WG2: Impact and explosion resistance

COST C26: Urban Habitat Construction under Catastrophic Events

Prague, 31 March, 2007

Veronika SENDOVA, Blagojce STOJANOVSKI,
Ljubomir TASHKOV

Reconstruction, Seismic Strengthening and Repair of St. Athanasius Church damaged by explosion

Institute of Earthquake Engineering and Engineering Seismology
University “Ss. Cyril and Methodius”,
Skopje, Republic of Macedonia

- **regional studies**
- **local soil studies**
- **vulnerability studies**
- **building and engineering structures**
- **nuclear engineering**
- **control engineering**
- **dynamic testing**
- **information & computer science**
- **protection of cultural heritage**

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IZIIS' activities in the field

Skopje, 1963

Budva, 1979

Pagan-
Burma 1979

Dubrovnik, 1986

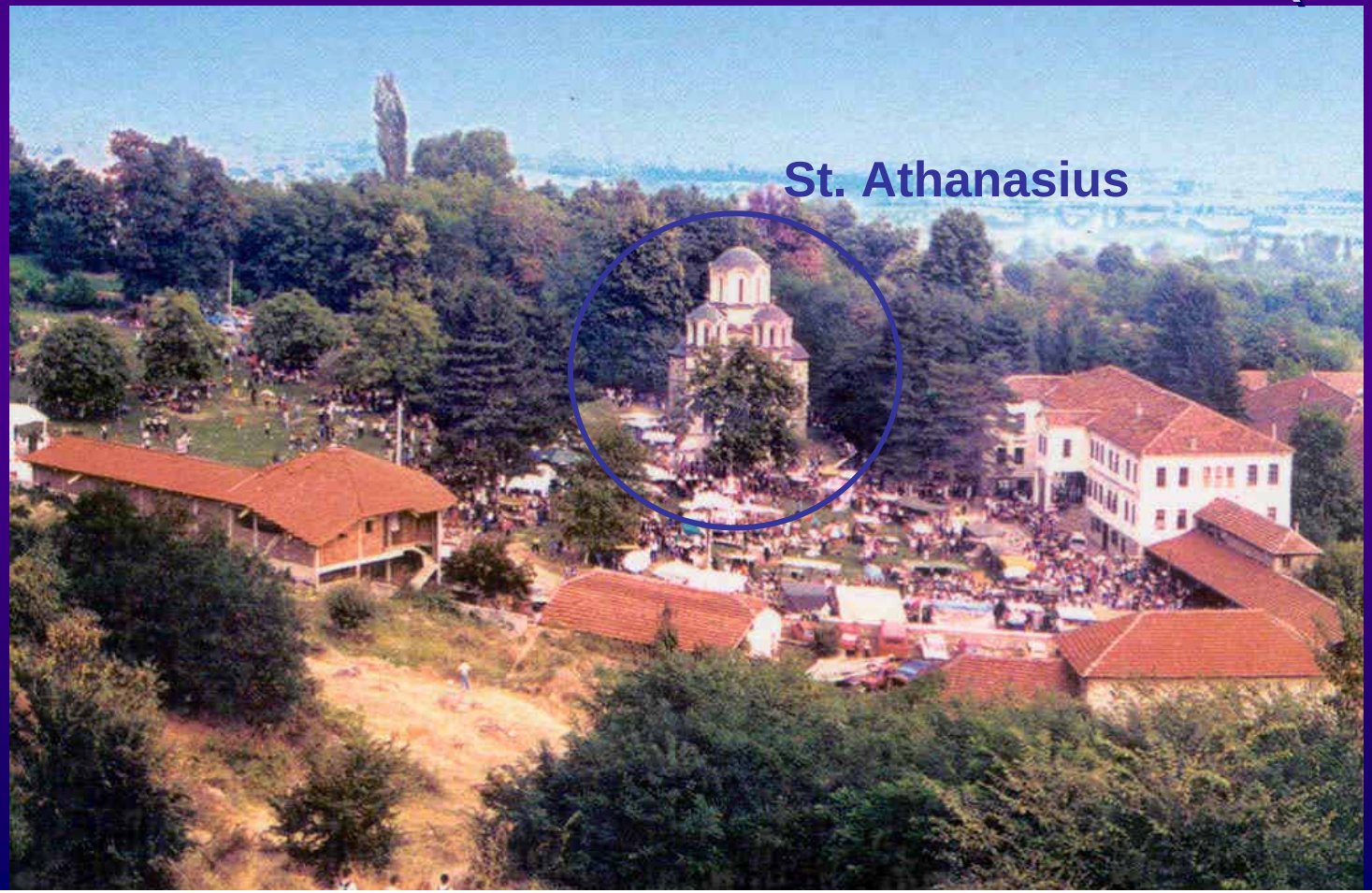
Angkor-
Cambodia, 1990

Implementation of knowledge

Reconstruction, Seismic Strengthening and Repair of St. Athanasius Church damaged by explosion

Monastery of “St. Mother of God”, v. Leshok

- 8 km north - east from Tetovo
- 700 years existence
- under the Law on Protection of Cultural Monuments (1957)

