure has rigid diaphragms.

Eigenvalue Analysis? Need to determine which is the dominant translational mode





Application Example:
A 1893 URM Structure, developed damage in the 1978 Thessaloniki Earthquake



Stone Masonry: f_k = 5.5 MPa, Specific Weight= 28.5 kN/m^3

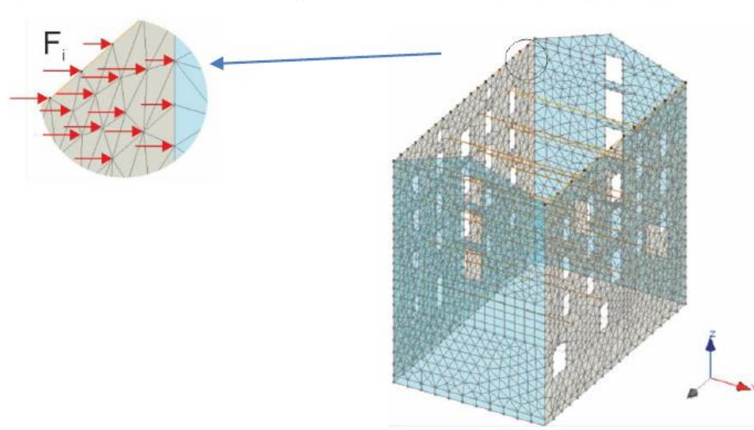
Clay bricks: *fk* = 4.0 MPa, Specific Weight = 18.0 kN/m^3

Timber: *E* = 10 GPa ,
Iron beams: E = 150 GPa

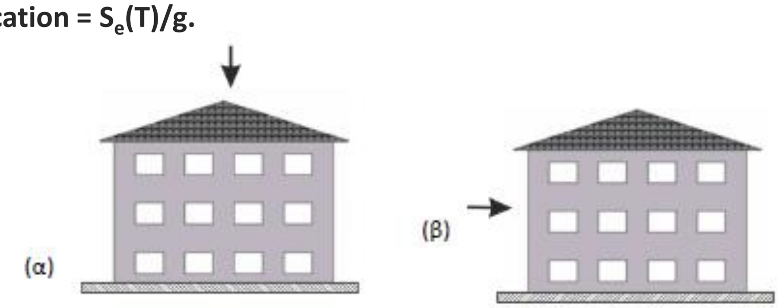
Roofing: 1.5 kN/m^2

Moving loads: 3.5 kN/m^2

3D-Modeling using FEA: Pushover curve by applying a gravitational field in the horizontal direction.



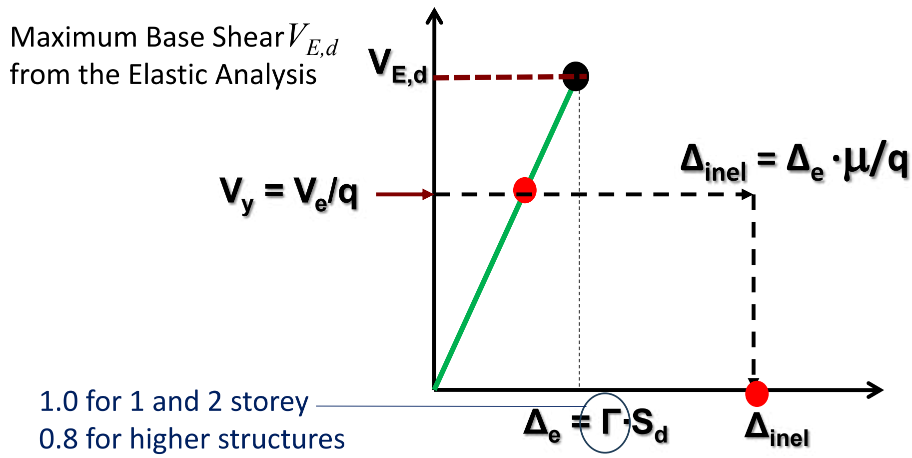
(α) Analysis for gravitational loads for the Seismic Load Combination. (β) Determine internal forces and displacements for a total spectral response acceleration of 1g. To determine the elastic forces in the seismic load combination, the values from analysis (β) are multiplied with seismic amplification = $S_e(T)/g$.



Estimating the Inelastic Deformations from the Elastic Analysis Results:

Multiply with the ratio : $\mu/q = \Delta_{inel}/\Delta_{el}$

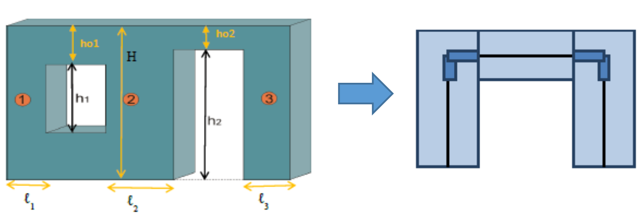
- Estimating the response modification factor (known as “Behavior Factor”) $q=V_{E,d}/V_y$, where $V_{E,d}=C_m \cdot S_e(T) \cdot W/g$
- $\Delta_{inel}/\Delta_{el} = 1$ για $T > T_C$
- $\Delta_{inel}/\Delta_{el} = (1+(q-1) \cdot T_C/T)/q$ για $T < T_C$



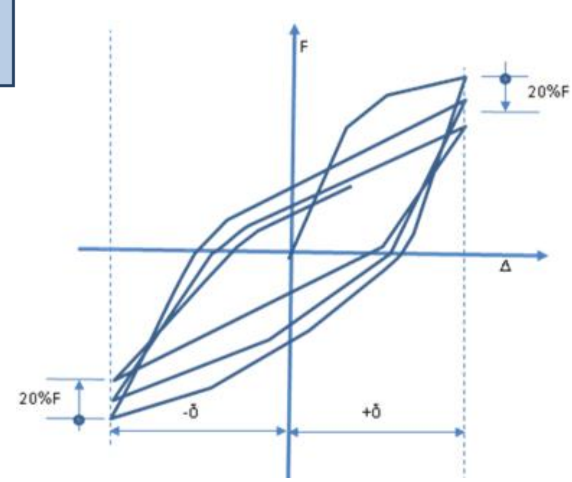
- **For calculation of Notional Yield Lateral Force V_y:** Chapter 7: The force that the system develops when the lateral relative drift ratio is in the range of 0.15 - 0.2%

Evaluation Checks & Modelling Parameters:

I. Frame Method: You need to input Moment – Rotation Resistance Curves for the «Members». Significant points of reference: «Notional Yielding», και «Failure»



$$V_{res} = min\{V_{flex}, V_v, V_{slid}, V_d \ldots\}$$

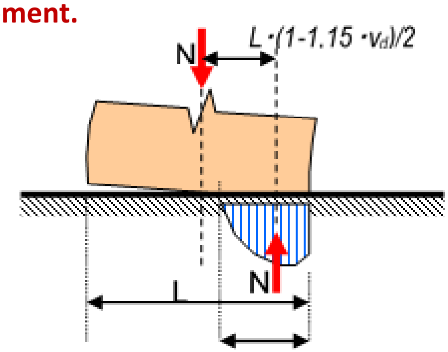


- Mechanisms that are controlled by deformation: ***Flexure, Shear Sliding***
- Mechanisms that are controlled by force (brittle): ***Compression Toe Crushing; Diagoral Tension Cracking***

#1 Important Element for Comprehension of the Methods for Modelling and Evaluation:

(α) In unreinforced masonry, the flexural strength of a section is owing to the presence of axial load (compression).

➔ Without an Axial Force, the cross section (and the structural member) cannot resist moment.



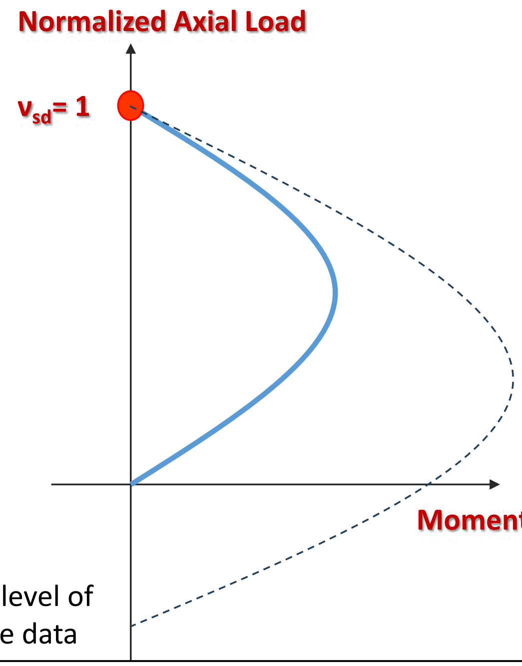
$$M_{Rd} = N_{sd} \cdot (1 - 1.15\nu_{sd}) \cdot L/2$$

Normalized Axial Load

$\nu_{sd} = N_{sd}/(L \cdot t \cdot f_d)$

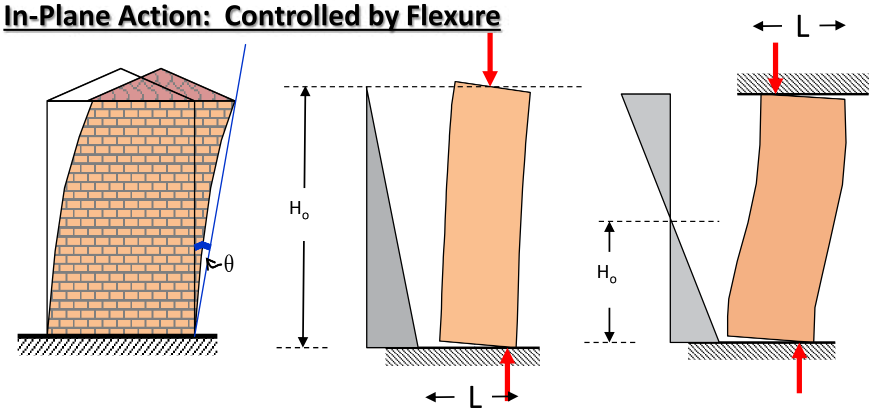
$f_d = f_{mc}/\gamma_w$

Depends on the level of confidence of the data



- **Definition of Yield Strength, F_y, of a member (and definition of mode of failure)**

In-Plane Action: Controlled by Flexure



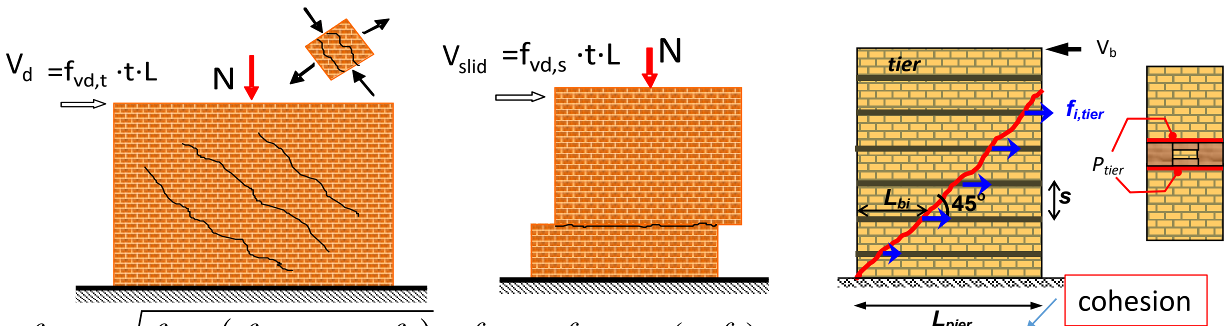
$$F_{y,fl} = \frac{L \cdot (1 - 1{,}15 \cdot \nu_d)}{2H_o} \cdot N$$

Definition of Yield Strength, F_y, of a member (and definition of mode of failure)

In-Plane: Controlled by Shear

$$F_{y,v} = f_{vd} L' t$$

$$f_{vd} = min(f_{vd,t}, f_{vd,s}) \leq 0{,}065 f_{bc}$$



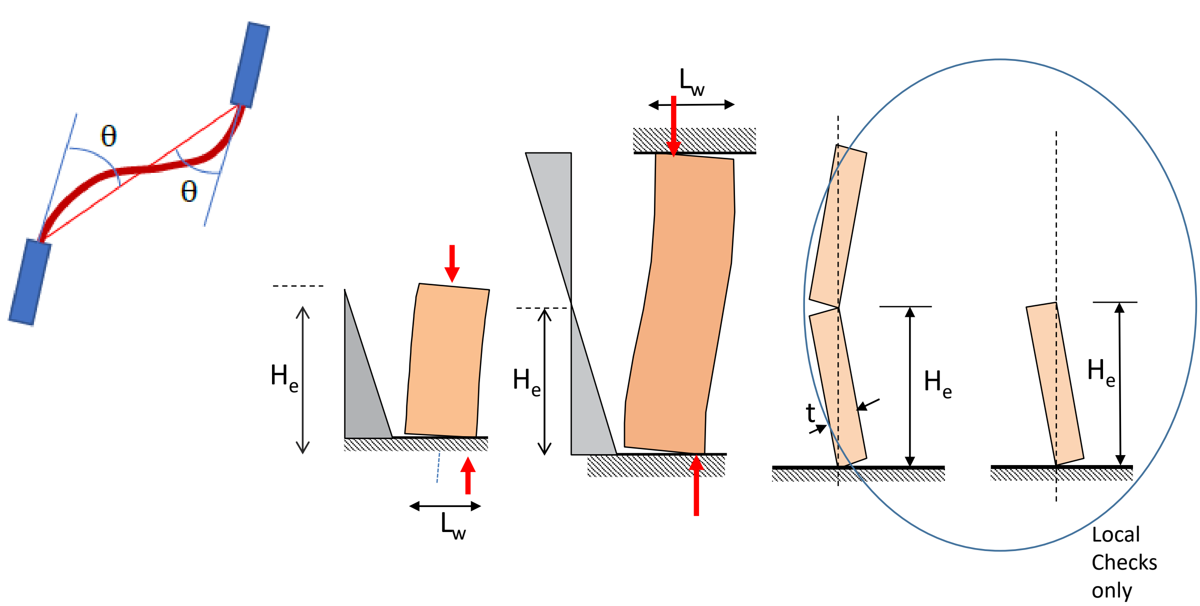
$$f_{vd,t} = \sqrt{f_{wtd} \cdot (f_{wtd} + v_d \cdot f_d)} \qquad f_{vd,s} = f_{v0} + \mu \cdot (v_d f_d) \qquad F_{y,tier} = u_{b,tier} \cdot p_{tier} \cdot L_{b,tier}$$

The smaller of all these estimated strengths defines the pier resistance

$$V_{res} = min\{V_{flex}, V_v, V_{slid}, V_d \ldots\ldots\}$$

• Safety Checks and Acceptance Criteria:

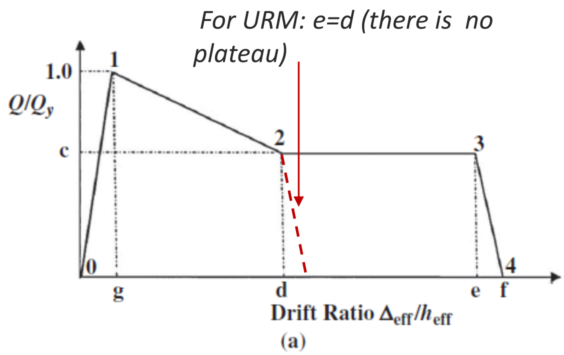
- **Frame Method:** **Moment – Rotation Relationships for the «Members». Points of reference: «Notional Yielding», and «Failure»**



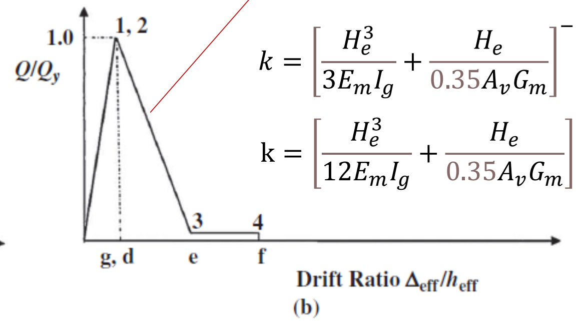
Flexural Pier (a) in-plane, and (b) out of plane, and equivalent cantilever

Modelling Parameters according with ASCE-41 for each type of Wall Pier (i.e., either URM or RM).

For Actions that are controlled by Deformation



For Actions that are controlled by Forces (ASCE 41)



$$k=\left[\frac{H_e^3}{3E_mI_g}+\frac{H_e}{0.35A_vG_m}\right]^{-1};$$

$$k=\left[\frac{H_e^3}{12E_mI_g}+\frac{H_e}{0.35A_vG_m}\right]^{-1}$$

Reference Performance Limit States for URM:

Type	Structural Performance Levels		
	Immediate Occupancy: A: IO / DL (περιορισμός βλαβών)	Life Safety: B: LS / SD (Επισκευάσιμες Βλάβες)	Collapse Prevention: Γ: CP / NC (αποφυγή κατάρρευσης)
Primary Elements	Minor cracking of veneers. Minor spalling in veneers at a few corner openings. No observable out-of-plane offsets.	Major cracking. Noticeable in-plane offsets of masonry. Minor out-of-plane offsets	Extensive cracking; face course and veneer might peel off. Noticeable in-plane and out-of-plane offsets
Secondary Elements	Same as for primary elements	Same as for primary elements	Non-bearing panels dislodge
Drift	Transient drift that causes minor or no non-structural damage. Negligible permanent drift.	Transient drift sufficient to cause non-structural damage. Noticeable permanent drift.	Transient drift sufficient to cause extensive non-structural damage. Extensive permanent drift.

