Knowledge FOr Resilient soCiEty

EARTHQUAKE PROTECTION OF HISTORIC BUILDINGS AND MONUMENTS IN REPUBLIC OF NORTH MACEDONIA

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K-FORCE TRAINING VISIT AT UKIM - May 9th, 2019

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Co-funded by the Erasmus+ Programme of the European Union

Outline

- **INTRODUCTION**
  - Disasters
  - Earthquakes in general, Skopje 1963 earthquake
  - Institute of Earthquake Engineering and Engineering Seismology, SS Cyril and Methodius University, UKIM-IZIIS, Skopje
- **CULTURAL HERITAGE**
  - Importance, Protection, Vulnerability
  - Cultural Heritage in North Macedonia
- **EARTHQUAKE PROTECTION OF MONUMENTS- IZIIS' APPROACH**
  - Scientifically based methodology for seismic upgrading od churches
  - Implementation in reconstruction of important monuments
- **CONSLUDING REMARKS**

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Disasters

Natural disasters:

- wind, hurricanes, typhoons, tornadoes, heavy rain, landslips, avalanches and earthquakes
- cannot be prevented but can be anticipated

Man-made disasters:

- war, terrorism including bomb threats, riots and panic, gas explosions, release of harmful matter
- preventable, but with unpredictable extent of damage that they might cause should they occur

Disaster Event health crisis affecting Europe (1990 – 2005)	**No**	**Human deaths**	**Total affected**	**Economic losses (in thousand US$)**
Floods	413	3 912	12 137 319	**84 072 159**
Extreme temperatures	141	**80 993**	3 442 803	16 245 450
Droughts	36	2	**15 875 965**	15 082 309
Fires	72	329	1 293 432	10 653 811
Earthquakes	110	21 943	5 903 433	37 859 949
Accidents	**695**	18 848	154 410	12 431 777
Other natural hazard	59	2 220	190 880	1 610 698
Storm	302	1 680	8 360 716	68 486 129
Total	**1 828**	**129 927**	**47 358 962**	**246 442 273**

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Disaster Management – UN efforts

2005-2015 (Hyogo Framework for Action):

- Important instrument for raising public and institutional awareness
- Disaster have continued - overall 1.5 billion have been affected in various ways:
  - 700 thousand deaths, 1.4 million injuries, 23 million homeless, 144 million displaced
  - 1.3 trillion US dollars total economic loss
- Significantly impede progress in sustainable development
- **Exposure of people and assets has increased faster than vulnerability has decreased**

2015-2030 (Sendai Framework for Disaster Risk Reduction):

Substantial Reductions

A. Global disaster mortality
B. Number of affected people
C. Economic losses in relation to global GDP
D. Economic damage to critical infrastructure and disruption of basic services

Substantial Increases

E. The number of countries with national and local DRR strategies by 2020
F. International cooperation to developing countries
G. Access to multi-hazard early warning system

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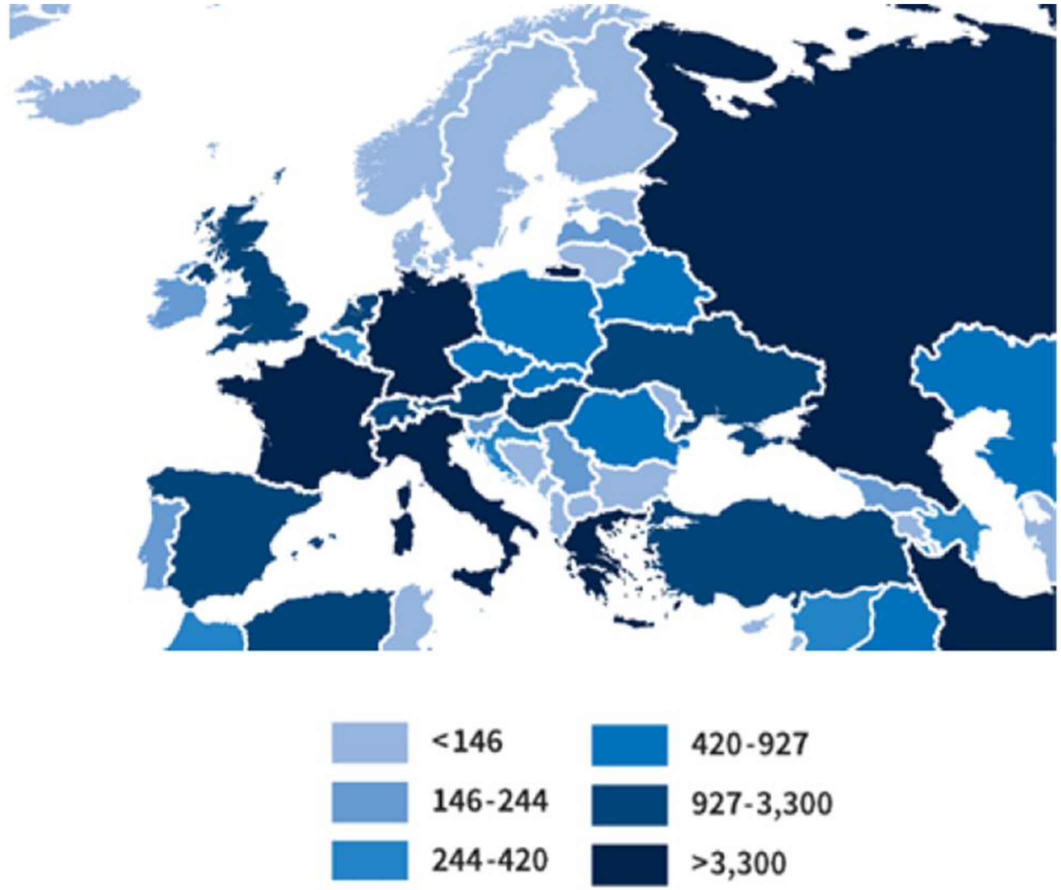
Disasters Management - EU strategy

in line with Sendai Framework:

- strategic objective – to **increase resilience**
- **qualitative shift** from reacting to emergencies to a more proactive role of prevention and preparedness
- **prevention and protection** - more cost-effective - driver for economic grow

assessment of seismic resilience of urban areas:

1. Description/understanding of hazards
2. Inventory of the exposed assets
3. Accurate estimation of their vulnerability



Multi –hazard (earthquakes, floods, cyclones) average annual loss in million US$

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Earthquakes – how they happen?

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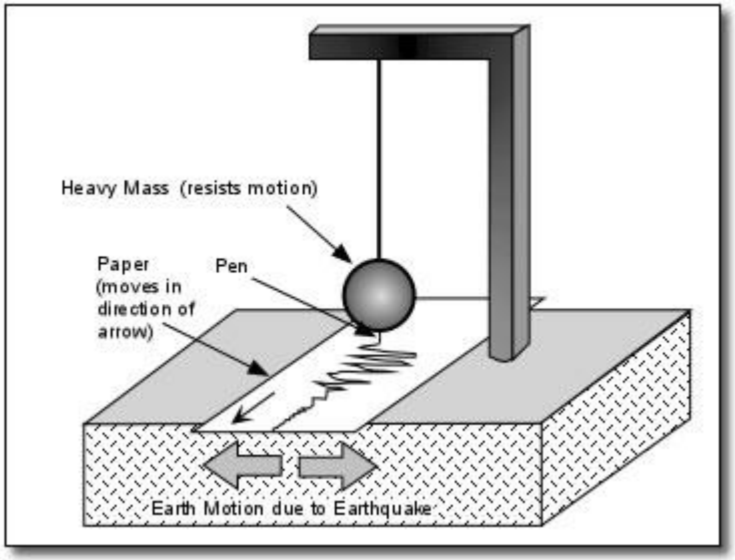
Earthquakes – how can be measured?

Magnitude, *(Charls Richter, 1936)*

- relative measure of energy released in the earthquake *focus*,
- the logarithm of the maximum seismic wave amplitude recorded on a standard seismograph
- an unnamed number ***1 to 9***



Intensity

- severity of earthquake effects on buildings and people on earth *surface*,
- a scale of ***I to XII degrees*** according MSC (1946), EMS (1988)
- depends on the depth, geology, type of buildings, observer

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Earthquakes – frequency, energy , power

Magnitude M	Energy	Explosive Power	Average Annually
9	U.S. Energy Use for a month (10^{14}kJ)		1[1]
8	U.S. Energy Use for a day (10^{13}kJ)	400 atomic bombs 1 hydrogen bomb	17[2]
7	10^{12} kJ	One Megaton	134[2]
6	U.S. Energy Use for a minute (10^{10} kJ)	Large thunderstorm 6 Kilotons	1319[2]
5	10^{9} kJ	One Kiloton	13 000 (est.)
4	10^{8} kJ	Ten tons	130 000 (est.)
3		One ton	1 300 000 (est.)

[1] based on observations since 1900
[2] based on observations since 1990

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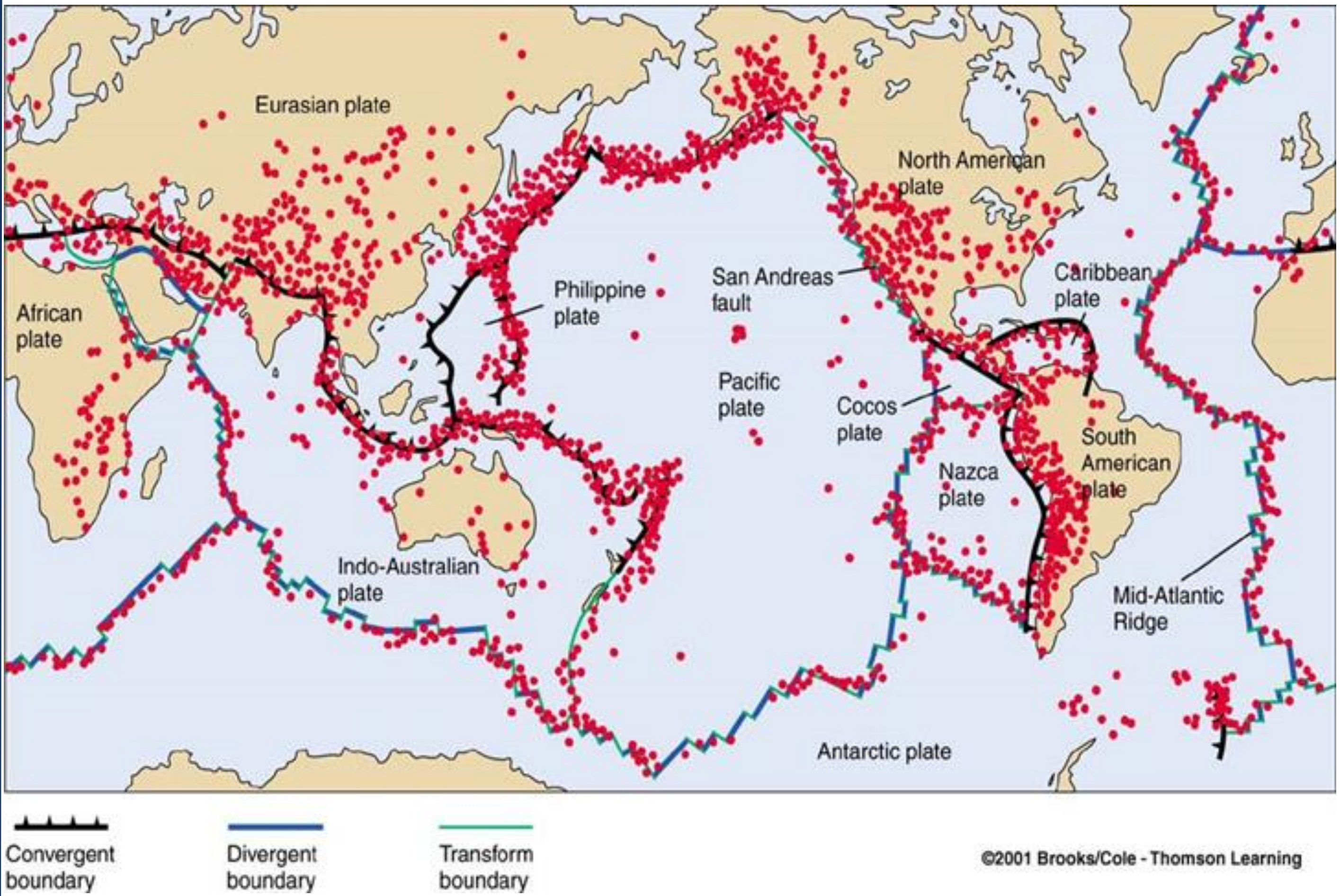
Earthquakes – global seismicity



