Date: July, 2018
Place: Ohrid, Macedonia

Knowledge FOr Resilient soCiEty

EARTHQUAKE PROTECTION OF HISTORIC BUILDINGS AND MONUMENTS IN REPUBLIC OF MACEDONIA

Dr. Veronika SHENDOVA
University Ss. Cyril and Methodius in Skopje

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Erasmus+ Programme
of the European Union

University Ss. Cyril and Methodius in Skopje

Institute of Earthquake Engineering and Engineering Seismology, UKIM-IZIIS - Skopje

EARTHQUAKE PROTECTION OF HISTORIC BUILDINGS AND MONUMENTS IN REPUBLIC OF MACEDONIA

IZIIS' EXPERIANCE

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

Dr. Veronika SHENDOVA

HEAD OF DEPARTMENT:
BUILDING STRUCTURES AND MATRIALS: DESIGN, ANALYSIS AND TESTING

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

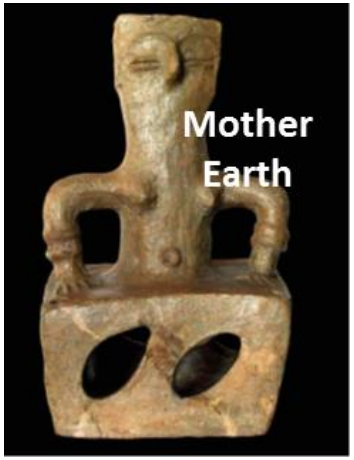
PROTECTION:

- 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

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

Cultural Heritage in Republic of Macedonia

- Archeological heritage



Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

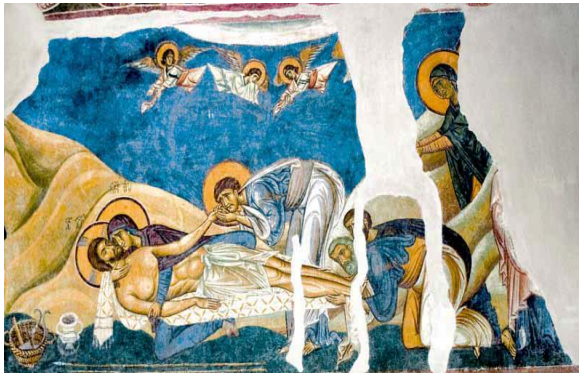
Cultural Heritage in Republic of Macedonia

- Medieval Heritage

St. Panteleymon, Nerezi, XII

St. Marry Perivleptos, XIII

St. Andreas, Matka, XIV



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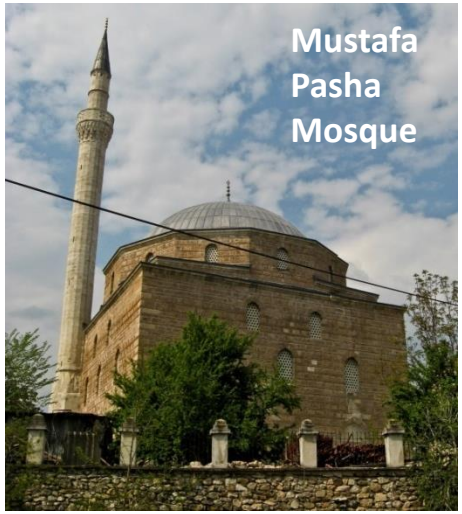
veronika@iziis.ukim.edu.mk

Cultural Heritage in Republic of Macedonia

- Ottoman Heritage



Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

1963 Skopje Earthquake: M=6.1 1070 deaths 3300 injured

- Brick wall structures - the most damaged
- Mixed construction - considerably damaged
- Old adobe structures (timber bracing) - some damage
- RC frame - slightly damaged

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

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

1963 Earthquake effect on Architectural Heritage

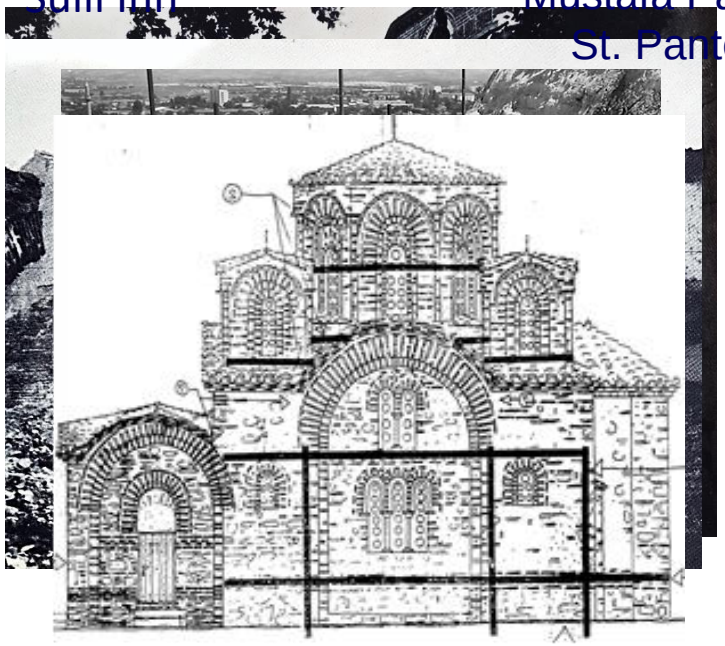
- entire monument fund was more or less damaged
- failure of individual parts of the structures
- large cracks
- inclination and deformations of structural elements
- part of it was completely destroyed

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

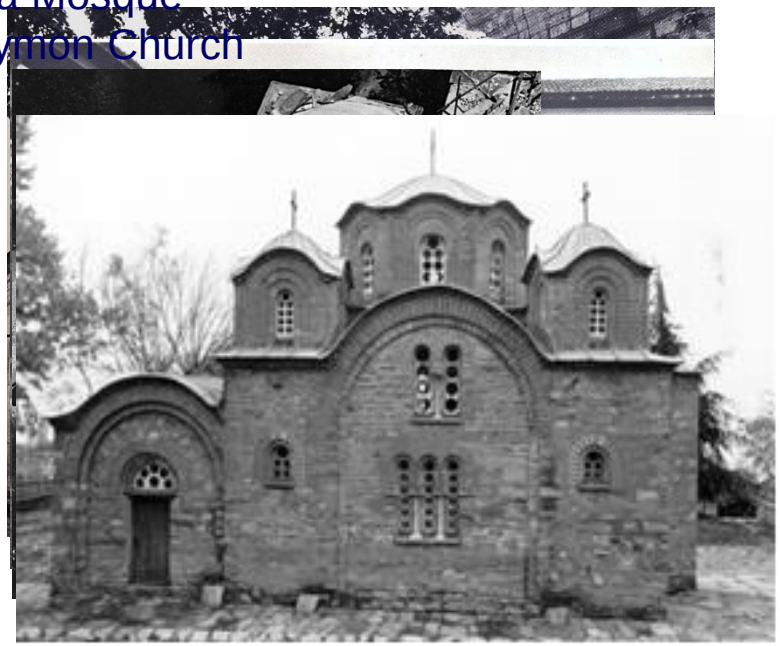
Post-earthquake Repair and Seismic Strengthening

- 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



Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

Effects of Post-earthquake Protection of Monuments

- adverse affect of cement – *Skopje recommendation 1988* – unite efforts of architects, engineers, conservators, restaurateurs, material scientists….
- 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;

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

Protection of Cultural Heritage – new approach

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

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

and

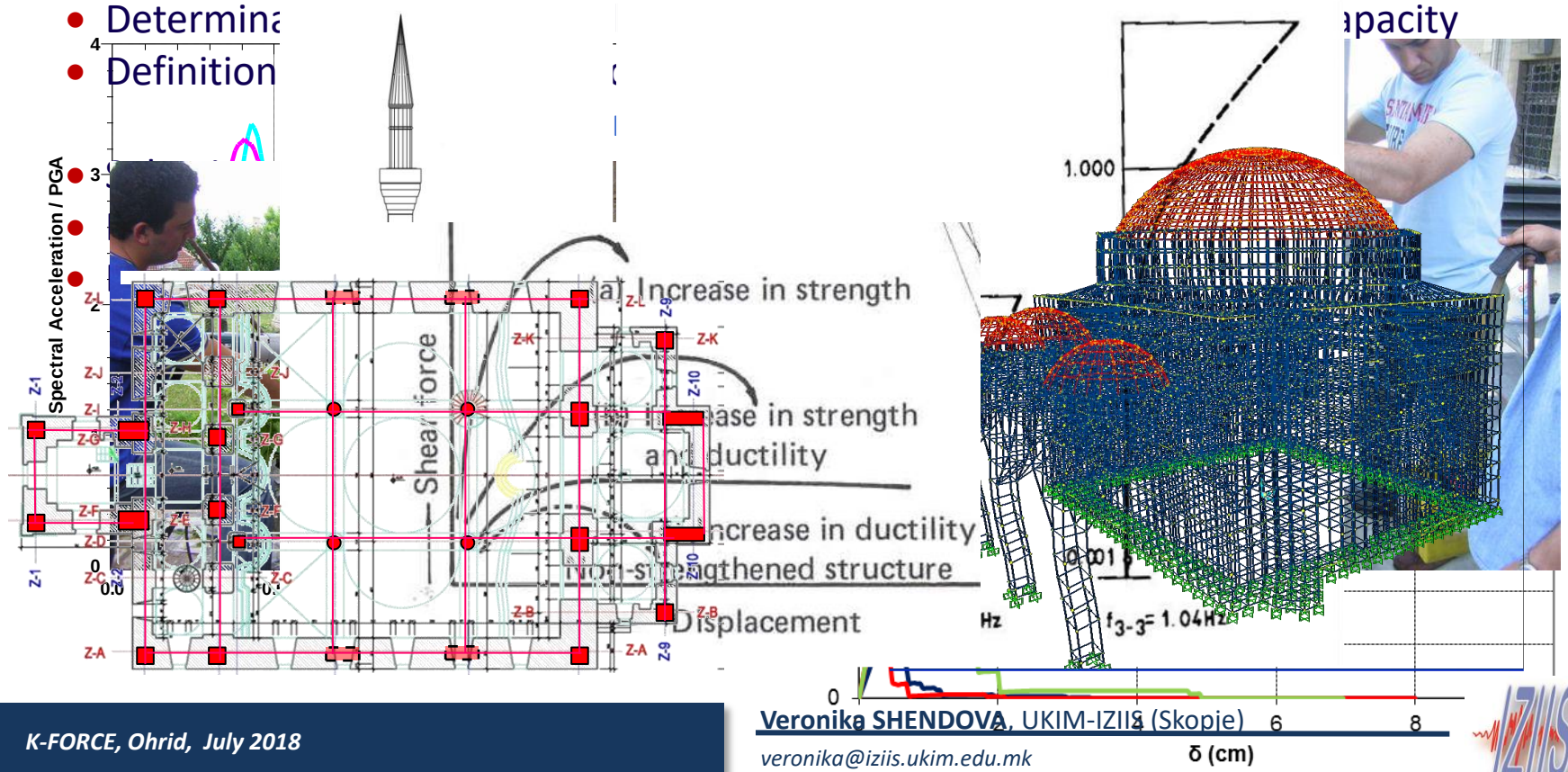
Scientifically based methodology for earthquake protection of historic buildings and monuments during their protection