Modelling Parameters for URM Walls with $v_{tL} \geq 0.2\ MPa$ (ASCE-41)

Limiting Behavior Mode for URM Walls/Piers	Modelling Parameters			
	c	d	e	f
Rocking	$Q_{toe,L}/Q_{roc,E}$	Δ_c/H_e %	Δ_c/H_e %	$\frac{\Delta_c+\Delta_y}{H_e}$ %
Bed-joint sliding	$Q_{c,E,F}/Q_{slid,E}$	0.4%	1.0%	$1.0+\frac{\Delta_y}{H_e}$ %

Δ_c= Lateral displacement associated with the onset of toe crushing $V_{tc,r}$, Table 11-4

Limiting Behavior Mode		Drift Ratio limits		
		IO ➔ A	LS ➔ B	CP➔ Γ
Rocking	Simplified	0.1%	0.4(h_{eff}/L)≤1.5%	0.6(h_{eff}/L)≤2.25%
	Comprehensive	0.1%	0.6(h_{eff}/L)≤2.25%	$\delta_{c,u}/h_{eff}$≤2.5%
Bed-joint Sliding		0.1%	0.75%	1.0%

EC8-III (2022):

Flexural (Rocking)			Bed-joint shear sliding			Diagonal shear cracking		
θ_{DL}	$\theta_{SD}=\theta_{f,u}$	$\theta_{NC}=\theta_{f,u2}$	θ_{DL}	$\theta_{SD}=\theta_{s,u}$	$\theta_{NC}=\theta_{s,u2}$	θ_{DL}	$\theta_{SD}=\theta_{d,u}$	$\theta_{NC}=\theta_{d,u2}$
elastic limit θ_y	(1-ν)%	$\left(\frac{4}{3}\right)\theta_{f,u}$	elastic limit θ_y	0.4% (solid bricks) 0.5% (hollow bricks) 0.8% (stone)	$\left(\frac{4}{3}\right)\theta_{s,u}$	elastic limit θ_y	0.5%• or 0.6%▲	$\left(\frac{4}{3}\right)\theta_{d,u}$

#2 Important Point for Comprehension of the Modelling Methods and Safety Checks:

The modulus of «Elasticity» which is estimated from the initial secant slope (to 40% of peak) in the stress – strain law in compression, has little relevance with the stiffness of masonry to lateral loads.

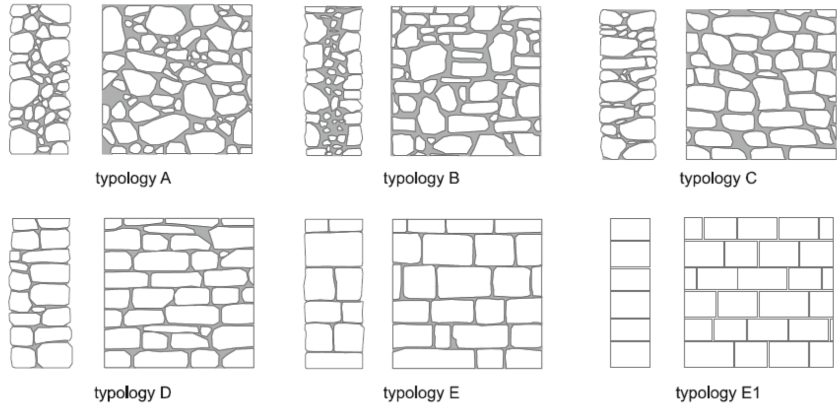


Fig. 2 Stone masonry typologies: sketches of typical textures and cross-sections

Table 6 Elastic and effective stiffness ranges for the various masonry typologies

	Masonry typology					
	A	B	C	D	E	E1
Effective stiffness, E_{eff}						
Median (MPa)	320	(2240)[b]	900	430	550	630
CoV	0.49	(0.22)[b]	0.38	0.42	0.57	0.42
$(E_{eff}/f_c)_{ref}$	400	(700)[b]	300	250	200	250

$$E_{eff} \approx \alpha \cdot f_w$$

α between 200 and 400 depending on the URM morphology
➔ Small Values!

- **Stiffness of Cracked Section** (EI) & (GA) ≈ ½ of the corresponding elastic sectional stiffness of the gross section of the member.

- **Rotation Capacity:**
  Experimental Evidence

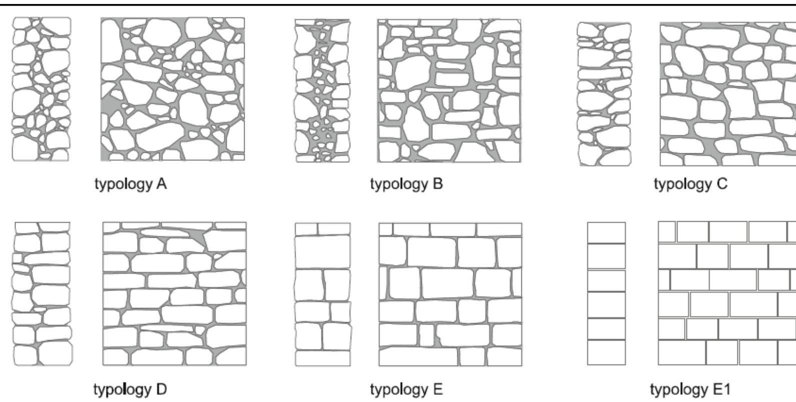


Fig. 2 Stone masonry typologies: sketches of typical textures and cross-sections

DISPLACEMENT CAPACITY

Drift at cracking:	$\delta_{cr} = 0.20\%$	Drift at SD limit state	$\delta_{SD} = 0.50 \cdot \delta_u$
Yielding drift:		Drift at max. force:	$\delta_{max} = 0.70 \cdot \delta_u$
- shear	$\delta_y = 1/4 \cdot \delta_u$	Drift at collapse	$\delta_c = 1.15 \cdot \delta_u$
- flexure	$\delta_y = 1/6.5 \cdot \delta_u$		

Ultimate drift: - Model 1: reference values from table

	A-B-C-D		E-E1	
	Shear failure	Flexural failure	Shear failure	Flexural failure
Model 1: δ_u	0.60	0.90	1.50	2.25
CoV	0.50	0.50	0.50	0.50

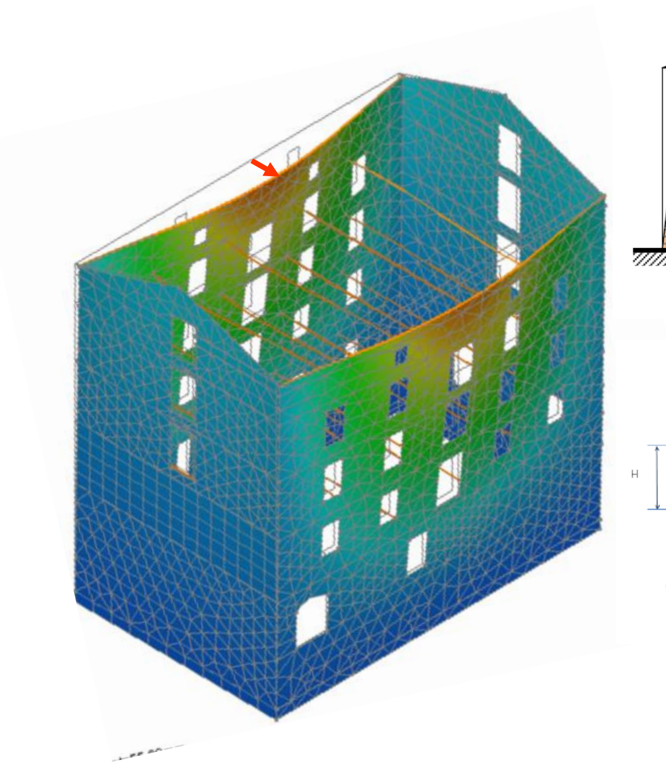
- Model 2:

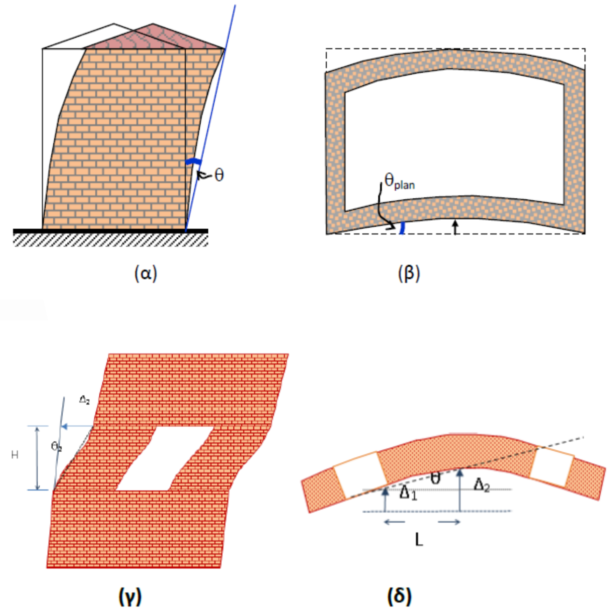
$$\delta_u = \max(1.5\% - 4\% \cdot \frac{\sigma_{0,tot}}{f_c}, 0.3\%) \cdot \frac{H_0}{\min(H,L)}$$ (typologies A-B-C-D)

$$\delta_u = \max(2.25\% - 6\% \cdot \frac{\sigma_{0,tot}}{f_c}, 0.3\%) \cdot \frac{H_0}{\min(H,L)}$$ (typologies E-E1)

ALEATORIC VARIABILITY	Suggested coefficients of variation							
	K_{eff}	V_u	δ_{cr}	δ_y	δ_{SD}	δ_{max}	δ_u	δ_c
A-E1	0.20	0.10	0.10	0.20	0.30	0.30	0.30	-

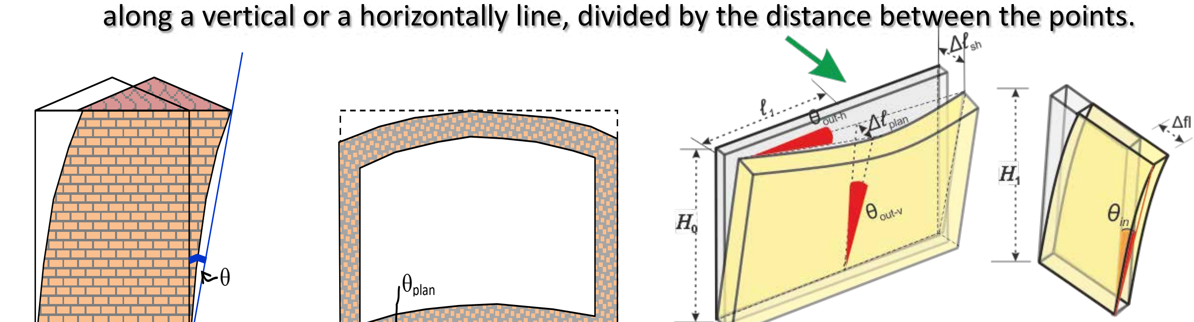
II. 3D-Modeling using FEA: Relative Drift Ratios. **Demands and Capacities are calculated again, however their values are determined in terms of deformation.**





Definition of Acceptance Criteria in terms of Drift Ratios:

Relative Lateral Displacement between any two points that lie on the surface of a masonry pier, along a vertical or a horizontally line, divided by the distance between the points.



In-Plane, Heightwise, **Out of Plane, Horizontally**

$\theta_{out\text{-}h}=\Delta\ell_{plan}/\ell_1$

$\theta_{out\text{-}v}=\Delta\ell_{plan}/H_o$

$\theta_{in}=\Delta_{fl}/H_1$

<u>Flexure Controlled:</u>
Yield Point: θ_y=0.15%
Failure: $\theta_u=0.008\cdot H_0/L$
(for Secondary Elements, $\theta_u=0.012\cdot H_0/L$)

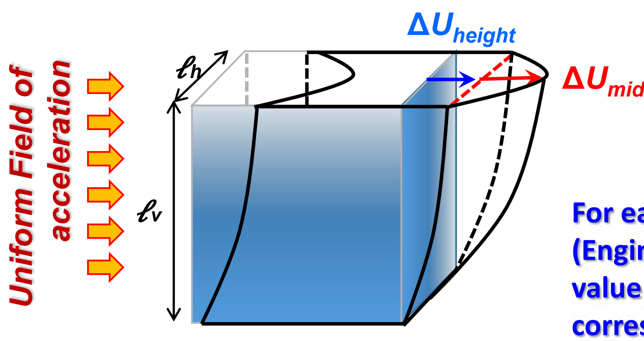
<u>Shear Dominated:</u>
Yielding: γ_y=0.20%
Failure: γ_u=0.40%
(for Secondary Elements, γ_u=0.60%)

Yielding: $\theta_{plan,y}$=0.2%

<u>Piers in Shear Buildings (Rigid Diaphragms)</u>
Failure: $\theta_{plan,u}$=0.72% for solid bricks; s.d =35%
$\theta_{plan,u}$= 0.45% for hollow bricks; s.d. 30%
$\theta_{plan,u}$= 0.6% for Stone; s.d 25%

Acceptance Criteria: Check Demands Against the Capacities

Photo: Dr. Karantoni

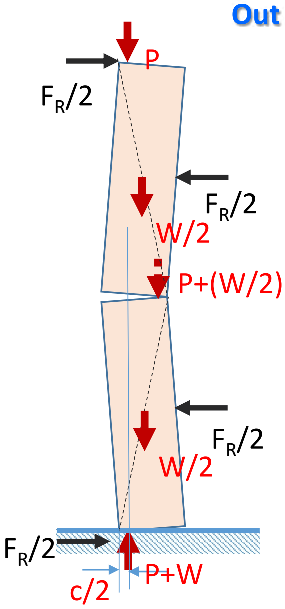


$\theta_{height} = \Delta U_{height} / \ell_v$

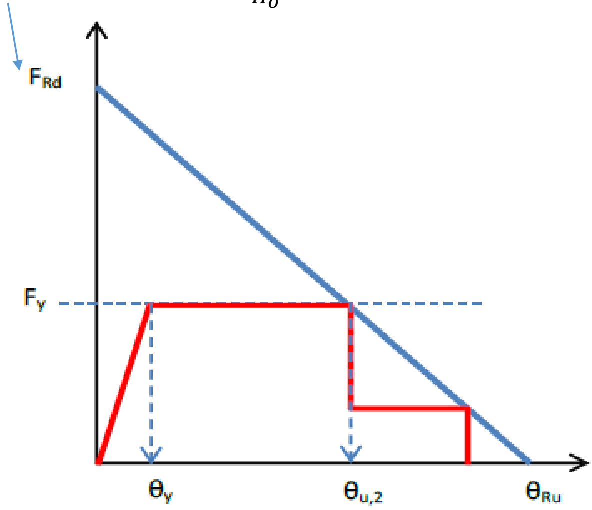
$\theta_{plan} = 2 \cdot \Delta U_{mid} / \ell_h$

For each performance limit state, the EDP (Engineering Demand Parameter given as the value of rotation, γ or θ) is checked against the corresponding limit values given previously

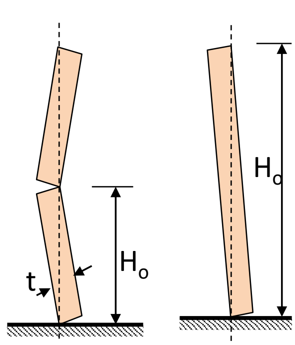
Out of Plane Action - Risk of Toppling



$$F_{Rd} = \lambda W \cdot (1 + \Psi) \cdot \frac{t_w}{H_o} \quad ; \quad \Psi = 2P/W$$



(c) Out of Plane Action (H_o: Measured from the point of Max. Displacement to the pole of rotation)



$$\theta_{u,out} = \min\{\theta_{u,1}, \theta_{u,2}\}$$

$$\theta_{u,1} = 0.003 \cdot H_o / t$$

$$\theta_{u,2} = \theta_{R,u} \cdot (1 - F_y / F_{Rd})$$

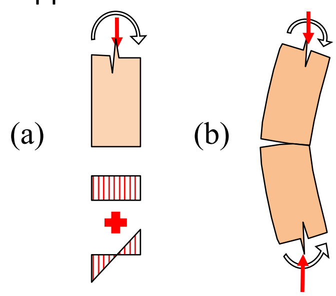
Force required to cause out-of-plane toppling of the wall

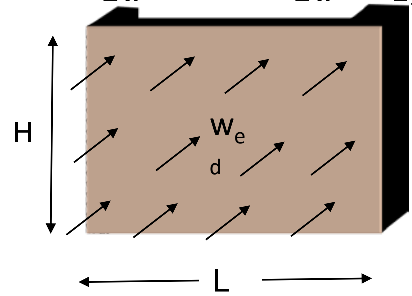
Importance of Out-of-Plane Action:

$$F_{Ed} = \lambda \cdot W_{Ed} \cdot A_{L,w}$$

$A_{L,w}$ Wall pier surface.