80%
Pacific belt

15%
Mediterranean Asiatic belt

5%
Interiors of plates

150000 strong enough to be felt each year

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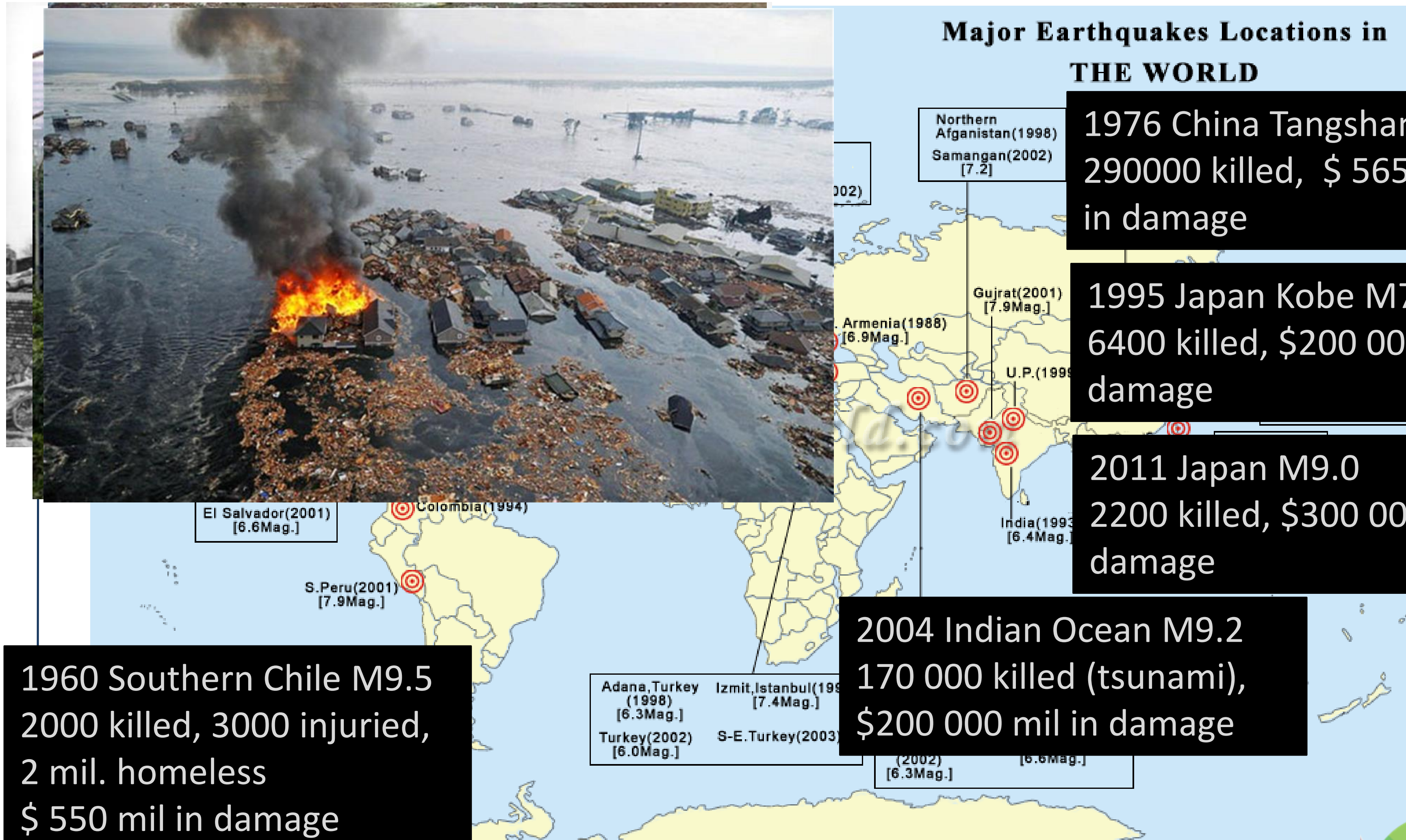
Earthquakes – strongest in the world



1976 China Tangshan M8.0
290000 killed, $ 5650 mil in damage

1995 Japan Kobe M7.2
6400 killed, $200 000 mil in damage

2011 Japan M9.0
2200 killed, $300 000 mil in damage

2004 Indian Ocean M9.2
170 000 killed (tsunami), $200 000 mil in damage

1960 Southern Chile M9.5
2000 killed, 3000 injuried,
2 mil. homeless
$ 550 mil in damage

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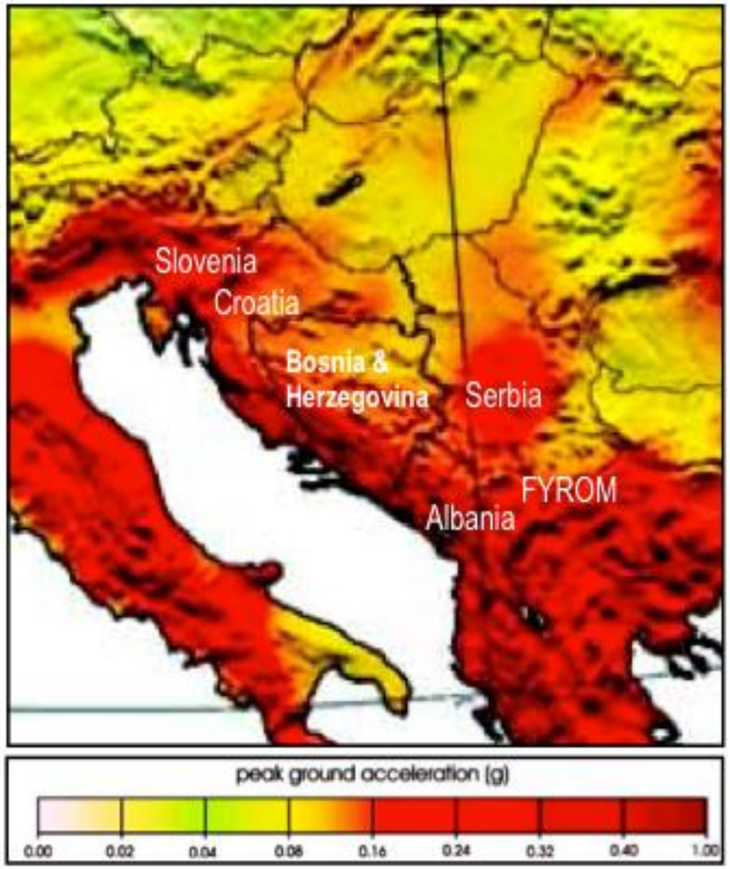
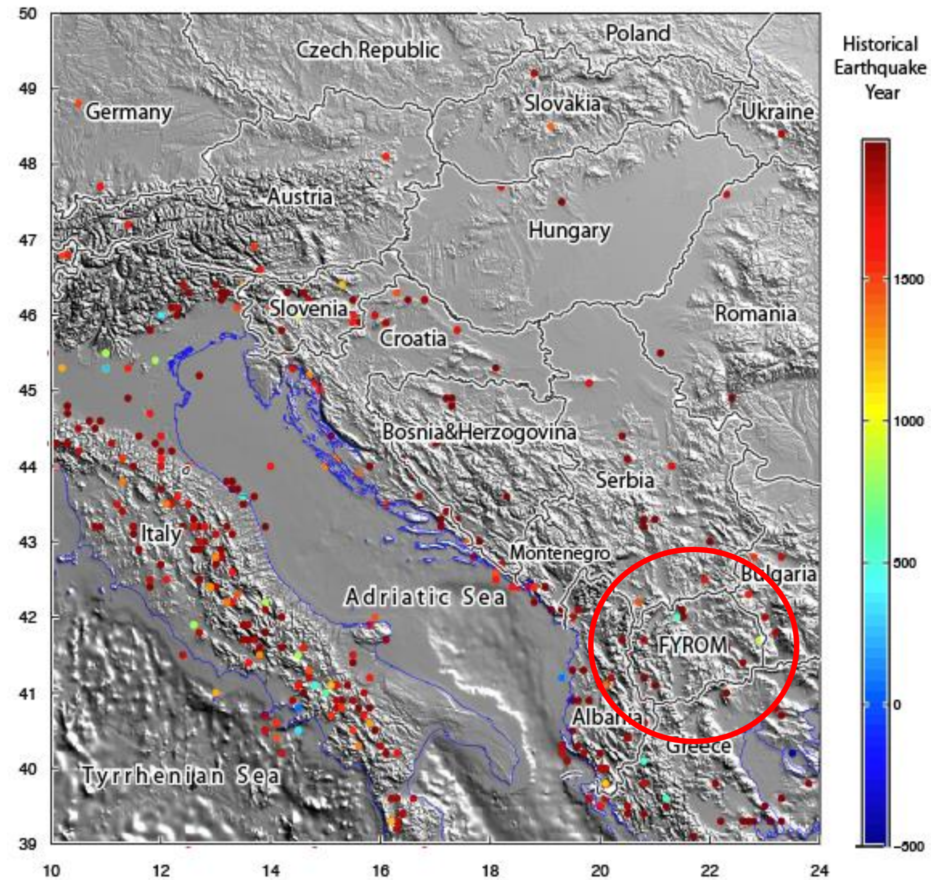
Earthquakes – seismicity of Balkans

Source: USGS, Seismic Hazard Mapping of Balkans



Peak Ground Acceleration



Historical seismicity (500BC-1970)

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Skopje 26.7.1963 5:17 - M6.1 1071 deaths 3300 injured

Damage degree	Residential buildings	Other buildings	Housing area	Percent of population
Destroyed	11.3	9.2	7.0	8.5
Heavily damaged	44.1	33.0	29.9	36.4
Damaged (%)	22.0	32.9	39.9	30.6
Slightly damaged	16.5	20.1	19.8	20.3
Undamaged	6.1	4.8	3.4	4.2

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Skopje – city of solidarity and humanity

First hours after: Response of ex YU community

- ~5000 people saved from under the ruins by JNA and Skopje citizens
- Special train with medical and surgical teams, engineers, water canisters, food, accommodation installations, civil engineering machines and other equipment left Belgrade at 11:00.
- Transfusion institutes in bigger ex YU cities started the action for blood donation at 10:00, at 16:00 their capacity were reached
- Entire community of ex YU and everyone in it is doing everything they can to help

First days after: Manifestation of the world solidarity

- Over 80 countries, their governments, humanitarian organizations and citizens contributed to the lessening of repercussions
- USA (mobile hospital with 200 beds and 209 specialists), SSSR (military engineering unit of 500 persons), Germany (84 professionals for precast building) Great Brittan (military technical team of 134 specialists) France (10 surgical specialists), Greece (37 medical specialists), Sweden (13 surgical specialists), Denmark (special military engineering unit), Japan (specialist in civil engineering and seismology), UN agency, Mexico, Mongolia…….

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Recovery of Skopje

Repair and strengthening and construction of new residential buildings:

- lack of corresponding technical regulations and directions
- lack of experience in seismic construction

September 1963 - *General recommendations for repair and strengthening of structures damaged by Skopje earthquake* and *Rulebook on proportioning and construction of engineering structures in earthquake prone areas*, (Republic secretariat for construction and public works)

1964 - Temporary Technical Provisions for Building in Seismic Regions

- initiated by the needs for fast and professional reconstruction of the city
- additional load type: horizontal seismic loads, calculated according to the building characteristics and seismicity of the region

- Beginning of European Earthquake Engineering

- Initiative for establishing of EAEE and its first conference in Skopje

1965 – Institute of Earthquake Engineering and Engineering Seismology, IZIIS

- established upon UN recommendation for repair, reconstruction of Skopje

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UKIM-IZIIS strategic orientation

- Permanent progress in research, (basic and applied), education and training,
- Protection of population and property, reduction of physical and economic damage and protection of socio-economic systems against effects of earthquakes

IZIIS Departments

1. Natural and Technological Hazards & Ecology
2. Building Structures and Materials: Design, Analysis and Testing
3. Engineering Structures
4. Risk, Disaster Management and Strategic Planning
5. Geotechnics and Special Structures
6. Dynamic Testing Laboratory and Informatics

IZIIS Laboratories

- Dynamic Testing Laboratory
- Geophysical Laboratory
- Soil Dynamics Laboratory
- Strong Motion Laboratory

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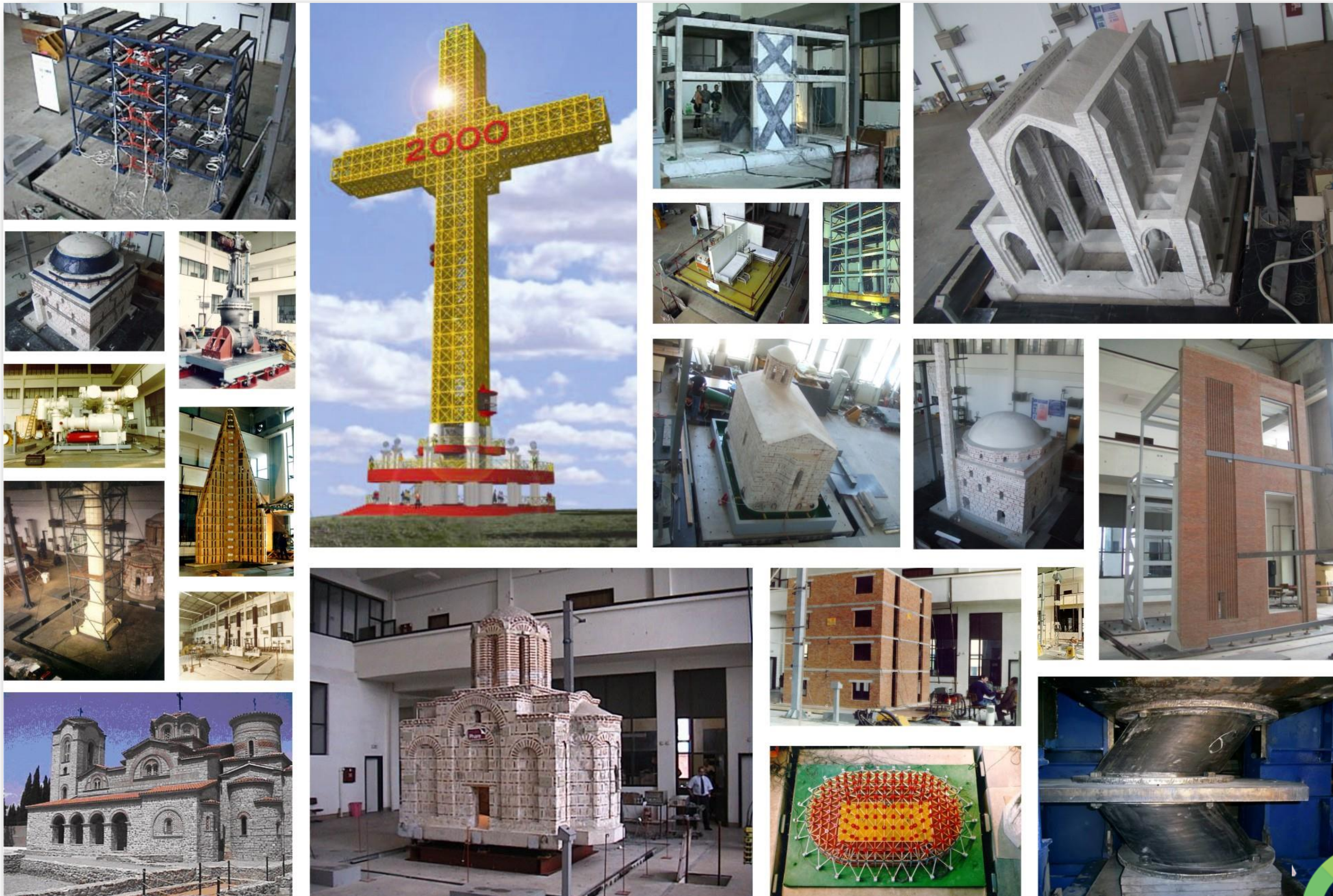
UKIM-IZIIS shaking table programme



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Cultural Heritage - earthquakes

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Cultural Heritage – man made disasters

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Cultural Heritage

IMPORTANCE:

- key element for the history and the identity of the society, contributing to its economic and other well-being
- only remnant of human existence, creation and achievements in the past
- deserve special attention due to their individual historic, architectonic, documentary, economic, social and even political or spiritual value
- when damage or destruction of cultural historic monuments is considered, the reason does not play a primary role anymore

PROTECTION:

- multidisciplinary approach: team of experts from different profiles
- one of the main tasks and problems: how far we should go as to the level of safety and the extent of the intervention
- a moral and legal obligation and the duty of present civilization

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Cultural Heritage

EARTHQUAKE PROTECTION:

- Materials:

✓ reversible interventions - only a few limitations

✓ irreversible interventions - additional compatibility of new with old materials and their durability.