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

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



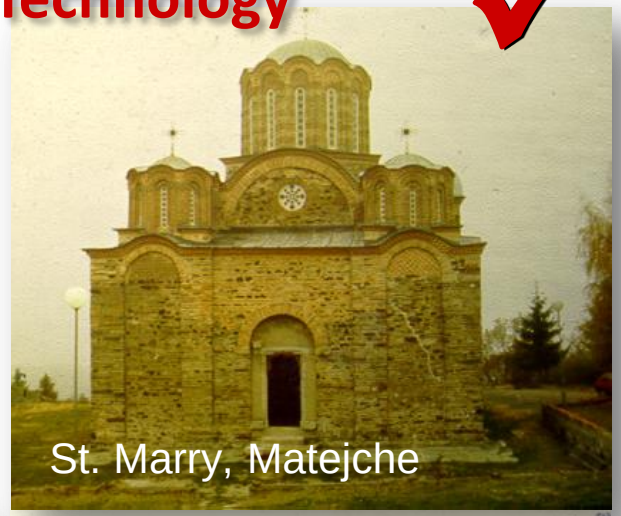
Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

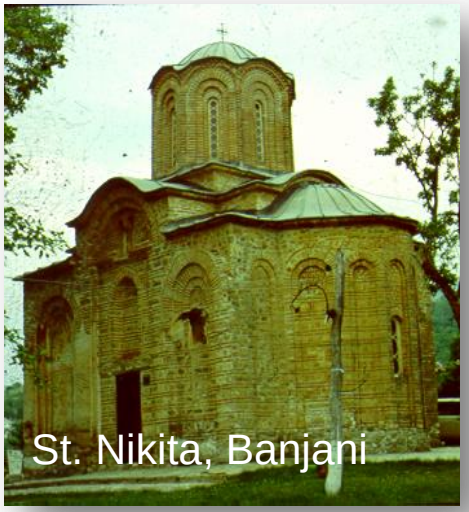
Methodology for Seismic Strengthening of Byzantine Churches

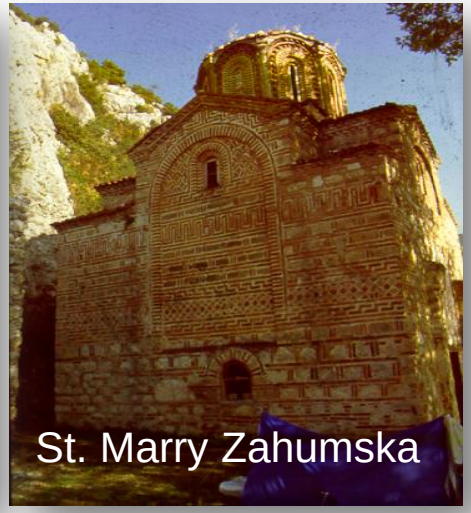
scientific-research projects

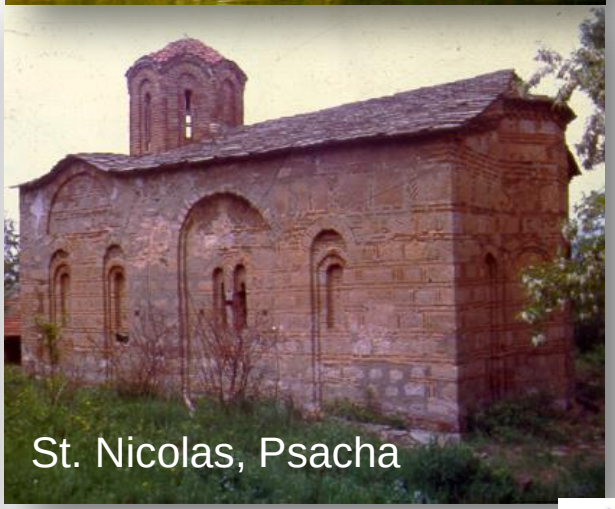
Traditional Technology vs. New Technology

- Typology
- Existing state
- Interventions
- Authenticity


St. Marry, Matejche


St. Nikita, Banjani


St. Marry Zahumska


St. Nicolas, Psacha

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

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 of the church model

scientific-research projects

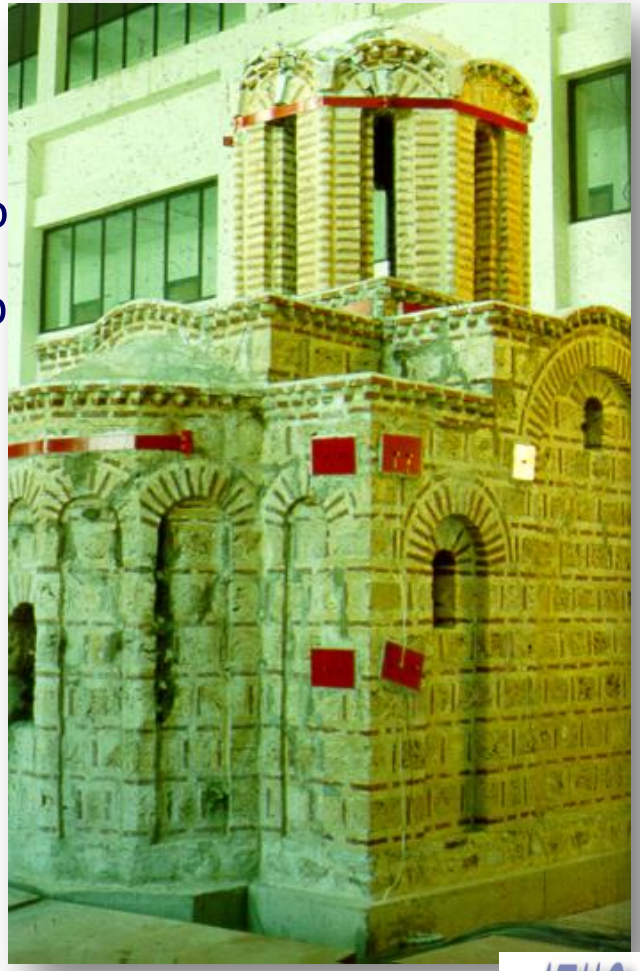
Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

Concept for Repair and Strengthening - traditional

scientific-research projects

Design Criteria:

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



Selected method for strengthening:

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

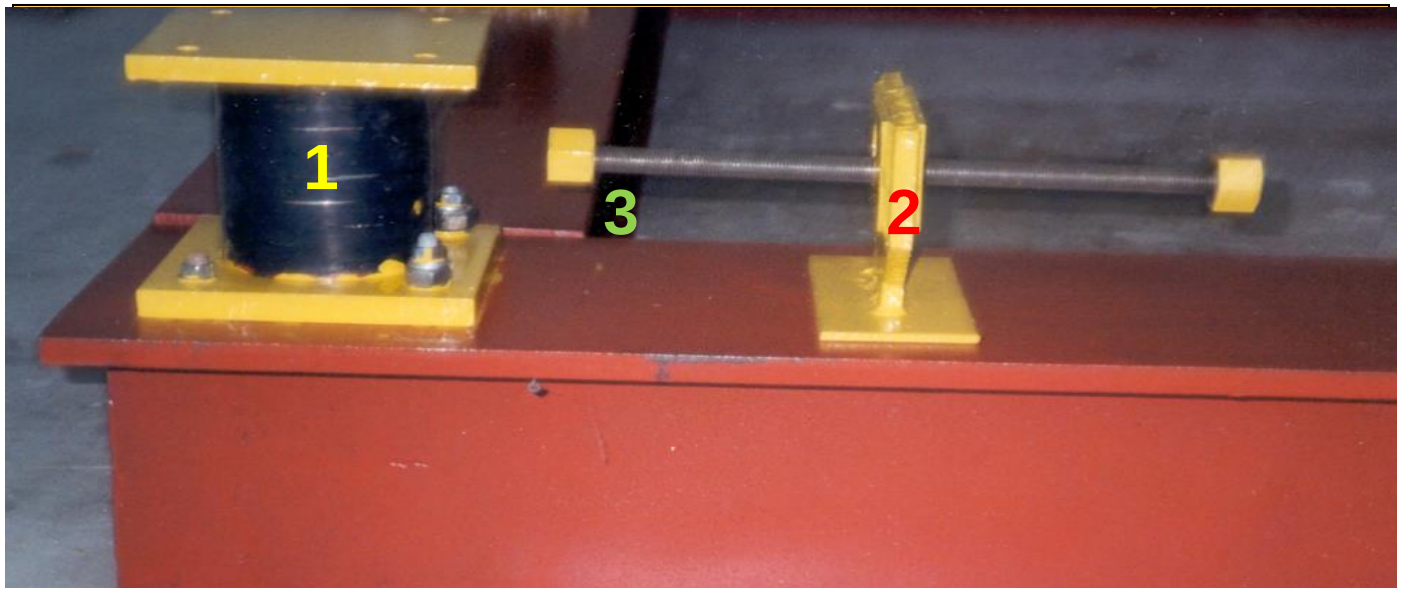
Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