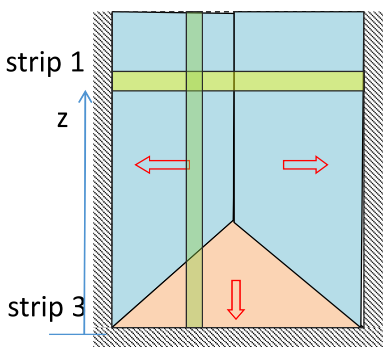
λ: Support Conditions

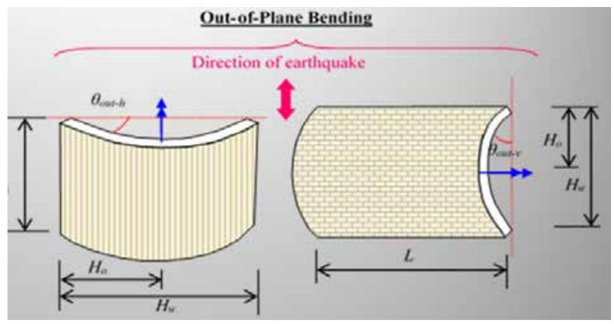




(a) Stress superposition at cracking,
(b) Ultimate Flexural Strength

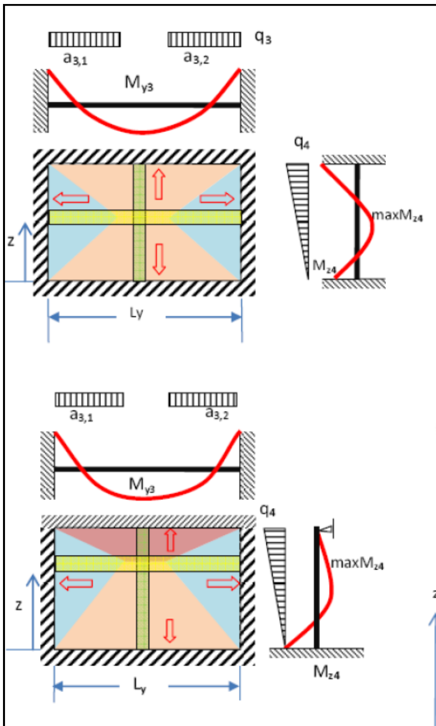
Example: Wall with a thickness of 0,5 m and specific weight of 18 =KN/m^3, for an acceleration response equal to 0,5g at the top floor, is subjected to lateral pressure: w_e= 4,5 KPa (≈ the same as the self-weight of a RC slab)

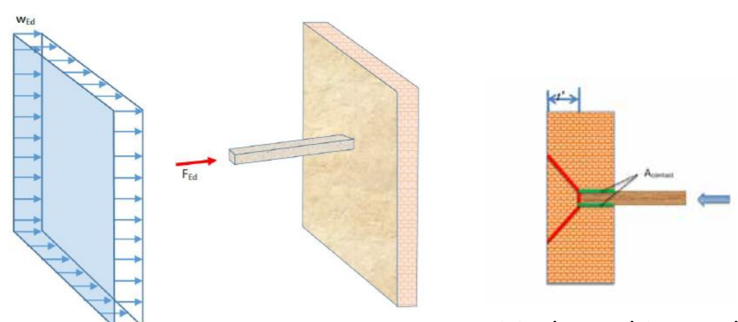




Vertical cracking — Horizontal cracking

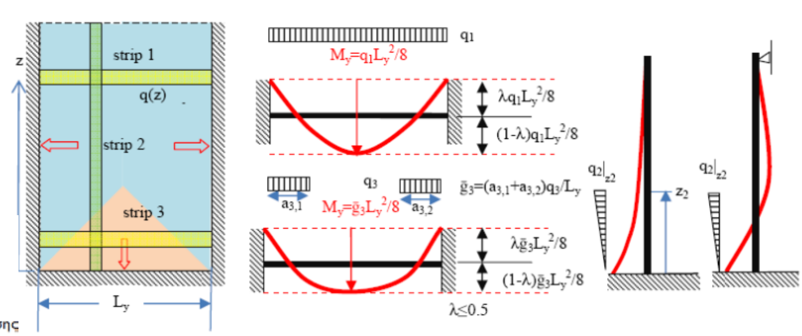
Horizontal strips — Vertical strips





Critical punching path

Fig. Σ 5-B.1: Out of Plane Forces acting on the wall



$S_e^{fail} = S_e(T)\, w_u/w_{Ed}$

όπου

S_e^{fail} η μέγιστη «ανεκτή» επιτάχυνση

$S_e(T)$ η φασματική επιτάχυνση από το ελαστικό φάσμα απόκρισης

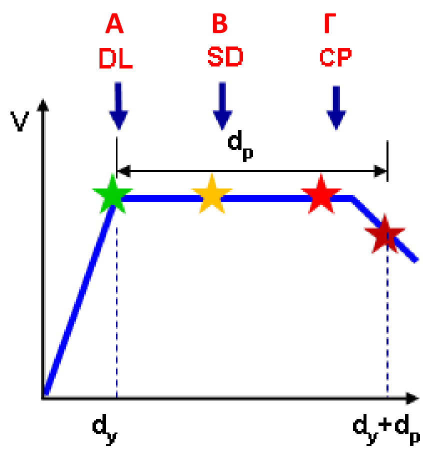
w_u το σεισμικό φορτίο στην αστοχία του τοίχου

w_{Ed} το σεισμικό φορτίο που αντιστοιχεί στην $S_e(T)$ (Εξ. 5.13)

Chapter 9: Checking the Design Inequality

Acceptance Criteria: Check the Demands against the Capacities

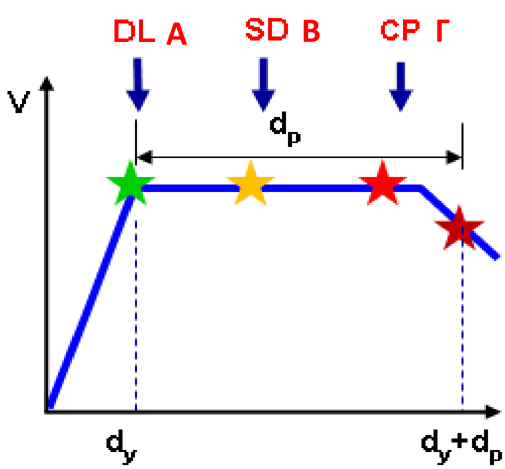
The design values for the demand (or assessment, per the Paragraph 9.3.2) are compared with the corresponding values of the acceptance criteria in order to determine whether the design inequality is satisfied for the building, and to estimate the anticipated level of damage (performance limit state) that will be developed in the building when the design or evaluation demands will be realized (depending on the assessment performance objective per paragraph 9.3.2)



9.1.3 α) If the assessment's objective is intended to demonstrate that the structure meets the capacity requirements, then all the individual members ought to satisfy the corresponding acceptance criteria.

β) If the assessment is conducted in order to support decisions related to redesign and retrofit, all the structural members should satisfy the corresponding acceptance criteria after the intervention.

Acceptance Criteria: Relating Performance with Deformation Capacity:



Performance Limit State	Magnitude of Rotation Limit
A: Damage Limitation	Can be conducted either in terms of forces or in terms of deformation (rotation) at notional «yielding»
B: Significant (Repairable) Damage	¾ γ_u, ¾ θ_u
Γ: Collapse Prevention	4/3 γ_u, 4/3 θ_u

Deformation Capacity in terms of Rotation (drift), for In-Plane and Out-of-Plane Action	
Type of Seismic Response	**Limit Value for Rotation at Failure**
In plane, piers that belong to the system of lateral resistance (i.e., contribute to lateral resistance).	Elements controlled by Flexure: $\theta_{u,in}=0.008 \cdot H_o/L$
	Elements controlled by Shear: $\theta_{u,in}=0.004$
Out of Plane - Toppling	$\theta_{u,out} = \min\{\theta_{u,1}, \theta_{u,2}\}$

Performance Limits (Acceptance Criteria) for in- and out- of plane Actions

Type of Seismic Response	Relative Drift Limits	Performance Limit State
In plane	$\theta_{in} < 0.15\%$	A: Immediate Occupancy – Damage Limitation
	$0.15\% \le \theta_{in} < 0.75 \cdot \theta_{u,in}$	B: Significant but Repairable Damage
	$0.75 \cdot \theta_{u,in} \le \theta_{in} < 1.33 \cdot \theta_{u,in}$	Γ: Life Safety – Collapse Prevention
Out of Plane (in the horizontal direction)	$\{\theta_{out-v}\ ;\ \theta_{out-h}\} < 0.20\%$	A: Immediate Occupancy – Damage Limitation
	$0.20\% \le \{\theta_{out-v}\ ;\ \theta_{out-h}\} < 0.75 \cdot \theta_{u,out}$	B: Significant but Repairable Damage
	$0.75 \cdot \theta_{u,out} \le \{\theta_{out-v}\ ;\ \theta_{out-h}\} < 1.33 \cdot \theta_{u,out}$	Γ: Life Safety – Collapse Prevention

In Conclusion:

3 principal stages are defined in the Method of Analysis and Assessment regardless of modelling approach, and material response idealization:

- **Stages / Steps:**

I. ***Determine the relative distribution of lateral Drifts in the URM structure for an applied displacement at the control point***

II. ***Quantify for the structure the peak displacement response (whether that is modeled as a MDOF or as a ESDOF system) and obtain the drift demands for the peak displacement at the control point – either using elastic or inelastic response***

III. ***Find the local demands in terms of deformation, and apply the acceptance criteria in order to quantify the anticipated damage and therefore the anticipated PLS.***

Capacity is evaluated at each different floor level of the building, in the direction of seismic action as follows:

(α) In the case of flexible diaphragms, lateral load capacity is evaluated for each individual structural component.

(β) In the case of stiff or rigid diaphragms, structural capacity may be taken as the sum of the strengths of the individual parallel walls.

Strength of each individual wall in the direction of seismic action is calculated according with Chapter 7, depending on whether it is controlled by flexure (Eq. (7.1)) or by shear (Eq. (7.2)).

α) ***For ductile behavior and modes of failure of the structural elements,***

Performance is assessed in terms of deformation:

$$R_d = \delta_{d,B} = \frac{\delta_u}{\gamma_{Rd}}$$

- **In Plane: γ_{Rd} =1,33. Out of Plane: γ_{Rd}=2,0.**
- **For secondary elements γ_{Rd} is 1.33 always for Performance Limit State B, but 1.15 for Performance Limit State Γ**

β) ***For brittle behavior and mode of failure,***

Performance is assessed in terms of Strength.

ECILS/ECPFE Workshop

"Seismic Assessment and Retrofitting of Masonry and Preserved Structures"

Protection of heritage structures from earthquake effects: status of regulations and practice in the Republic of Serbia

Dr. Svetlana Brzev

Adjunct Professor, Department of Civil Engineering,
University of British Columbia, Canada

President, Serbian Association for Earthquake Engineering (SUZI-SAEE)

SU | SA
ZI | EE

IZIIS, Skopje, 23rd May 2024

SU | SA
ZI | EE

Serbian Association for Earthquake Engineering (SAEE)
Srpsko Udruženje za Zemljotresno Inženjerstvo (SUZI)

- Established in 2018 as a non-governmental non-profit organization in Belgrade, Serbia.
- Main objective is to raise awareness and the level of knowledge and practice of earthquake engineering in the Republic of Serbia.
- Governed by the Board of Directors (11 members) headed by the president (currently Svetlana Brzev).
- Currently has 46 members from Serbia and neighbouring countries, mostly civil engineers, architects, seismologists, etc.
- Member of the International Association for Earthquake Engineering (IAEE) since 2018.

Srpsko Udruženje za Zemljotresno Inženjerstvo - SUZI
Serbian Association for Earthquake Engineering - SAEE

Web site: www.suzi-saee.rs

SU | SA
ZI | EE

Main activities:

- Lectures/seminars - published on Youtube channel https://www.youtube.com/@suzi-saee9813
- International workshops held in Belgrade:

- Seismic risk, recovery, and resilience workshop in 2022

https://suzi-saee.rs/akcije/international-workshop-seismic-risk-recovery-and-resilience-held-in-belgrade-on-june-16-and-17-2022

- SERA Seismic Risk at Balkans workshop in 2019

- Earthquake reconnaissance visits (Albania, Croatia, and Turkiye)

- organized seminars/lectures and prepared articles for the newsletter

Srpsko Udruženje za Zemljotresno Inženjerstvo - SUZI
Serbian Association for Earthquake Engineering - SAEE

Web site: www.suzi-saee.rs

- Exhibitions – e.g. an exhibition on the 100th anniversary of the Great earthquake of 1922 (strongest earthquake in Serbia in the 20th century)

https://suzi-saee.rs/akcije/izlozba-povodom-stogodisnjice-najjaceg-zemljotresa-u-srbiji-u-xx-veku-otvorena-u-lazarevcu

See attached posters – an example shown below

- Newsletter (eGlasnik) - twice a year

Example: last issue (July 2023)

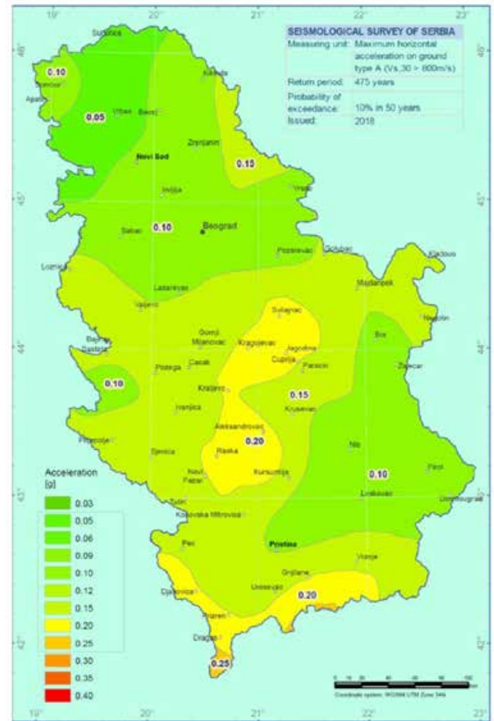
https://suzi-saee.rs/img/suzi-eglasnik_broj-11-jul2023_final_1_1.pdf

- Other publications – a monograph re the 2019 Albania earthquake

https://suzi-saee.rs/img/suzi-publikacija_zemljotres_albanija2019_1.pdf

Introduction

- Serbia is located in a region of moderate seismic activity, however its territory is close to regions of high seismic hazard which triggered major earthquakes in recent history, e.g. the 1979 Montenegro earthquake (M 6.9) the 1977 Vrancea, Romania earthquake (M 7.2).
- In the last 100 years more than 10 earthquakes with magnitude 5.0 or higher occurred in Serbia.
- The most significant earthquake in the 20th century occurred in 1922, had magnitude 6.0 and epicenter near Lazarevac (approximately 60 km aerial distance from the capital Belgrade).
- More recently, the 2010 Kraljevo earthquake (M 5.4) caused 2 fatalities and more than $100 million in damages, based on the World Bank's (WB) country risk profile for Serbia (WB 2017).
- Several other earthquakes affected rural areas of Serbia, such as the 1927 Rudnik earthquake (M 5.9), the 1980 Kopaonik earthquake (M 5.8), and the 1998 Mionica earthquake (M 5.5).



Seismic hazard map of Serbia
10% probability of exceedance in 50 years
PGA in the range from 0.05g-0.25g

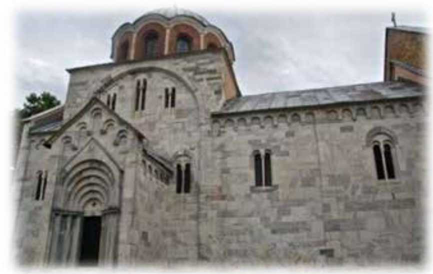
Cultural heritage portfolio – Serbia (1/2)

- Cultural heritage ranges from individual buildings of secular architecture, to civil buildings typologically linked with urban centres, public objects, fortifications and religious buildings
- Key government institution: Republic institute for the protection of monuments of culture, Belgrade, established in 1947 (currently under the Ministry of culture and information)
- Cultural heritage portfolio for Serbia:
  - ✓ 155 monuments of exceptional importance, and
  - ✓ 512 monuments of great importance.