- Methods: detail analysis of existing structure

✓ sufficient bearing and deformability capacity - only repair

✓ not sufficient bearing and deformability capacity - strengthening (increase of strength or/and deformability)

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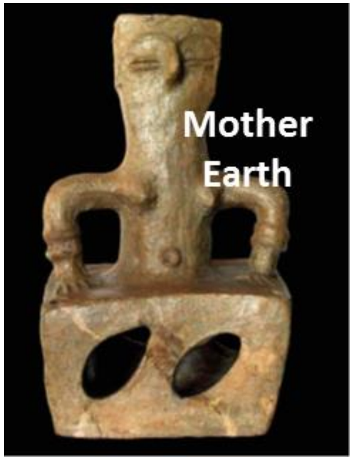
Cultural Heritage in Republic of North Macedonia

- Archeological heritage



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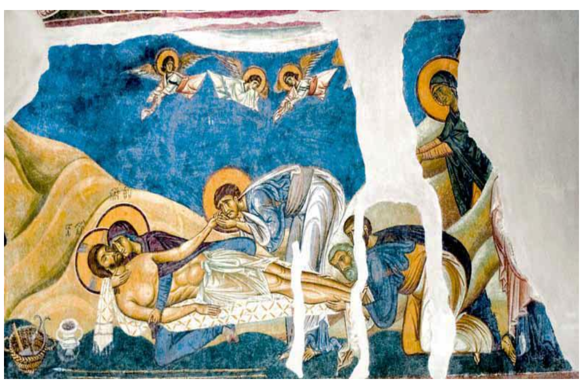
Cultural Heritage in Republic of North Macedonia

- Medieval Heritage

St. Panteleymon, Nerezi, XII

St. Marry Perivleptos, XIII

St. Andreas, Matka, XIV



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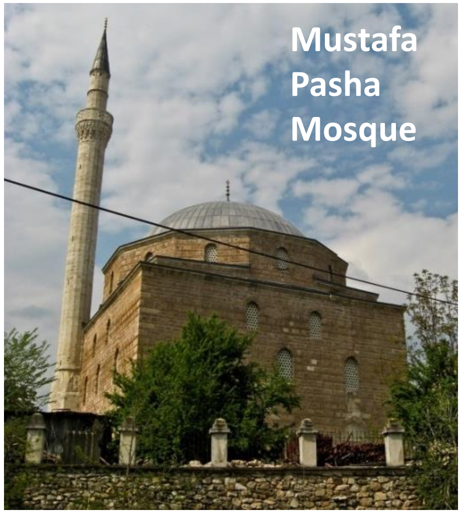
Cultural Heritage in Republic of North Macedonia

- Ottoman Heritage



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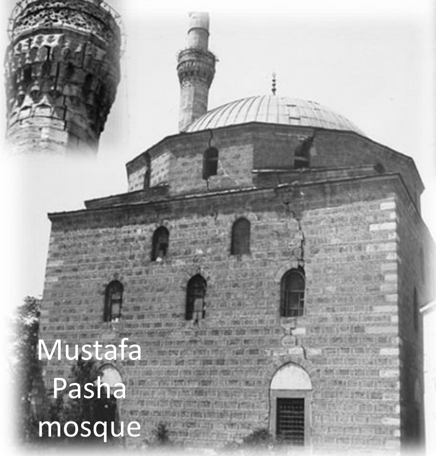
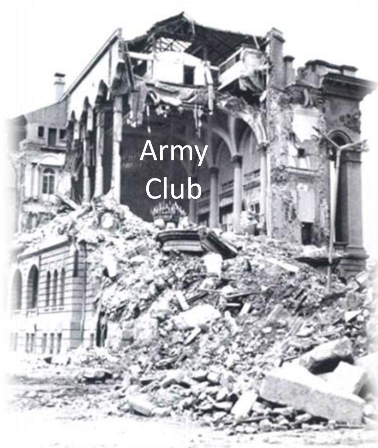
1963 Earthquake effect on Architectural Heritage

- 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





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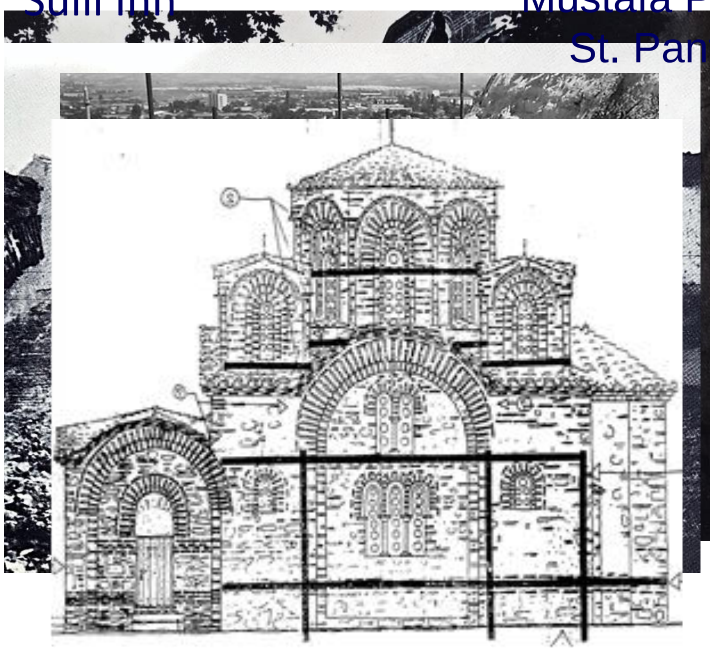
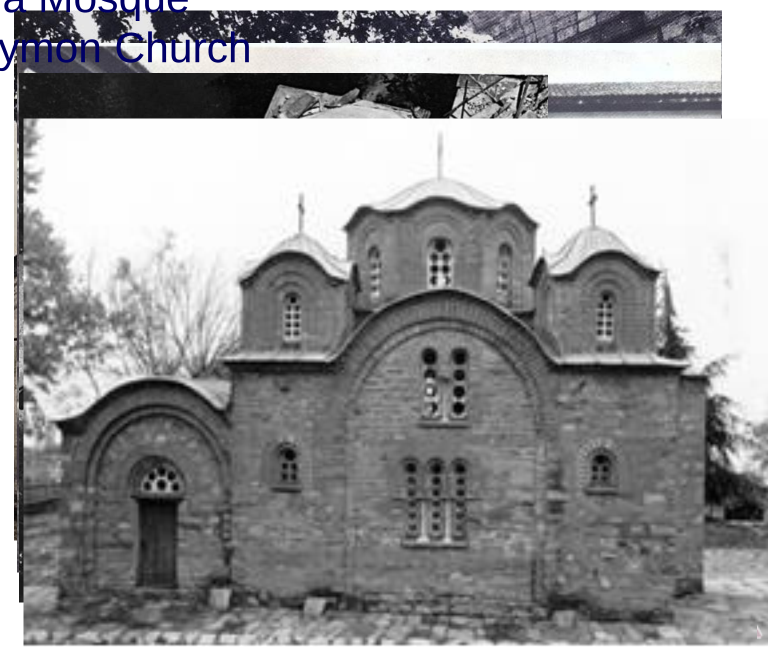
Post-earthquake Repair and Seismic Strengthening

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

Ishak Bay Mosque
Sulli Inn

Mustafa Pasha Mosque
St. Panteleymon Church





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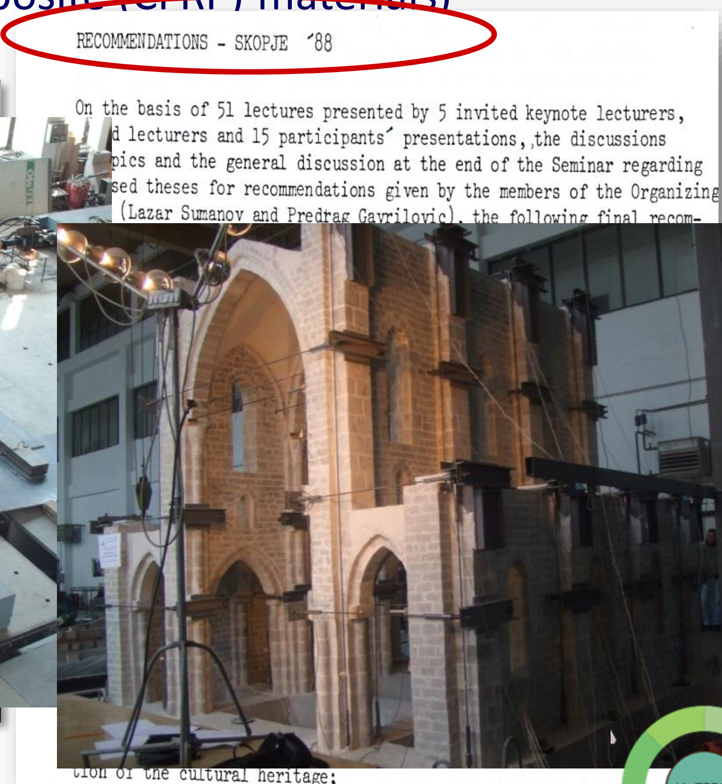
Effects of Post-earthquake Protection of Monuments

- adverse affect of cement – *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, seismic base isolation, composite (CFRP) materials)



RECOMMENDATIONS - SKOPJE '88

On the basis of 51 lectures presented by 5 invited keynote lecturers,
d lecturers and 15 participants' presentations, the discussions
pics and the general discussion at the end of the Seminar regarding
sed theses for recommendations given by the members of the Organizing
(Lazar Sumanov and Predrag Gavrilovic), the following final recom-

tion of the cultural heritage;

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K-FORCE

Protection of Cultural Heritage – new approach

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

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

and

Scientifically based methodology for earthquake protection of historic buildings and monuments during their protection

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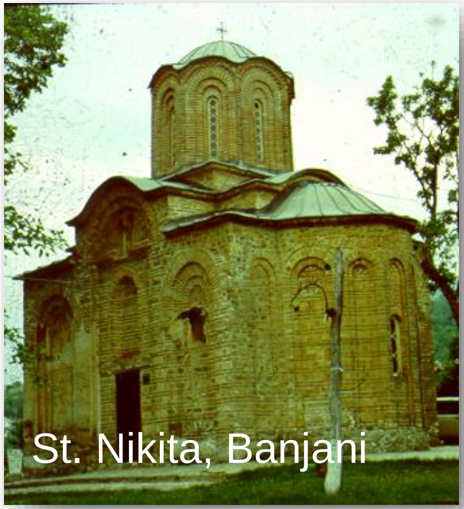
Methodology for Seismic Strengthening of Byzantine Churches

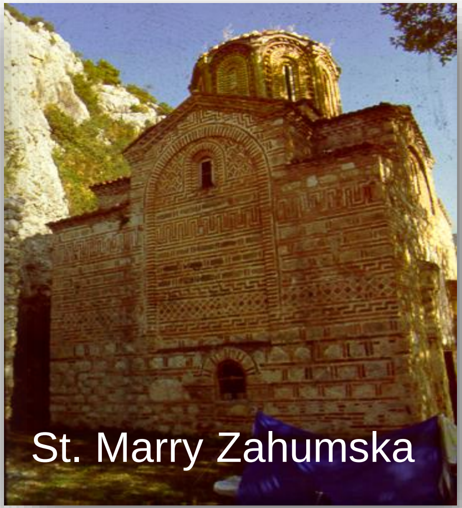
Traditional Technology vs. New Technology

- Typology
- Existing state
- Interventions
- Authenticity

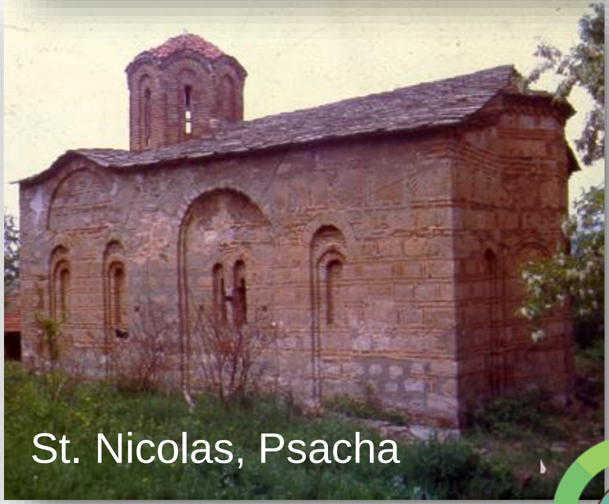
St. Marry, Matejche



St. Nikita, Banjani



St. Marry Zahumska



St. Nicolas, Psacha

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Experimental Investigations of the Model

- **OBJECTIVES** → Investigation of seismic resistance and verification of the proposed strengthening concept
- Selection of the geometrical scale → **Lr = 1:2.75**
- Investigation of the model materials →

- Experimental testing of wall elements →

- Design and testing of the church model in typical Byzantine style

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Concept for Repair and Strengthening - traditional

Design Criteria:

- ***Level I:*** without damage, tp = **100** years
- ***Level II*****:** linear behaviour, limited nonlinear deforr
- ***Level III*****:** deep nonlinearity- not disturbed stabili

Selected method for strengthening:

- ***incorporation of horizontal steel ties***
- ***systematic injection of elements***
- ***incorporation of vertical steel ties***