Experimental verification of methodology

lower damage level even under higher level of input excitation

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

Earthquake Protection using Seismic Isolation - new



element 1: Laminated rubber bearing element

element 2: Steel plate damper (hysteretic behavior)

element 3: Stopper element (limited displacement)

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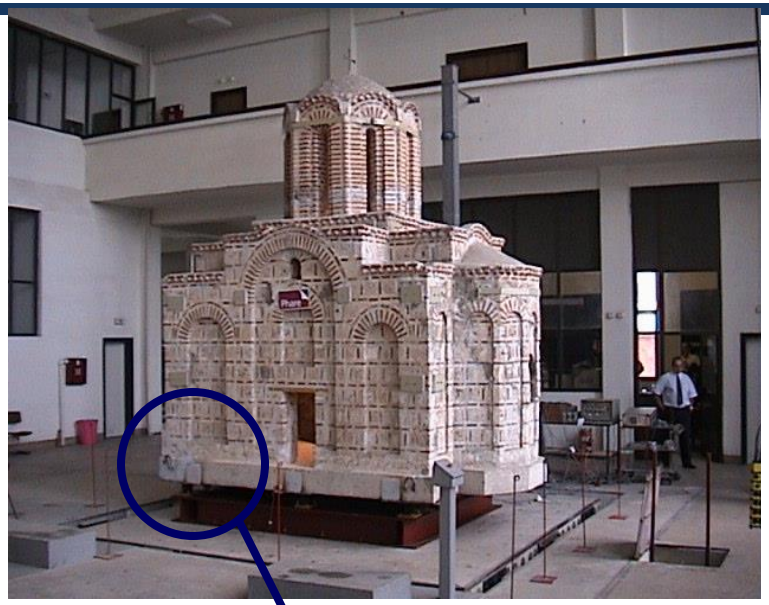
veronika@iziis.ukim.edu.mk

Shaking table testing of base-isolated model

Steel structure and Isolators



Isolator in action

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

Traditional Technology vs. New Technology ✓

Test No: *10*

Input Excitation:

El Centro Earthquake, acc=0.54g

return period t_p =1000 years

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

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

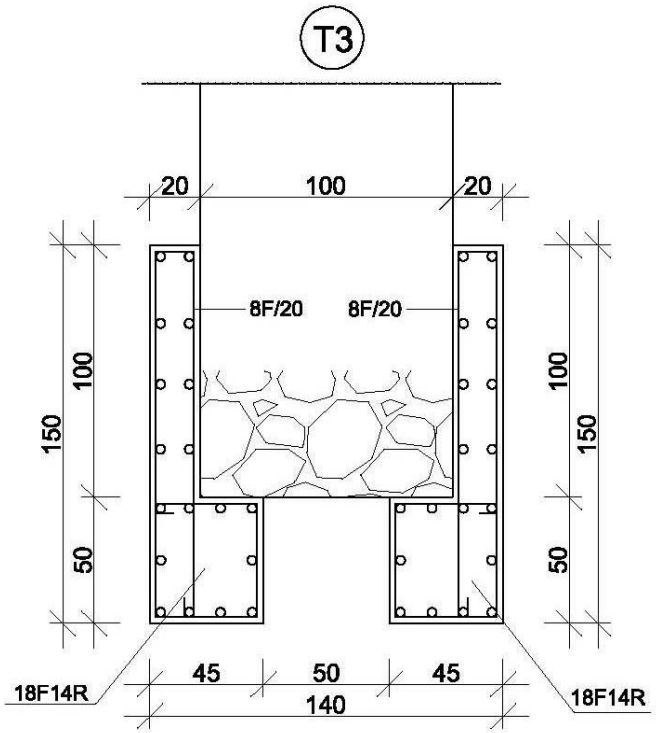
Concept for Consolidation and Rebuilding

- ✓ 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

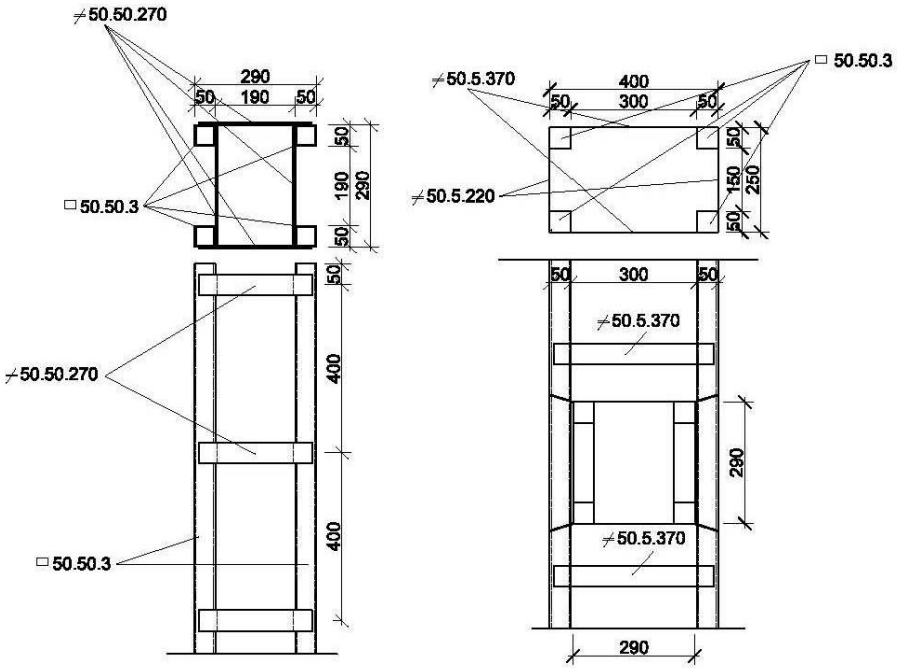
Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

