SS Cyril and Methodius University, Skopje
INSTITUTE OF EARTHQUAKE ENGINEERING AND ENGINEERING SEISMOLOGY, IZIIS
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EUROPEAN CENTER FOR VULNERABILITY OF INDUSTRIAL AND LIFELINE SYSTEMS DOOEL

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

"Seismic assessment and retrofitting of masonry and preserved structures"
Athens, 13 September 2023

Prof. Dr. Veronika SHENDOVA
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Outline

- **INTRODUCTION**
  - About Institute of Earthquake Engineering and Engineering Seismology, IZIIS, Skopje
  - Historic background of *Earthquake Engineering*
- **SEISMIC STRENGTHENING OF EXISTING BUILDINGS IN BALKAN REGION**
- **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**

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about IZIIS

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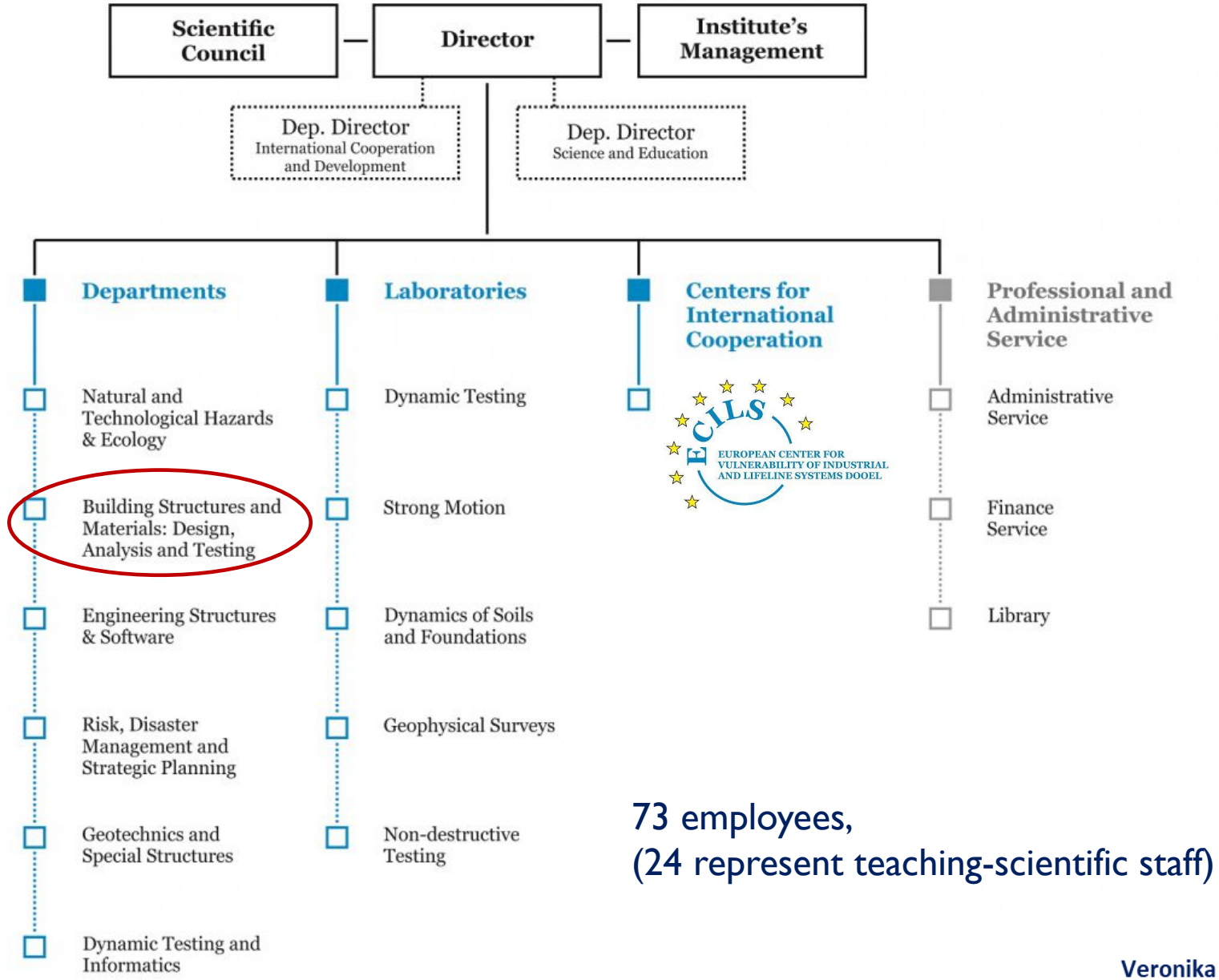

73 employees,
(24 represent teaching-scientific staff)

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about IZIIS

Building Structures and Materials: Design, Analysis and Testing

primarily focused on:

- Design of new earthquake-resistant high-rises and diagnosis, repair, strengthening and reconstruction of existing buildings and monuments, by application of traditional and innovative techniques and materials.
- Professional opinions – expertise on stability and safety of existing high rises under gravity and seismic effects.
- Testing of structural elements and integral structures.
- Consultancy in the process of design, construction, supervision etc..

Prof. Dr.
Veronika Shendova

Asst. Prof. Dr.
Goran Jekic

Assistant, M. Sc.
Aleksandar Zlateski

Assistant, M. Sc.
Aleksandar Zurovski

M. Sc. (Doctoral student)
Elena Delova

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Historic background of International Earthquake Engineering

early civilization

19th early 20th century

1956 1st WCEE

40 participants, 11 countries, 3 topics

- *earthquake ground motion*
- *analysis of structural response*
- *aseismic construction*

1960 2nd WCEE

formation of the International Association for Earthquake Engineering, (IAEE)

.

1977 6th WCEE

- *repair, strengthening and retrofitting*

.

2021 17th WCEE

toward resilient society

2024 18th WCEE

~3000 participants, topics proposed by convenors

ral Engineers
tion
ake Engineering
h Institute (EERI)

Committee for

ation of the Messina
ake- recommendation
nquake resistant structures
s of *equivalent static*

Earthquake Research Institute
within Tokyo Imperial College

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Historic background of European Earthquake Engineering

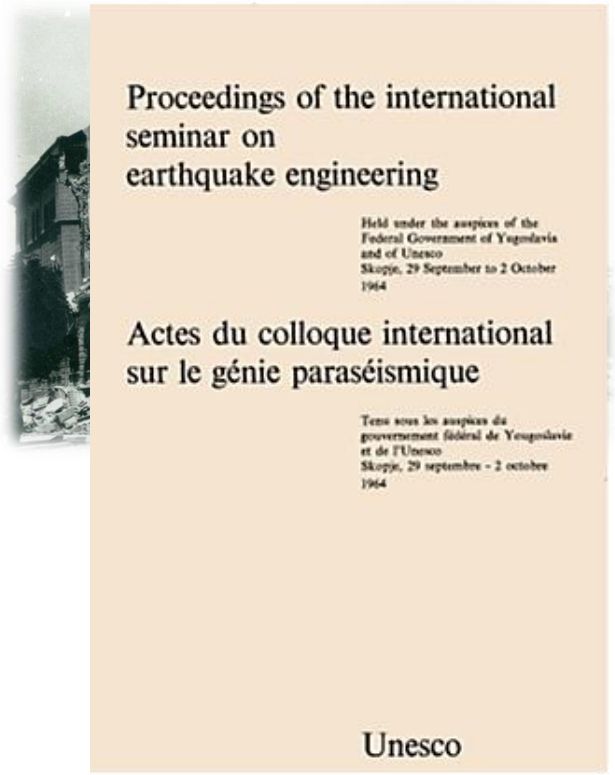
1963 Skopje earthquake

- 1071 deaths, 3300 injured
- losses of 15% of 1963 gross national product
- unique among the catastrophic earthquakes in Europe and Mediterranean

1964

- first code for seismic design and standardization of construction materials in ex-Yu
- **1st ECEE in Skopje**
- **formation of EAEE**
- **beginning of European EE**
-
-
-

2026 18th ECEE, Berlin



- triggered a high level of awareness and activity by the government, population, scientists and engineers
- dominant activity and financial support by UNESCO' agencies in the coming years

- great lessons have been, and will be, learned during WCEE and ECEE about the nature of earthquakes, performance of geotechnical, structural, non-structural and lifeline systems, social and economic aspects…

- majority of these developments have reached the **modern building seismic codes**

- however, regulation for **existing buildings** is an area less well defined

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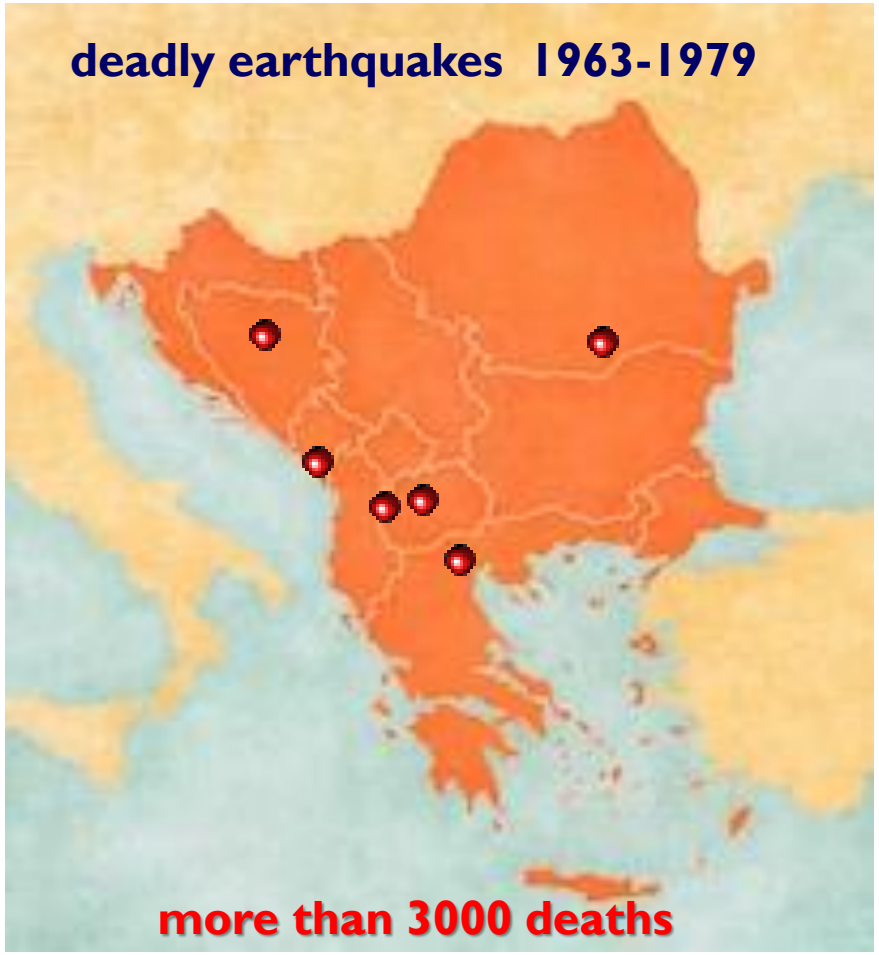
Seismicity in Balkan Region



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Earthquake Risk Reduction in Balkan Region

UNESCO' agencies - extremely important role in overcoming problems in Balkans:

- formation of IZIIS and financial support for its development (1965-1982)
- 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