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Experimental verification of methodology

scientific-research projects

lower damage level even under higher level of input excitation

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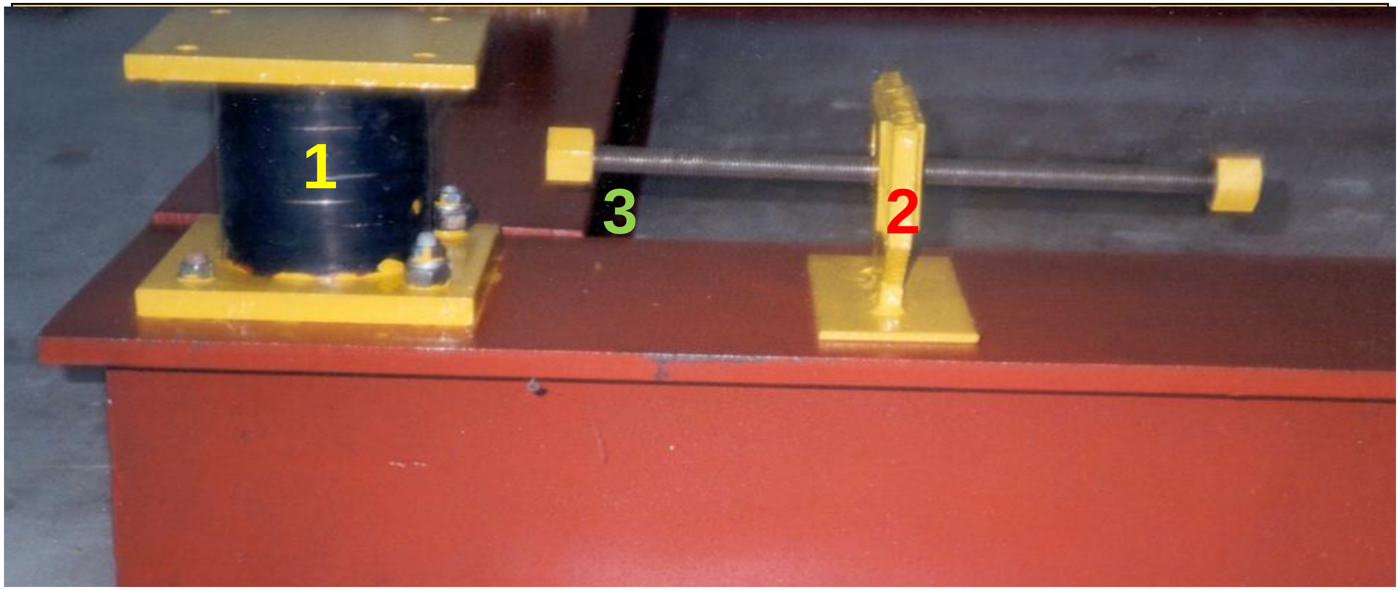
Earthquake Protection using Seismic Isolation - new

scientific-research projects



element 1: Laminated rubber bearing element

element 2: Steel plate damper (hysteretic behavior)

element 3: Stopper element (limited displacement)

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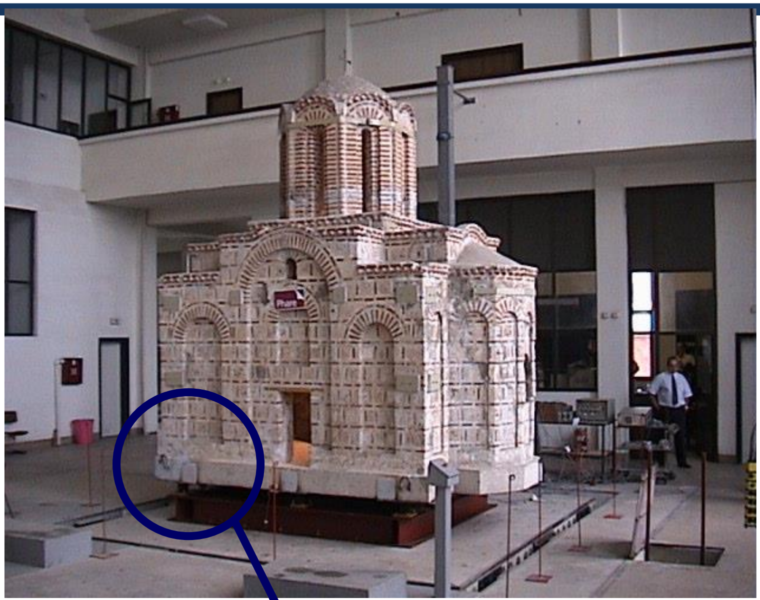
Shaking table testing of base-isolated model

Steel structure and Isolators



Isolator in action

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Traditional Technology vs. New Technology ✔

Test No: *10*

Input Excitation:

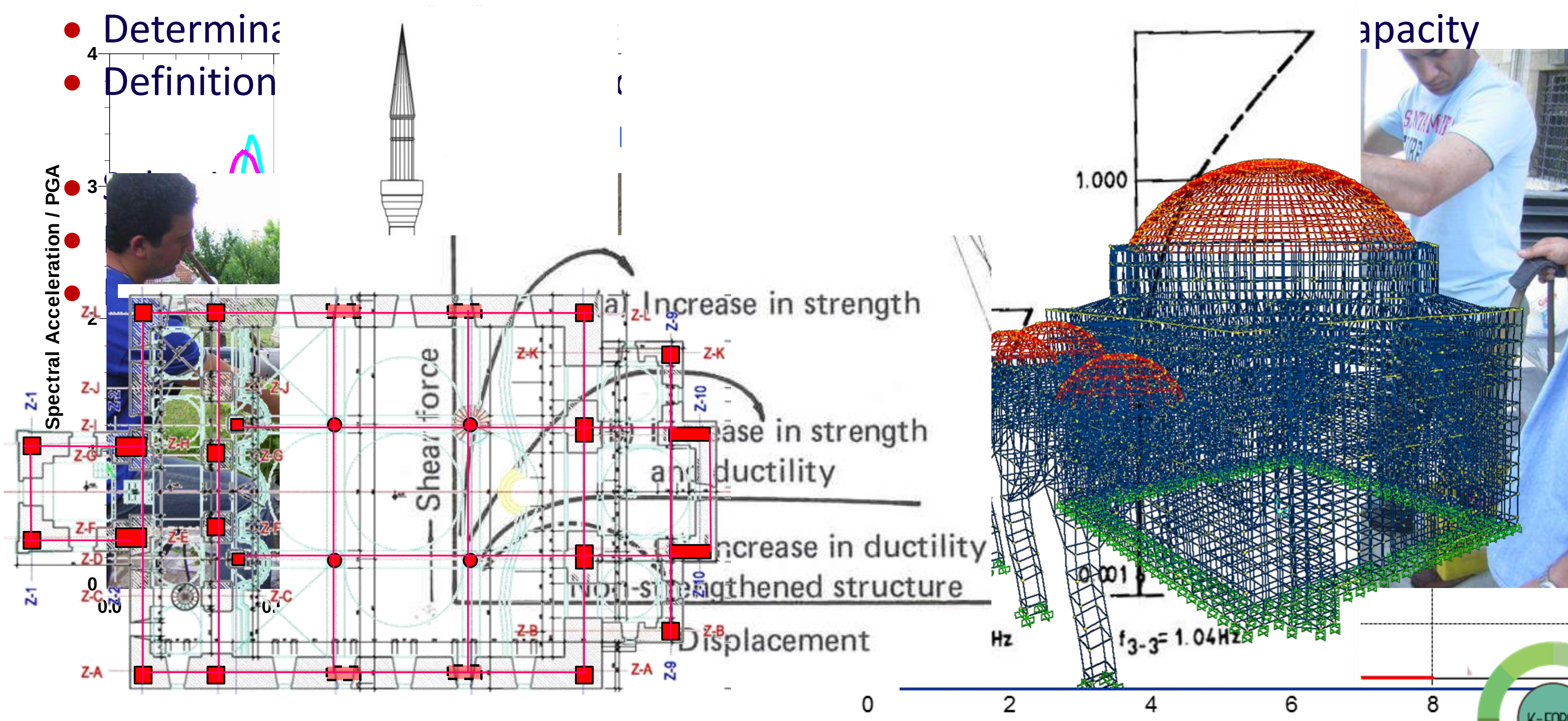
El Centro Earthquake, acc=0.54g

return period t_p =1000 years

Earthquake Protection of Monuments – IZIIS approach

Minimum interventions – Maximum protection

- Definition of expected seismic hazard, investigation of soil conditions
- Investigation of the characteristics of built-in materials
- Investigation of the dynamic characteristic by AVT
- Determina… apacity
- Definition…



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1

P.Gavrilovic, G.N.Cvetanovska, R. Apostolska (2001)

Implementation....... In reconstruction

Consolidation and Reconstruction of the Structure of the St.Pantelymon Church in Plaoshnik, Ohrid

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Concept for Consolidation and Rebuilding

- ✓ Injection of the walls:
  - Walls below the floor level with cement emulsion
  - Walls over the floor by use of lime-based emulsions
- ✓ Contact between the existing and the rebuilt walls
- ✓ Strengthening and the consolidation of the existing foundation walls up to level 0.00
- ✓ Reinforced concrete floor slab with a thickness of 20 cm
- ✓ Construction of the church as massive stone and brick masonry in lime mortar with incorporated horizontal and vertical steel ties

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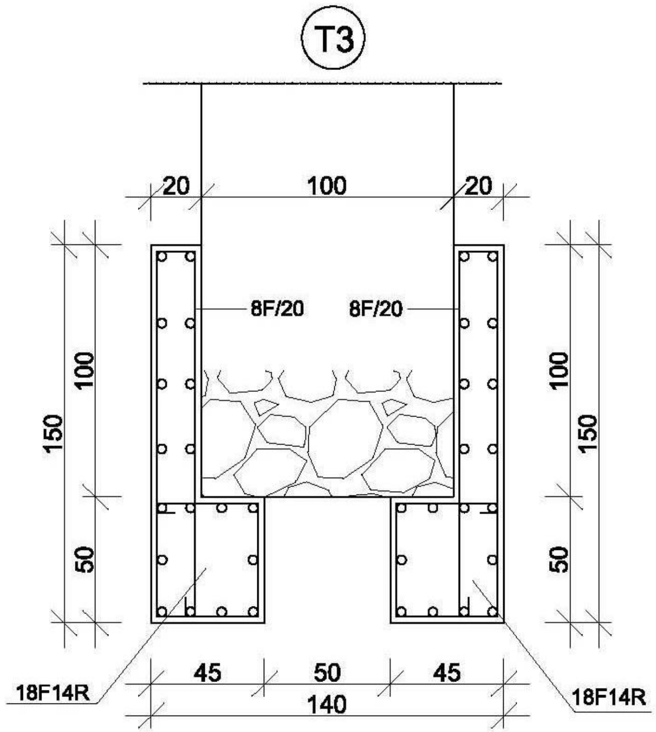
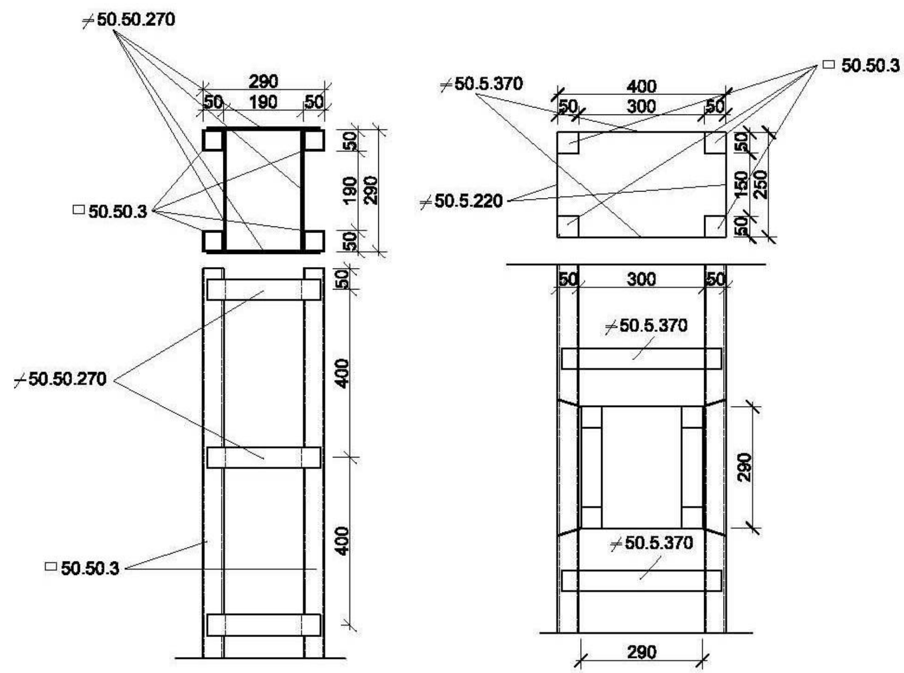
Implementation....... In reconstruction