Cultural heritage portfolio – Serbia (2/2)

Five UNESCO heritage sites in Serbia

Location of UNESCO World Heritage Sites within Serbia and Kosovo (striped area)



The Studenica Monastery (12th century)

The Sopoćani Monastery (13th century) + Stari Ras

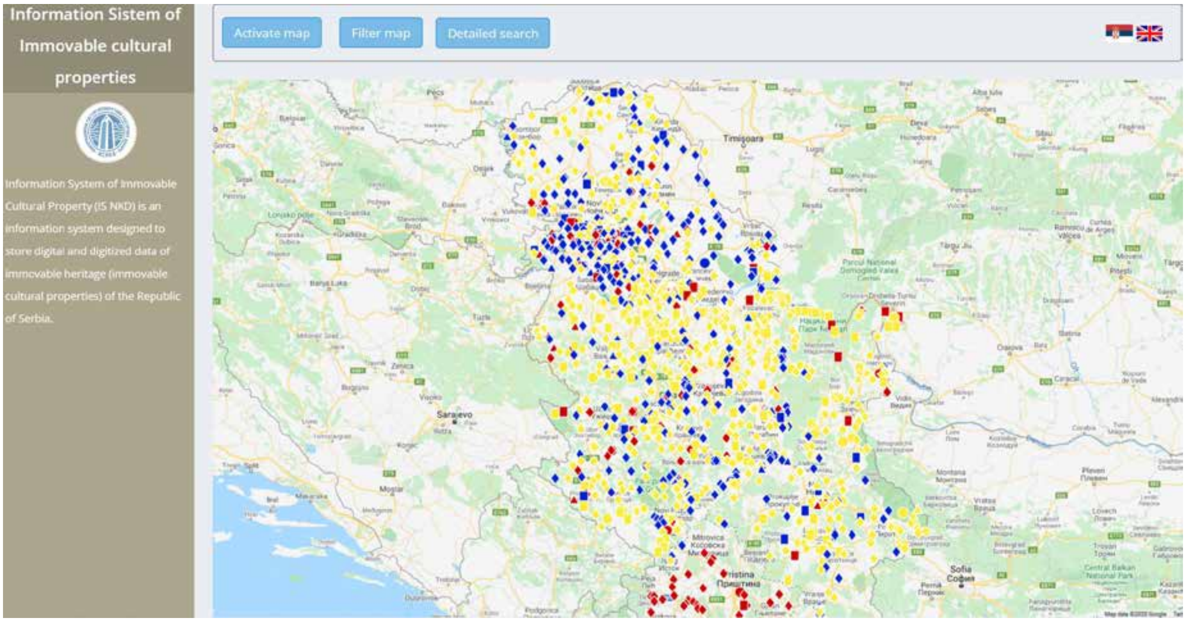
Cultural heritage portfolio: documentation

- Several publications related to cultural heritage monuments in Serbia, including the UNESCO heritage sites

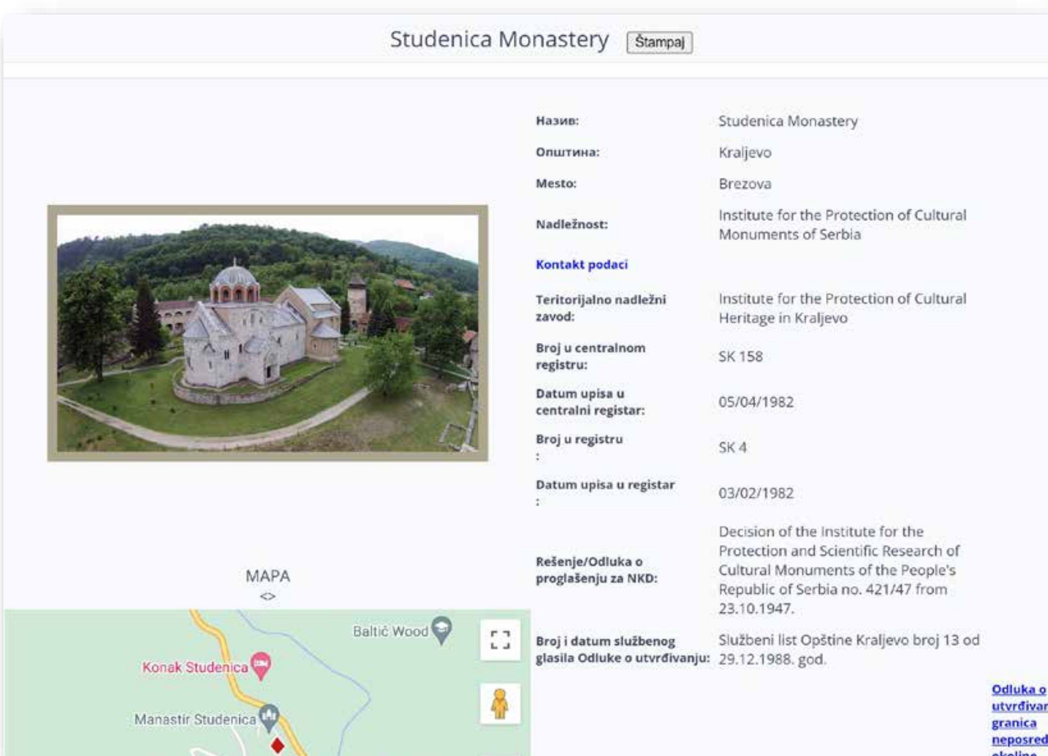
https://www.heritage.gov.rs/cirilica/Download/Svetska__bastina__Srbija__World__heritage__Serbia__book.pdf

- An interactive online information system
  https://nasledje.gov.rs/index.cfm

Cultural heritage: interactive online information system



Cultural heritage online database: an example of the collected info



Technical regulations: past (before 2022)

- 1981: Technical Regulations for the Design and Construction of Buildings in Seismic Regions (Pravilnik o tehničkim normativima za izgradnju objekata visokogradnje u seizmičkim područjima). Yugoslav Institute for Standardization, Official Gazette of SFRY No. 31/81 (Amendments 49/82, 29/83, 21/88, 52/90)
- 1985: Technical Regulations for Repair, Strengthening and Reconstruction of Building Construction Damaged by Earthquakes and for Reconstruction and Rehabilitation of Building Structures (Pravilnik o tehničkim normativima za sanaciju, ojačanje i rekonstrukciju objekata visokogradnje oštećenih zemljotresom i za rekonstrukciju i revitalizaciju objekata visokogradnje). Yugoslav Institute for Standardization, Official Gazette of SFRY No. 52/85.

Technical regulations: present (post-2022)

- 2022: Building regulations (Pravilnik za građevinske konstrukcije). Institute for Standardization of Serbia, Official Gazette of Republic of Serbia No. 89/2019, 52/2020, 122/2020, **https://www.paragraf.rs/propisi/pravilnik-za-gradjevinske-konstrukcije.html**
- Eurocode 8 - Design of structures for earthquake resistance-Part 1: General rules, seismic actions and rules for buildings (SRPS EN 1998-1/NA:2018 Evrokod 8 - Projektovanje seizmički otpornih konstrukcija, Deo 1: opšta pravila, seizmička dejstva i pravila za zgrade). Institute for Standardization of Serbia, Serbia, 2018 (in Serbian).
- Eurocode 8 - Design of structures for earthquake resistance-Part 3: Assessment and retrofit of buildings (SRPS EN 1998-3/NA:2018 Evrokod 8 - Projektovanje seizmički otpornih konstrukcija, Deo 3: procena stanja i ojačanje zgrada). Institute for Standardization of Serbia, Serbia, 2018 (in Serbian).

Cultural Heritage Law – Republic of Serbia

- 2021: Cultural heritage law (Zakon o kulturnom nasledju), Official Gazette of Serbia, No. 71/94, 52/2011, 99/2011, 6/2020, 35/2021, 129/2021) (in Serbian) https://pravno-informacioni-sistem.rs/eli/rep/sgrs/skupstina/zakon/2021/129/11
  - Article 1: the law establishes the system for preservation and protection of cultural heritage.
  - Article 71: the cultural heritage at risk has a priority for conservation compared to remaining cultural heritage objects. Natural hazards (including earthquakes, floods, etc.) have been identified as a potential source of risk. It has been stated that a responsible minister makes a decision regarding the intervention based on the recommendation by a responsible institute for the protection of cultural heritage.

Preservation of cultural heritage in Serbia from earthquake effects

- Due to relatively few seismic events in the recent history there is a limited focus on reduction of seismic vulnerability of existing building stock and cultural monuments.
- The November 2010 Kraljevo earthquake (Mw 5.5) caused damage of unreinforced masonry structures, including religious heritage structures (churches)

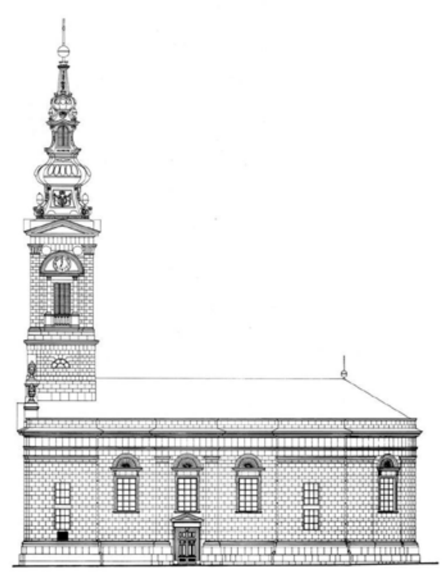
a) b)

Figure 31 – Post-earthquake rehabilitation of a church in the Sirča village near Kraljevo after the 2010 earthquake: a) severe damage in the vaulted ceiling and b) horizontal steel ties provided to improve the overall structural integrity (Krstivojević, N., 2014).

Structural rehabilitation of Serbian cultural heritage: an example

- Cathedral Church of St. Michael the Archangel (Saborna Crkva), Belgrade
- Greek orthodox church built in a neoclassical style – in general not common in Serbia, but it was common during the reign of Milos Obrenovic
- Built around 1840 – one of the few preserved monuments in Belgrade from that era.
- The church was considered as a central support in the independence fight from the Ottoman rule.
- One of the most important churches in Serbia and a landmark of Belgrade

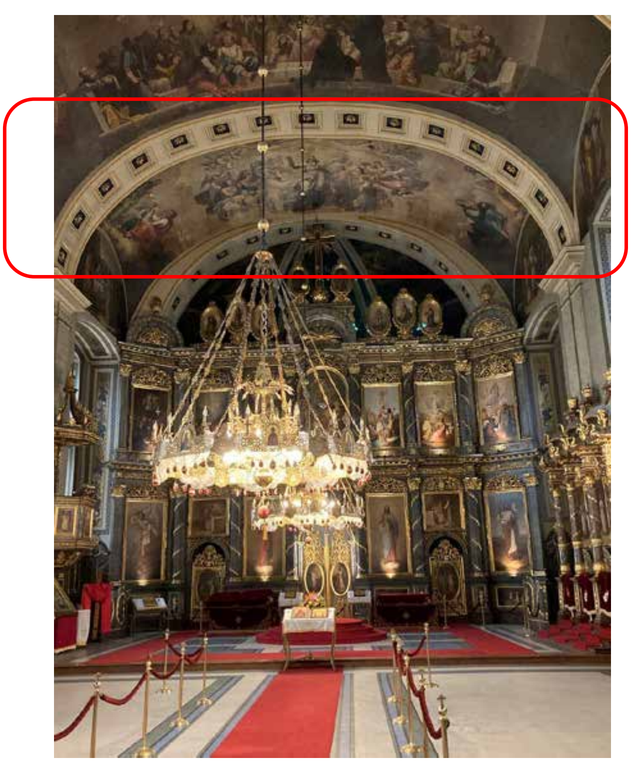
Structural rehabilitation of Serbian cultural heritage: Cathedral Church (Saborna Crkva), Belgrade

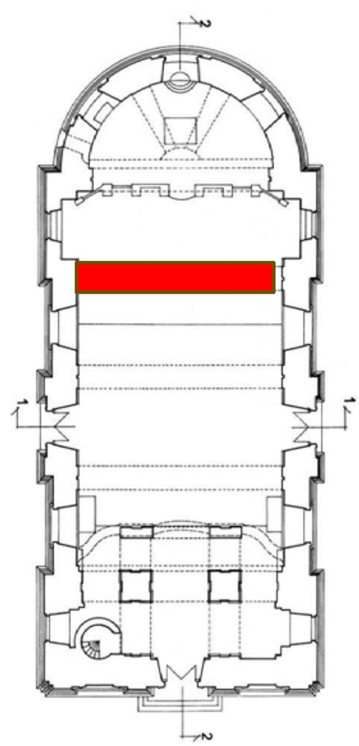


The Cathedral Church (Saborna Crkva), Belgrade: description of loadbearing structure

- Massive brick masonry walls (2.45 m thickness at some locations) with the pilasters in longitudinal walls
- Plan dimensions: 45 m length by 19.6 m width
- Four elliptical brick masonry arches in transverse direction.
- It is believed that the original design assumed that the arches are rigidly supported by the walls.
- Two internal (hidden) metal ties (15 x 45 mm) were placed in the upper portion of each arch and embedded in the walls at the ends.

The Cathedral Church (Saborna Crkva), Belgrade: Arches and Vaults





The Cathedral Church (Saborna Crkva), Belgrade: damage and rehabilitation

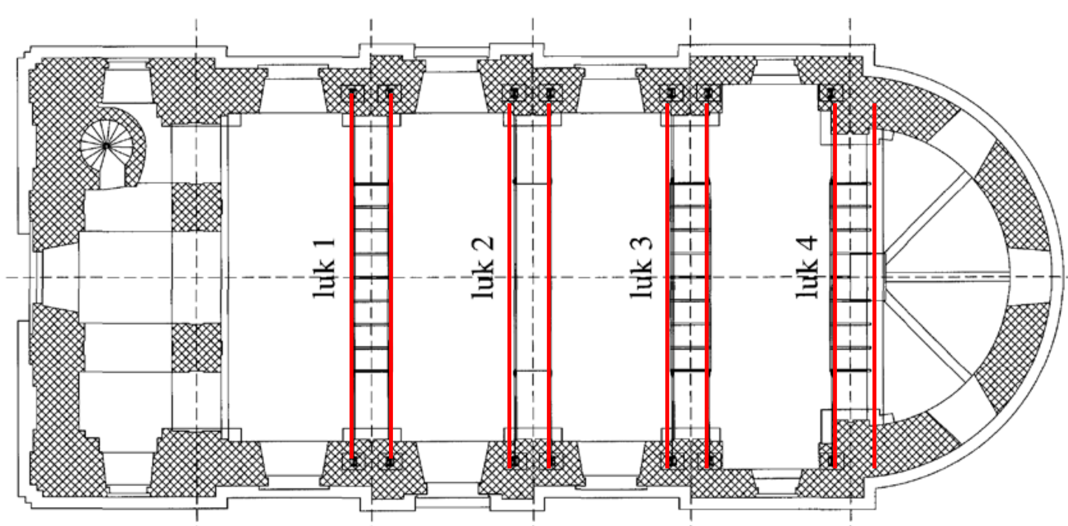
- Damage in the form of cracks and relative horizontal movements in the walls at the top (in some cases on the order of 10 cm or more)
- Cracking of the masonry at the tie support area due to excessive tensile stresses – the original ties were no longer effective…
- Rehabilitation had to be performed without any exposed ties (a heritage conservation requirement).

=> A rehabilitation solution had to involve the hidden ties (similar to the original design, but more effective)

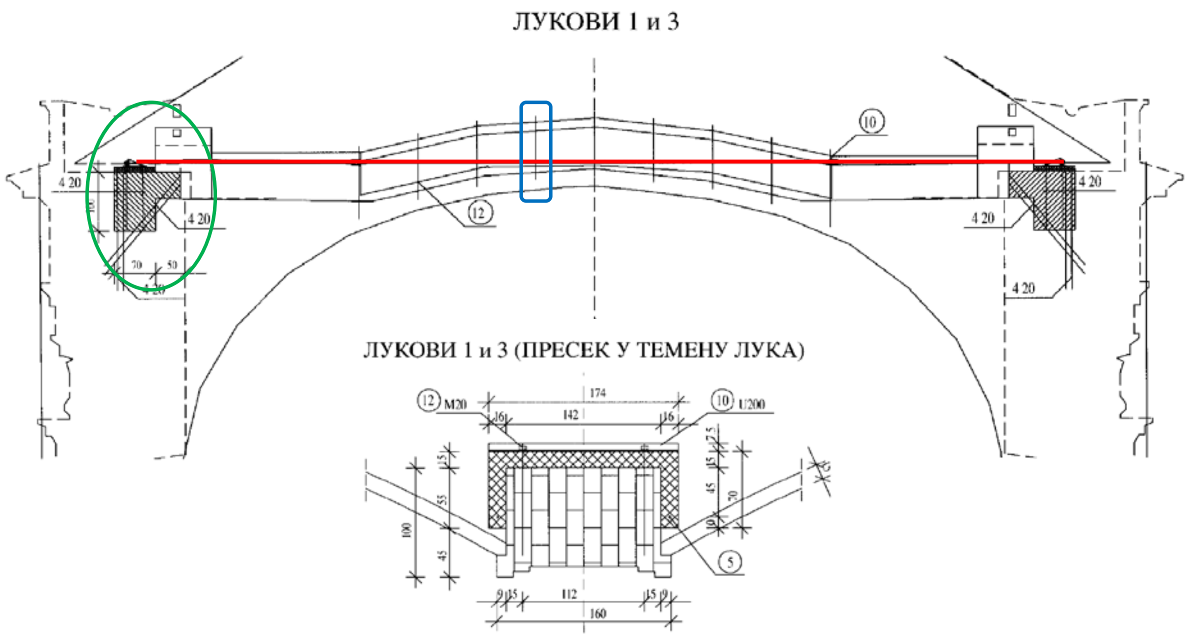
A detailed description of the rehabilitation project presented in the paper by Aleksandar Malić and Djordje Marinković: "Structural rehabilitation of arched structures of the Cathedral Church in Belgrade" (Sanacija konstrukcije lukova Saborne crkve u Beogradu), Nasledje, 2001, Vol. 3, pp. 155-164
https://beogradskonasledje.rs/wpcontent/uploads/2013/nasledje3/12_aleksandar_malic_djordje_marinkovic.pdf

The Cathedral Church (Saborna Crkva), Belgrade: rehabilitation solution

1. Installation of new post-tensioned rods/ties 20 mm diameter (two for each arch)
2. Strengthening of the damaged portion of the arches, by connecting new and existing material through metal fasteners
3. Construction of new anchor blocks using a "special" concrete



The Cathedral Church (Saborna Crkva), Belgrade: rehabilitation solution

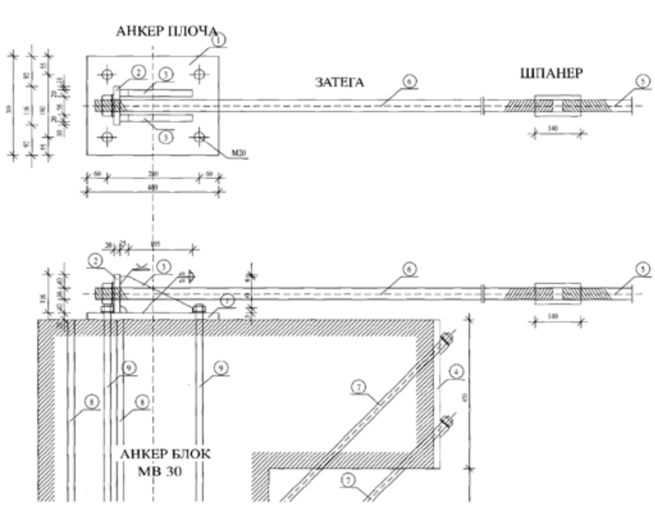


The Cathedral Church (Saborna Crkva), Belgrade: anchor block detail

A special concrete mix was custom developed for this project by the Faculty of Civil Engineering, University of Belgrade – using recycled bricks

Mass density at 14 days: 1770 kg/m3

Compressive strength: 17 MPa



ADRISEIMIC – an Interreg Project (2020-2022)

Full title: New approaches for seismic improvement and renovation of Adriatic and Ionian historic urban centres

Main objectives:

- To share the methodologies for assessing the seismic vulnerability of existing buildings in historic urban centers.
- To share simple, effective and economical techniques and strengthening strategies.
- To develop ADRISEISMIC methodology for seismic risk assessment of buildings in historic urban centers.
- To develop action plans for seismic risk assessment for a region of the country

The main focus areas are the historic urban centers and historical squares and their surrounding buildings, conceived as symbol of local identity.

https://adriseismic.adrioninterreg.eu/

ADRISEISMIC project - partners

Lead institution:

University of Bologna – Department of Architecture (IT)

Partners:

1. Institute for Vocational Training of Construction Workers in the province of Bologna – I.I.P.L.E. (IT)
2. City of Kaštela (HR) <-> Faculty of Civil Engg, University of Zagreb
3. Municipality of Gjirokaster (AL)
4. Regional Development Agency Bačka (RS) <-> SUZI-SAEE
5. Slovenian National Building and Civil Engineering Institute ZAG (SI)
6. University of Crete (GR)
7. Region of Crete (GR)

ADRISEISMIC Methodology for Rapid Visual Assessment of Masonry and Reinforced Concrete Buildings (“expeditious methodology”)

The expeditious methodology must be able to fit into the existing context of the region and respect the following fundamental criteria:

- Provide qualitative analysis in a short time, useful as a preliminary tool for subsequent quantitative analysis.
- Identify the most likely criticality/collapse mechanisms for a given structure (total/partial).
- Needs to be applicable to reinforced concrete and masonry buildings.