Implementation…….. In reconstruction

foundation



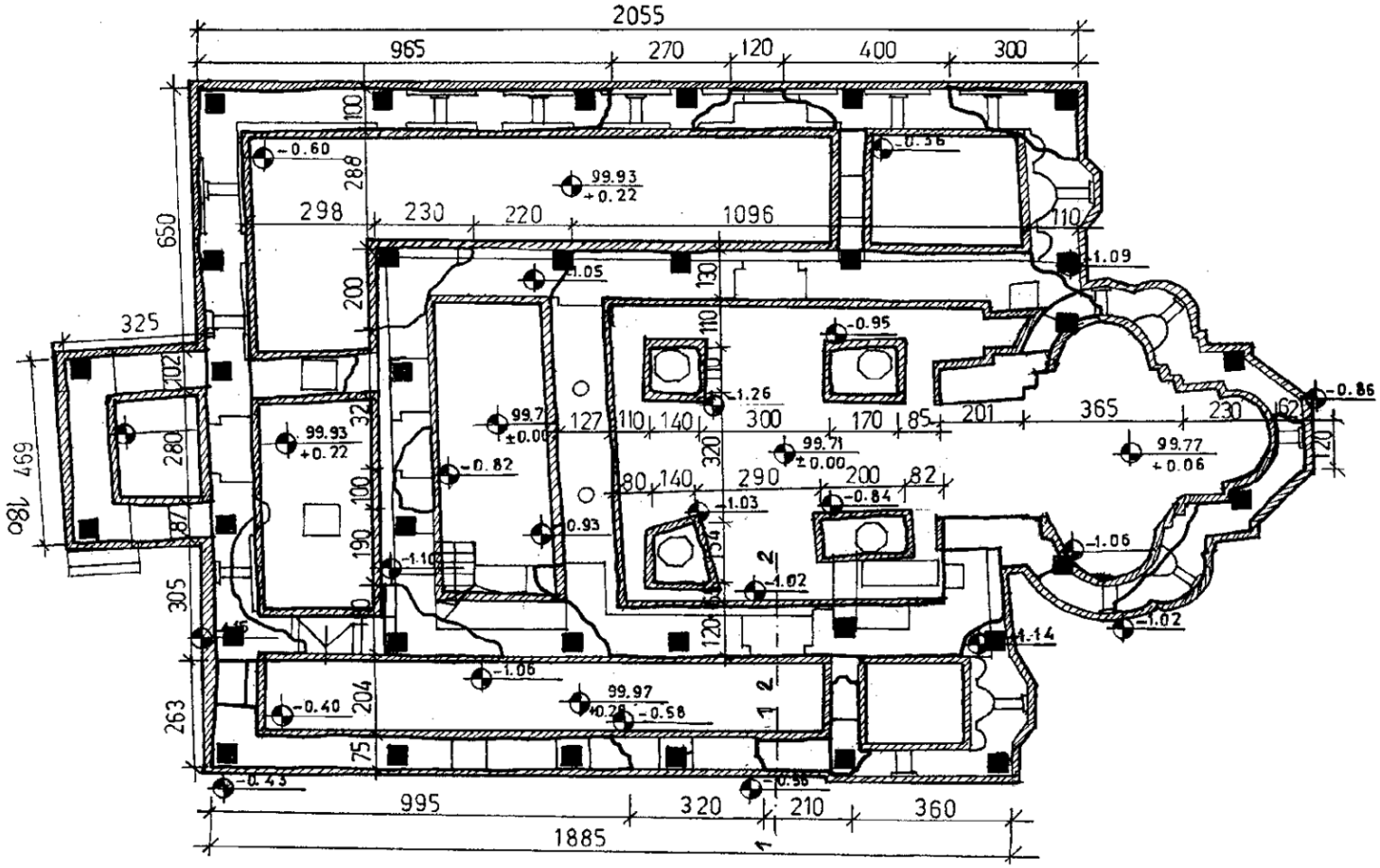
horizontal & vertical steel ties



Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

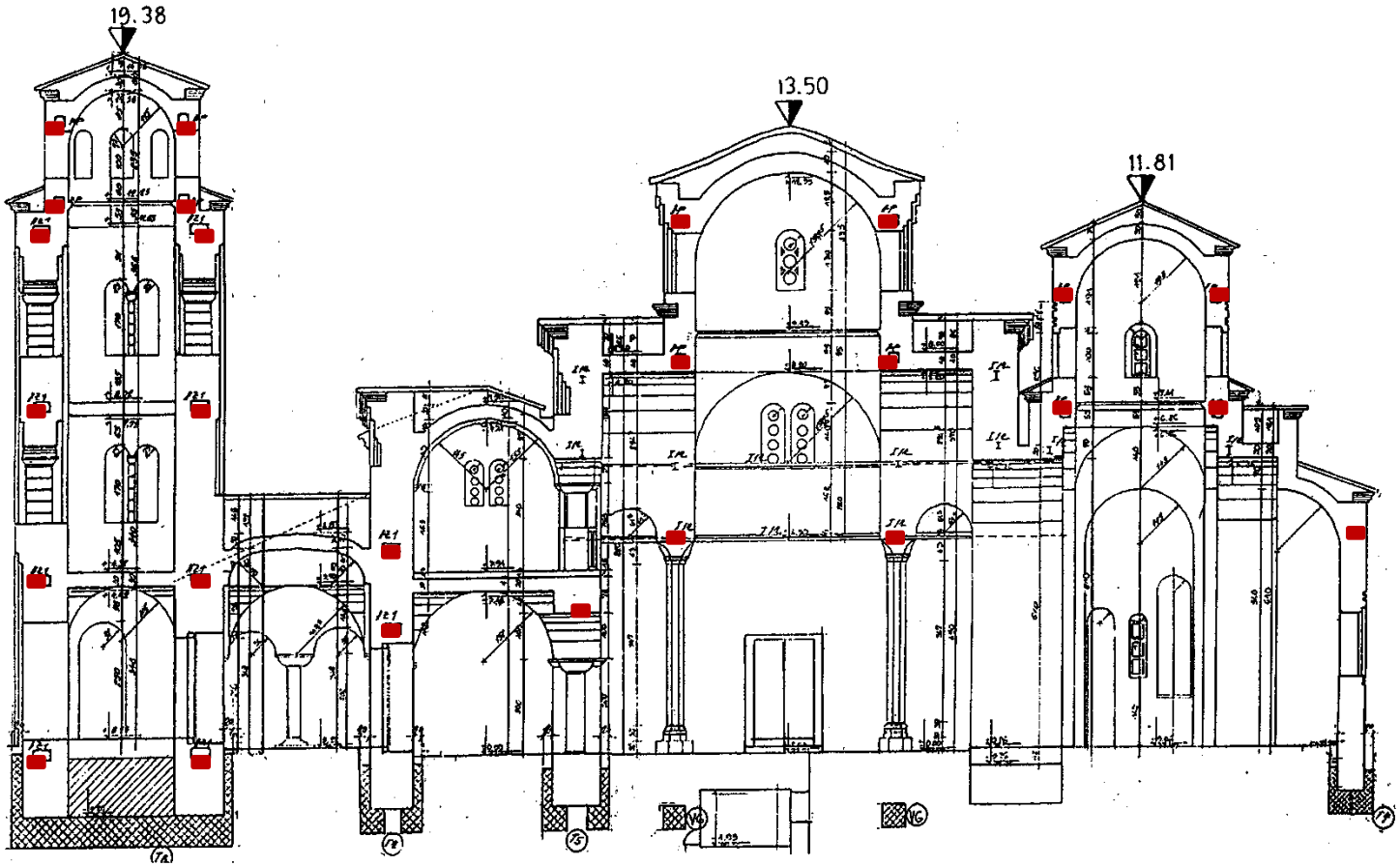
Implementation..... In reconstruction

plan of the structure at the level of -0.22m



Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

St.Pantelymon Church in Plaoshnik, Ohrid



cross section of the structure

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

1

St.Pantelymon Church in Plaoshnik, Ohrid

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

Implementation…….. In reconstruction

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

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

Implementation…….. In reconstruction

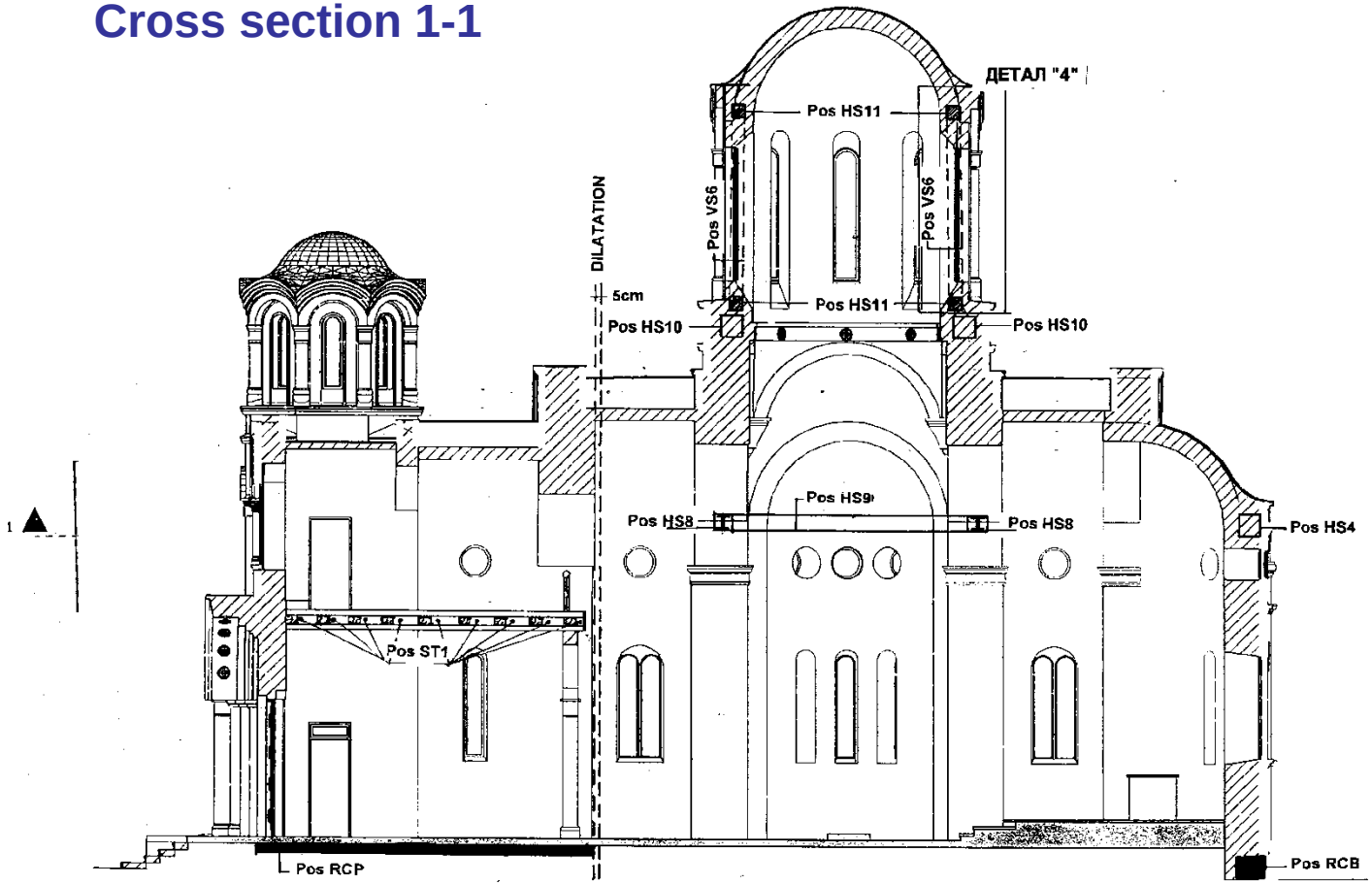
Concept for Repair, Strengthening and Reconstruction

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

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

Implementation…….. In reconstruction

Cross section 1-1



Level +1.90 m

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

2

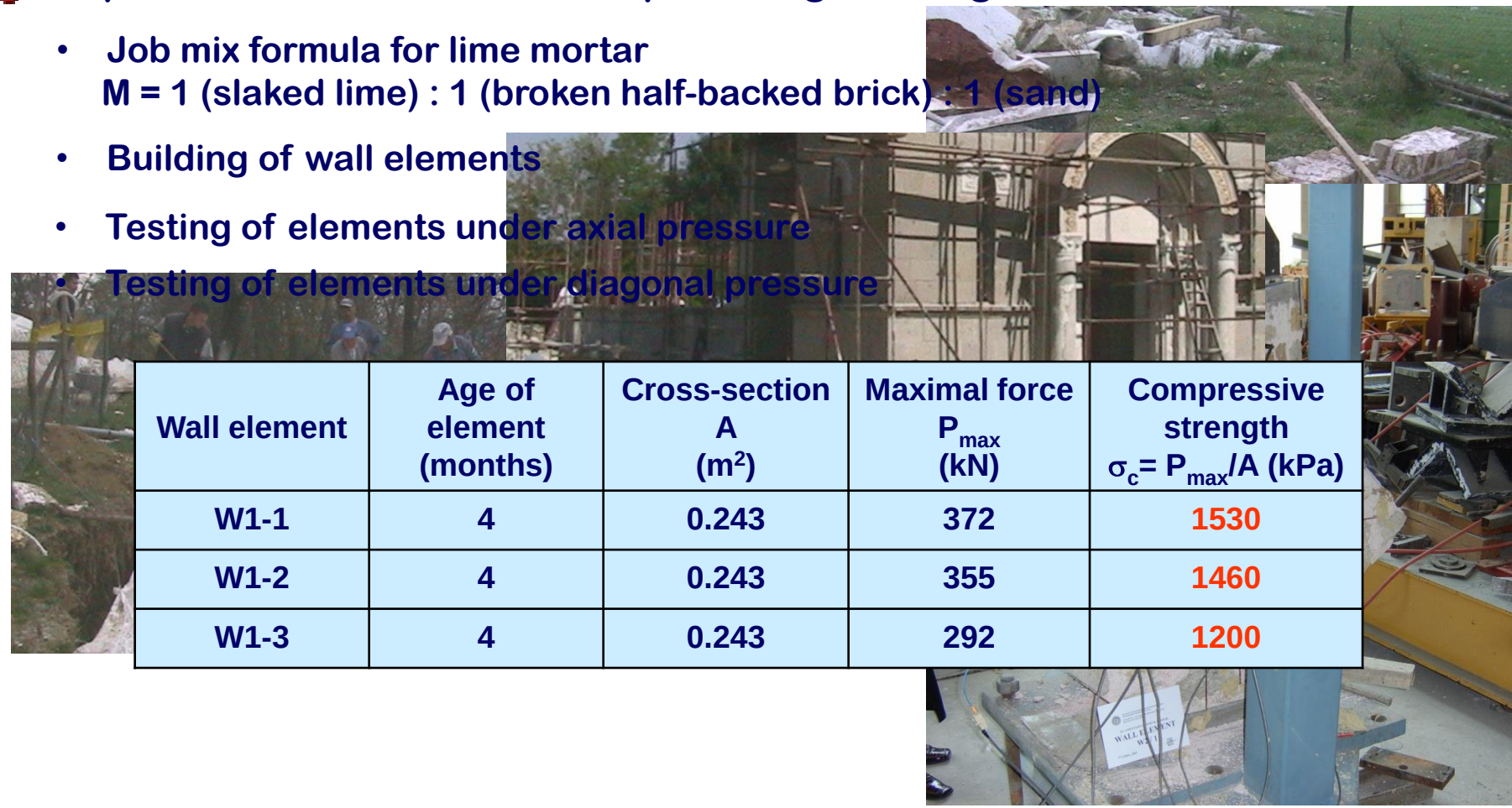
St. Athanasius Church in Leshok, (2004)