foundation



horizontal & vertical steel ties



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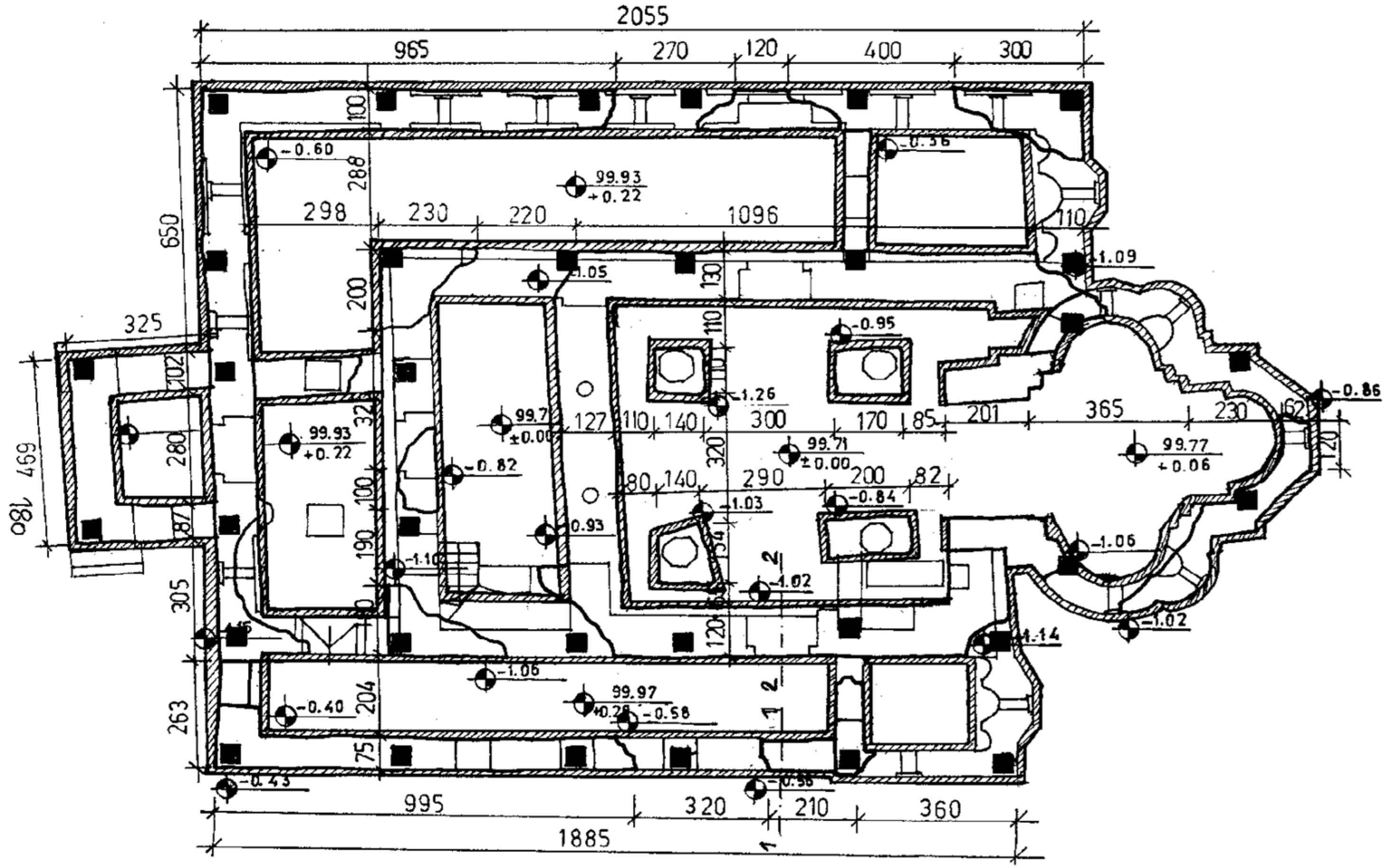
Implementation……. In reconstruction

plan of the structure at the level of -0.22m



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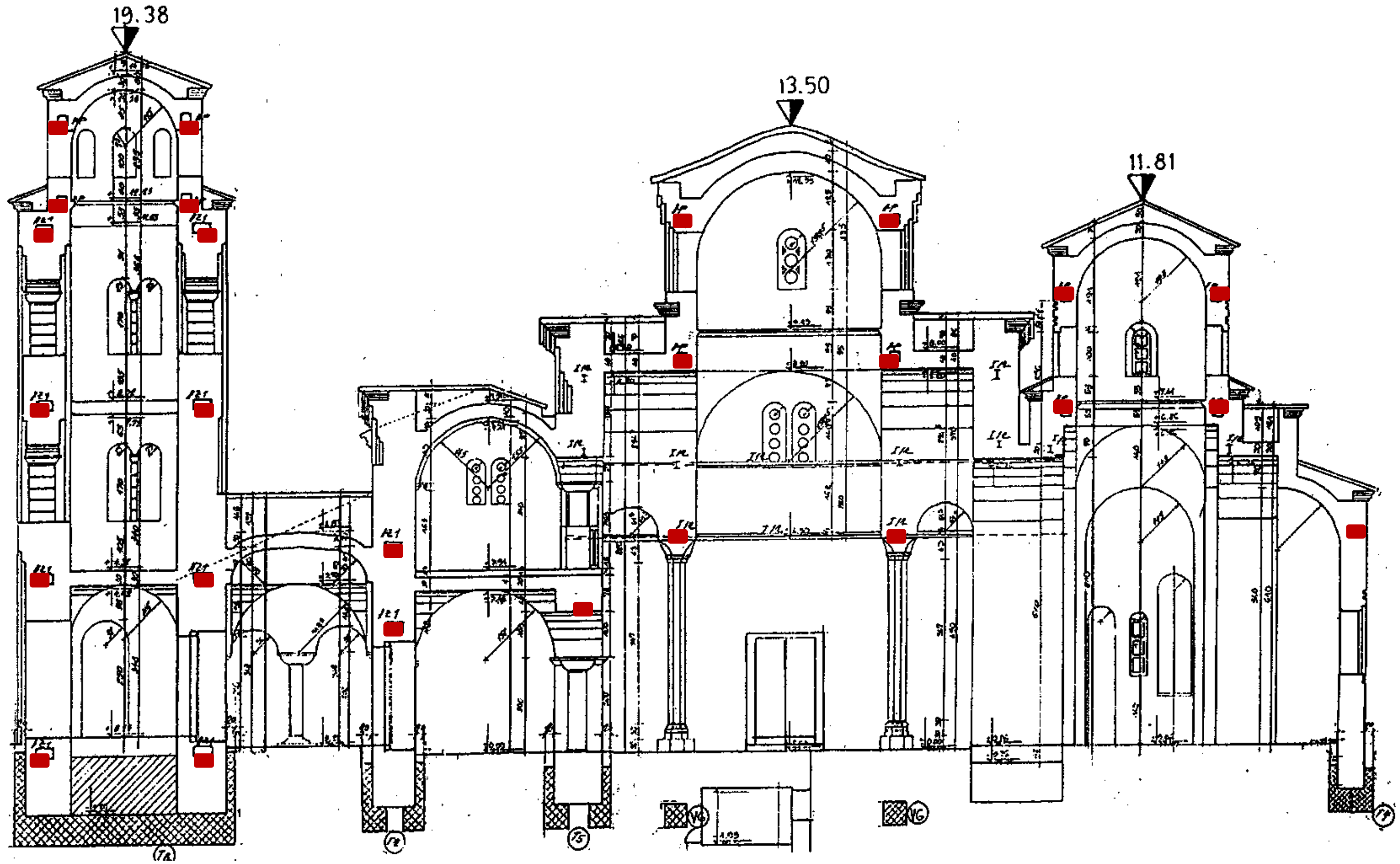
1

St.Pantelymon Church in Plaoshnik, Ohrid

Implementation……. In reconstruction



cross section of the structure

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St.Pantelymon Church in Plaoshnik, Ohrid

V. Shendova, B. Stojanoski, P.Gavrilovic, (2004)

Reconstruction, Seismic Strengthening and Repair of the St. Athanasius Church in Leshok

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Concept for Repair, Strengthening and Reconstruction

1. Repair and structural strengthening up to the design level of seismic safety for the *damaged existing part*
2. Complete reconstruction by maximum possible use of selected material in lime mortar plus structural strengthening elements for the design level of seiemic safety for the *demolished part*
3. Dilatation (not less than 3 cm) between the structural units

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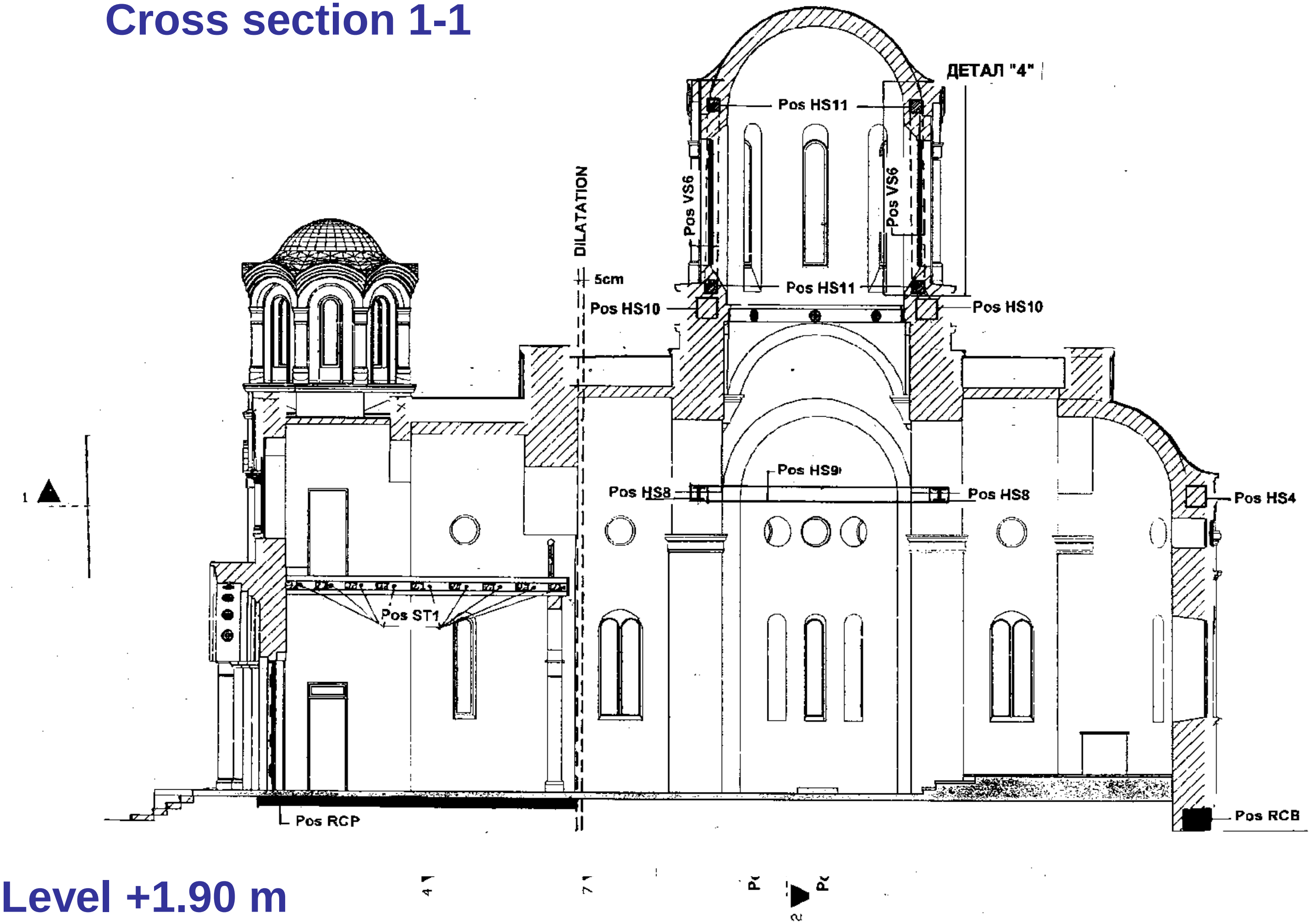
Implementation……. In reconstruction

Cross section 1-1



Level +1.90 m

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St. Athanasius Church in Leshok, (2004)

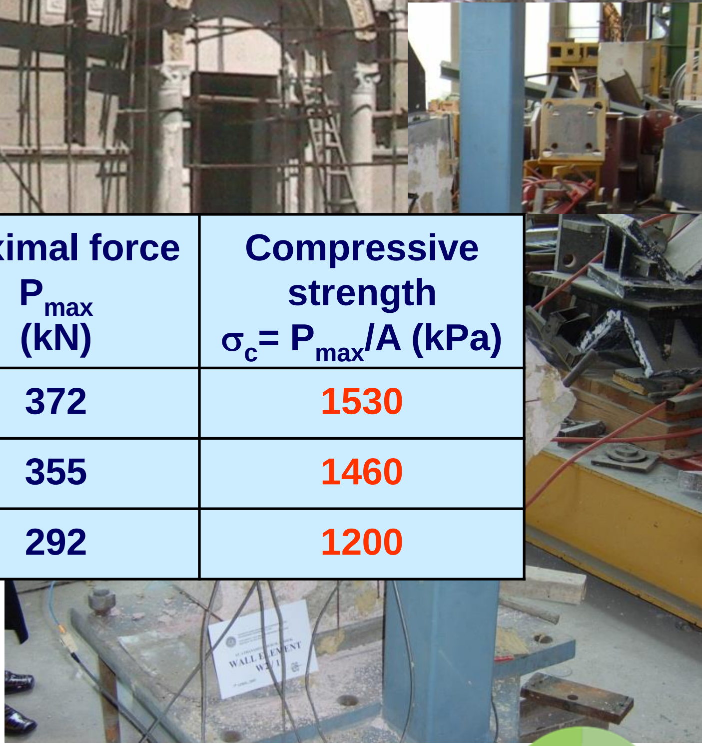
Implementation........ In reconstruction

- **Providing architectural documentation**
- **Cleaning up and identification**
- **Urgent preventive measures**
- **Archeological investigations**
- **Chemical analysis**
- **Other investigations**

Implementation……. In reconstruction

- **Experimental verification of Input Design Strength of Lime Mortar (1MPa)**
  - **Job mix formula for lime mortar**
    M = 1 (slaked lime) : 1 (broken half-backed brick) : 1 (sand)
  - **Building of wall elements**
  - **Testing of elements under axial pressure**
  - **Testing of elements under diagonal pressure**






Wall element	Age of element (months)	Cross-section A (m^2)	Maximal force P_{max} (kN)	Compressive strength $\sigma_c = P_{max}/A$ (kPa)
W1-1	4	0.243	372	1530
W1-2	4	0.243	355	1460
W1-3	4	0.243	292	1200

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St. Athanasius Church in Leshok, (2004)

Implementation……. In reconstruction

V. Shendova, Z. Bozinovski, M. Garevski (2010)

Implementation....... In reconstruction

Reconstruction and Seismic Strengthening of the Blown Up Church of the Holy Trinity in Mostar

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Concept for Strengthening and Reconstruction

1. Full reconstruction with maximum possible use of the existing preserved material and minimum additional intervention
2. Three general states have been analyzed:

(1) structural system of plain stone masonry (PS);

(2) strengthened structure by horizontal steel element (HS)