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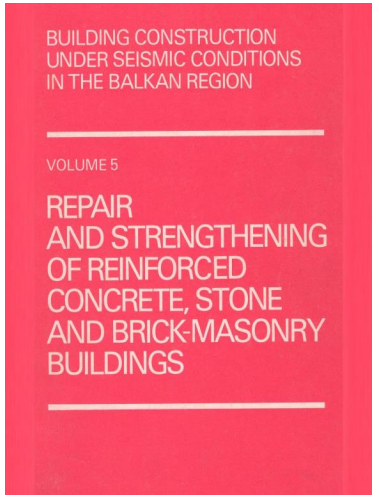
Repair and Strengthening of existing buildings in Balkan Region

STEP-BY-STEP procedure of post-earthquake repair and strengthening:

- *Emergency damage evaluation (rapid visual damage & safety level detection)*
- *Preliminary investigation (detail damage detection, need for emergency, temporary shoring)*
- *Definition of Seismic Parameters for the region (expected $a_{max}^{bedrock}$ for different t_r, DAF of soil deposits, time histories and average spectra for design of structural strengthening)*
- *Design Criteria for Repair and Strengthening:*
  - ✓ *Level I: linear behavior for slight and moderate earthquake, $d_{rel}^{storey} \leq h/350$, Duc≤1*
  - ✓ *Level II: nonlinear behavior for more severe earthquakes, $d_{rel}^{storey} \leq h/150$, Duc (RC) ≤3-4 , Duc (PM) ≤1.5-2, Duc (CM) ≤2-2.5*
- *Additional investigations (completion of knowledge to as-built condition: documentation, bearing elements, built-in materials, construction details, damage analysis and evaluation]*
- *Selection of a repair and strengthening method (calculation in enough detail for each alternative solution; for selected one - complete analysis according to design criteria)*
- *Final Design Procedures (detailed calculation and structural analysis for defined seismic parameters, drawings, specification, procedures and instructions)*



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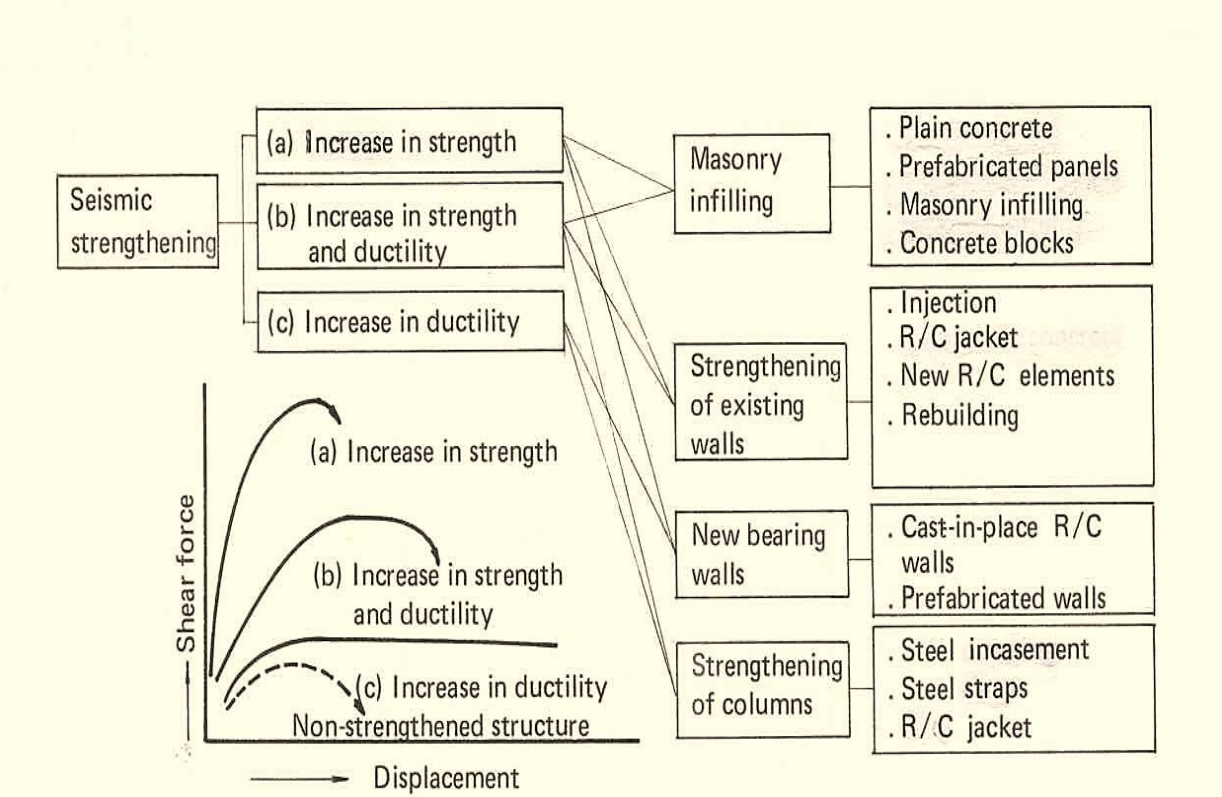
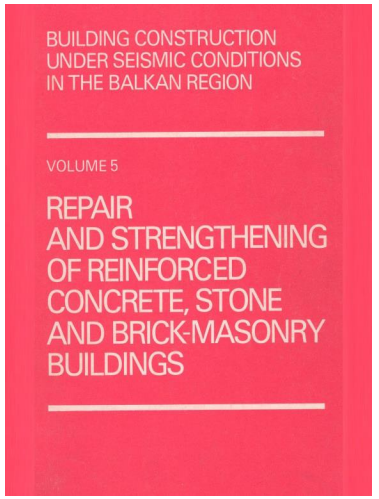
Repair and Strengthening of existing buildings in Balkan Region



- **REPAIR** - reestablishment 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

required strength and deformability

strengthening

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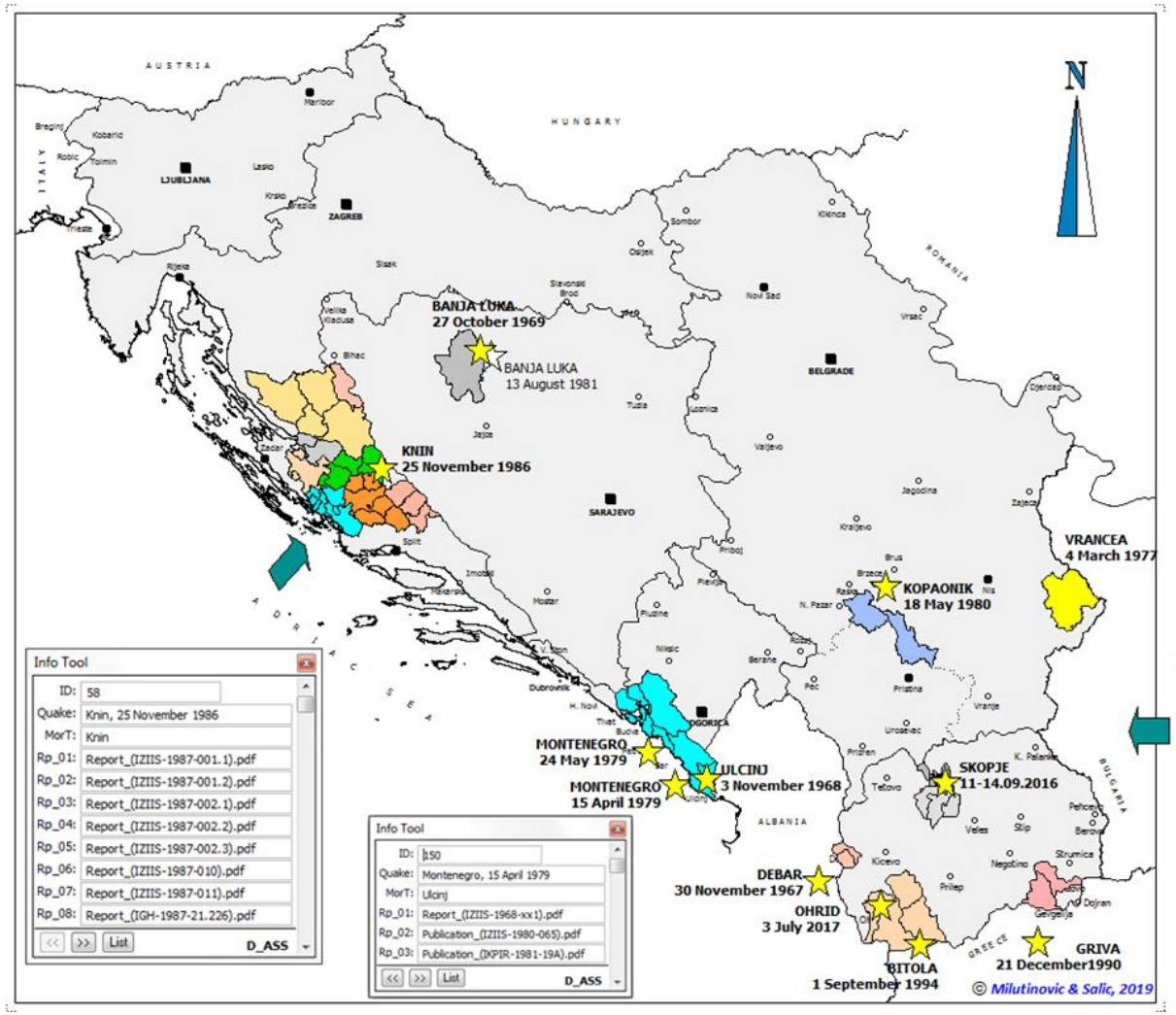
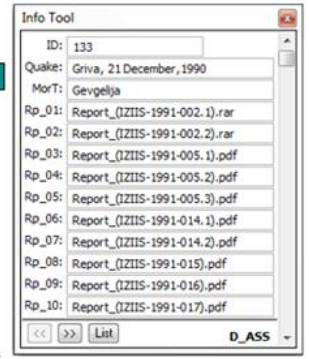
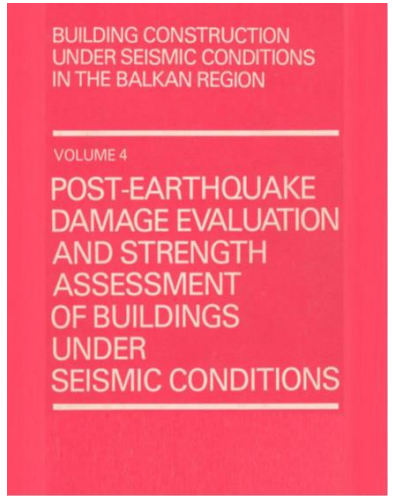
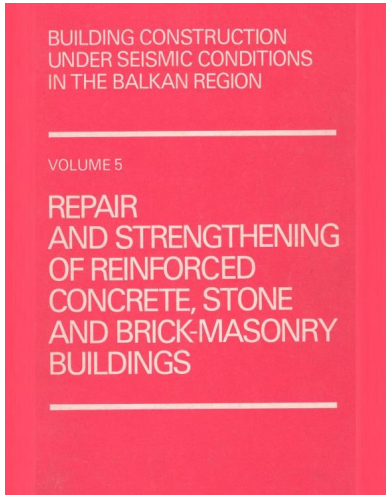
Major earthquakes in ex-YU:
Damage Evaluation and Strengthening of buildings









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Cultural Heritage – vulnerability to earthquakes


Greece


Italy


Valandovo


Skopje


Kotor


Budva


Bam


L'Aquila


Haiti

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Cultural Heritage – vulnerability to man made disasters

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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

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Republic of North Macedonia

- crossroads of important traffic routes
- rich, but 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