Implementation…….. In reconstruction

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

Experimental verification of Input Design Strength of Lime Mortar

- 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

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

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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

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

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);

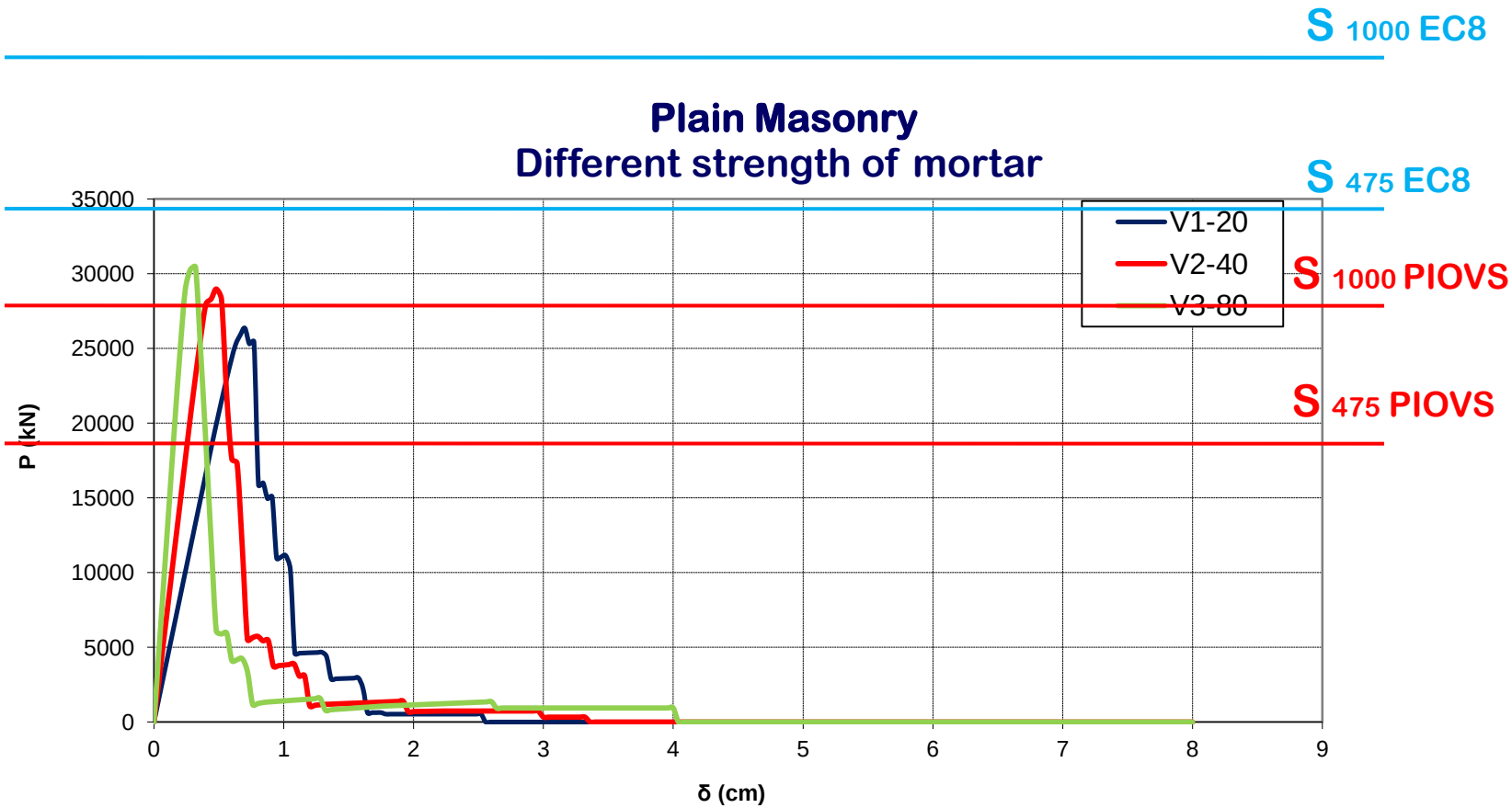
   (2) strengthened structure by horizontal steel element (HS)

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

Veronika SHENDOVA, UKIM-IZIIS (Skopje)

veronika@iziis.ukim.edu.mk

Church of the Holy Trinity in Mostar, (2010)



Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

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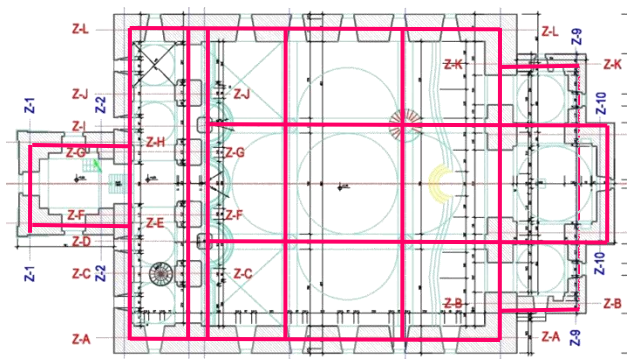
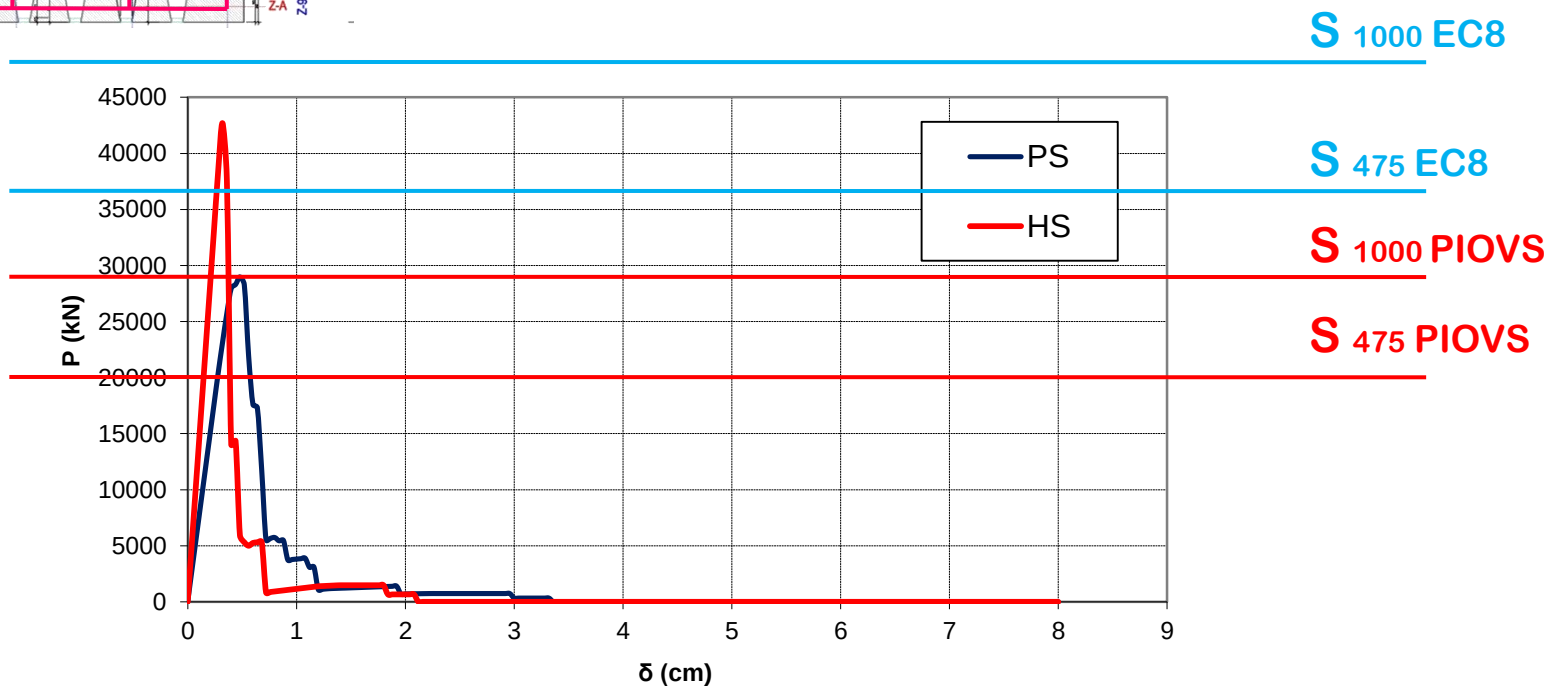
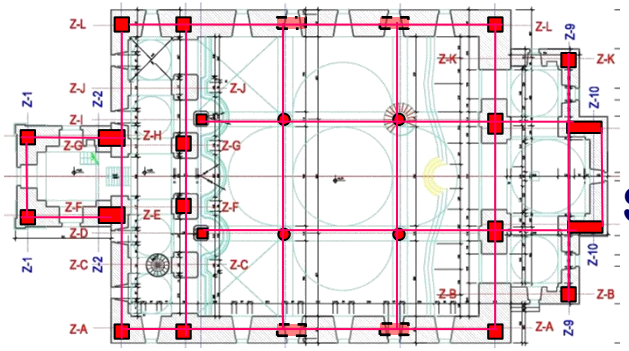