(3) strengthened structure by horizontal & vertical steel strengthening elements -confined masonry (HVS)

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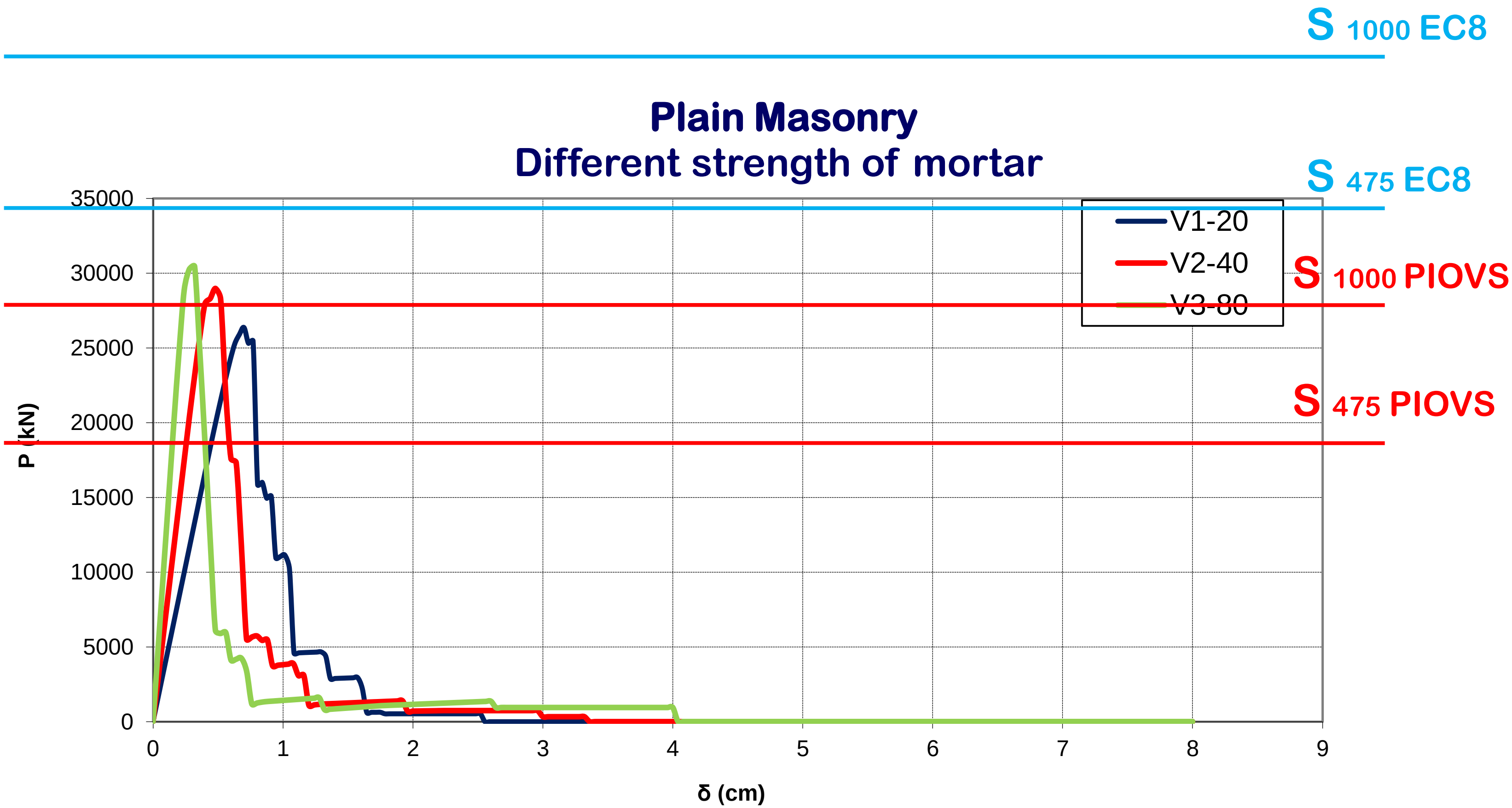
Implementation……. In reconstruction



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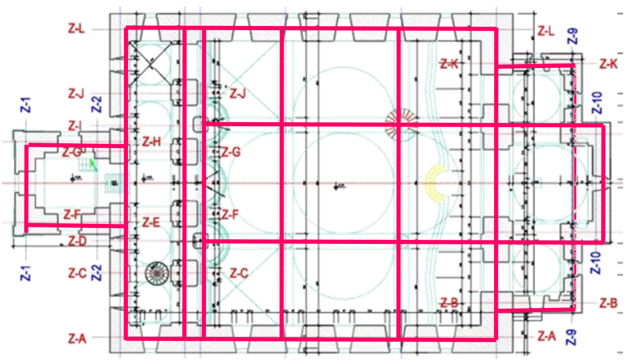
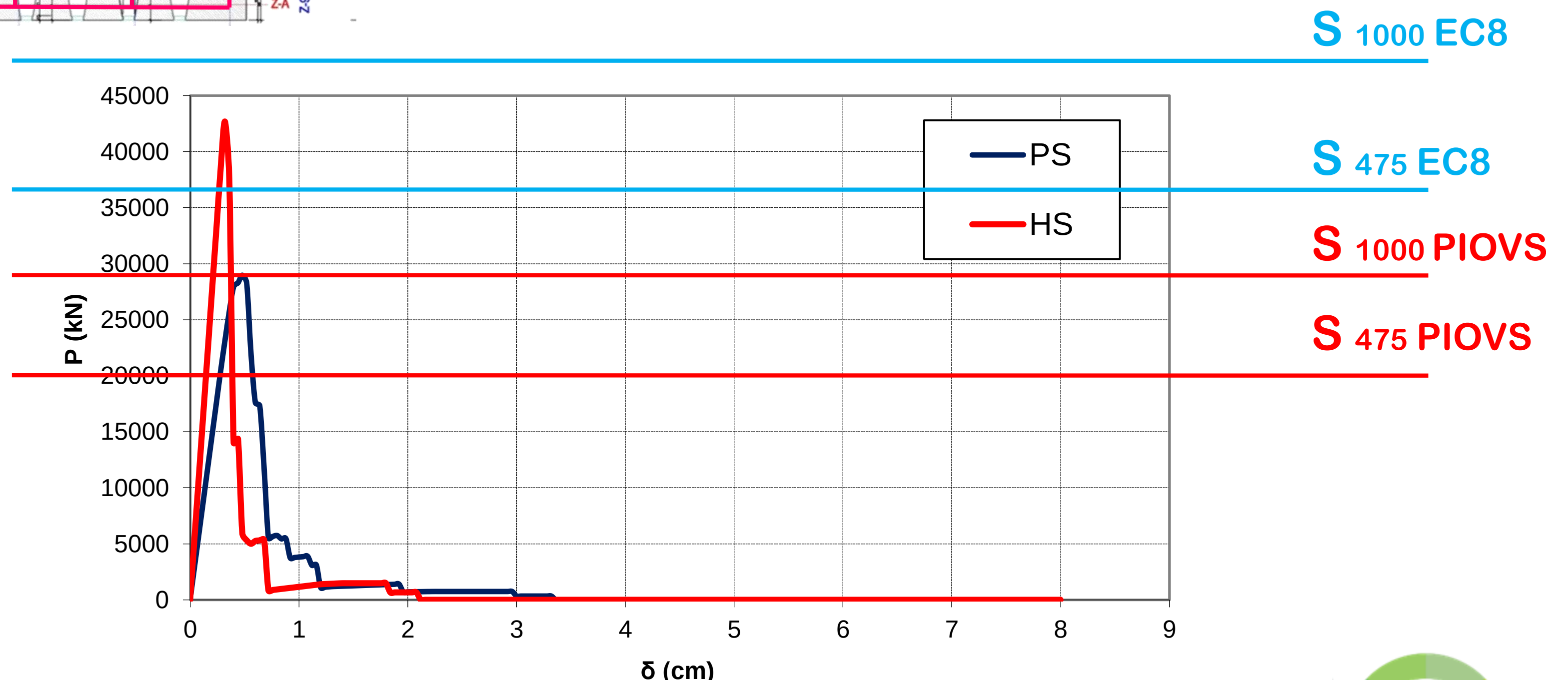
Implementation……. In reconstruction



Strengthening with horizontal strengthening elements



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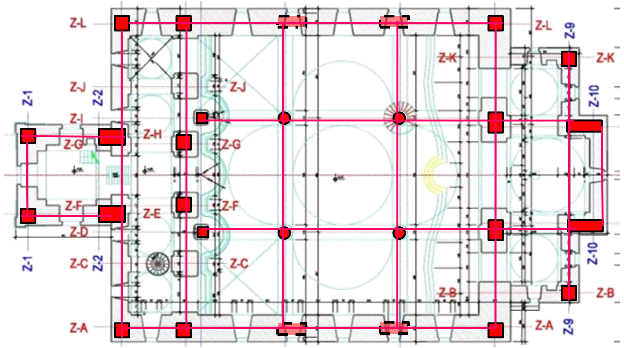
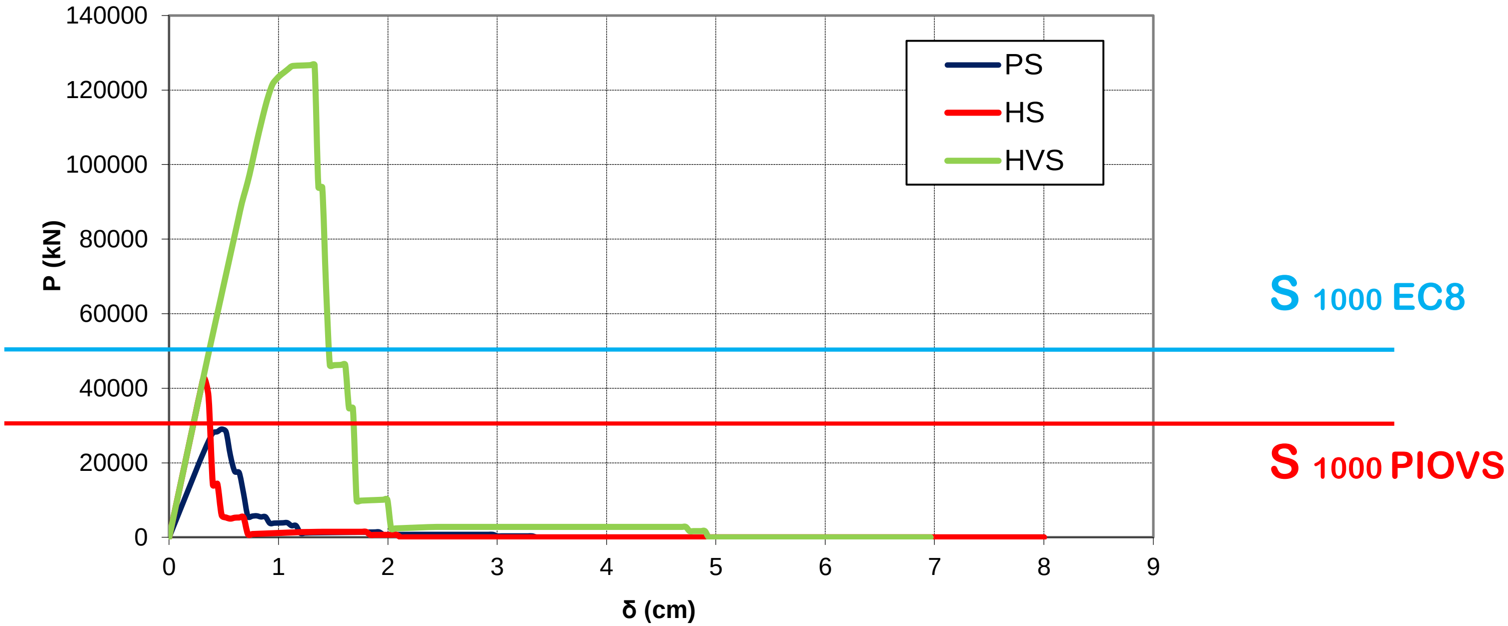
Church of the Holy Trinity in Mostar, (2010)

Implementation……. In reconstruction



Strengthening with horizontal and vertical strengthening elements



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3

Church of the Holy Trinity in Mostar, (2010)

Implementation……. In reconstruction

Realization 2011- 2017

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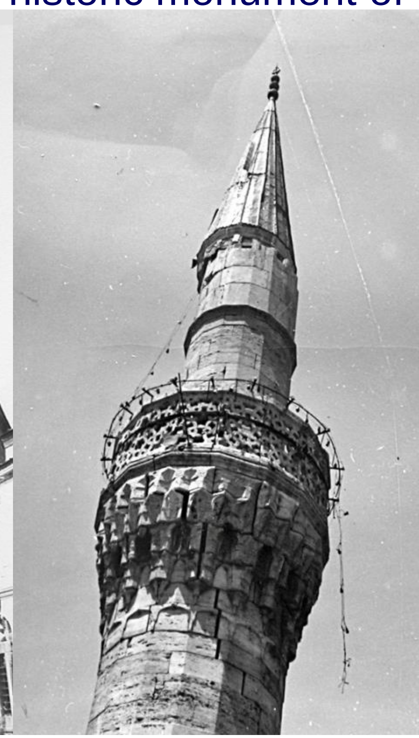
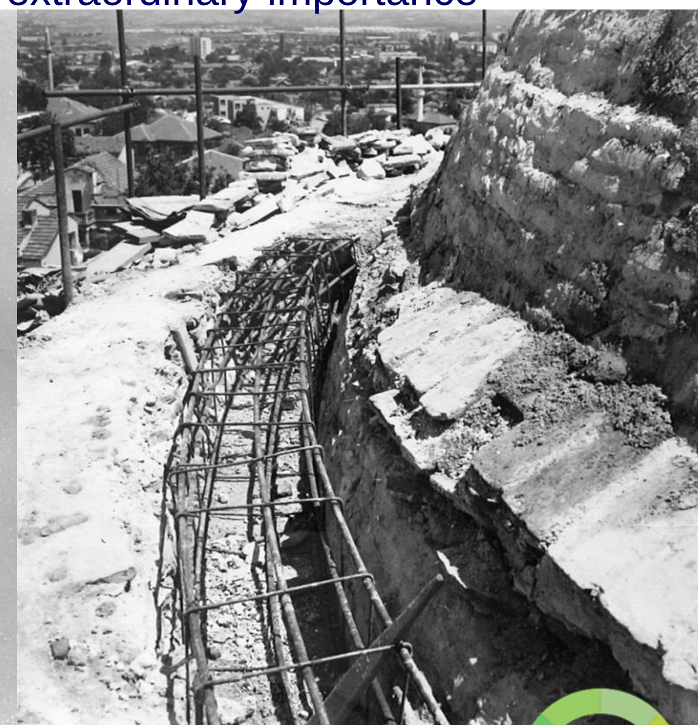
Seismic Upgrading of Mustafa Pasha Mosque, Skopje