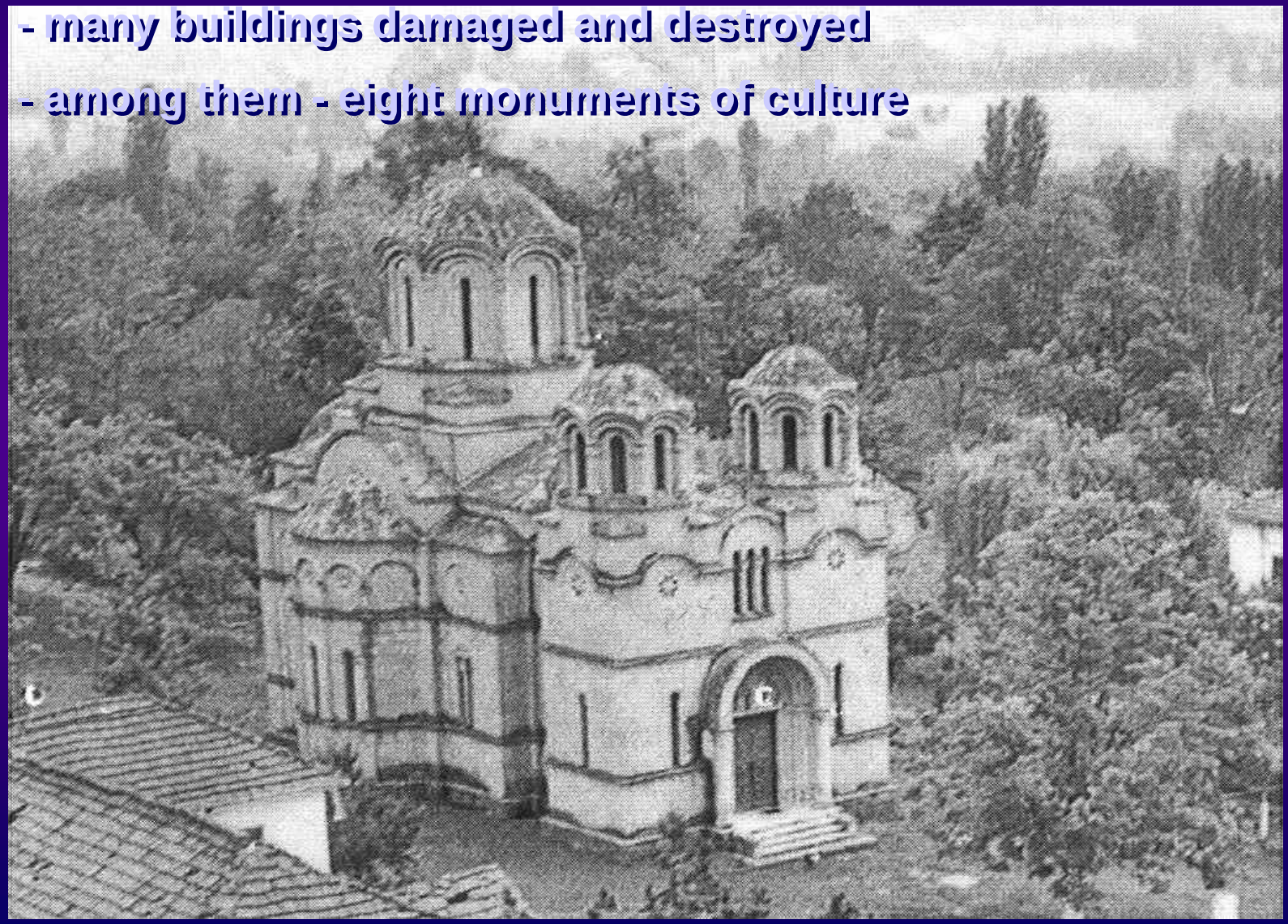


Monastic Church St. Athanasius, Leshok

- three conched structure with nartex and belfries
- massive circular (inside) and polygonal (outside) apses
- pendentives, tambour, central dome

2001 - war crisis in Macedonia

- many buildings damaged and destroyed
- among them - eight monuments of culture



21 August 2001

21 August 2001

before

after

Damage

June 2002

- European Agency for Reconstruction
- Ministry of Culture of R. Macedonia

Republic Institute for protection of cultural monuments
- Architectural and Archeological Investigations
- Project for Reconstruction of the Church

IZIIS

Project on Reconstruction, Seismic Strengthening and Repair of the Structure of St. Athanasius Church

July 2002

PHASE 1

-Providing architectural documentation

-Cleaning up and identification

-Urgent preventive measures

-Archeological investigations

-Chemical analysis

-Other investigations

28th July 2002

-Last day of Phase 1

September 2002

Principal Project on Reconstruction, Seismic Strengthening and Repair of the Church