The methodology was explained in the paper (free access journal)

Predari, G.; Stefanini, L.; Marinković, M.; Stepinac, M.; Brzev, S. (2023). Adriseismic Methodology for Expeditious Seismic Assessment of Unreinforced Masonry Buildings. Buildings, 13, 344. https://doi.org/10.3390/buildings13020344

SEISMIC BEHAVIOUR OF MASONRY BUILDINGS: CRITICAL PARAMETERS

Possible failure mechanisms for masonry buildings:

Mechanism 1. Disintegration

IQM method – used in Italian practice (not included in the code)

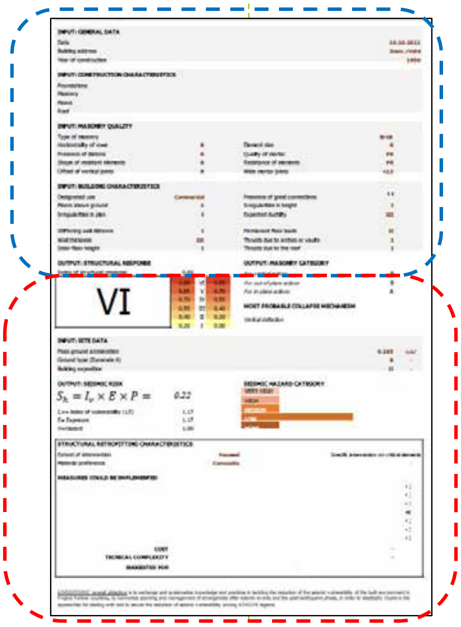
Mechanism 2. Kinematic failure mechanism – out-of-plane seismic actions

Basis: C.I.N.E. Method (Italy)

Mechanism 3. Kinematic failure mechanism in-plane

These mechanisms depend on the mechanical characteristics of masonry and are usually analyzed using numerical models.

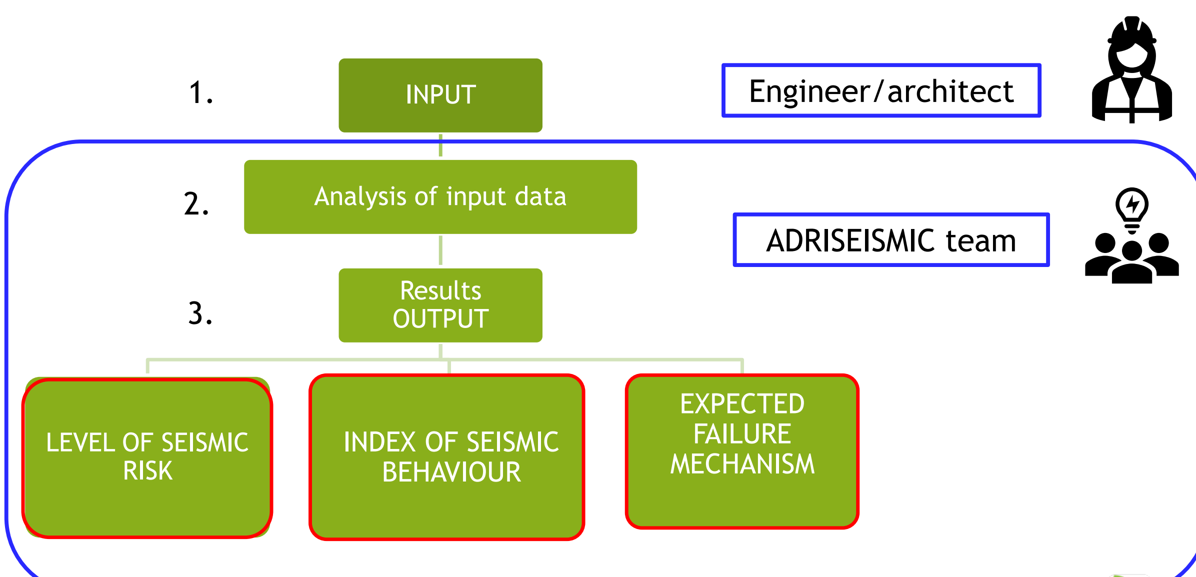
ADRISEISMIC METHODOLOGY: EXCEL FORM



INPUT

RESULTS (OUTPUT)

ADRISEISMIC METHODOLOGY FOR RAPID VISUAL ASSESSMENT



INPUT - MASONRY

Four categories:

1. General data
2. Construction characteristics
3. Masonry quality
4. Building data

CRITICAL INPUT PARAMETERS FOR MASONRY STRUCTURES

Mechanism 1: Disintegration <-> Quality of masonry

IQM method (masonry quality index) developed at the University of u Perugia, Italy around 2000 (Borri, de Maria). IQM – an approximate system for determining masonry quality in a specific building.

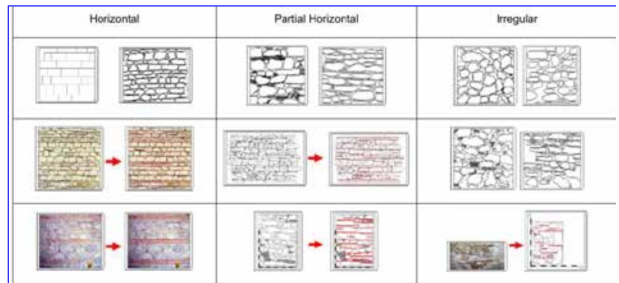
Masonry Quality – 9 input parameters:

1. Type of masonry
2. Horizontal alignment of brick/stone rows in a wall
3. Presence of headers
4. Shape of masonry elements
5. Alignment of vertical joints
6. Masonry element size
7. Quality of mortar
8. Resistance of masonry elements
9. Thickness of mortar joints

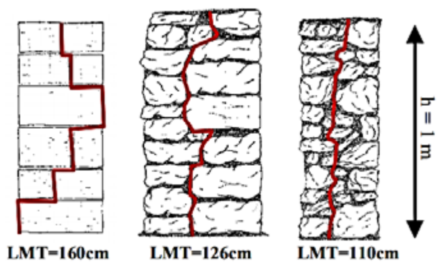
CRITICAL INPUT PARAMETERS FOR MASONRY STRUCTURES

Mechanism 1: Disintegration – examples of input data

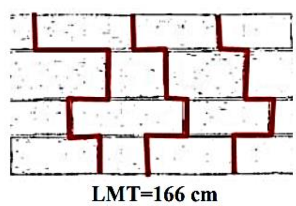
1. Type of masonry
2. Horizontal alignment of brick/stone rows
3. Presence of headers
4. Shape of masonry elements
5. Alignment of vertical joints
6. Masonry element size
7. Quality of mortar
8. Resistance of masonry elements
9. Thickness of mortar joints

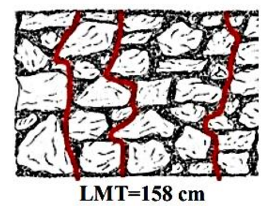


2. Horizontal alignment of brick/stone rows



3. Presence of headers





5. Alignment of vertical joints

CRITICAL INPUT PARAMETERS FOR MASONRY STRUCTURES

Mechanism 1: Disintegration <-> IQM values

Type of failure mechanism

	IQM_V			IQM_{FP}			IQM_{NP}		
	NR	PR	R	NR	PR	R	NR	PR	R
2. Horizontal alignment of brick/stone rows	0	1	2	0	1	2	0	0,5	1
3. Presence of headers	0	1	1	0	1,5	3	0	1	2
4. Shape of masonry elements	0	1,5	3	0	1	2	0	1	2
5. Alignment of vertical joints	0	0,5	1	0	0,5	1	0	1	2
6. Masonry element size	0	0,5	1	0	0,5	1	0	0,5	2
7. Quality of mortar	0	0,5	2	0	0,5	1	0	1	2
8. Resistance of masonry elements	0,3	0,7	1	0,5	0,7	1	0,3	0,7	1

IMPORTANT: NR minimum number of points (0)
R maximum number of points (2)

CRITICAL INPUT PARAMETERS FOR MASONRY STRUCTURES
Mechanism 1: Disintegration <-> Masonry category

- Three failure mechanisms:
  1) IQM_V - disintegration
  2) IQM_{FP} – out-of-plane seismic effects
  3) IQM_{NP} – in-plane seismic effects
- IQM classifies masonry into 3 categories (A, B, C) based on the total number of points for Masonry Quality:
  - Category A = minimum collapse risk (maximum number of points)
  - Category C = maximum collapse risk (minimum number of points)

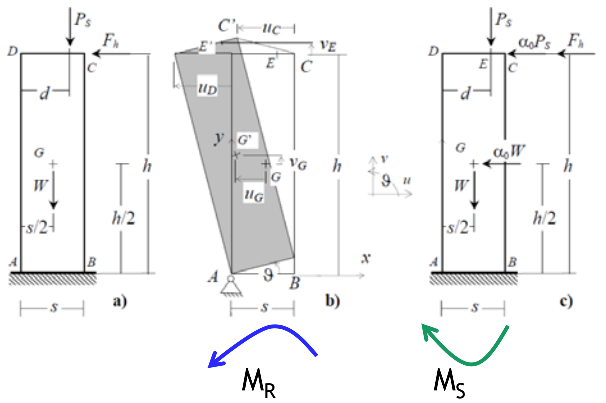
	Masonry category		
	A	B	C
Mechanism 1: IQM_V	$5 \le IQM_V \le 10$	$2{,}5 \le IQM_V < 5$	$0 \le IQM_V < 2{,}5$
Mechanism 2:IQMFP	$7 \le IQM_{FP} \le 10$	$4 < IQM_{FP} < 7$	$0 \le IQM_{FP} \le 4$
Mechanism 3: IQM_{NP}	$5 < IQM_{NP} \le 10$	$3 < IQM_{NP} \le 5$	$0 \le IQM_{NP} \le 3$

CRITICAL INPUT PARAMETERS FOR MASONRY STRUCTURES
Mechanism 2: Kinematic mechanisms due to out-of-plane seismic actions

Fig 10.1 – Meccanismi di ribaltamento semplice (Foto da: MEDEA – *Papa e Zuccaro*, 2001)

CRITICAL INPUT PARAMETERS FOR MASONRY STRUCTURES

Mechanism 2: Kinematic mechanisms due to out-of-plane seismic actions



(9.32) $$\mathbf{S}_G = \begin{Bmatrix} u_G \\ v_G \end{Bmatrix} = \begin{Bmatrix} -h/2 \\ s/2 \end{Bmatrix} \vartheta; \ \mathbf{S}_C = \begin{Bmatrix} u_C \\ v_C \end{Bmatrix} = \begin{Bmatrix} -h \\ s \end{Bmatrix} \vartheta; \ \mathbf{S}_E = \begin{Bmatrix} u_E \\ v_E \end{Bmatrix} = \begin{Bmatrix} -h \\ d \end{Bmatrix} \vartheta$$

Gli spostamenti, con le convenzioni della (9.1), e le corrispondenti forze valgono:

(9.33)
$$W: \quad \delta_{x,1} = -u_G = (h/2)\vartheta; \quad \delta_{y,1} = v_G = (s/2)\vartheta$$
$$P_s: \quad \delta_{x,2} = -u_E = h\vartheta; \quad \delta_{y,2} = v_E = d\vartheta$$
$$F_h: \quad \delta_h = u_C = -h\vartheta$$

L'equazione dei lavori virtuali si particolarizza come segue:

(9.34) $$\alpha_0 (W \delta_{x,1} + P_s \delta_{x,2}) - (W \delta_{y,1} + P_s \delta_{y,2}) - F_h \delta_h = 0$$

da cui, sostituendo i valori della (9.33) si ha:

(9.35) $$\alpha_0 [W(h/2)\vartheta + P_s h\vartheta] - [W(s/2)\vartheta + P_s d\vartheta] + F_h h\vartheta = 0$$

Il moltiplicatore α_0 vale perciò:

(9.36) $$\alpha_0 = \frac{[W(s/2) + P_s d] - F_h h}{W(h/2) + P_s h}$$

$$M_R = \alpha_0 [W(h/2) + P_s h] + F_h h; \quad M_S = [W(s/2) + P_s d]$$

Pilot case study: application of ADRISEISMIC methodology in Serbia: Vukov Spomenik, Belgrade

Studentski dom i menza „Kralj Aleksandar I"

Stambene zgrade

Viša poslovna škola

Pozorište „Vuk"

Stambeni objekti sa komercijalnim sadržajem u prizemlju

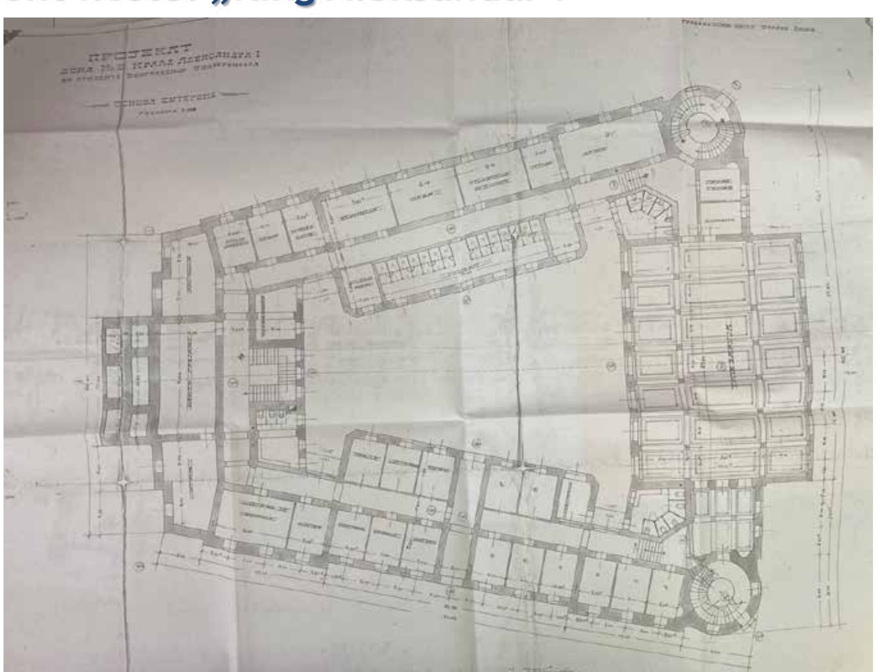
Source: Marko Marinković, University of Belgrade

Student Hostel „King Aleksandar I“

- Izgradnja je počela 1926
- Završeno 1928
- Najstariji studentski dom na Balkanu
- Nearmirana zidarija, AB rebrasta tavanica
- Koristi se kao studentski dom, menza i restoran

Source: Marko Marinković, University of Belgrade

Student hostel „King Aleksandar I“



Istorijski arhiv Beograda: osnova objekta

Source: Marko Marinković, University of Belgrade

Student Hostel „Kralj Aleksandar I“

Source: Marko Marinković, University of Belgrade

Student Hostel „Kralj Aleksandar I“

Source: Marko Marinković, University of Belgrade

Student Hostel „King Aleksandar I“

OUTPUT: STRUCTURAL RESPONSE

Index of structural response 0.49

III

1	VI	0.85	
0.85	V	0.7	
0.7	IV	0.55	
0.55	III	0.4	
0.4	II	0.2	
0.2	I	0	

OUTPUT: MASONRY CATEGORY

For vertical actions	B
For out-of-plane actions	A
For in-plane actions	A

MOST PROBABLE COLLAPSE MECHANISM

Vertical Deflection

INPUT: SITE DATA

Peak ground acceleration	0.1	*m/s2*
Ground type (Eurocode 8)	C	-
Building exposure	III	-