- One of the biggest and best preserved Ottoman monuments in Skopje and Balkan
- Damaged by Skopje earthquake in 1963 (domes, east facade, minaret)
- Today represents cultural historic monument of extraordinary importance

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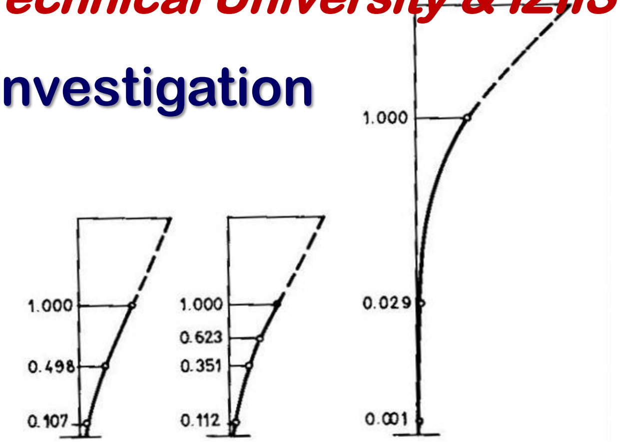
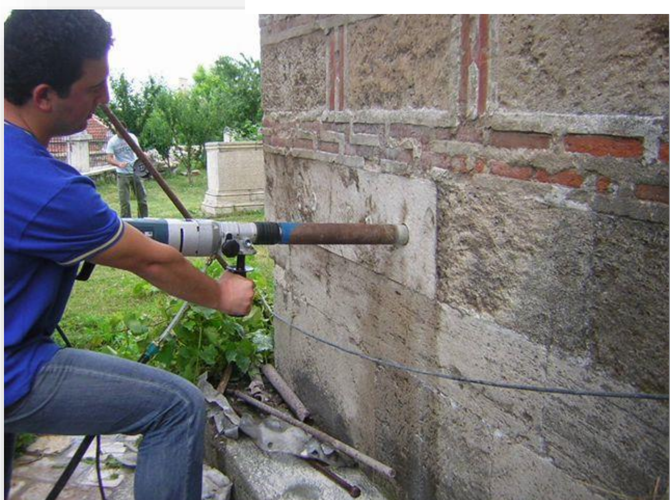
YILDIZ Technical University & IZIIS

In-situ investigation

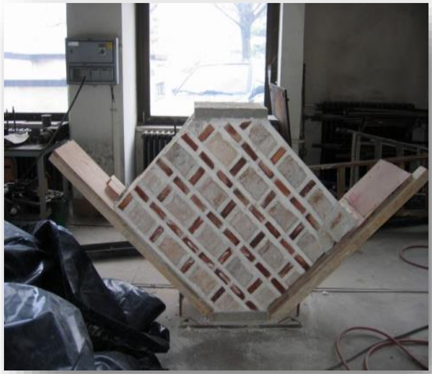


$f_{1\text{-}1}$=3.0Hz $f_{2\text{-}2}$=3.2Hz f_m=1.04Hz

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



Quasi-static testing



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Implementation……. In Strengthening

EU FP6 – PROHITECH Project (2004 – 2007)

Shaking table testing of the mosque model (2006-2007)

original state

strengthened by CFRP bars & wrap

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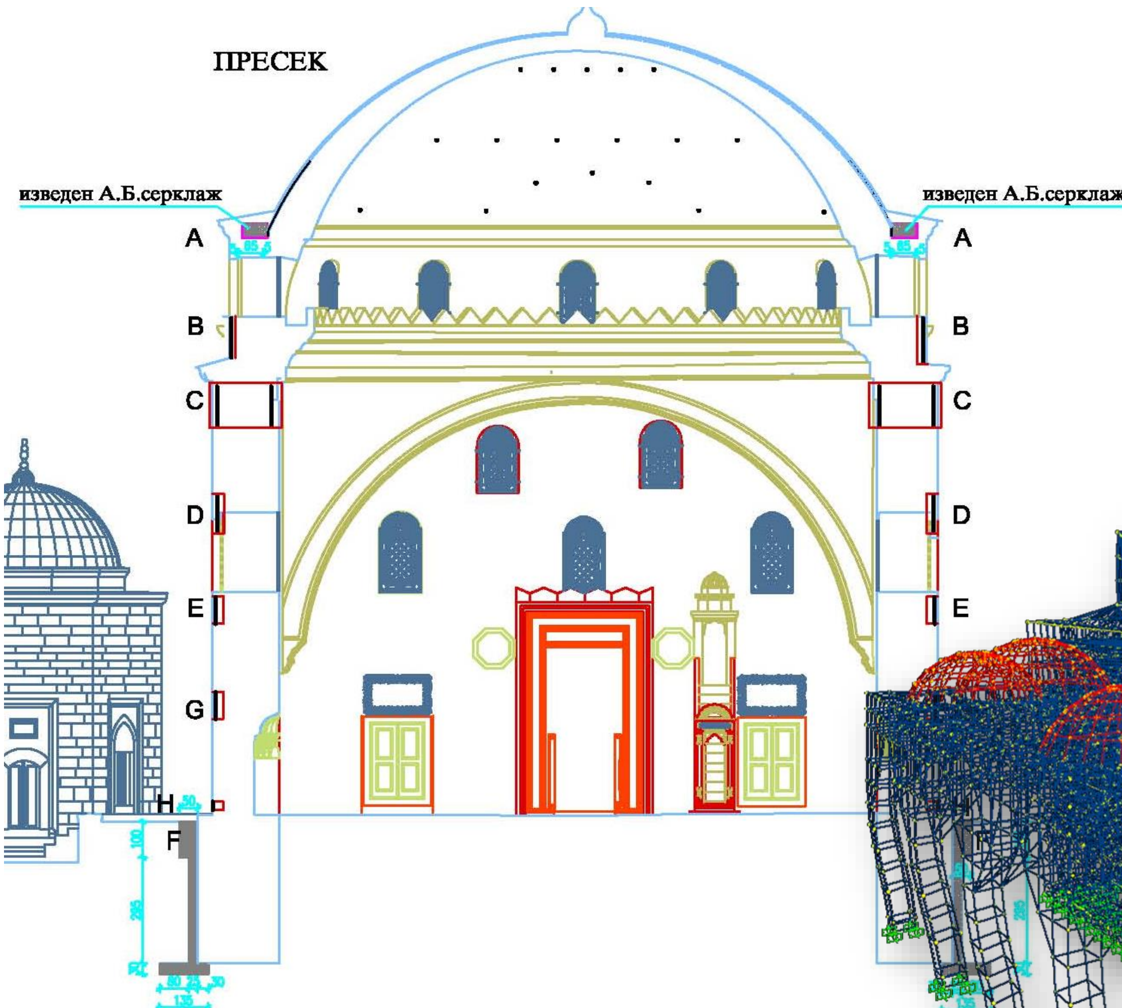
Mustafa Pasha Mosque, Skopje (2011)



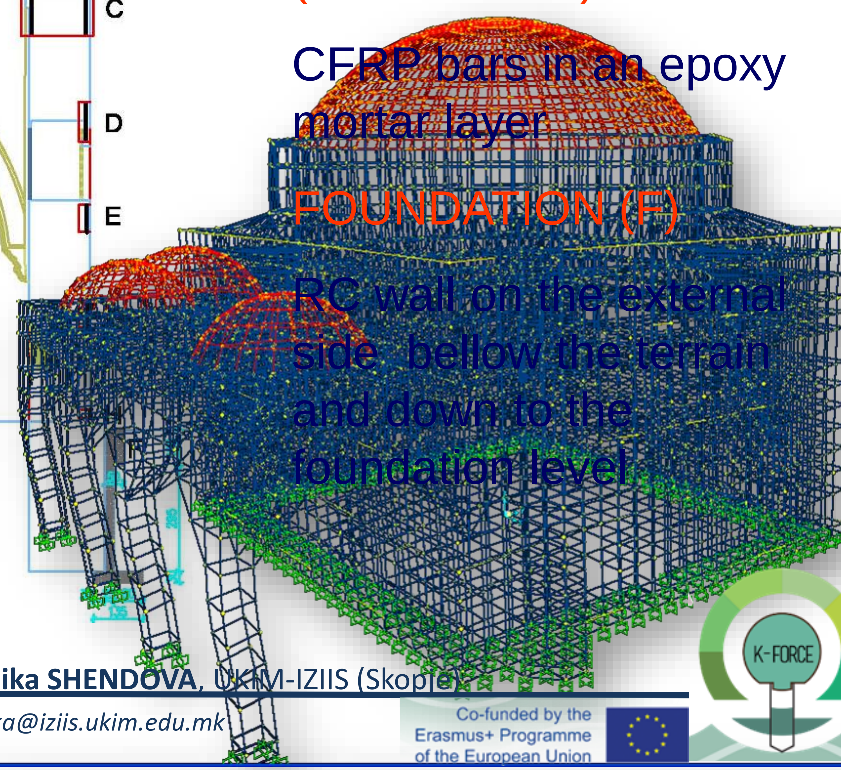
DOME Structure (A)
CFRP wrap in a layer of epoxy glue within a width of 2.9m

BEARING WALLS (B,C,D,E,G,H)

CFRP bars in an epoxy mortar layer

FOUNDATION (F)

RC wall on the external side, bellow the terrain and down to the foundation level



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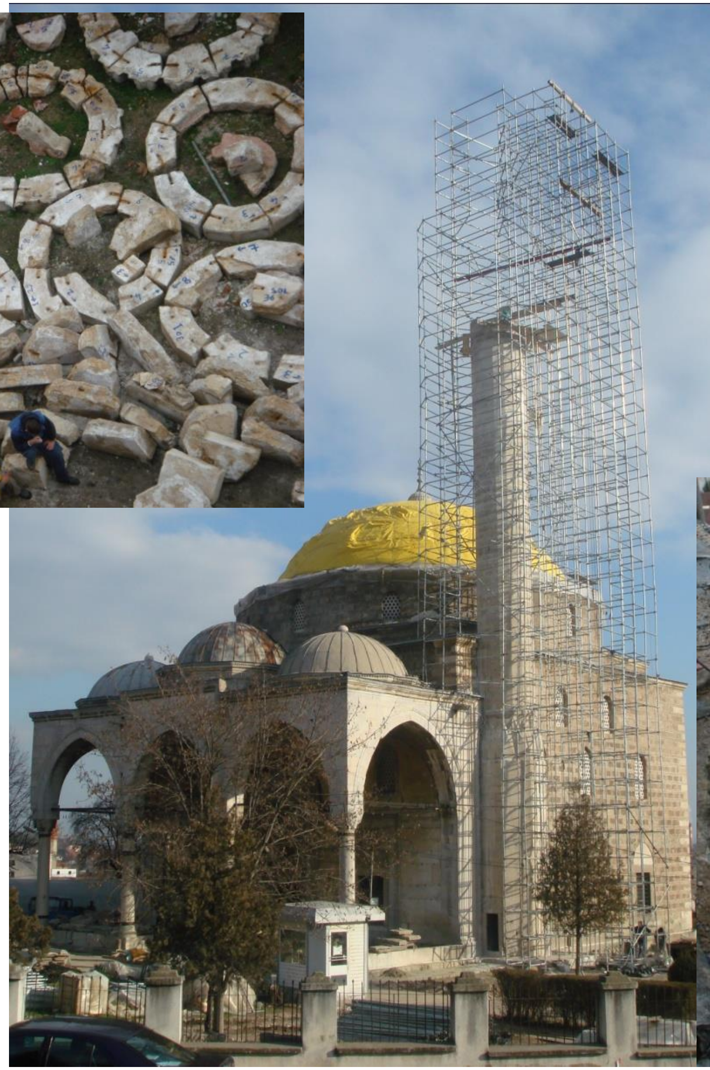
Mustafa Pasha Mosque, Skopje (2011)

Implementation……. In Strengthening



Repair of minaret

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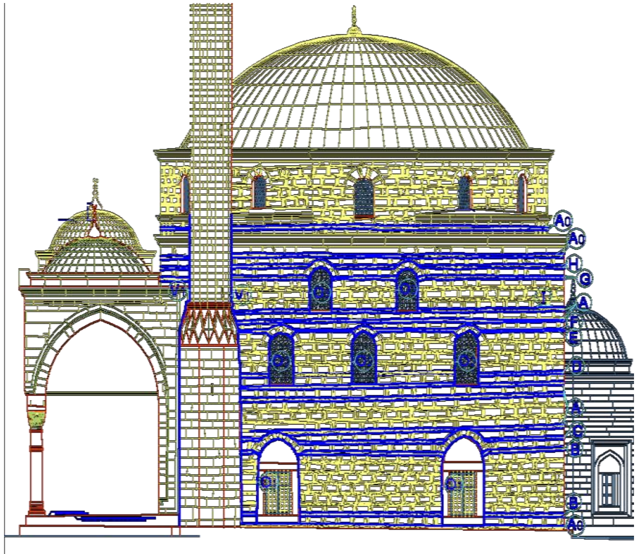
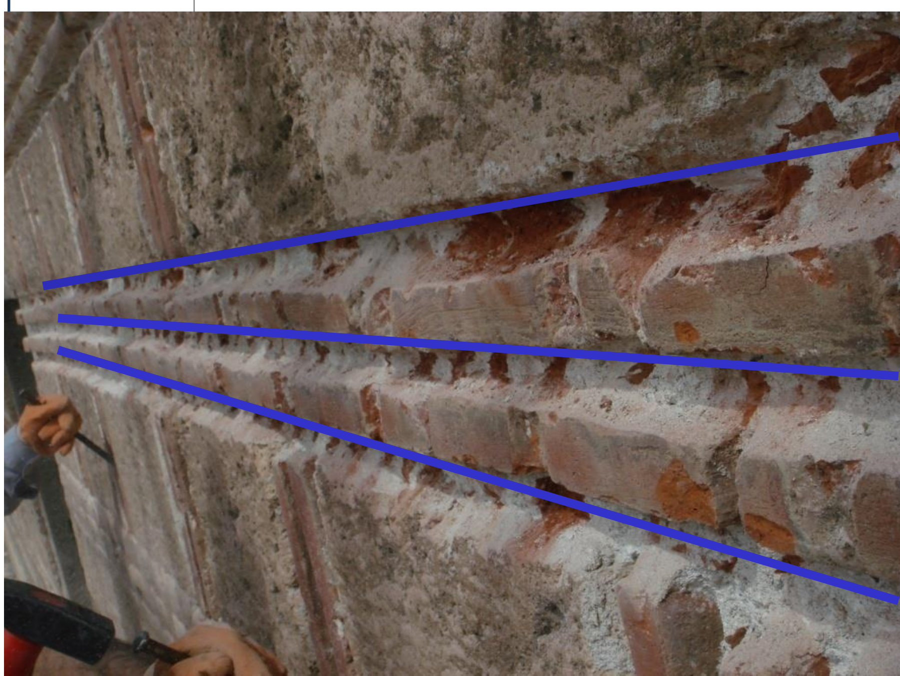
Implementation……. In Strengthening