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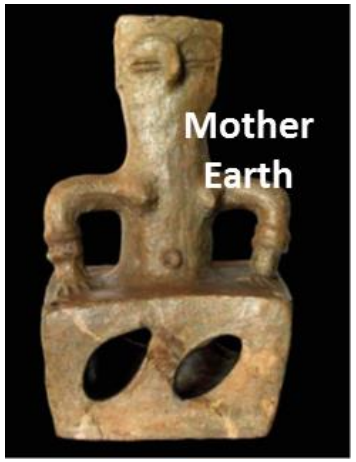
North Macedonia – archeological sites



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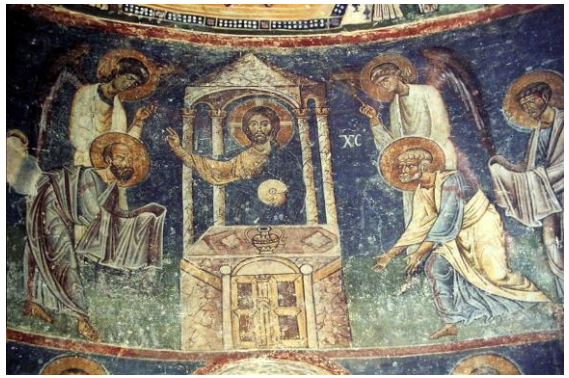
North Macedonia – medieval churches

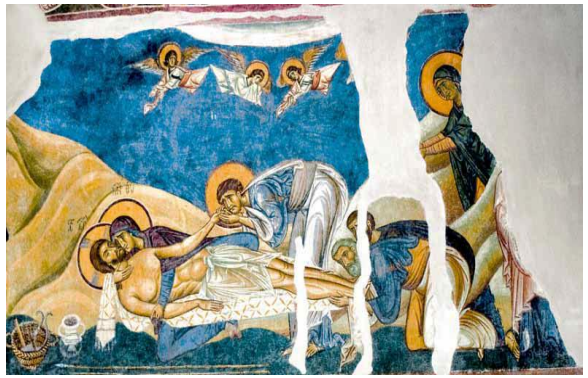
St. Sophia, Ohrid, X

St. Panteleimon, Skopje, XII

St. Marry Peribleptos, XIII

St. Andreas, Matka, XIV





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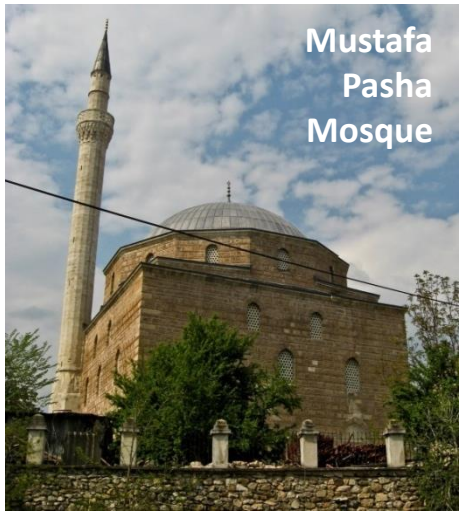
North Macedonia – Ottoman architecture



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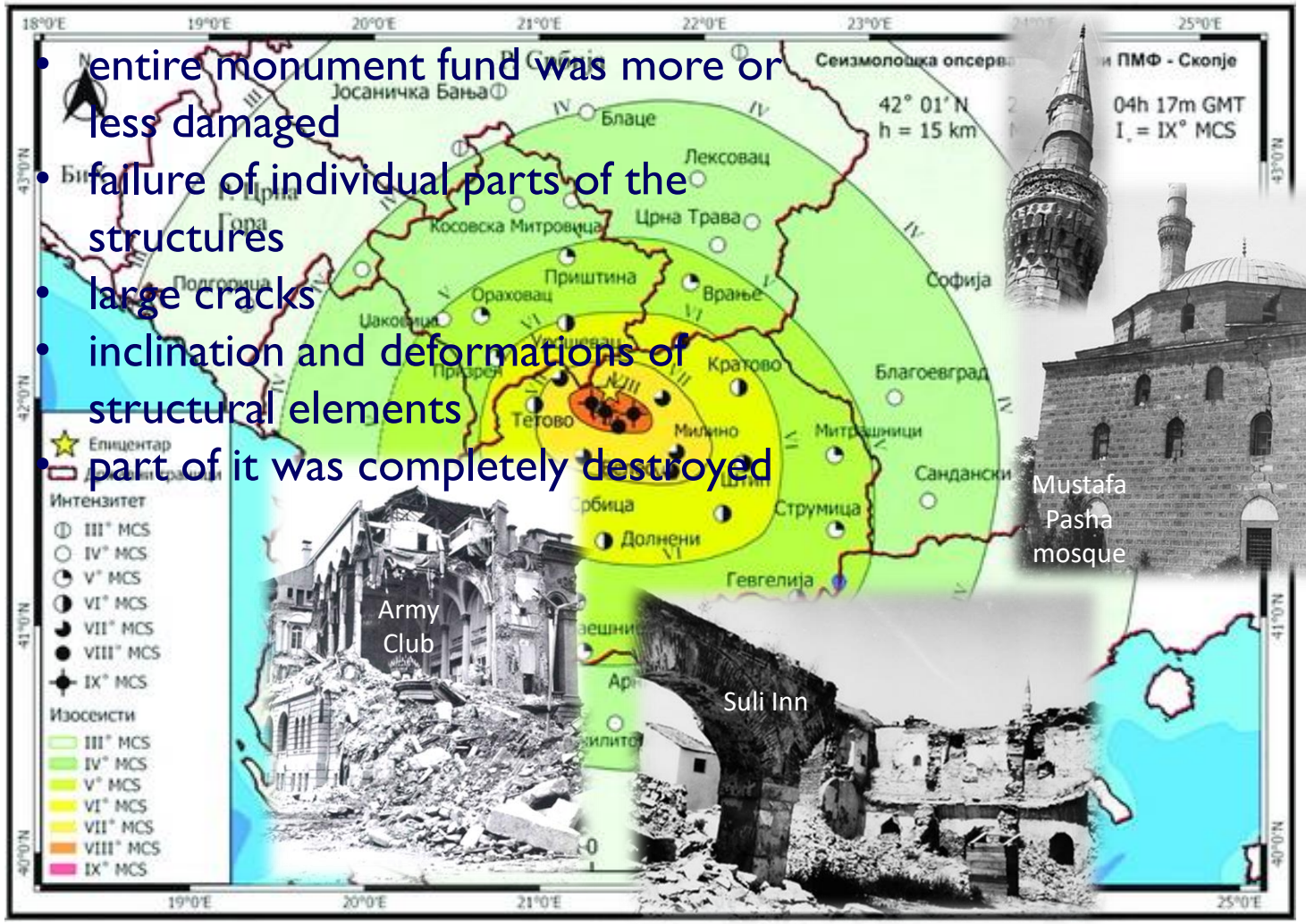
Skopje 26 July 1963, 5:17

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 cracks
- inclination and deformations of structural elements
- part of it was completely destroyed



Mustafa Pasha mosque

Army Club

Suli Inn

Chifte Hammam

Kurshumli Inn

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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, national ICOMOS

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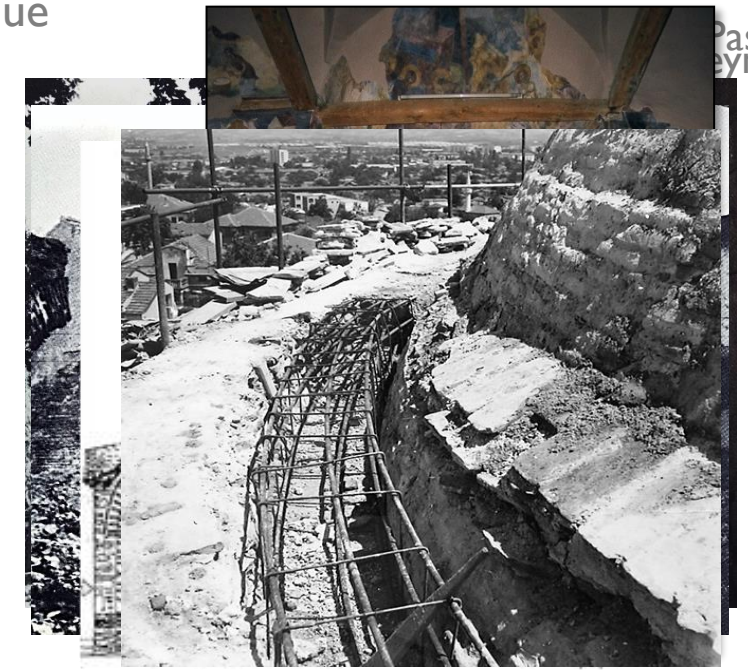
Post-earthquake treatment of monuments – activities on the field

- 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



Pasha Mo
eymon C

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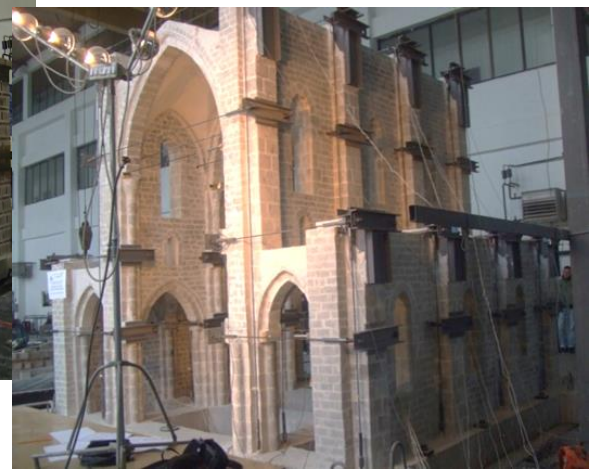
IZIIS' contribution in the field

- IZIIS&ICCROM - *Skopje recommendation 1988* – unite efforts of architects, engineers, conservators, restaurateurs, material scientists – prohibition of cement….
- extensive research 1990 – 2000 (IZIIS & National conservations center)
- experimental verification of different retrofitting techniques (ties and injection, base isolation, composite materials)

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;



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IZIIS' contribution in the field

~~"Code for Historical Buildings and Monuments"~~

"Guide", "Recommendations", "Resolutions", "Charters"

and

Scientifically based methodology
for earthquake protection of historic buildings and monuments