Strengthening with horizontal strengthening elements

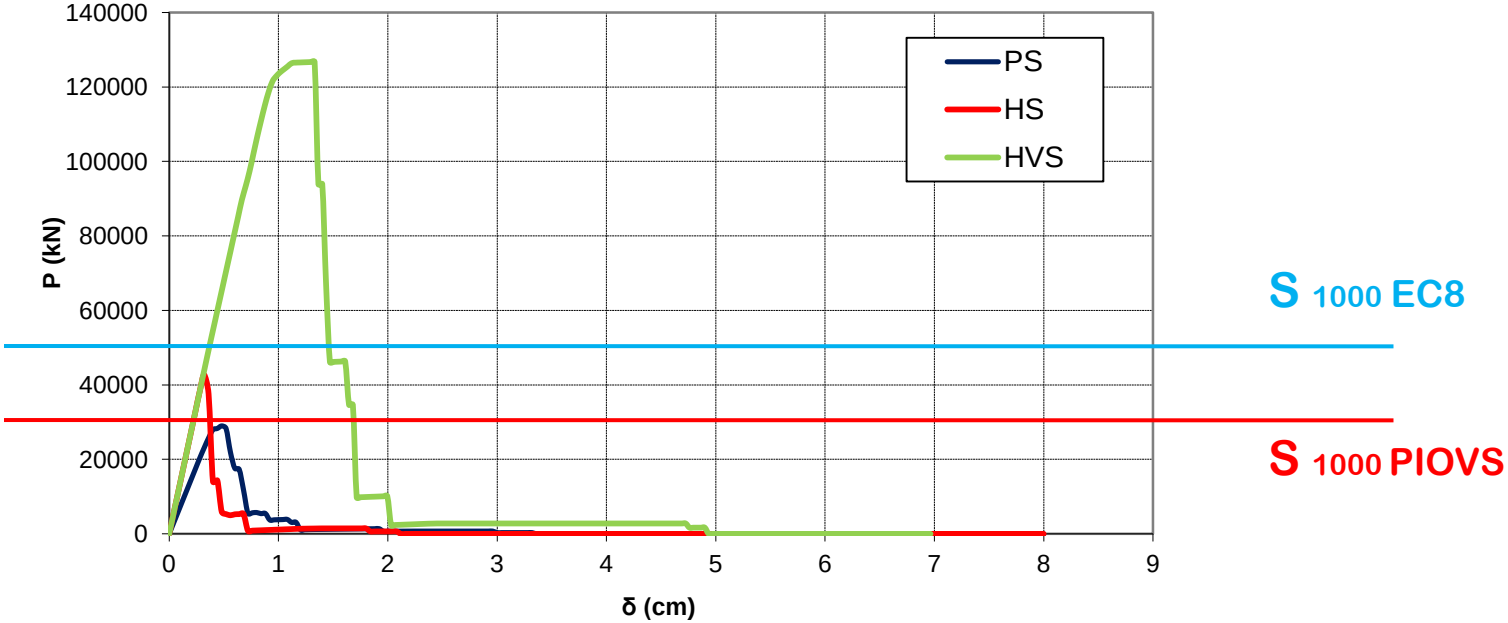


Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

Church of the Holy Trinity in Mostar, (2010)



Strengthening with horizontal and vertical strengthening elements



Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

Church of the Holy Trinity in Mostar, (2010)

Implementation…….. In reconstruction

Realization 2011- 2017

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

Seismic Upgrading of Mustafa Pasha Mosque, Skopje

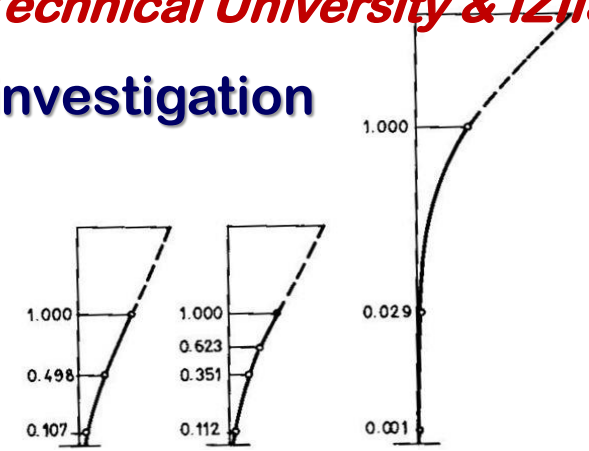
- One of the biggest and best preserved Ottoman monuments in Skopje and Balkan
- Damaged by Skopje earthquake in 1963 (domes, east facade, minaret)
- Today represents cultural historic monument of extraordinary importance

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

Mustafa Pasha Mosque, Skopje (2011)

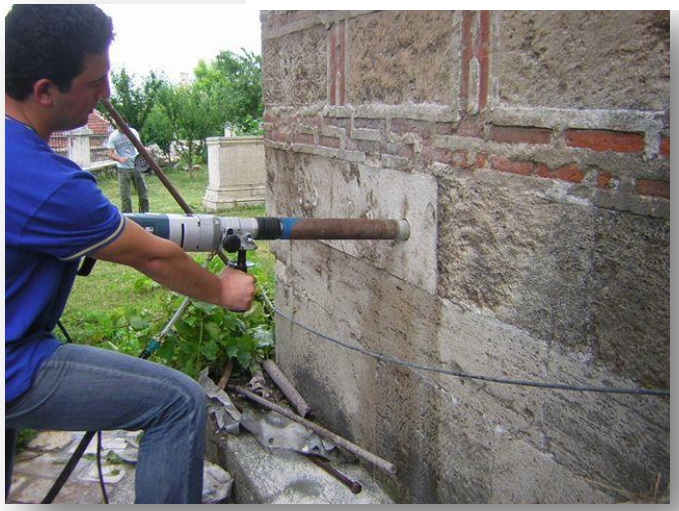
YILDIZ Technical University & IZIIS

In-situ investigation

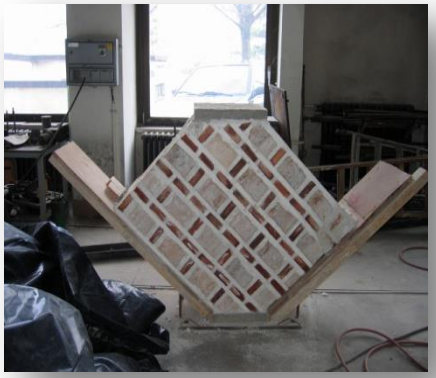


f_{1-1}=3.0Hz f_{2-2}=3.2Hz f_m=1.04Hz

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



Quasi-static testing



Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

Implementation…….. In Strengthening

EU FP6 – PROHITECH Project (2004 – 2007)

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

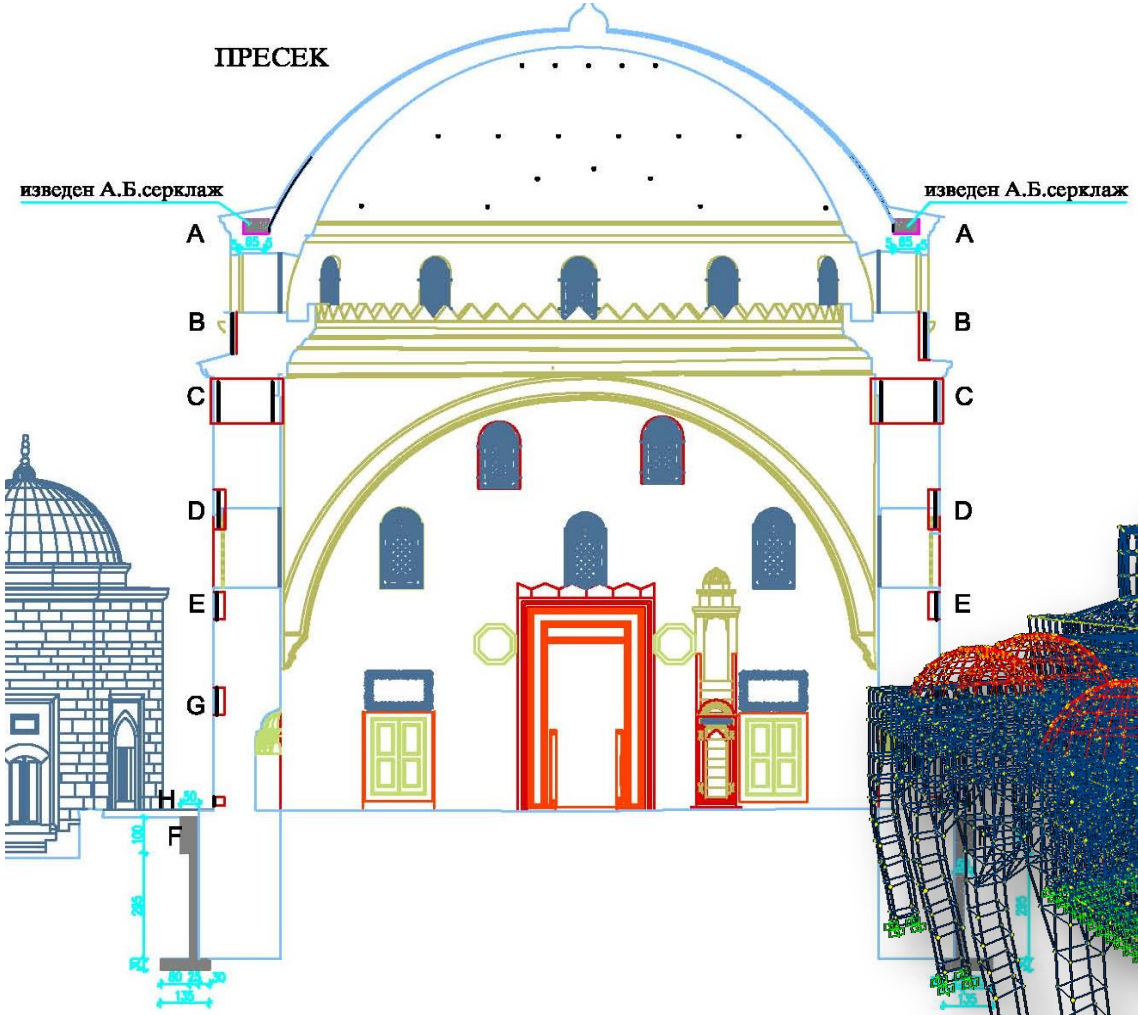
original state

strengthened by CFRP bars & wrap

Veronika SHENDOVA, UKIM-IZIIS (Skopje)

veronika@iziis.ukim.edu.mk

Mustafa Pasha Mosque, Skopje (2011)