OUTPUT: SEISMIC RISK

$$S_h = I_v \times E \times P = \quad 0.36$$

I,v= index of vulnerability (1/I)	2.02
E= Exposure	1.20
H=Hazard	0.15

SEISMIC RISK CATEGORY

VERY HIGH
HIGH
MEDIUM
LOW ■
NONE

Masonry Expeditious Assessment v1.4 ADRISEISMIC PROJECT

MASONRY ASSESSMENT

INPUT: GENERAL DATA

Data	24.08.2022
Building address	Bulevar Kralja Aleksandara 197, 11000 Belgrade
GPS coordinates	44.8041, 20.4798

INPUT: CONSTRUCTION CHARACTERISTICS

Foundations	Brick masonry foundations
Masonry walls	Solid brick masonry with lime mortar
Floors	Cast-in-situ reinforced concrete slab
Roof	Single or double timber floors (beams and joints) with brick tiles
Notes on input:	–

INPUT: MASONRY QUALITY

Type of masonry			Brick
Horizontal alignment of brick/stone rows	R	Masonry element size	PR
Presence of headers	R	Quality of mortar	PR
Shape of masonry elements	R	Resistance of masonry elements	R
Alignment of vertical joints	R	Thickness of mortar joints	<13

INPUT: BUILDING CHARACTERISTICS

Designated use	Public	Connections between structural elements	☑
Floors above ground	5	Inegularties in height	I
Irregularties in plan	III	Expected ductility	II
Trasversal wall distance	II	Permanent floor loads	III
Wall thickness	III	Thrusts due to arches or vaults (floor level)	I
Floor height	II	Thrusts due to arches or vaults (roof level)	I

STRUCTURAL RETROFITTING CHARACTERISTICS

Extent of intervention	Extensive	Intervention extended to all elements of the building
Material preference	Composite	-

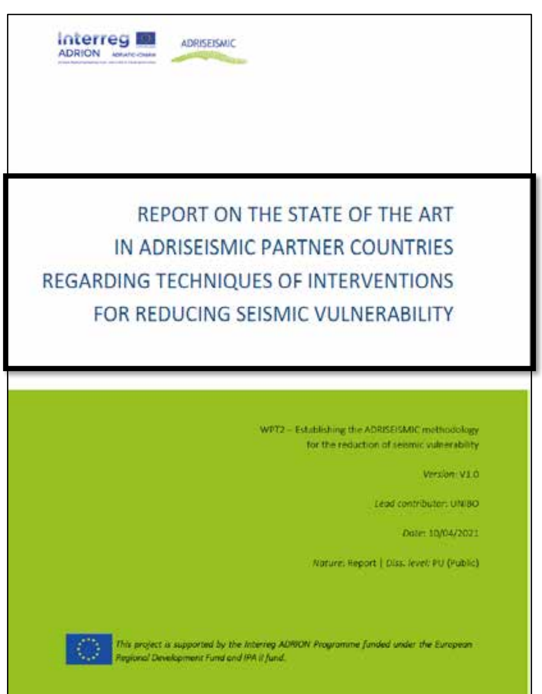
MEASURES COULD BE IMPLEMENTED

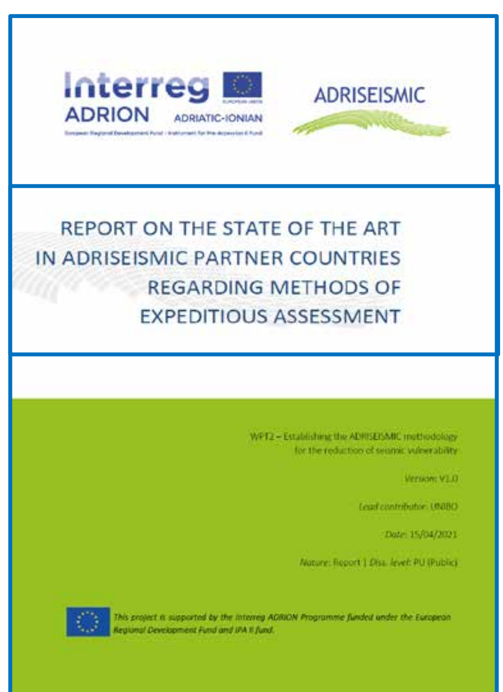
Jacketing, through a reinforced plaster with fibres mesh

COST	MEDIUM	$$
TECNICAL COMPLEXITY	MEDIUM	
SUGGESTED FOR	*All collapse mechanisms*	

Source: Marko Marinković, University of Belgrade

ADRISEISMIC REPORTS (1/2)





ADRISEISMIC REPORTS (2/2)

European Centre for Vulnerability of Industrial and Lifeline Systems
ECILS, North Macedonia

European and Mediterranean Major Hazard Agreement (EUR-OPA)
ECILS/ECPFE workshop

"Seismic Assessment and Retrofitting of Masonry and Preserved Structures"

Historic buildings and monuments in North Macedonia: Treatment and retrofitting aspects

STRUCTURAL PERSPECTIVE

Dr. Veronika SHENDOVA
ECILS Director

Ss. Cyril and Methodius University in Skopje
Institute of Earthquake Engineering and Engineering Seismology - IZIIS

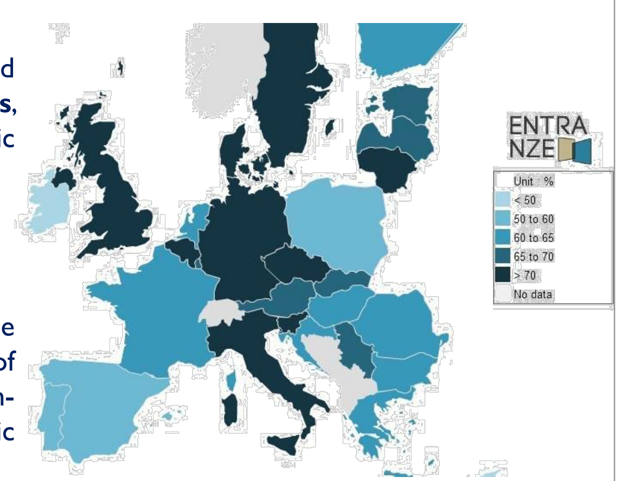
Skopje, 23rd May 2024

Outline

- **INTRODUCTION**
- **CULTURAL HERITAGE**
  - Vulnerability, Importance, Protection
  - Cultural Heritage in North Macedonia
- **EARTHQUAKE PROTECTION OF HISTORIC BUILDINGS AND MONUMENTS - IZIIS' APPROACH -**
  - Scientifically based methodology for seismic upgrading
  - Implementation in reconstruction/seismic upgrading of important monuments
- **CONSLUDING REMARKS**

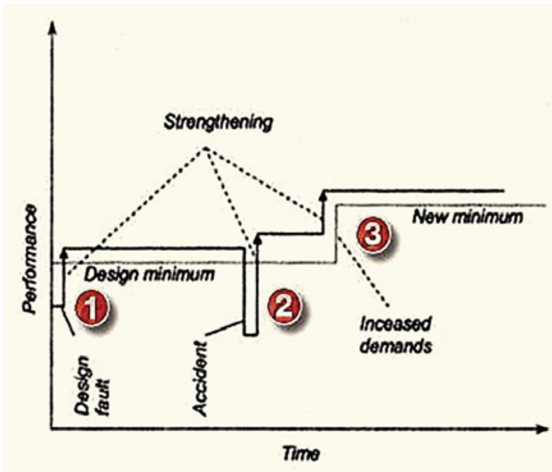
modern vs existing buildings

- **building stock -** mix of **modern buildings,** designed according to modern building codes, and **older buildings**, most often not compliant to any code, especially seismic one
- **older existing buildings -** largest risk to communities
- **modern building seismic codes -** reached by the developments from the learned lessons on the nature of earthquakes, performance of geotechnical, structural, non-structural and lifeline systems, social and economic aspects…
- **regulation for existing buildings -** an area less well defined



% of buildings built before 1980 in total building stock in Europe (ENTRANZE 2017)

existing buildings – need for *structural* strengthening

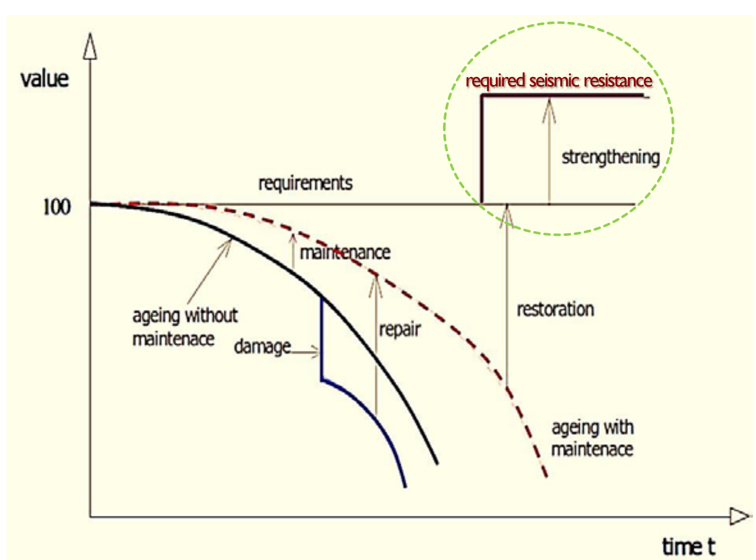


1. errors in designing or construction
2. load increases, damage to structural parts, modification of structural system
3. improvements in suitability for use, upgrading of standards or national technical provisions

existing references do not provide a clear path toward addressing the hazards, assesment and retrofitting of existing buildings

existing buildings – need for *seismic* retrofitting

- to make *existing earthquake-damaged* or *earthquake-vulnerable* buildings more resistant
- *necessarily modification* of existing structural system
- lack of standards for risk assessment, evaluation and retrofitting methods
- variability of effectiveness of each retrofitting method



Seismicity in Balkan Region

Earthquake Risk Reduction in Balkan Region

UNESCO' agencies - <u>extremely important role</u> in overcoming problems in Balkans:

- implementation of several projects (1970 – 1985)
- 1979-1984: UNDP/REP/79/015: *Building Construction under Seismic Conditions in Balkan Region* (Governments of Bulgaria, Greece, Hungary, Romania, Turkey, Yugoslavia)

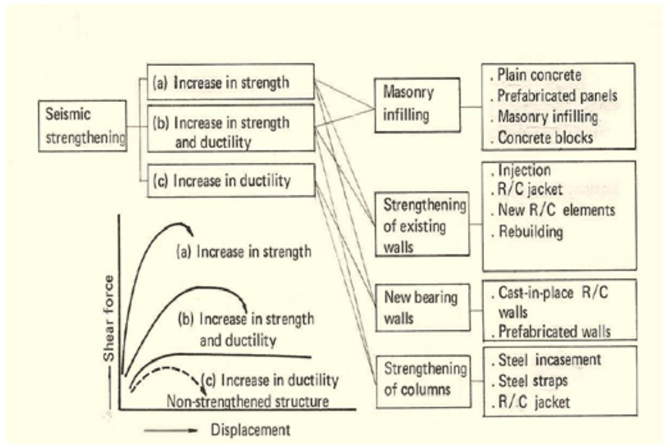
Defined procedure

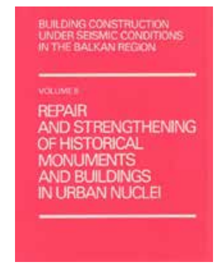
Drawn on experience following recent earthquakes

Agreed and adopted by all Balkan countries

Repair and Strengthening of existing buildings in Balkan Region

- **REPAIR** - re-establishment of initial strength of damaged structural members
- **STRENGTHENING** - judicious modification of the strength, stiffness and/or deformability of structural members or structural system





existing strength and deformability → **strengthening** ← **required** strength and deformability

Cultural Heritage – vulnerability to earthquakes


Greece


Italy


Valandovo


Skopje


Kotor


Budva


Bam


L'Aquila


Haiti

Cultural Heritage – vulnerability to man made disasters

Cultural Heritage

Cultural Heritage – importance / protection

IMPORTANCE:

- key element for the history and the identity of the society, contributing to its well-being
- deserve special attention due to their value
- the reason does not play a primary role when damage of cultural historic monuments is considered

PROTECTION:

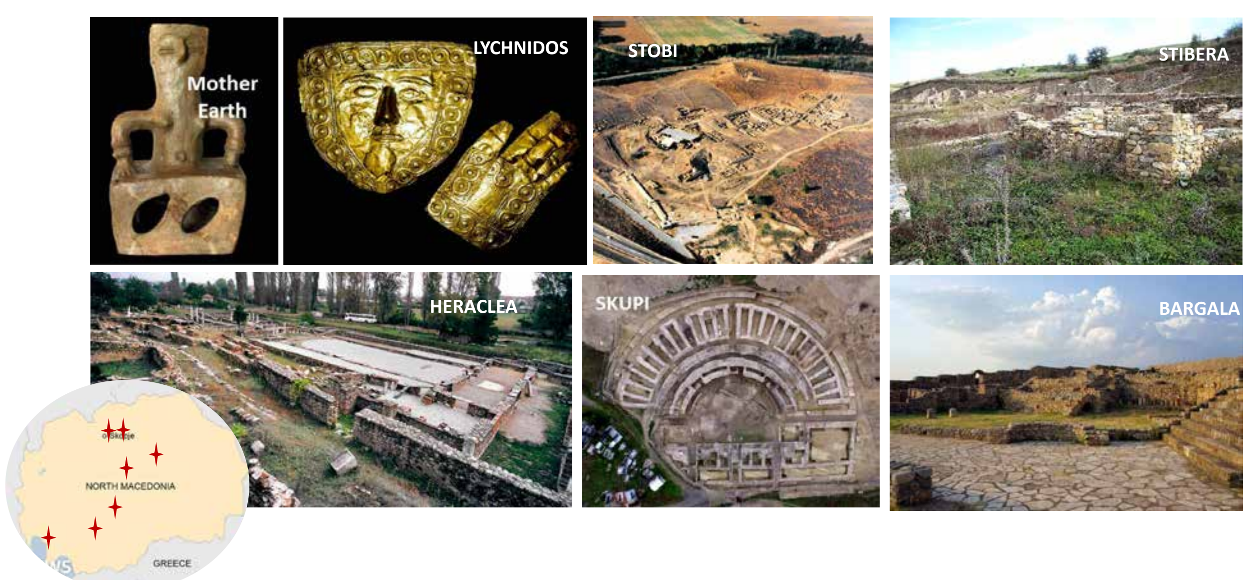
- multidisciplinary approach: team of experts from different profiles
- the main tasks/problem: how far we should go as to the level of safety and the extent of the intervention
- present civilization' moral and legal obligation: to protect CH in its authenticity for next generation

Republic of North Macedonia

- crossroads of important traffic routes
- turbulent economic, cultural and political history
- different spiritual influences, military campaigns and ethnic migrations, ups and downs, fires and earthquakes…
- marks in material and spiritual culture

Cultural Heritage in North Macedonia

North Macedonia – archeological sites



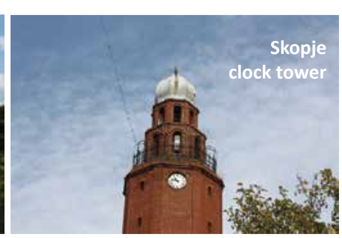
North Macedonia – medieval churches

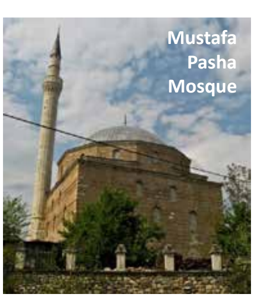



St. Sophia, Ohrid, X | St. Panteleimon, Skopje, XII | St. Marry Peribleptos, XIII | St. Andreas, Matka, XIV




North Macedonia – Ottoman architecture

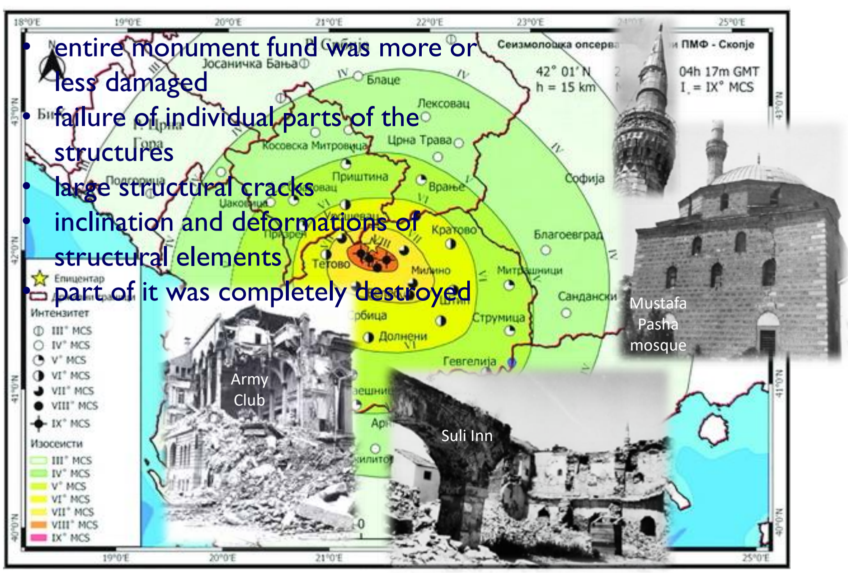




Skopje 26 July 1963, 5:17

earthquake M 6.1 1071 deaths 3300 injured 83% of buildings - unusable

- entire monument fund was more or less damaged
- failure of individual parts of the structures
- large structural cracks
- inclination and deformations of structural elements
- part of it was completely destroyed



Cultural Heritage in North Macedonia

Post-earthquake treatment of monuments - legal framework

Recovery of Skopje:

- lack of corresponding technical regulations and directions
- lack of experience in aseismic design and practice

1963 *General recommendations for repair and strengthening of structures damaged by Skopje earthquake*

1964 Temporary Technical Provisions for Construction in Seismic Regions (monuments not treated separately)

1981 Code for Design and Construction of Buildings in Seismic Regions (for design of new buildings, predominantly RC and confined masonry)

1985 Code for Repair, Strengthening and Reconstruction of Buildings Damaged by Earthquake (for ordinary buildings)

2005 Law for Construction

2020 Eurocodes, introduced in parallel to national code

1976 Law for protection of cultural heritage (first legal framework: glossary, registration, labeling, organization of protection...)