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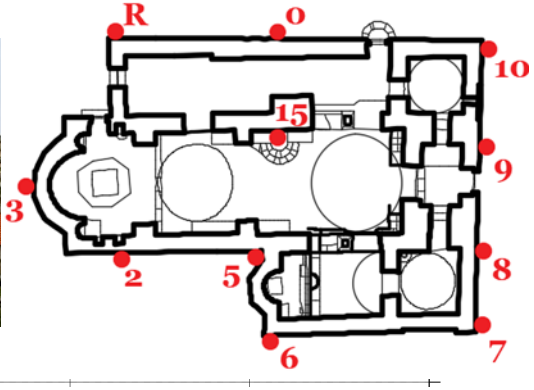
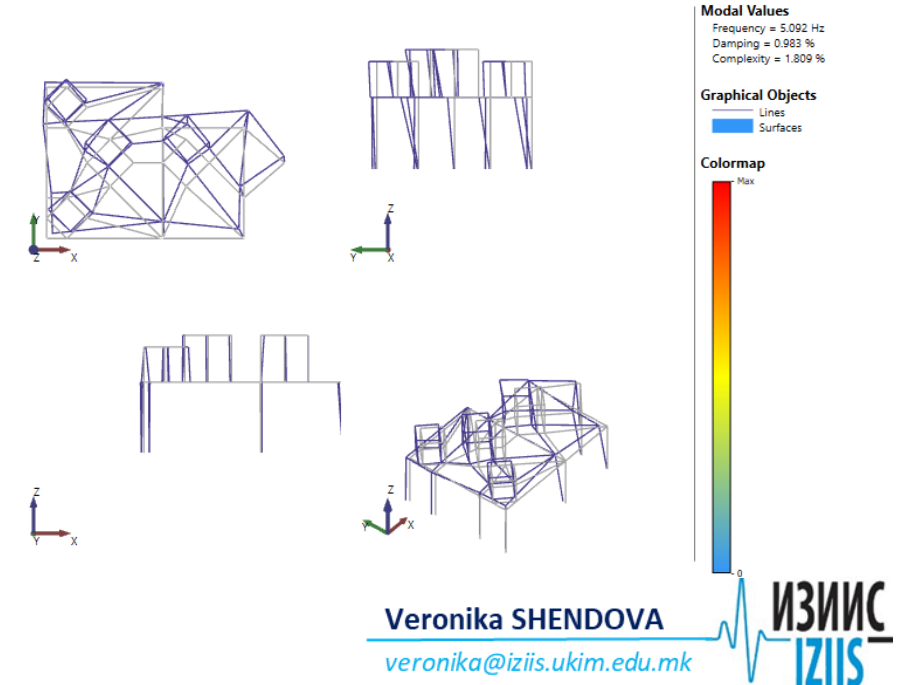
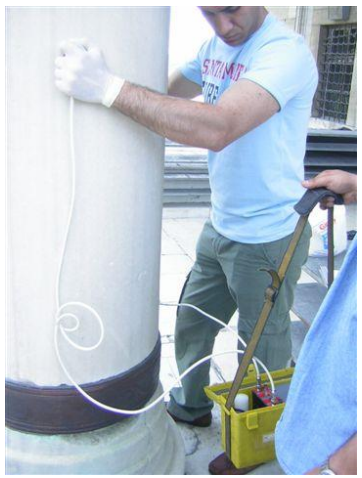
IZIIS' integrated approach:
minimum intervention – maximum protection

1. **Available data review**
   - ✓ technical, written and photo documentation, archive investigation, interviews, professionals' statements
2. **Definition of expected seismic hazard**
   - ✓ geophysical surveys for definition of geotechnical and geodynamic models of the site, including local soil effects
3. **Structural identification**
   - ✓ in-situ technical measurements, investigation of the built-in materials, determination of dynamic characteristic through AVT







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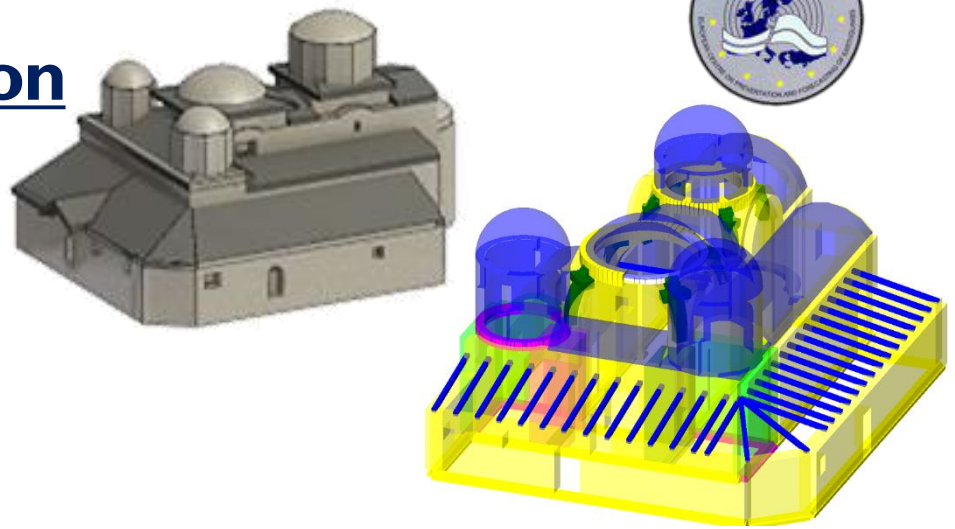
IZIIS' integrated approach: minimum intervention – maximum protection

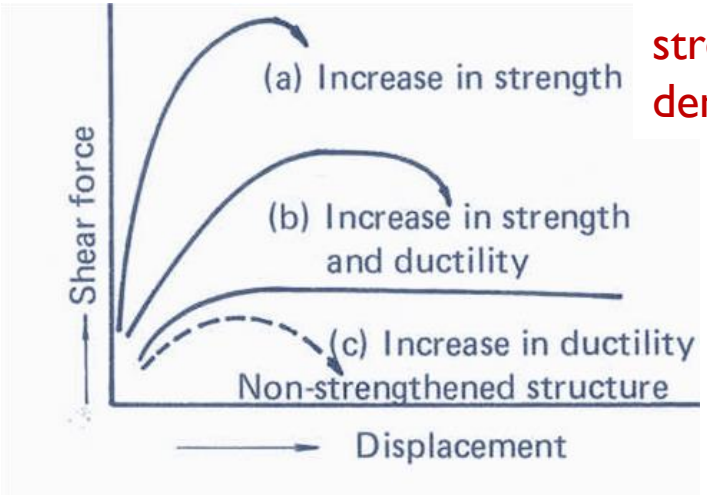


4. Structural analysis

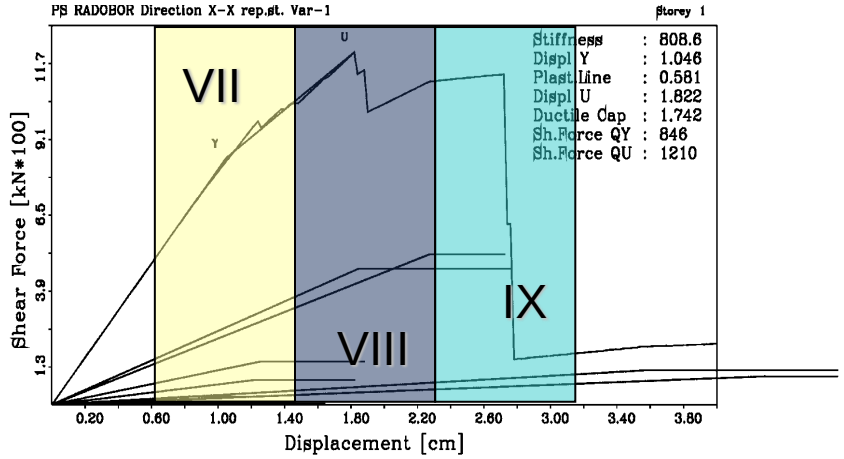
- ✓ 3D finite element modeling (calibrating until $T^{AVT} \approx T^{3Dmodel}$)
- ✓ definition of bearing and deformation capacity of existing structure
- ✓ dynamic response of structure for defined seismic parameters

5. 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



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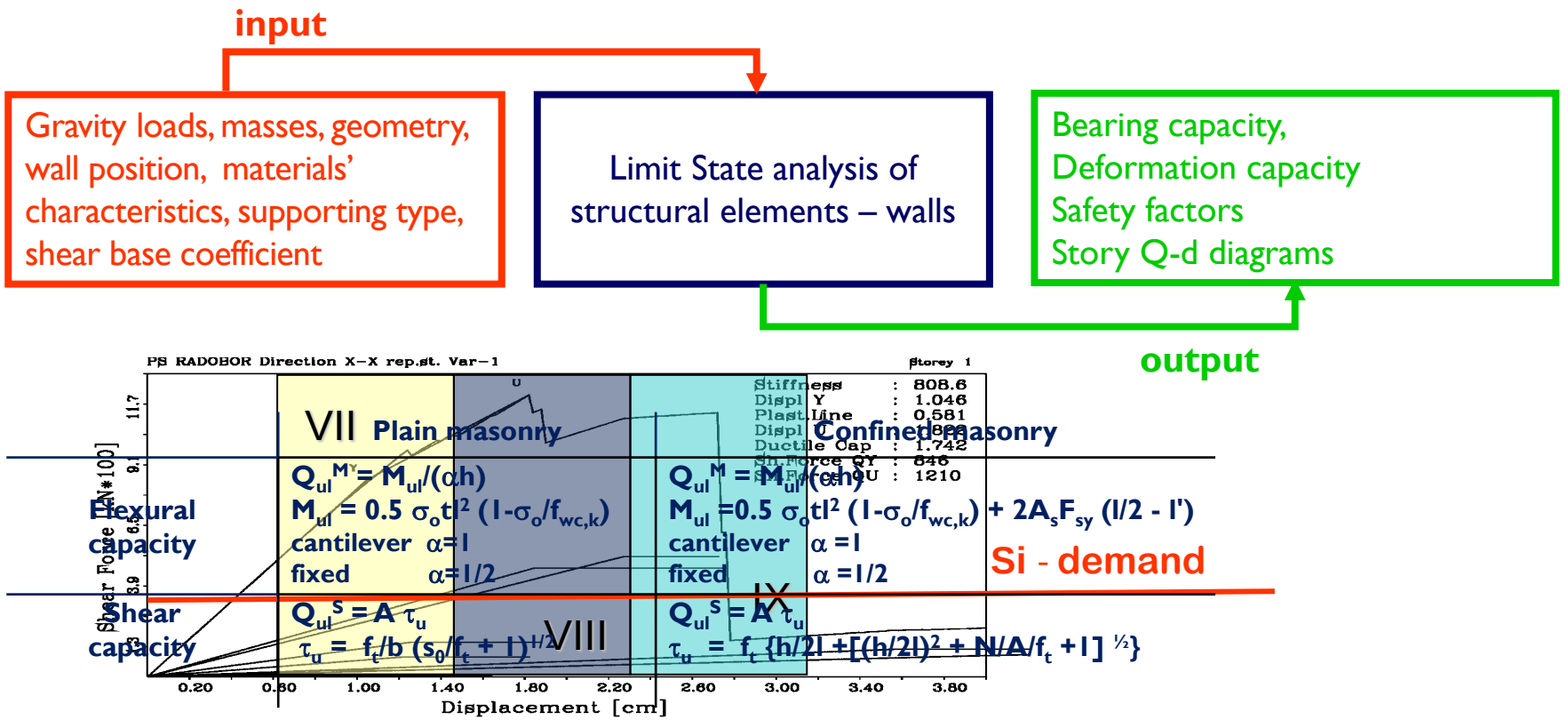
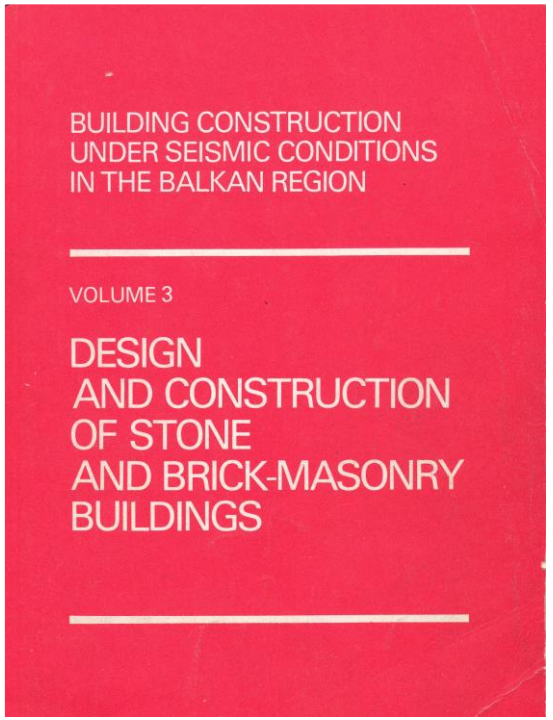
IZIIS' integrated approach:

Bearing and deformation capacity of existing structure

Bearing Capacity (Q_{ul}) = ultimative storey transversal force Q_{ul}, which compared with the demanded equivalent seismic force **Si**, gives the safety factor against failure, $F_u=Q_{ul}/S_i$

Deformation Capacity (μ) = storey ductility capacity as ratio between maximum story displacement and displacement at yield point, $\mu_{max} = d_{max}/d_y$





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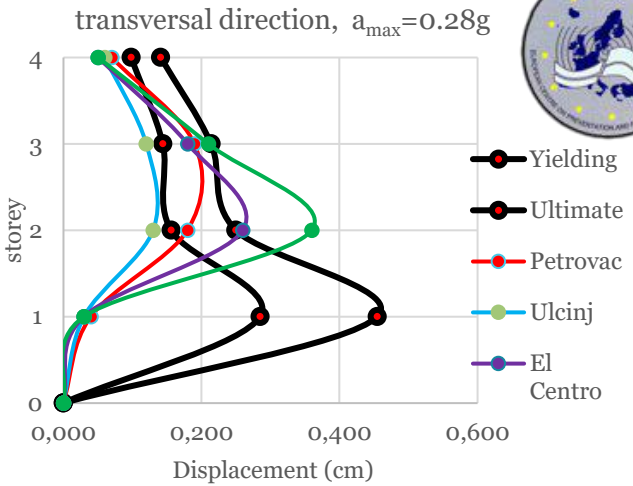
IZIIS' integrated approach:
Response to the defined seismic parameters



Nonlinear time history analysis:

Masses - concentrated at floor level

Hysteretic models – cumulative storey Q-d diagrams, (by summing of Q-d of separate walls)

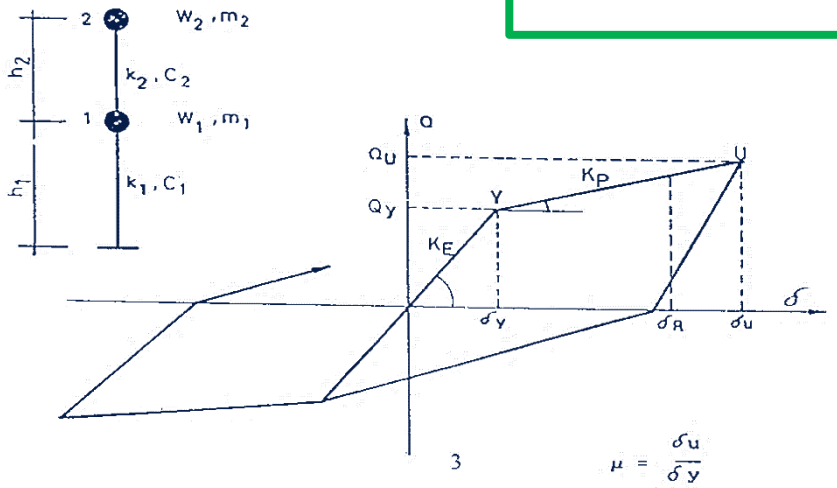
input

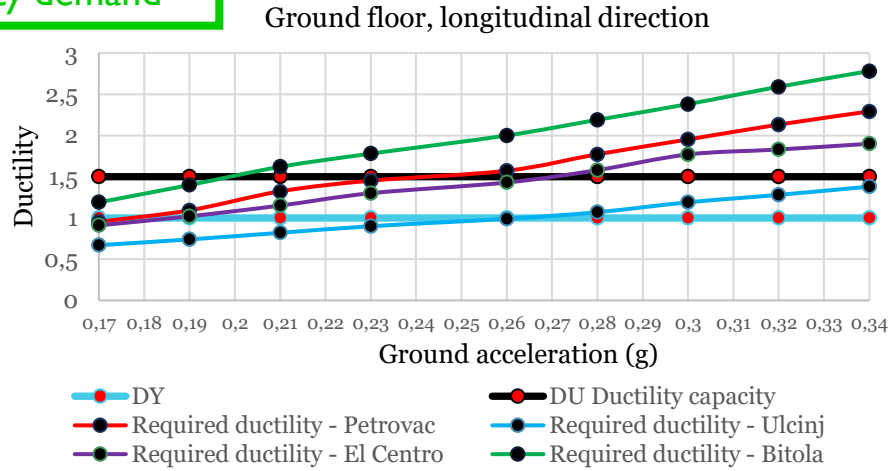
Seismic parameters, PGA and time history of acceleration, (2) Story Q-d diagrams

Nonlinear dynamic analysis: shear type structural modeling bilinear hysteretic model

time history of storey' displacements and accelerations, displacement / ductility demand

output





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IMPLEMENTATION: IN HISTORIC BUILDINGS

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1. old towns along Mediterranean coast

- damages after 1979 Montenegro earthquake

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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)


in-situ testing


1:2 scaled model


repaired model

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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

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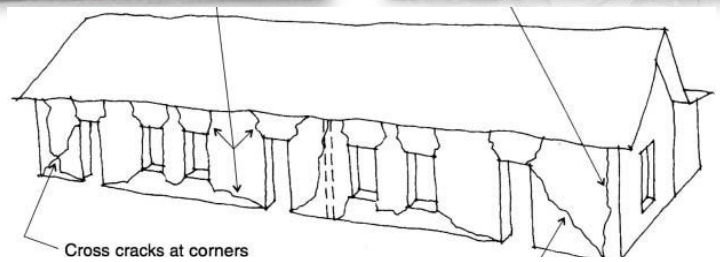
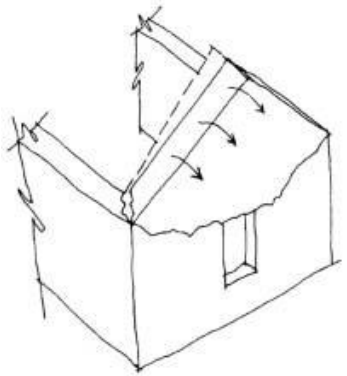
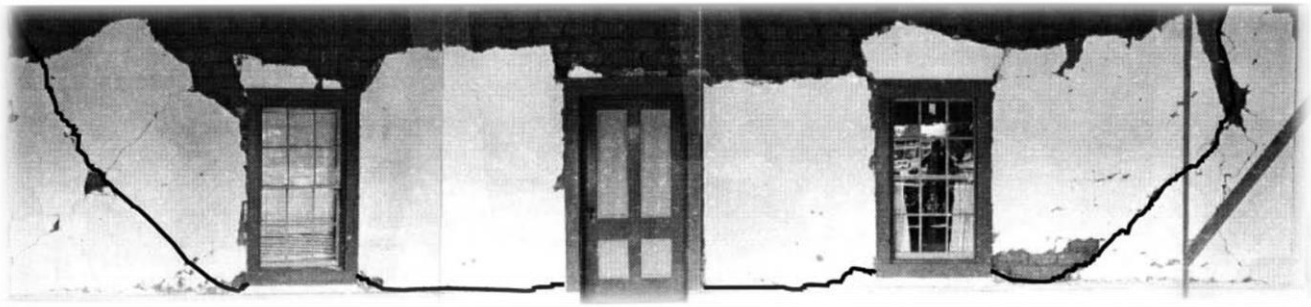
2. historic adobe buildings in California

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







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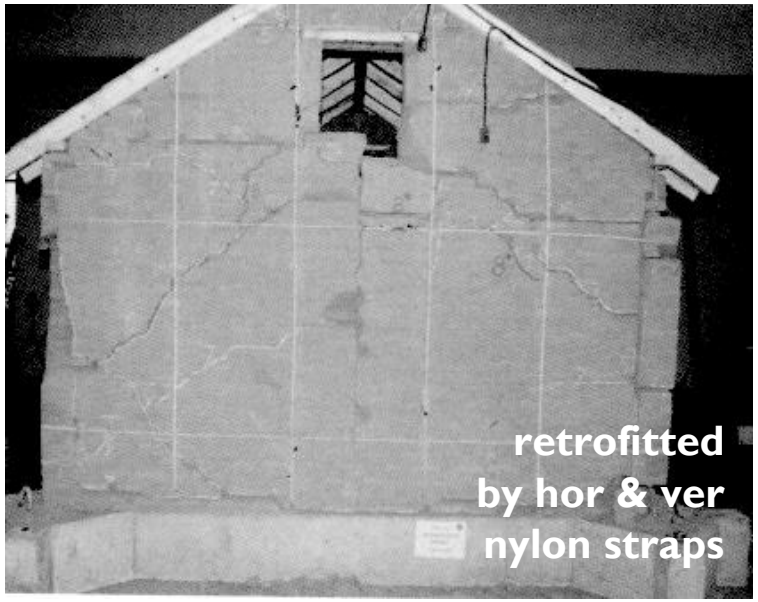
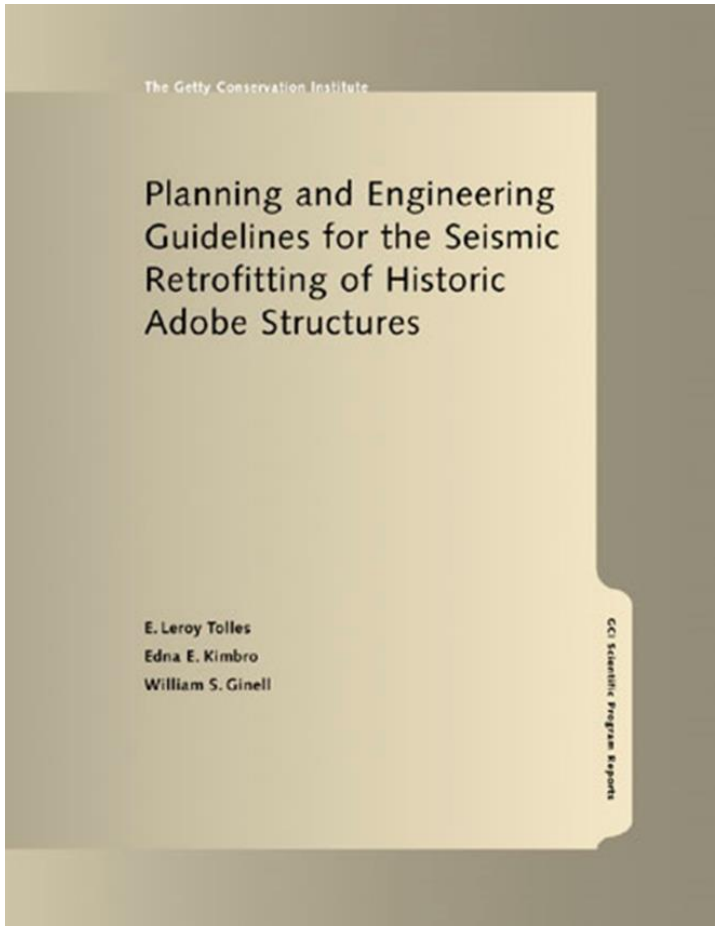
2. historic adobe buildings in California

- 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

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3. Parliament building in Skopje

since 1939

2008
project for Enlargement, Building of Another Story, Adaptation (+3600m^2)

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3. Parliament building in Skopje

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

no structural non nonstructural damage during 2016 Skopje earthquake, M 5.3

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IMPLEMENTATION: IN MONUMENTS