Strengthening of bearing walls

- ✓ Cleaning of all joints on the outside with a depth of max 7-8 cm
- ✓ Placement of CFRP bars (d=1cm) in an epoxy mortar layer
- ✓ Filling of the joints with pointing lime mortar



Mustafa Pasha Mosque, Skopje (2011)

Implementation…….. In Strengthening

Strengthening of central dome

- ✓ Removal of the cement mortar layer
- ✓ Coating of existing RC ring with injection mixture based on lime mortar
- ✓ Placement of CFRP wrap in a layer of epoxy glue along the perimeter with the width of 3m
- ✓ Coating of entire dome with a protective layer of lime mortar

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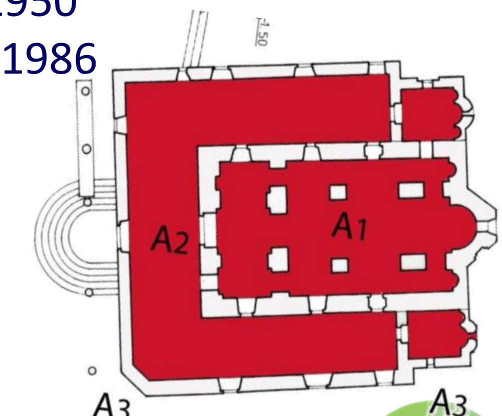
V. Shendova, V Sheshov, L. Krstevska (2015...)

Seismic Safety and Stability of Existing Structure of St. Mary Peribleptos Church in Ohrid

- single dome, inscribed developed cross
- among most important medieval monuments
- A1, church, 1295
- small chapels, XIV c.
- A2, A3 porch, XIX c.
- conservation 1950
- strengthening 1986



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K-FORCE

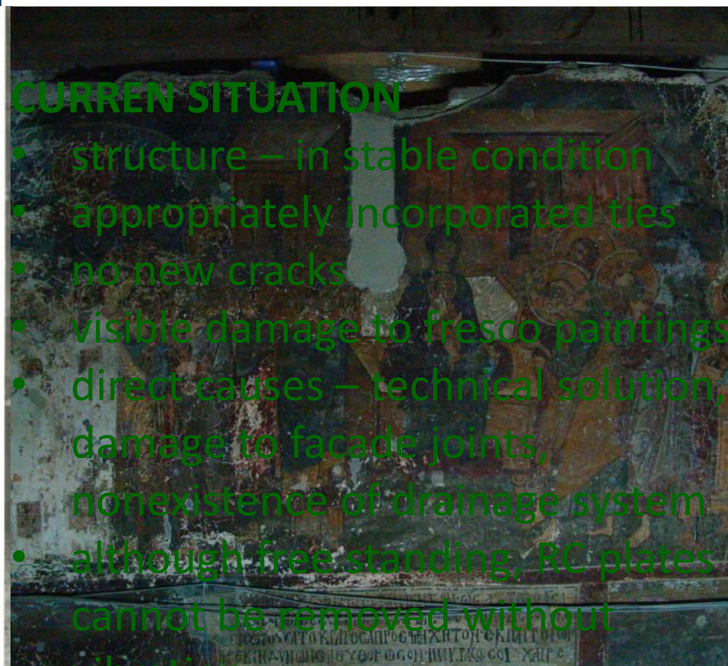
5

St. Marry Peribleptos, Ohrid (2015…)

- repairing of cracks
- inserting of steel ties in central area
- placing of RC slab over the vaults
- placing of RC rings in the tambour base
- covering of the dome with cement layer

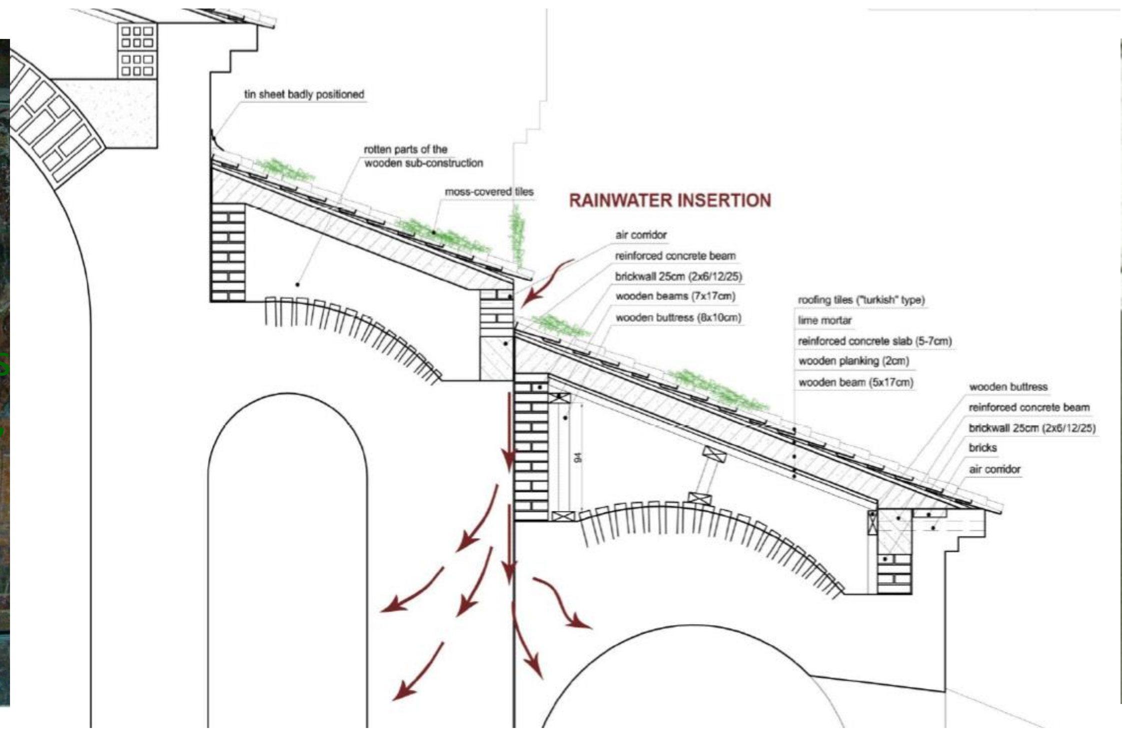
INCORRECT !

- historical respect for building authencity
- actual capacity to prevent leaks
- due to construction errors, unsuitable materials and lack of maintenance



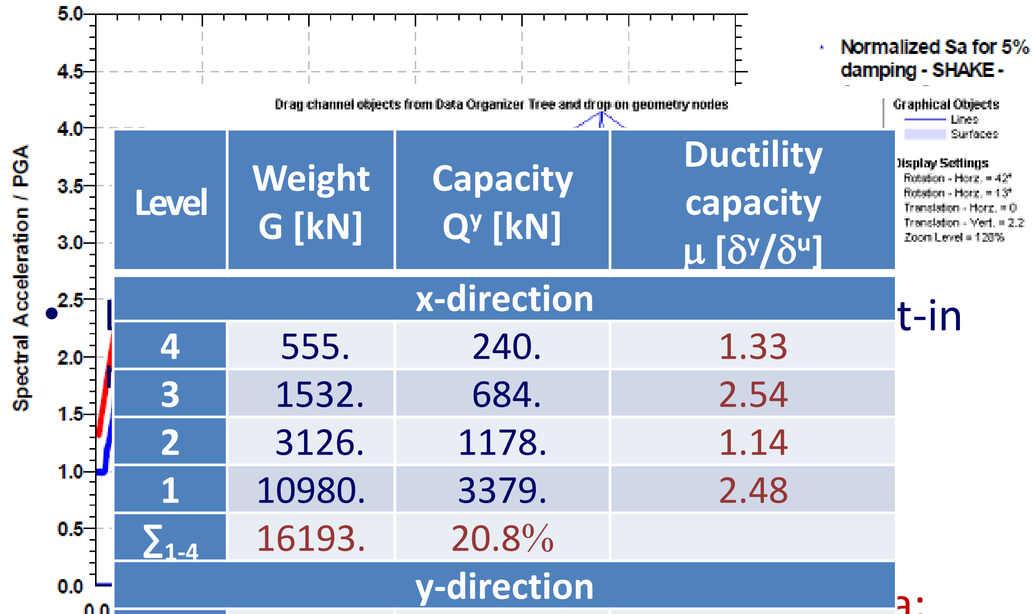
CURREN SITUATION

- structure – in stable condition
- appropriately incorporated ties
- no new cracks
- visible damage to fresco paintings
- direct causes – technical solution, damage to facade joints, nonexistence of drainage system
- although free standing, RC plates cannot be removed without vibration



Investigation on the site an structure:

- seismic potential of site
- dynamic characteristics by AVT
- built-in material testing
- relevant structural analysis shows sufficient bearing capacity, but non-sufficient deformation capacity



Level	Weight G [kN]	Capacity Q^y [kN]	Ductility capacity μ [δ^y/δ^u]
x-direction			
4	555.	240.	1.33
3	1532.	684.	2.54
2	3126.	1178.	1.14
1	10980.	3379.	2.48
$\sum_{1-4}$	16193.	20.8%	
y-direction			
4	555.	254.	1.10
3	1532.	583.	2.45

Mode	Frequency (Hz)	Damping ration (%)
Mode 1 – transversal	5.08	3.80
Mode 2 – longitudinal	6.45	2.20
Mode 3 – torsion	7.60	1.80
Mode 4 – lateral portico	8.80	2.30
Mode 5 - torsion	10.9	1.30

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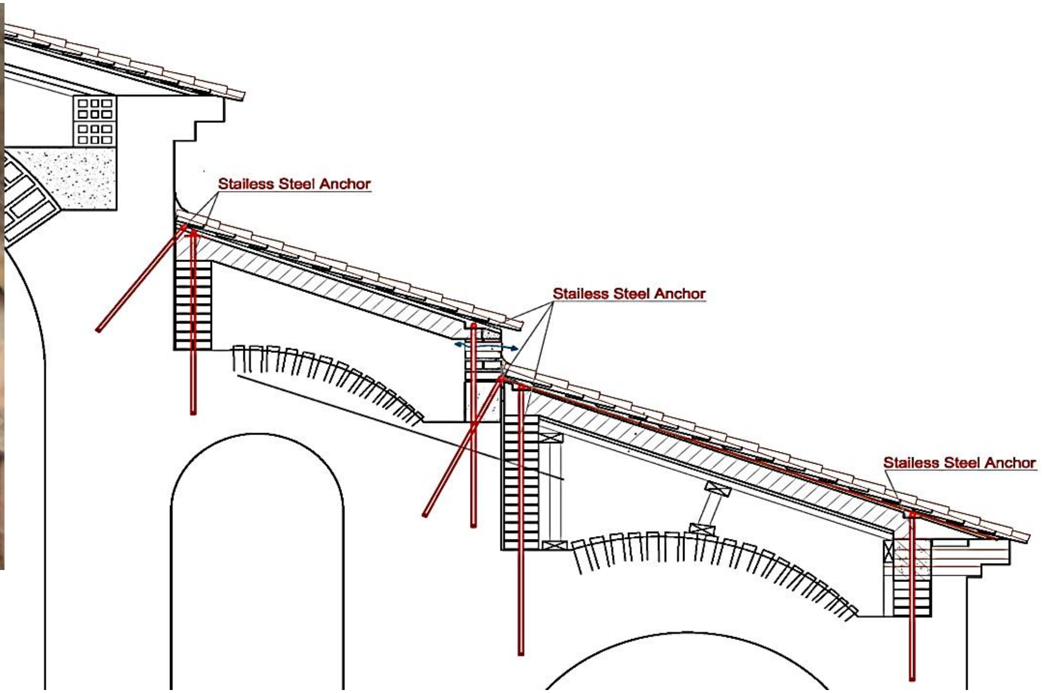
5

St. Marry Peribleptos, Ohrid (2015…)

- Proposed seismic upgrading:
- to convert the negative solution of placing the RC elements into a positive one by:
  - ✓ cleaning the openings and space between the plates and masonry to provide ventilation
  - ✓ using the RC plates for providing structural integrity by way of hinged connections of the plates with the bearing walls, thus preventing uncontrolled displacement of the reinforced concrete plates and enabling activation of all the bearing walls and behaviour of the structure as a whole;



- **St. George, Kurbinovo, XII Century**
- **Kurshumli An, Skopje, XVI Century**
- **Orta Mosque, Strumica, XVI Century**

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Instead of Conclusion………

Proving the effectiveness of the selected strengthening could be successfully overcome by using "design by testing" methodology.

It is very powerful tool, especially when the object of design is a complex structure, which is difficult and unsafe to analyze by using traditional methods.

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Thank you for your attention!

Knowledge **FO**r **R**esilient so**C**i**E**ty