DOME Structure (A)

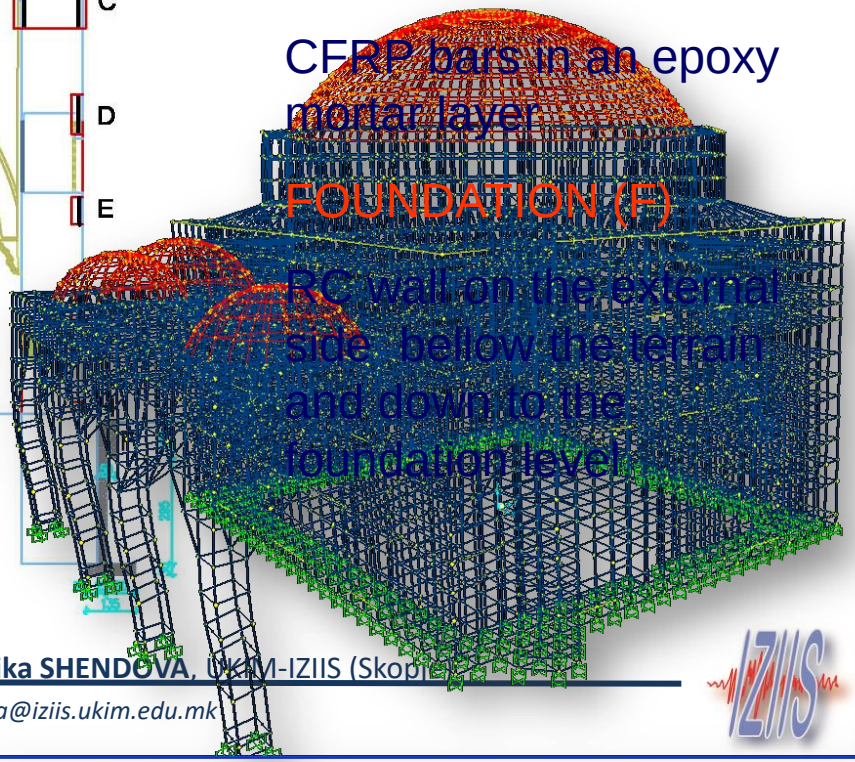
CFRP wrap in a layer of epoxy glue within a width of 2.9m

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



Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

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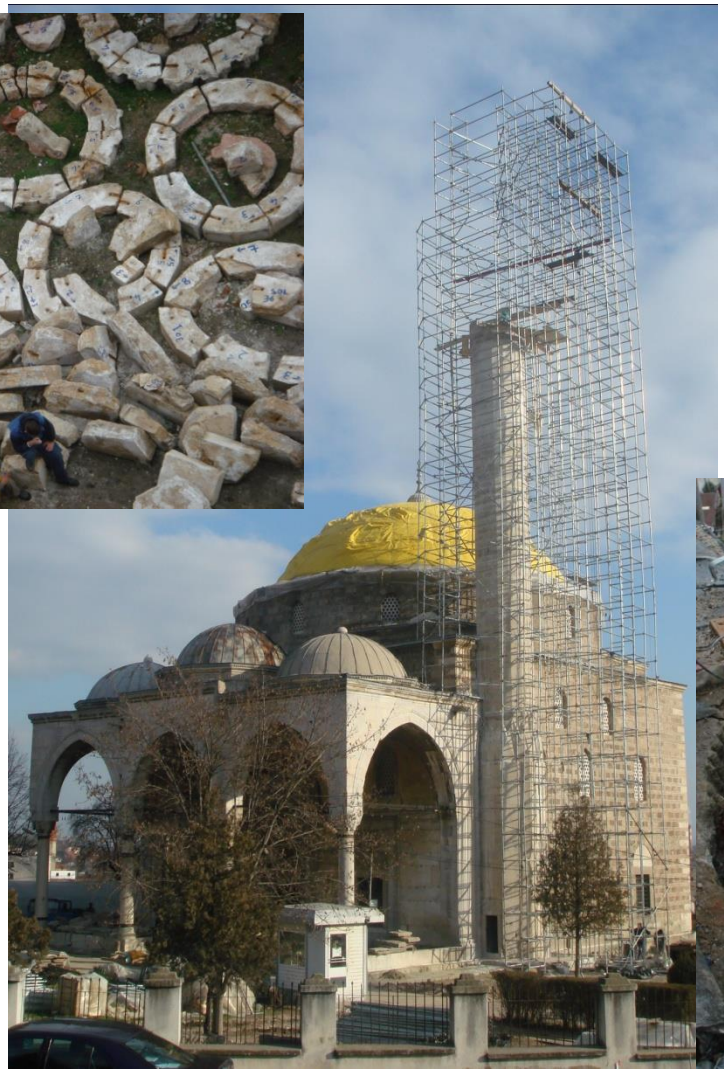
Mustafa Pasha Mosque, Skopje (2011)

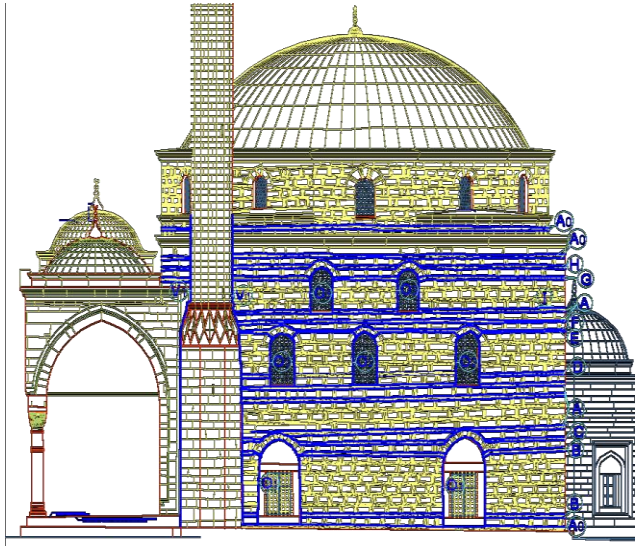
Implementation…….. In Strengthening



Repair of minaret

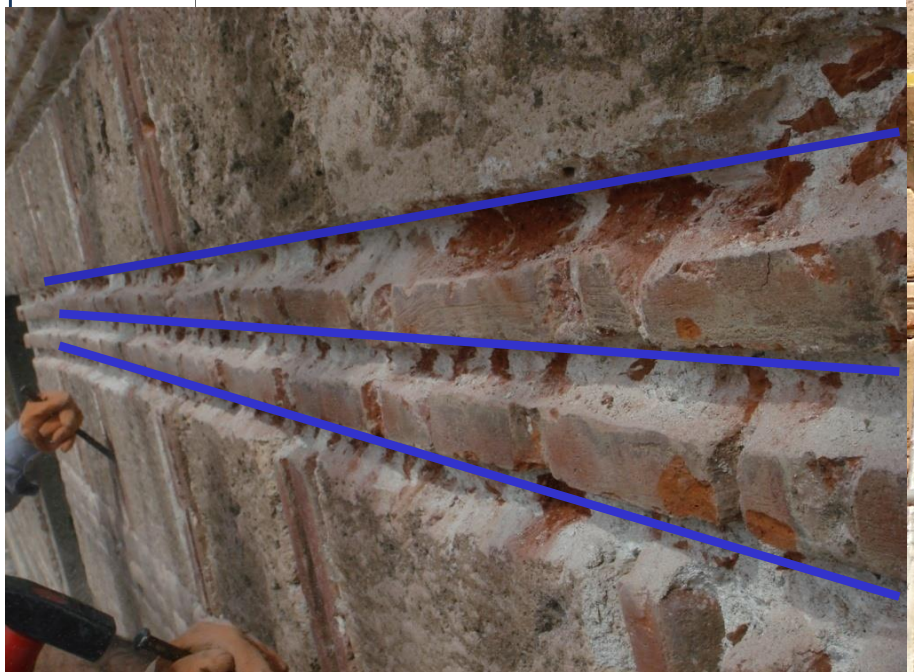
Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

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)

Strengthening of central dome

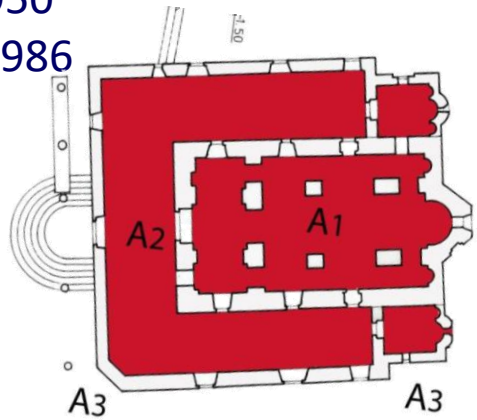
- ✓ Removal of the cement mortar layer
- ✓ Coating of existing RC ring with injection mixture based on lime mortar
- ✓ Placement of CFRP wrap in a layer of epoxy glue along the perimeter with the width of 3m
- ✓ Coating of entire dome with a protective layer of lime mortar