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

- damages after 1975 Pagan earthquake

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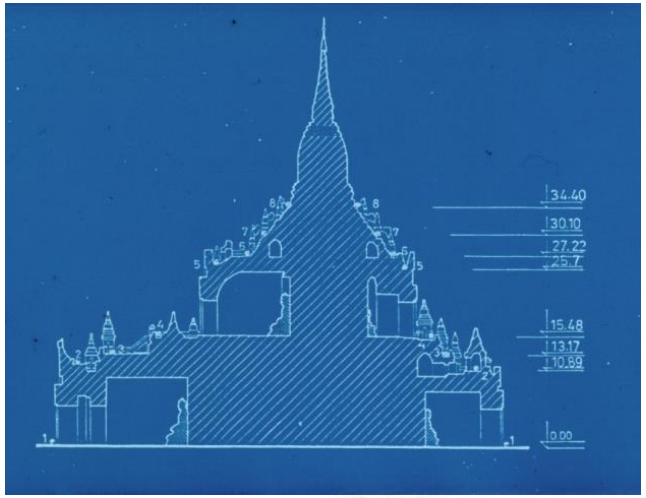
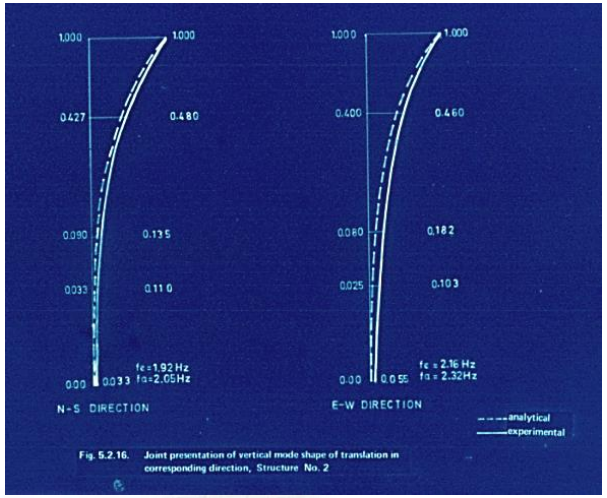
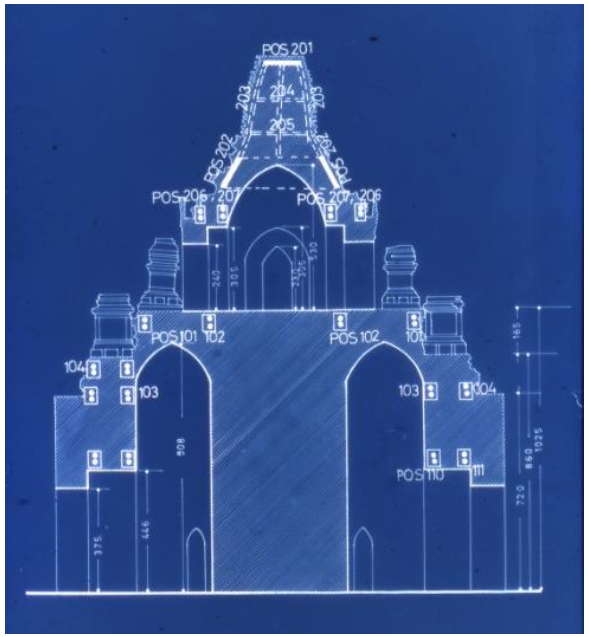
1. Monuments in Pagan - Burma (1978-1980)

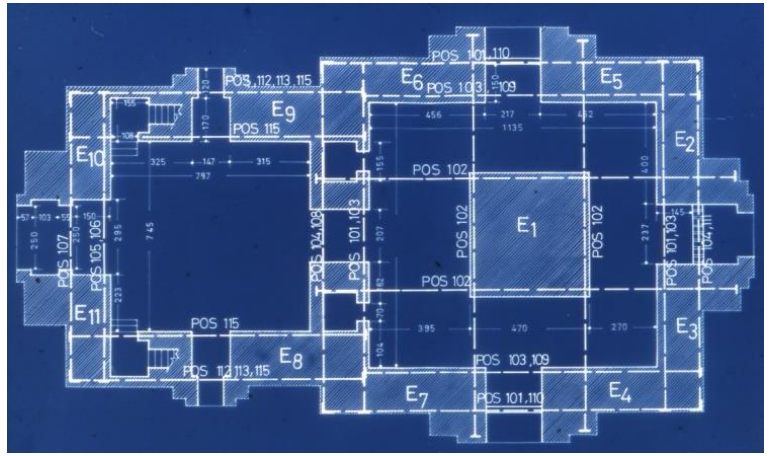
UNSECO/UNDP 78/023, (*Gavrilovic et al*):

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









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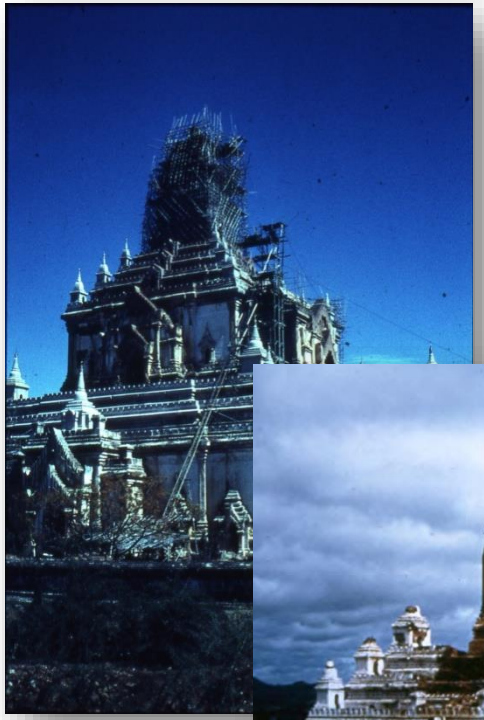
1. Monuments in Pagan - Burma (1978-1980)

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



no damage during
2016 earthquake with M 6.8

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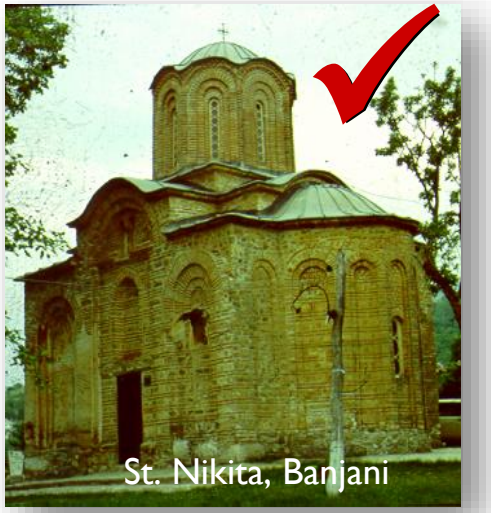
2. Byzantine Churches (1990-2000)

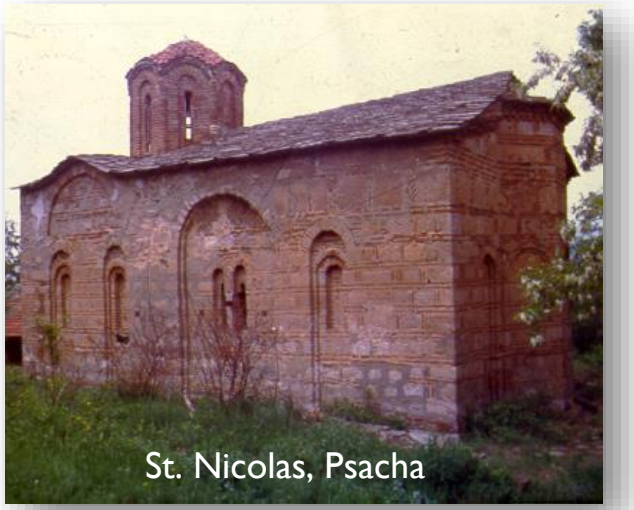
Scientific-Research Projects (IZIIS, GCI-USA, EU Phare Development Program)

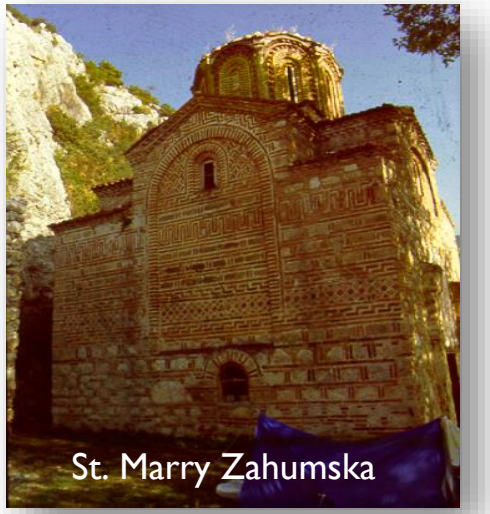
Conservation, Repair and Seismic Retrofitting of Byzantine Churches dated from IX – XIV century in Macedonia

- Typology
- Existing state
- Interventions
- Authenticity


St. Nikita, Banjani


St. Marry, Matejche


St. Nicolas, Psacha


St. Marry Zahumska

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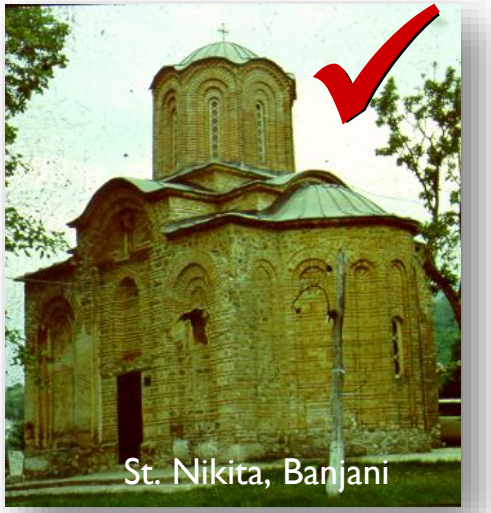
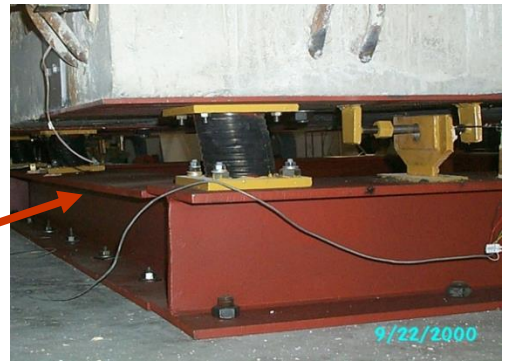
2. Byzantine Churches (1990-2000)

Scientific-Research Projects (IZIIS, GCI-USA, 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