2004 Law for protection of cultural heritage (responsible institutions, categorization, regime for protection and use, conservation research and projects, owners' rights and obligations, professional titles, other issues)

- conservation projects – team of architect, conservator, historian, structural engineer, archaeologist...
- Ministry of Culture, Directorate for protection of CH, Conservation Centers, Museums & Libraries,
- national ICOMOS

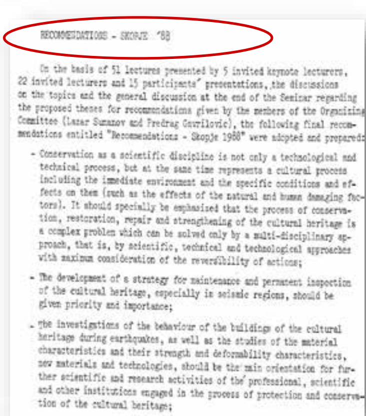
Post-earthquake treatment of monuments – activities on the field

- immediate structural consolidation, repair & strengthening during renovation process,
- involving RC bearing elements, columns and belt courses incorporated into the existing masonry
- later on - adverse affect of cement

Ishak Bay Mosque
Sulli Inn

IZIIS' contribution in the field

- IZIIS&ICCROM - *Recommendation - Skopje 1988:*
  united efforts of architects, engineers, conservators, restaurateurs, material scientists; prohibition of cement….
- extensive research 1990 – 2000 (IZIIS & National conservation center)
- experimental verification of different retrofitting techniques (ties and injection, base isolation, composite materials)
- scientifically based integrated approach in earthquake protection of preserved structures

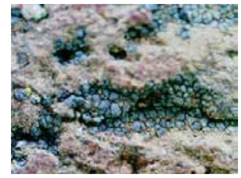


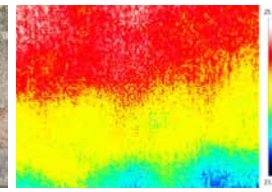
RECOMMENDATIONS - SKOPJE '88

On the basis of 51 lectures presented by 5 invited keynote lecturers, 22 invited lecturers and 15 participants' presentations, the discussions on the topics and the general discussion at the end of the Seminar regarding the proposed theses for recommendations given by the members of the Organizing Committee (Lazar Sumanov and Predrag Gavrilovic), the following final recommendations entitled "Recommendations - Skopje 1988" were adopted and prepared:

- Conservation as a scientific discipline is not only a technological and technical process, but at the same time represents a cultural process including the immediate environment and the specific conditions and effects on them (such as the effects of the natural and human damaging factors). It should specially be emphasized that the process of conservation, restoration, repair and strengthening of the cultural heritage is a complex problem which can be solved only by a multi-disciplinary approach, that is, by scientific, technical and technological approaches with maximum consideration of the reversibility of actions;
- The development of a strategy for maintenance and permanent inspection of the cultural heritage, especially in seismic regions, should be given priority and importance;
- The investigations of the behaviour of the buildings of the cultural heritage during earthquakes, as well as the studies of the material characteristics and their strength and deformability characteristics, new materials and technologies, should be the main orientation for further scientific and research activities of the professional, scientific and other institutions engaged in the process of protection and conservation of the cultural heritage;

IZIIS' integrated approach:
minimum intervention – maximum protection



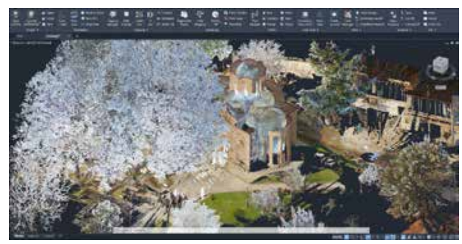
1. Available data review

- ✓ technical, written and photo documentation, archive investigation, interviews, professionals' statements, previous investigation and interventions

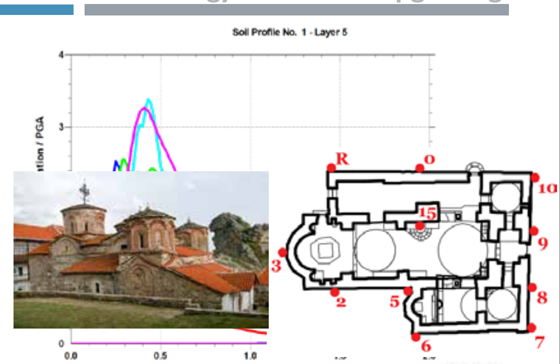
2. Visual inspection including NDT

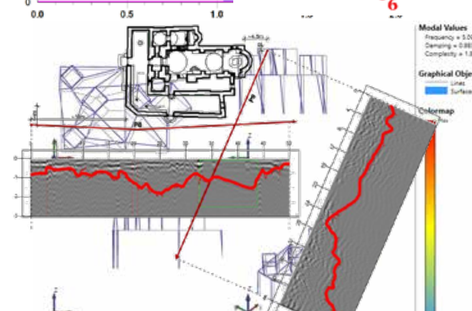
- ✓ observation and mapping, digital microscopy, infrared thermography, drone imaging and 3D laser scanning






IZIIS' integrated approach:
minimum intervention – maximum protection





3. Definition of expected seismic hazard

- ✓ geophysical surveys for definition of geotechnical and geodynamic models of the site, including local soil effects, geo-radar recording

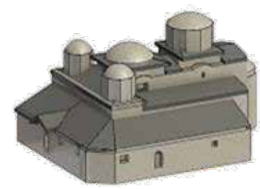
4. Structural identification

- ✓ in-situ technical measurements, investigation of the built-in materials
- ✓ determination of dynamic characteristic through AVT



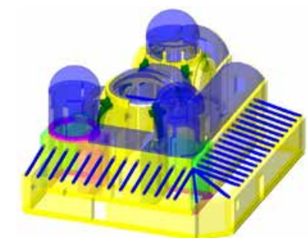
Scientifically based methodology for seismic upgrading

IZIIS' integrated approach:
minimum intervention – maximum protection



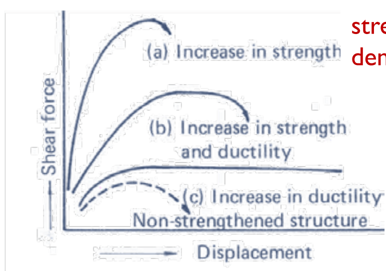
5. Structural analysis

- ✓ 3D finite element modeling (calibrating until $T^{AVT} \approx T^{3Dmodel}$)
- ✓ definition of bearing and deformation capacity of existing structure
- ✓ structural response to defined seismic parameters



6. Seismic retrofitting

- ✓ definition of safety criteria, selection of concept, materials, methods and techniques, verification structural analysis, definition of field works and subsequent documentation



strengthening =
demand - existing

Implementation

IMPLEMENTATION: IN HISTORIC BUILDINGS

1. old towns along Mediterranean coast

- damages after 1979 Montenegro earthquake

Implementation

1. old towns along Mediterranean coast

- extensive in-situ, experimental and analytical investigations for searching optimum conditions and methods for reconstruction, repair, strengthening of structures (1979-1984)

1. old towns along Mediterranean coast

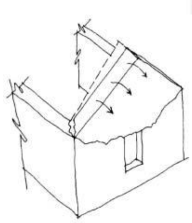
- repair and strengthening of more than 300 buildings in old town of Budva, applying acquired knowledge on application, material consumption and effect of injection

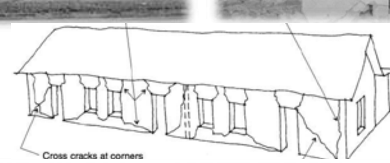

during reconstruction

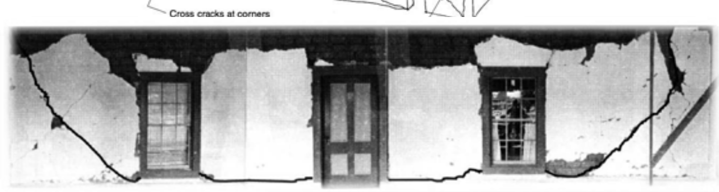

nowadays

2. historic adobe buildings in California

- damages after 1994 Northridge earthquake
- *1995, GCI, Getty Seismic Adobe Project, GSAP*

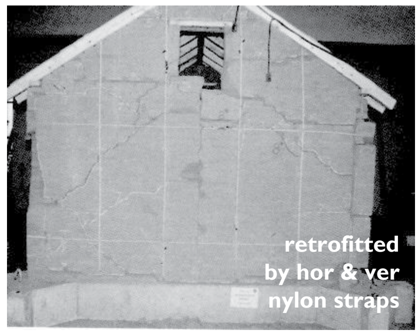


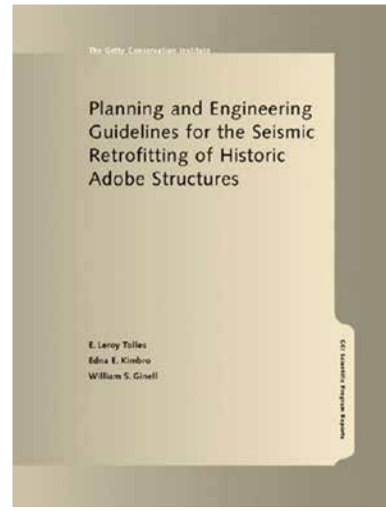




2. historic adobe buildings in California

- 1996-1998: extension of *GSAP* - shaking table testing at IZIIS of two 1:2 scaled models of a typical southwestern American *tapanco-style* building





- GSAP project ends with …

… practical aspects for technologically feasible, minimally invasive and inexpensive techniques for stabilization of adobe buildings

3. Parliament building in Skopje

since 1939

2008
project for Enlargement, Building of Another Story, Adaptation (+3600m²)

3. Parliament building in Skopje

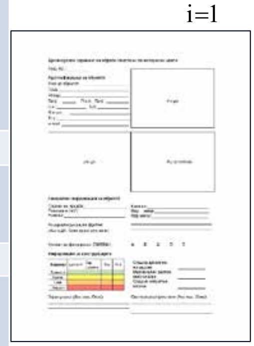
- **2010-2013 - Strengthening while continuously functioning**

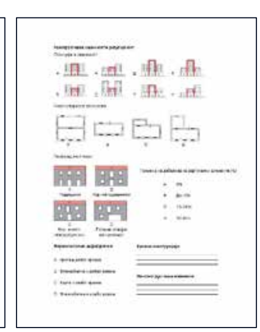
4. Assessment and upgrading of seismic resilience of urban cultural heritage centers

Benedetti D, Petrini V. (1984) → Vicente (2008) → Ferreira (2017) → **Zlateski (2023)**

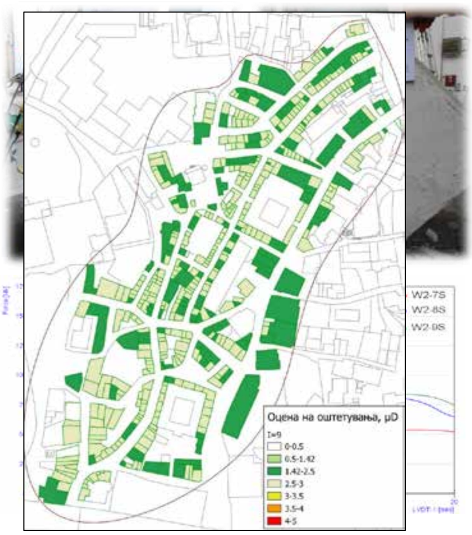
Parameter		Class, c_{vi}				Weight, p_i	
		A	B	C	D	ORIGINAL	CALIBRATED
1. Structural building system							
P1	Type of resisting system	0	5	20	50	0.75	2.50
P2	Quality of resisting system	0	5	20	50	1.00	2.50
P3	Conventional strength	0	5	20	50	1.50	1.00
P4	Maximum distance between walls	0	5	20	50	0.50	0.50
P5	Number of floors	0	5	20	50	1.50	0.50
P6	Location and soil condition	0	5	20	50	0.75	0.50
2. Irregularities and interactions							
P7	Aggregate position and interaction	0	5	20	50	1.50	1.50
P8	Irregularity in plan	0	5	20	50	0.75	0.50
P9	Irregularity in height	0	5	20	50	0.75	0.50
3. Floor slabs and roofs							
P10	Alignment of openings	0	5	20	50	0.50	0.50
P11	Horizontal diaphragms	0	5	20	50	1.00	0.75
P12	Roof systems	0	5	20	50	1.00	0.50
4. Conservation status and other elements							
P13	Fragilities and conservation status	0	5	20	50	1.00	1.00
P14	Non-structural elements	0	5	20	50	0.50	0.75

$$I^{*}_{vf} = \sum_{i=1}^{14} c_{vi} p_{vi}$$





4. Assessment and upgrading of seismic resilience of urban cultural heritage centers



IMPLEMENTATION: IN MONUMENTS

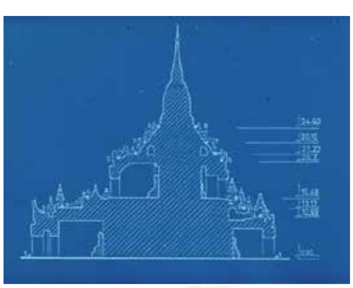
1. Monuments in Pagan - Burma (1978-1980)

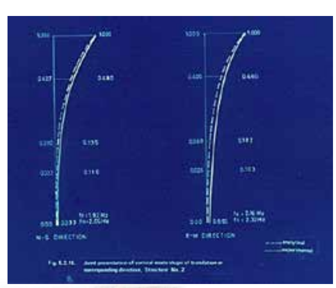
- damages after 1975 Pagan earthquake

1. Monuments in Pagan - Burma (1978-1980)

UNSECO/UNDP 78/023, (*Gavrilovic et al*):

Developing and implementation of a methodology for repair and strengthening of pagodas & temples by injection and inserting of steel bracing or RC belts





1. Monuments in Pagan - Burma (1978-1980)

UNSECO/UNDP 78/023: implementation in 15 pagodas and temples

no damage during
2016 earthquake with M 6.8

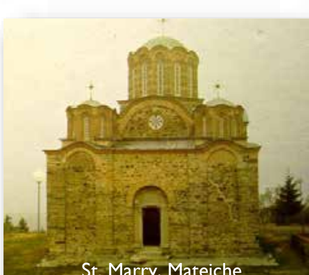
2. Byzantine Churches (1990-2000)

Scientific-Research Projects (IZIIS, GCI, NKC, EU Phare Development Program)

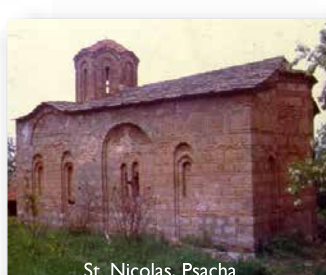
Conservation, Repair and Seismic Retrofitting of Byzantine Churches dated from IX – XIV century in Macedonia

- Typology
- Existing state
- Interventions
- Authenticity

St. Nikita, Banjani



St. Marry, Matejche



St. Nicolas, Psacha

St. Marry Zahumska

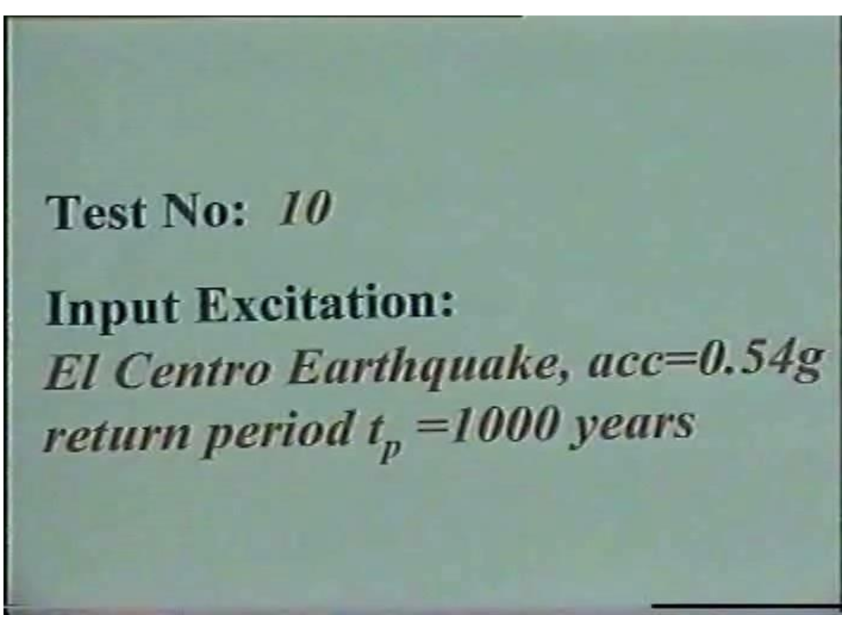
2. Byzantine Churches (1990-2000)

Scientific-Research Projects (IZIIS, GCI, NKC, EU Phare Development Program)

Conservation, Repair and Seismic Retrofitting of Byzantine Churches dated from IX – XIV century in Macedonia