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

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 porch, XIX c.
- conservation 1950
- strengthening 1986



Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

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St. Marry Peribleptos, Ohrid (2015…)

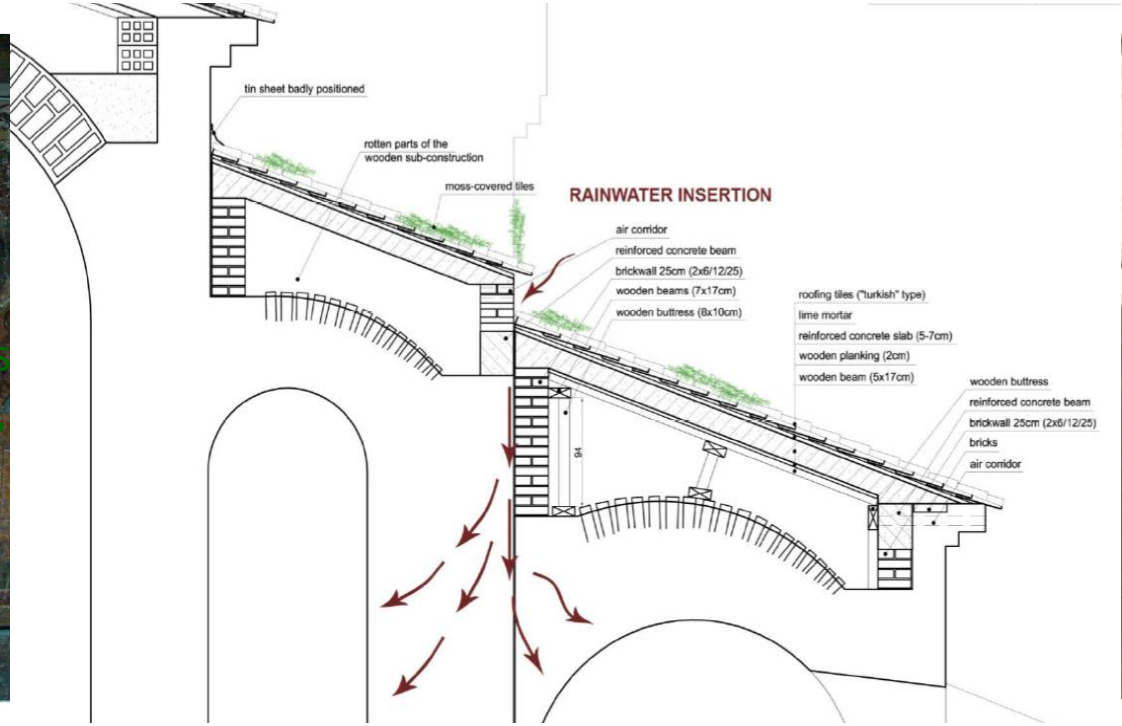
- repairing of cracks
- inserting of steel ties in central area
- placing of RC slab over the vaults
- placing of RC rings in the tambour base
- covering of the dome with cement layer

INCORRECT !

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

CURREN SITUATION

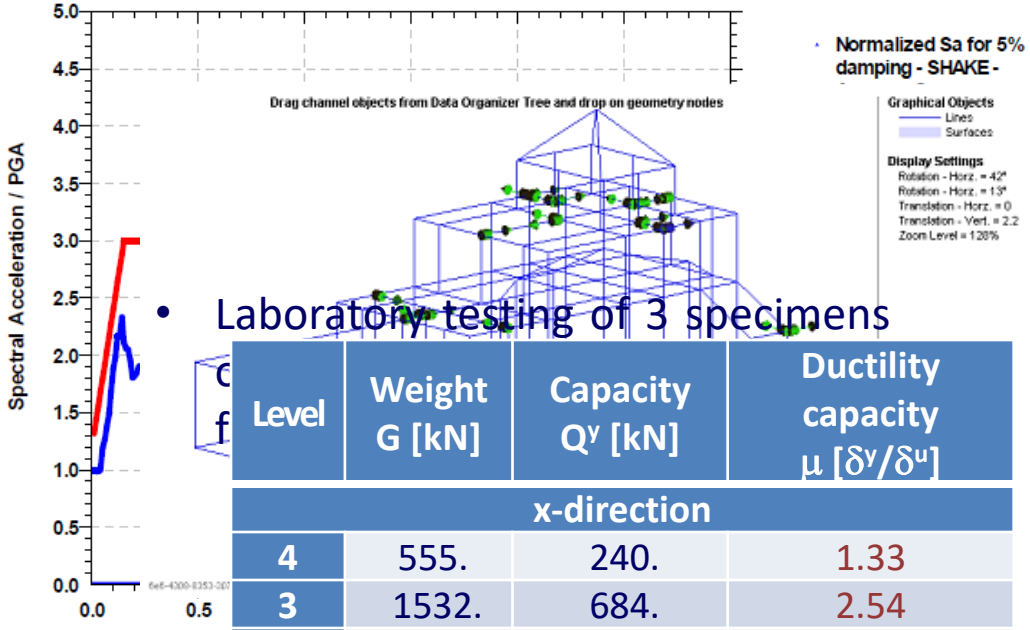
- structure – in stable condition
- appropriately incorporated ties
- no new cracks
- visible damage to fresco paintings
- direct causes – technical solution, damage to facade joints, nonexistence of drainage system
- although free standing, RC plates cannot be removed without vibration



St. Marry Peribleptos, Ohrid (2015…)

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



- Laboratory testing of 3 specimens

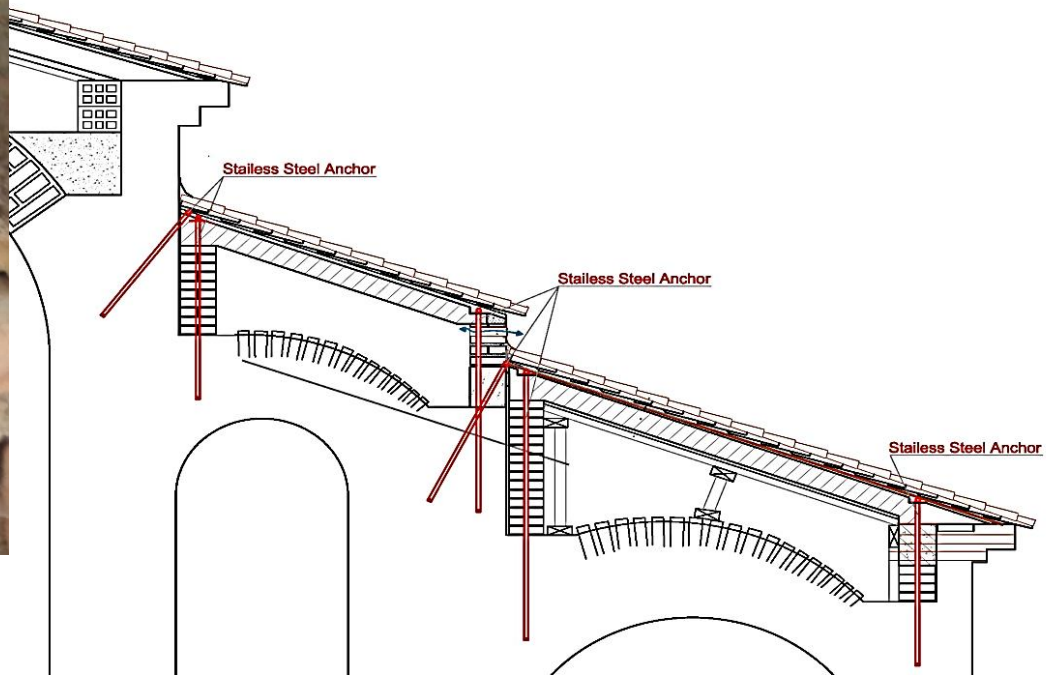
Level	Weight G [kN]	Capacity Q^y [kN]	Ductility capacity μ [δ^y/δ^u]
x-direction			
4	555.	240.	1.33
3	1532.	684.	2.54
2	3126.	1178.	1.14
1	10980.	3379.	2.48
$\sum_{1-4}$	16193.	20.8%	
y-direction			
4	555.	254.	1.10
3	1532.	583.	2.45
2	3126.	1485.	1.88
1	10980.	2973.	1.94
$\sum_{1-4}$	16193.	18.3%	

Serviceabi

Mod	%)
Mode 1 – tran	
Mode 2 – long	
Mode 3 – torsi	
Mode 4 – later	
Mode 5 - torsi	

St. Marry Peribleptos, Ohrid (2015…)

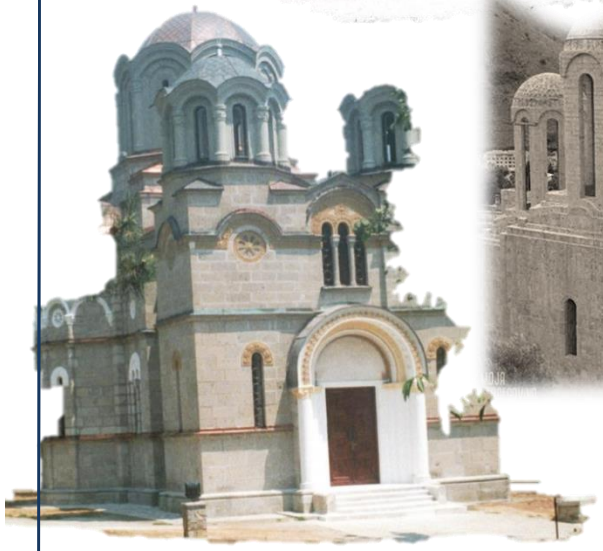
- Proposed seismic upgrading:
- to convert the negative solution of placing the RC elements into a positive one by:
  - ✓ cleaning the openings and space between the plates and masonry to provide ventilation
  - ✓ using the RC plates for providing structural integrity by way of hinged connections of 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**
- **Treskavets Monastery, Prilep, XIII Century**
- **Kurshumli An, Skopje, XVI Century**

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk

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.

THANK YOU!

Veronika SHENDOVA, UKIM-IZIIS (Skopje)
veronika@iziis.ukim.edu.mk