St. Nikita, Banjani



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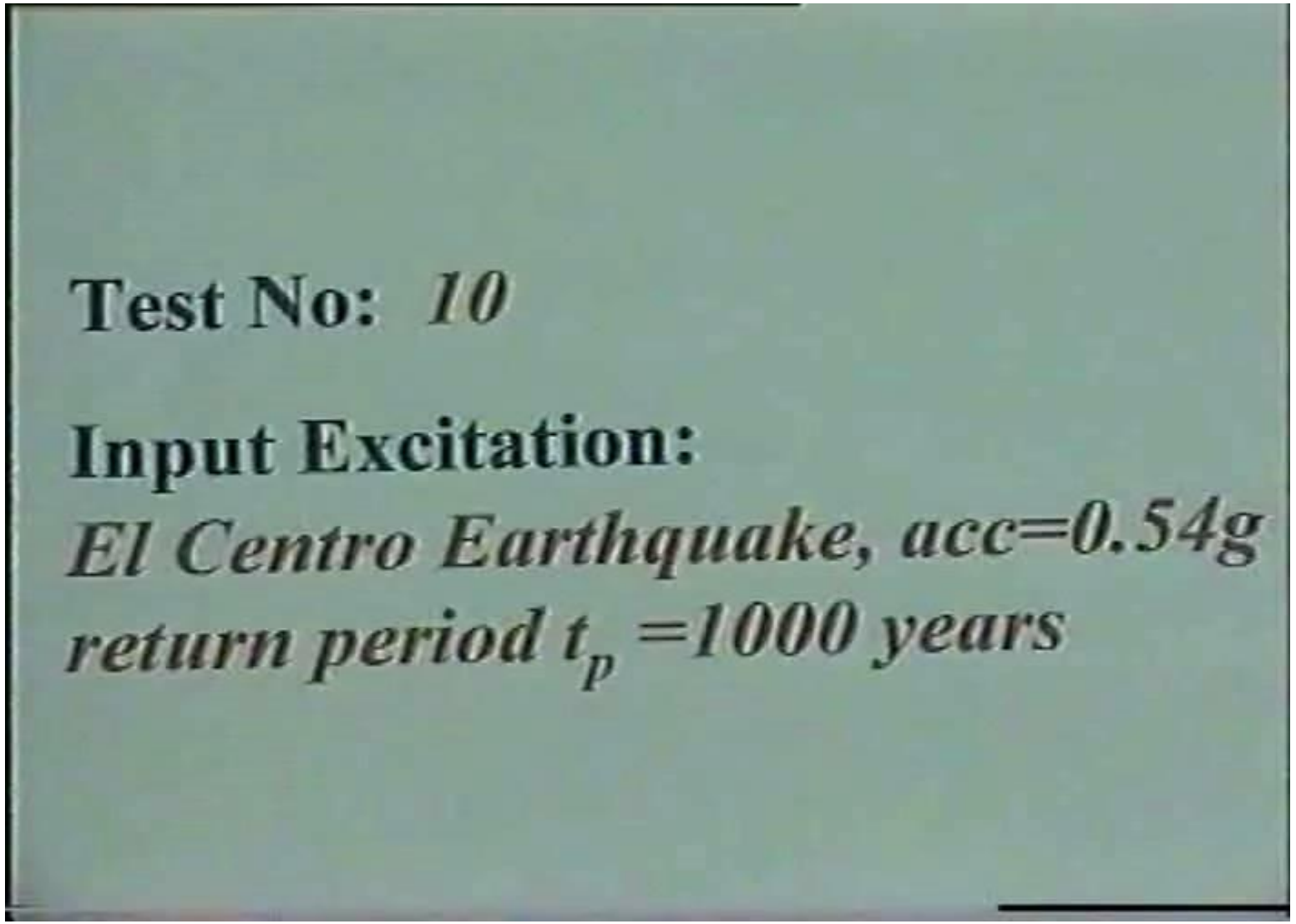
2. Byzantine Churches (1990-2000)



ties&injection versus base isolation

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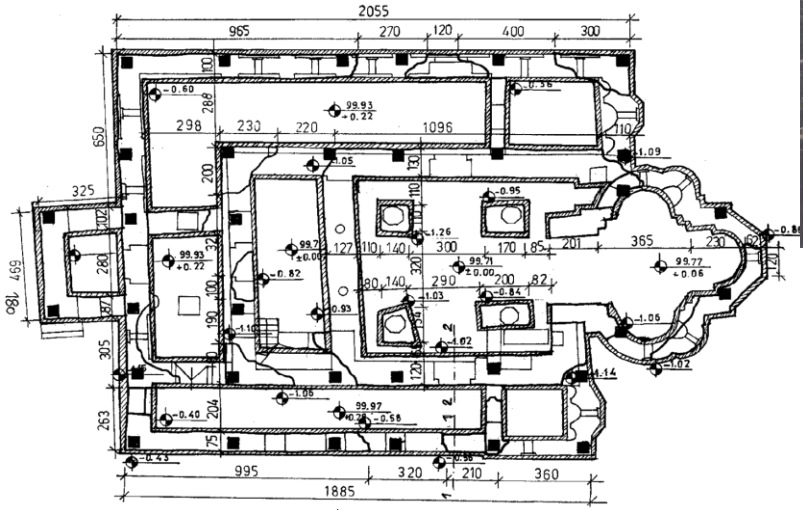
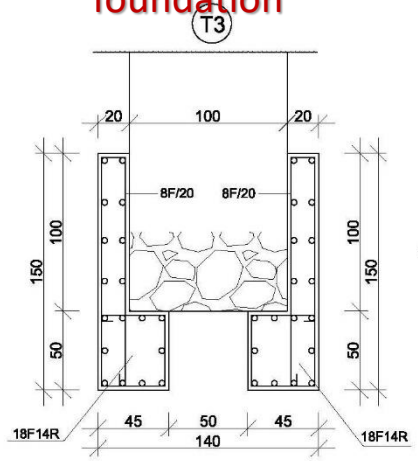
3. implementation in reconstruction of churches

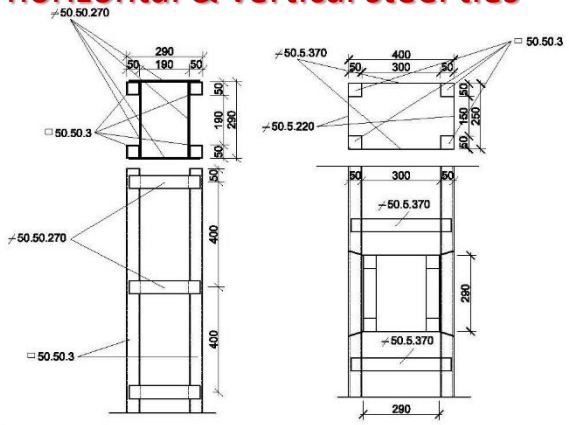
St. Pantelymon Church, Ohrid, (2001)

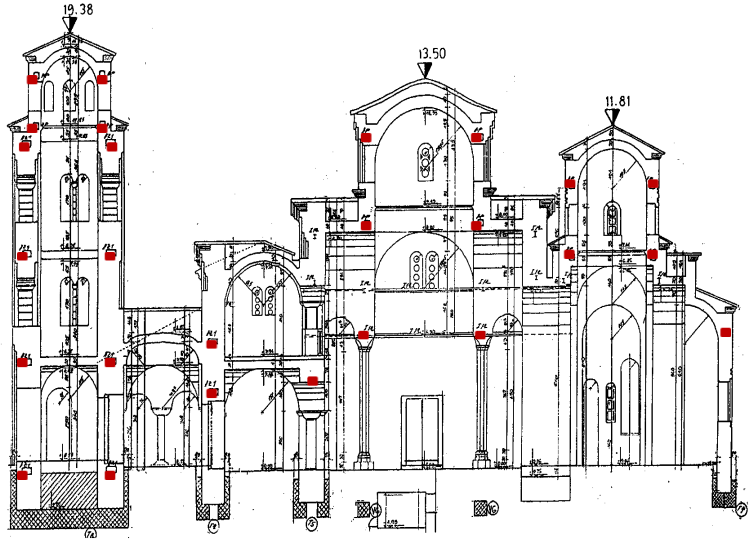


foundation



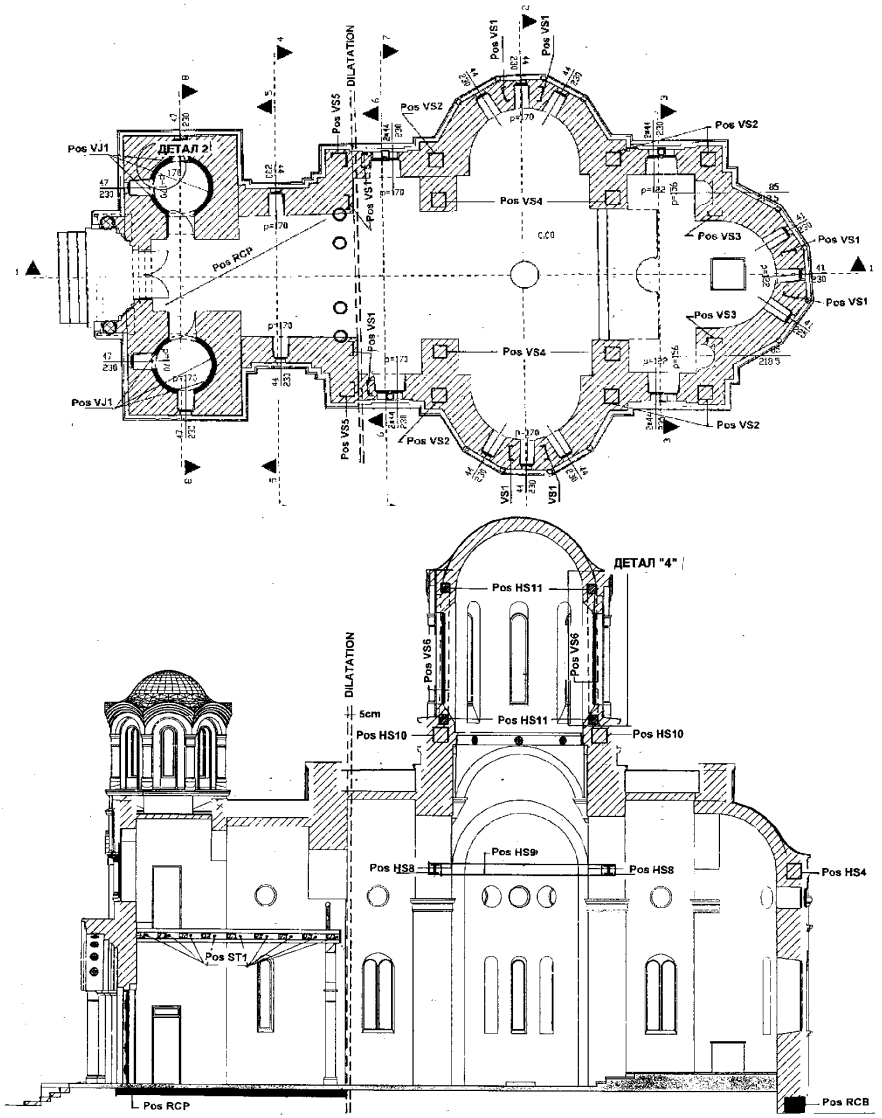
horizontal & vertical steel ties

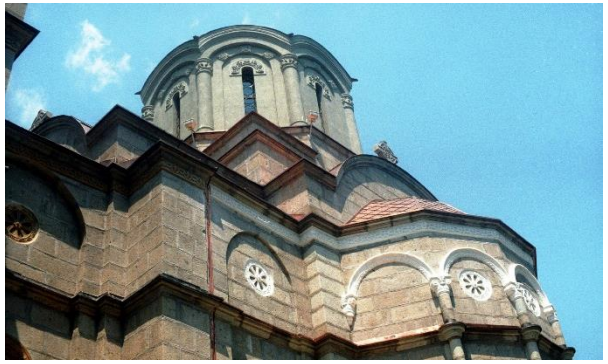


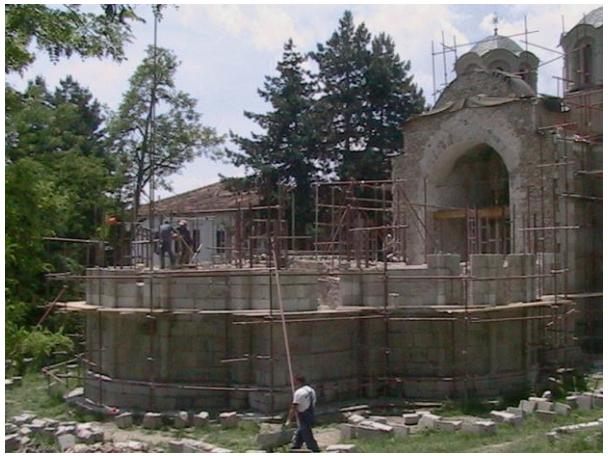


3. implementation in reconstruction of churches

St. Athanasius Church, Leshok (2007)