- Original - existing state
- Strengthened by ties and injection
- Base isolated

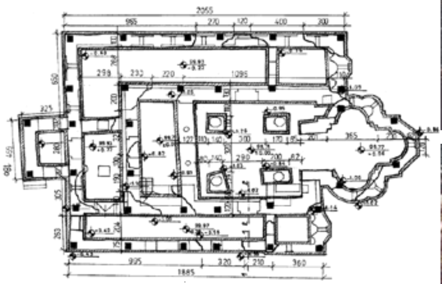
2. Byzantine Churches (1990-2000)

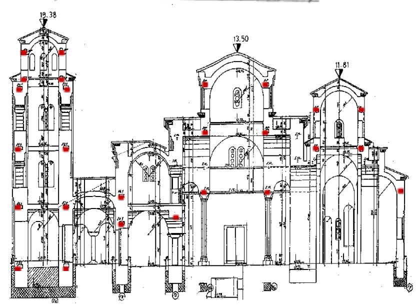


ties&injection versus base isolation

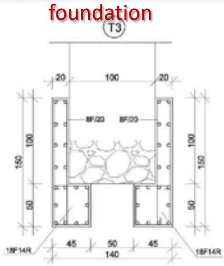
St. Pantelymon Church, Ohrid, (2001)

3. implementation in reconstruction of churches

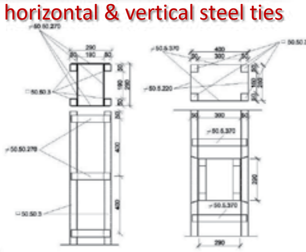




foundation

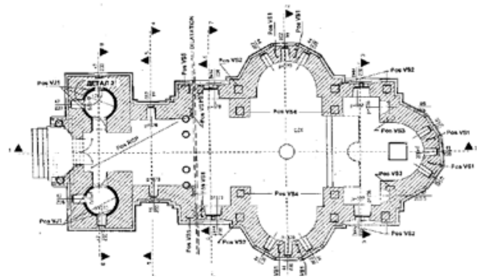


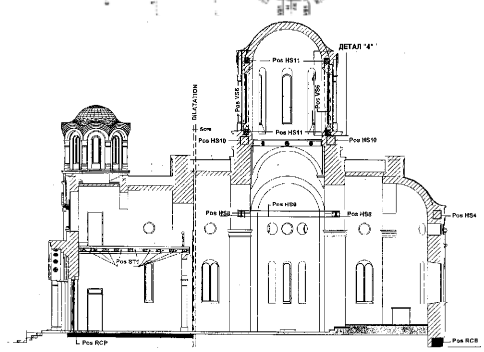
horizontal & vertical steel ties



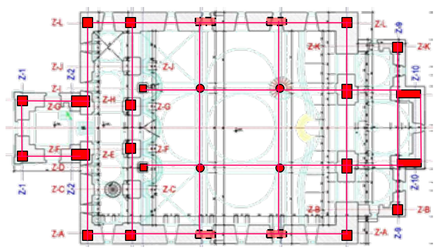
St. Athanasius Church, Leshok (2007)

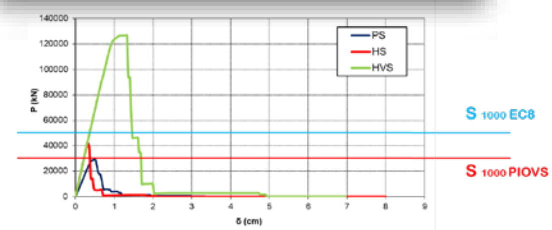
3. implementation in reconstruction of churches





3. implementation in reconstruction of churches





4. implementation in seismic upgrading of churches

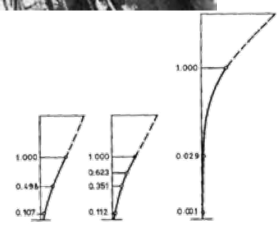
5. Mosques

Scientific-Research Projects (IZIIS, EU FP6 PROHITECH)

Seismic Retrofitting of Mustapha Pasha Mosque in Skopje, (2008-2010)

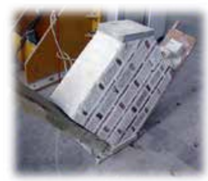
- one of the biggest and best-preserved Ottoman monuments in Skopje and Balkans
- damaged by Skopje earthquake in 1963 (domes, east facade, minaret)
- today monument of extraordinary importance

in-situ investigation



$f_{1\text{-}1}$=3.0Hz $f_{2\text{-}2}$=3.2Hz f_m=1.04Hz

Quasi-static testing



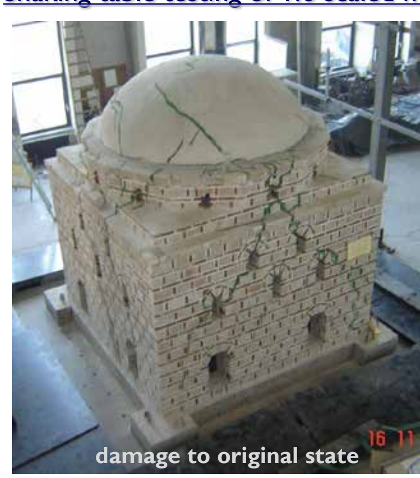
Implementation

5. Mosques

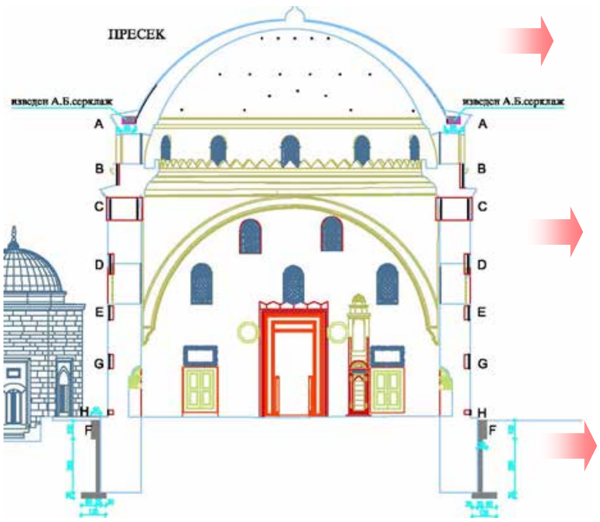
Scientific-Research Projects (IZIIS, EU FP6 PROHITECH)

Seismic Retrofitting of Mustapha Pasha Mosque in Skopje, (2008-2010)

Shaking table testing of 1:6 scaled mosque model

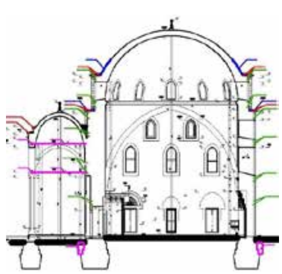


6. Implementation on Mustapha Pasha Mosque

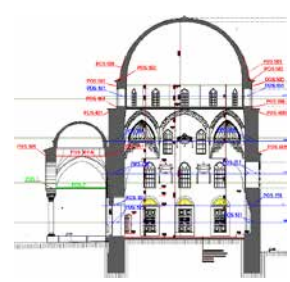


Implementation

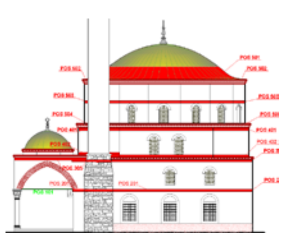
6. Implementation in other Mosques



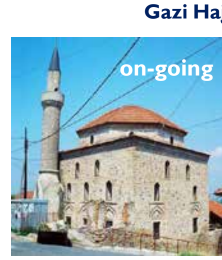
Sultan Mehmet and Fatih Mosque, Prishtina



Gazi Hajdar Kadi Mosque, Bitola



Ali Pasha Mosque, Ohrid



Orta Mosque, Strumica

Charshi Mosque, Prilep

Concluding remarks

- selection of methodology and materials for retrofitting: the delicate problem/challenge in long-term protection of monuments
- proving the effectiveness of the selected strengthening: successfully overcome by using "design by testing" methodology, very powerful tool, especially for complex structure, which are difficult and unsafe to analyze using traditional methods
- for seismic retrofitting od monuments, scientifically-based and experimentally-verified methodology was applied

Acknowledgement

- to all institutions - partners in the projects for the entrusted task and financial support
- to Scientific Committee and colleagues from IZIIS for participation in the projects

thanks for your attention!

ECILS/ECPFE WORKSHOP, SKOPJE, 23 MAY 2024

SEISMIC ASSESSMENT AND RETROFITTING OF MASONRY AND PRESERVED STRUCTURES

FINAL DISCUSSION/CLOSING

"coming together is beginning, keeping together is progress, working together is success"

- long-term collaboration between ECILS, ECPFE and other Centers within EUR-OPA
  (relevant assessment and retrofitting of preserved structures)
- enhancing (re-establishment) of overall cooperation between neighboring countries
  (engineering practice in applying Eurocodes, especially EC 8 part 3)

ECILS/ECPFE WORKSHOP, SKOPJE, 23 MAY 2024

SEISMIC ASSESSMENT AND RETROFITTING OF MASONRY AND PRESERVED STRUCTURES

FINAL DISCUSSION/CLOSING

"coming together is beginning, keeping together is progress, working together is success"

deepest gratitude to:

- guest for the excellent and comprehensive presentations
- attendees for fruitful discussion
- colleagues from IZIIS for organizing the event

CODE FOR THE ASSESSMENT AND STRUCTURAL INTERVENTIONS OF MASONRY STRUCTURES (KADET)

Executive Summary

Earthquake Planning and Protection Organization

English Version (Athens, 2023)

Background

KADET is the new Code for the Assessment and Structural Interventions of Masonry Structures that was first issued in Greece in 2022 responding to a long term need for a regulatory framework relevant to seismic interventions on existing masonry structures. This is a project of major importance for the seismic protection of structures in earthquake regions and a challenging task on its own right, given the inherent complexity of the problems associated with the seismic performance of masonry and the inevitable lack of scientific consensus on many open research topics. The need to prescribe simple, yet rigorous solutions and calculations for the practicing engineers in the framework of a legislative document is an additional challenge, which is further complicated by the fact that the vast majority of the existing masonry structures in Greece and beyond is not compliant to any code. It is therefore necessary to obtain good understanding of the load bearing mechanisms of both the existing (as built) and the retrofitted structures, digest and exploit the latest research results and compile them in a way that can be appreciated and implemented by the professional community.

The first drafting Committee for the development of this Code was formed in 2011 following the mandate of the Board of Directors of the Organization for Earthquake Protection and Planning and the enforcement of the Greek CSI (Code for Seismic Interventions – ΚΑΝ.ΕΠΕ.), which is applicable to Reinforced Concrete Structures. The latter was used as a guide in terms of structure and context. The first draft of KADET was introduced in April 2017 and was reviewed by 13 independent experts (D. Aggelou, I. Doudoumis, A. Kappos, G. Manos, Ch. Mouzakis, K. Spyrakos, K. Toumbakari, A. Triantafyllou, I. Psycharis). Moreover, 17 well established design offices acted as consultants that worked pro-bono to submit a series of design calculations for a set archetype structures in order to demonstrate and ultimately improve the applicability of the Code. All comments were addressed by the Committee and were taken on board leading to the next version of the KADET in March 2019. The code draft was open to public consultation in September 2019, with the final draft of the code being published in March 2021. KADET was finalized following a second round of public consultation in 2022. The English translation is expected to be released in December 2023.

Objectives

The main objective of the present code KADET is the introduction and enforcement of criteria for the assessment of the bearing capacity of existing masonry structures to resist seismic forces. The Code sets rules for the re-design of these structures following potential interventions (repair or strengthening), as well as for the interventions themselves. It mainly covers masonry structures, however, it is evident that the underlying first principles of mechanics are of general use.

More specific aims are to:

– offer a set of specific criteria for assessing the seismic response of masonry structures,
– describe the appropriate approach for select the appropriate measures of intervention,
– set criteria for the design of new structural elements and their connections, either between new and existing ones or among the new elements themselves.

Content

KADET comprises 11 chapters of approximately 350 pages dealing with the range of application of the code (Ch.1, see below), basic principles and assessment criteria (Ch.2), on-site investigation and pathology justification (Ch.3), basic data for assessment and redesign (Ch.4), numerical analysis before and after the intervention (Ch.5), principal finite element models for simulating structural behaviour (Ch.6), determination and quantification of the seismic response of structural members (Ch.7), design of repair and strengthening works (Ch.8), verification checks (Ch.9), documentation requirements (Ch.10), as well as quality assurance and maintenance aspects (Ch.11). It also contains several formative and informative Appendices related to seismic pounding among adjacent structures, simplified analysis methods, default values, minimum acceptable (re)design targets and overall synthesis guidelines for design.

Major advancements

KADET is deemed as a major advancement in relation to the current version of Eurocode 8 – Part 3 (CEN, 2004) and the provisions referring to masonry structures as outlined in its respective Appendix C for dealing with seismic assessment and retrofitting of buildings. It is also more detailed covering approximately 350 pages compared to the new draft of the Eurocode 8 – Part 3 (CEN, version 16-12-2022) and specifically to the provisions of Chapter 11, which is dedicated to masonry (40 pages). It is also noted that even though both codes cover masonry structures, they are conceptually quite distinct in several ways, the most important of which are outlined below:

1. mechanical properties in KADET are defined using semi-empirical relationships separately for different types of masonry (including single-, double- or triple leaf masonry), while also offering the opportunity to the Designer to update the default values based on in situ measurements.
2. several numerical analysis methods are offered by KADET such as, finite elements, macro-elements, equivalent frame method and the strut and tie model. They are all presented in great detail including recommendations for practical applications bespoke to masonry structures.
3. a modified behaviour factor q* is prescribed in KADET to account for different performance levels adopted for assessment or redesign, as opposed to the fixed value of q<1.5 prescribed in current version of Eurocode 8 – Part 3 (CEN, 2004). The values of ratio q*/q' are summarized in the following table using as reference value the value of q' that applies for Performance Level B (Significant Damage).

Performance Level		
Limited Damage (A)	**Significant Damage (B)**	**Near Collapse (C)**
0.6 (1.0<q*<1.2 applies)	1.0	1.4

Note that Performance Levels of the structural system are defined in relation to the acceptable (tolerable) degree of damage of the building as follows:

- "Limited Damage" (A): the structure has only experienced light damage. Its structural members retain a high degree of their capacity and stiffness. Residual relative displacements between storeys are negligible.
- "Significant Damage" (B): the structure has suffered major damage, some of which may be severe, without local collapses. However, it has retained residual bearing capacity and stiffness. The vertical structural members are able to bear permanent (gravity) and live loads. Some moderate residual relative displacements do exist among storeys, that can be large locally. The load-bearing structural system can resist moderate future earthquakes.
- "Near Collapse" (C): the structure has experienced severe damage, the majority of which is not repairable. Its residual capacity and stiffness are low; however, the vertical structural members are still able to bear permanent and live loads. Large residual relative displacements among storeys are observed. The load-bearing system does not possess adequate safety factor against collapse, and it is likely that it will not be able to resist future earthquakes even of moderate intensity.

4. KADET is more flexible to Eurocode 8 – Part 3 in terms of the envisaged Performance Levels. This is a strategic decision to serve socio-economic needs and yield redesign of masonry structures financially viable, hence, more at-

tractive. More precisely, the minimum mandatory requirements for seismic capacity that must be met by existing structures may, under conditions, be reduced in relation to the provisions of the current design regulations that apply at the time of the assessment for new structures. In this context, KADET defines three main Performance Levels (as have been already described above), but also nine levels for seismic (re)design. This essentially implies that each performance objective is the combined outcome of a Performance Level and a specific seismic action with a given "acceptable probability of exceedance during the design life of the building" (i.e., design earthquake).

The resulting 27 options of performance objectives are listed in the following table. Note that ag,ref is the reference horizontal acceleration defined with a 10% probability to be exceeded in 50 years as in the Greek National Annex of Eurocode 8 (ELOT, 2008), which is identical to the one defined in the Greek Seismic Code of 2000 (EAK 2000) following the update of the seismic hazard map for the country in 2003, and ag is the seismic acceleration adopted in the assessment and redesign.

$\alpha_g / \alpha_{g,ref}$	Performance Level of the load-bearing structural system		
	A Limited Damage	B Significant Damage	C Near Collapse
1.80	**A0**	**B0**	**C0**
1.30	**$A1^+$**	**$B1^+$**	**$C1^+$**
1.00	**A1**	**B1**	**C1**
0.75	**$A2^+$**	**$B2^+$**	**$C2^+$**
0.60	**A2**	**B2**	**C2**
0.45	**$A3^+$**	**$B3^+$**	**$C3^+$**
0.35	**A3**	**B3**	**C3**
0.25	**$A4^+$**	**$B4^+$**	**$C4^+$**
<0.25	**A4**	**B4**	**C4**

The above table illustrates the breadth of options that are provided to the designer in order to meet the specific needs of the respective owner or stakeholder of the existing masonry building that is assessed with the aim to be strengthened. It is deemed that the above flexible scheme will encourage pre-earthquake assessment and seismic upgrade of the existing stock of masonry structures and upscale the application of this new regulatory framework across the country. For details can be found in the documents listed below that are freely available online.

Downloads:

- Code for Seismic Interventions (ΚΑΝ.ΕΠΕ.): https://tinyurl.com/4dre57u3
- Code for the Assessment and Structural Interventions of Masonry Structures KADET: https://tinyurl.com/2p82hu28

References

CEN. (2004). *European Standard EN 1998-3. Eurocode 8: Design of structures for earthquake resistance - Part 3: Assessment and retrofitting of buildings", Committee for Standarization.*

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