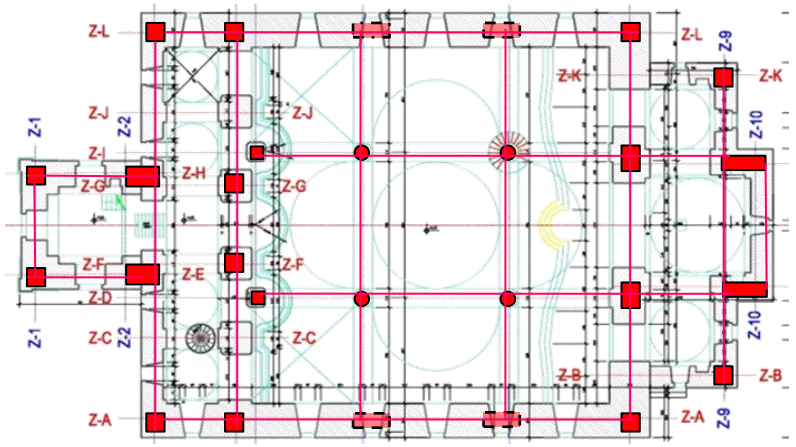


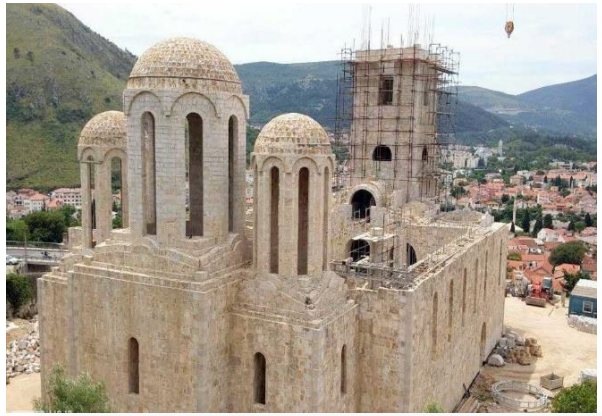


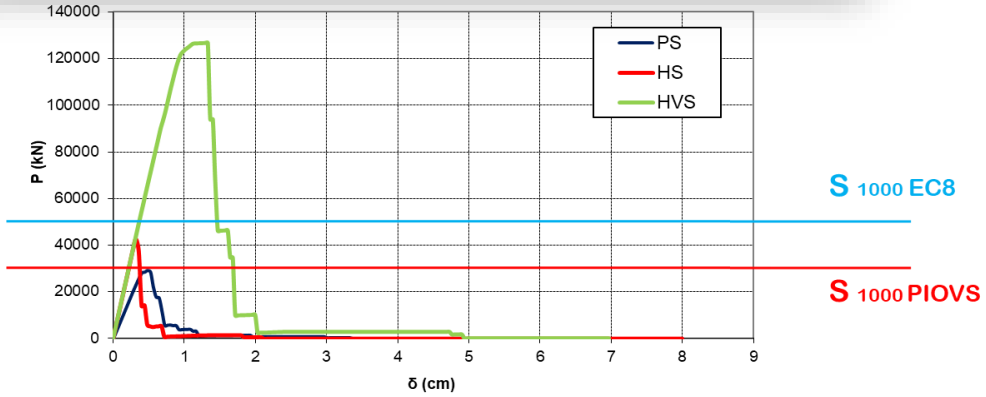


3. implementation in reconstruction of churches

Church of Holly Trinity, Mostar (2011)







4. implementation in seismic upgrading of churches

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5. Mosques

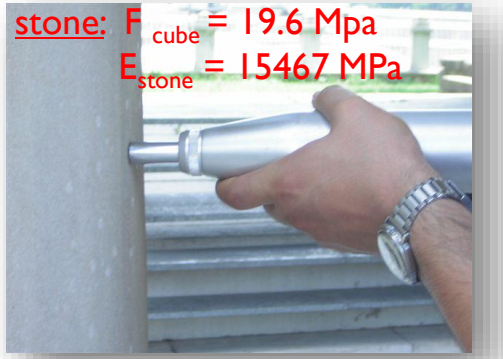
Scientific-Research Projects (IZIIS, EU FP6 PROHITECH)

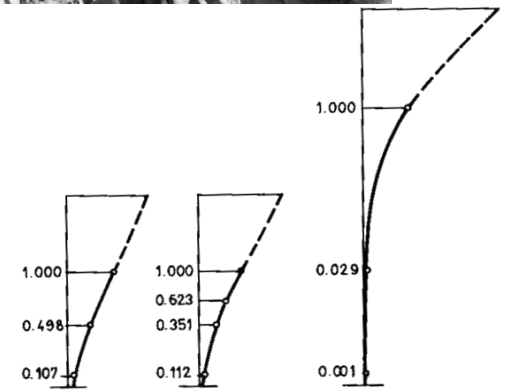
Seismic Retrofitting of Mustapha Pasha Mosque in Skopje, (2008-2010)

- 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

stone: F_{cube} = 19.6 Mpa
E_{stone} = 15467 MPa





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

Quasi-static testing

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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


original state


damage to original state


strengthened by CFRP bars&wrap

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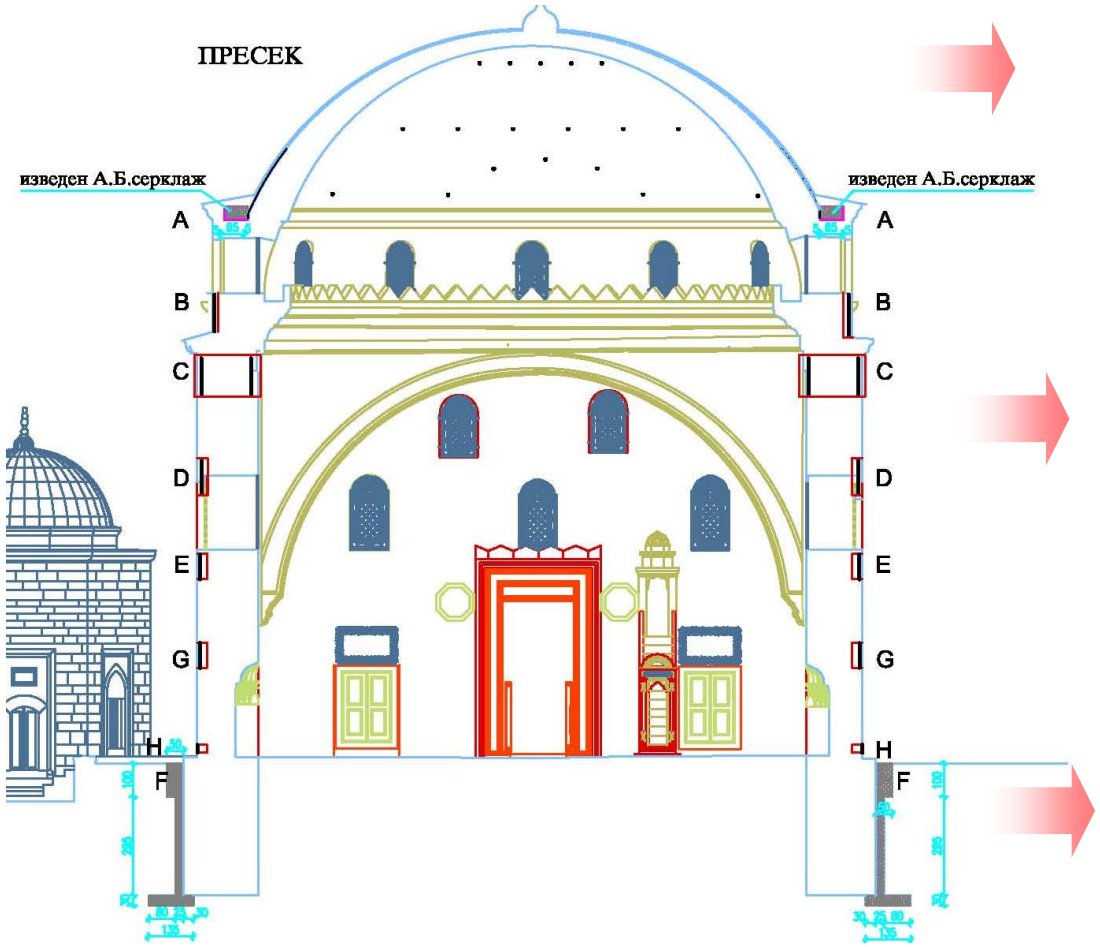
6. Implementation on Mustapha Pasha Mosque



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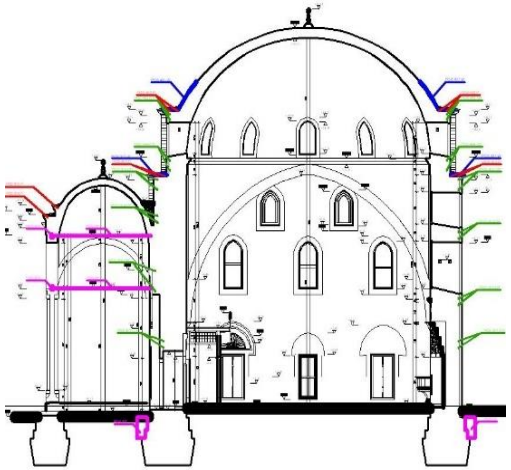
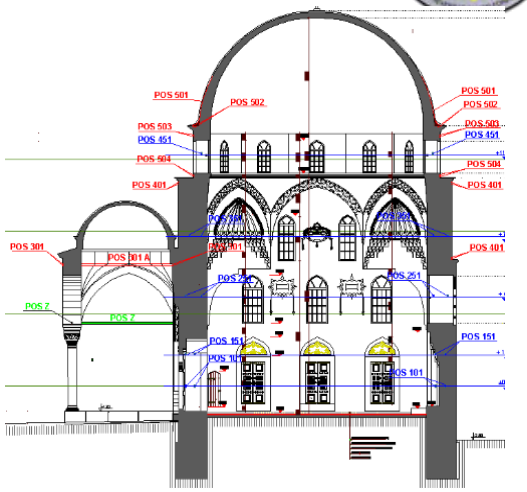
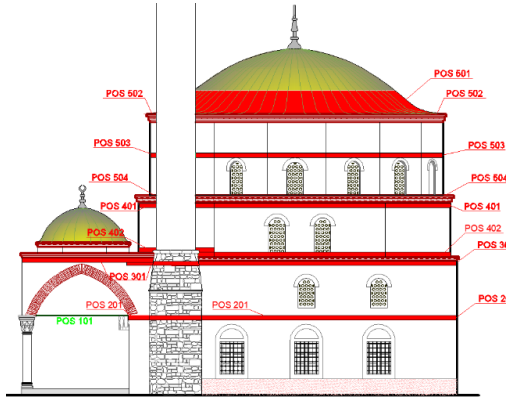
6. Implementation in other Mosques



Sultan Mehmet and Fatih Mosque, Prishtina



Gazi Hajdar Kadi Mosque, Bitola



Ali Pasha Mosque, Ohrid

Orta Mosque, Strumica

Charshi Mosque, Prilep

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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!

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