based on IZIIS' investigations in the filed

IZIIS Investigations In the Field

- Research projects on seismic strengthening, conservation and restoration, including seismic isolation of Byzantine Churches in the Republic of Macedonia were realized in the period 1990-2000, with motivation to:

1. develop appropriate methods for repair and strengthening of Byzantine churches, in general, and particularly churches located within Macedonia
2. provide an economically justified seismic protection and necessary bearing capacity of the structure for an acceptable risk level during future earthquakes

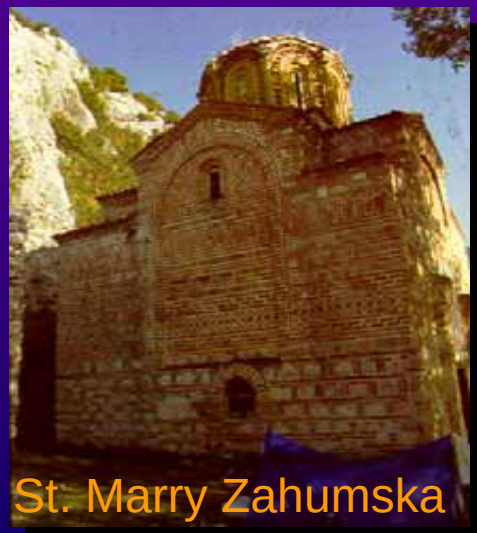
Traditional Technology vs. New Technology

Selection of the prototype church

- *Typology*
- *Existing state*
- *Interventions*
- *Authenticity*


St. Marry, Matejche


St. Nikita, Banjani


St. Marry Zahumska


St. Nicolas, Psacha

Investigations on the prototype church

- **Experimental and Laboratory Tests:**

  Mechanical and chemical characteristics of stone, brick and mortar

- **Seismic Hazard Parameters:**

  Maximum expected accelerations:

  0.146, 0.198 i 0.340 for return periods of ***100, 200 i 1000*** years

- **Dynamic characteristics:** $f^{N-S} = 4.8$ Hz, $f^{E-W} = 6.o$ Hz

- **Existing Seismic Stability**

Experimental Investigations of Church 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***

Church Models on Shaking Table

- *Determination of natural frequencies and mode shapes (models M-SN-EXIST and M-SN-STR)*
- *Shaking table testing testing of the models by gradual increase of the input intensity*

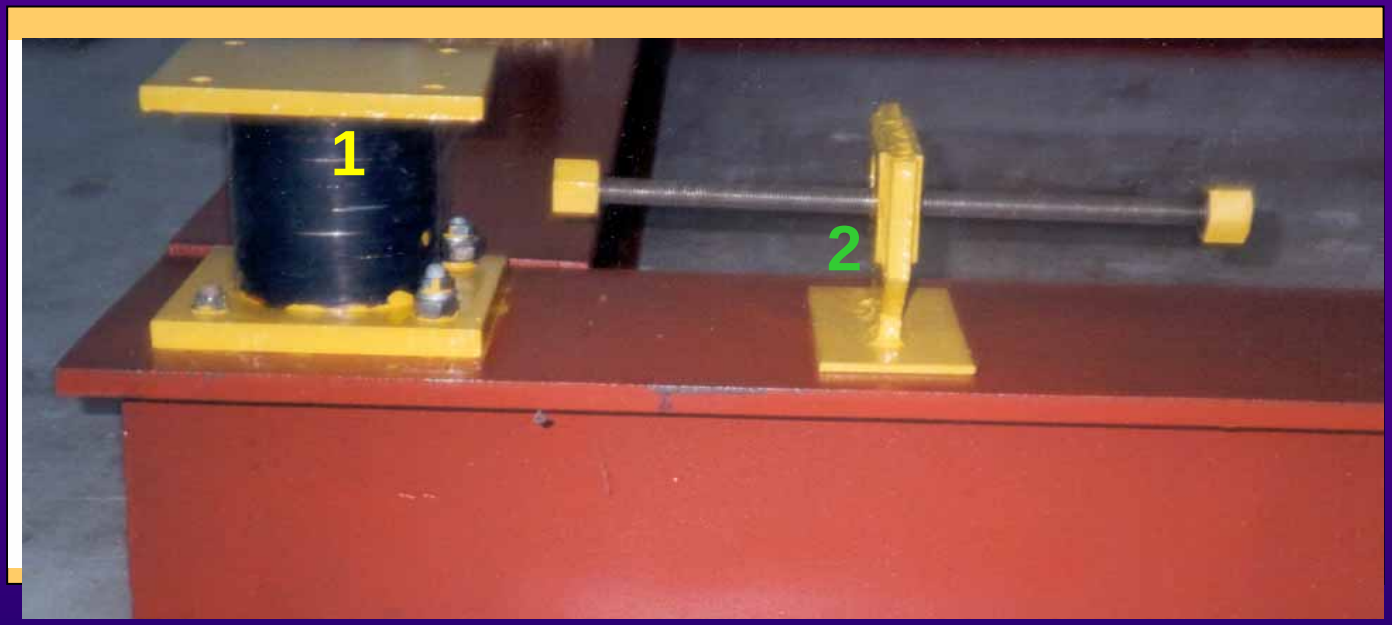
Comparison of the Results for Both Models

- *Lower damage level under higher level of input excitation*
- *Qualitatively different type of failure mechanism*
- *“minimum interventions - maximum protection”;*
- *Increasing of bearing capacity and deformability*

M-SN-EXIST M-SN-STR

Next Phase of Investigations

Investigation of the efficiency, technical, economical and conservation justification of a seismic isolation as a new approach to earthquake protection of historic monuments



D = 13.1 cm

H = 15.1 cm

K = 2.5 kN/cm

T = 0.8-1.0 s

Laminated Rubber Bearing (1) with Stopper Elements (2)

Shaking Table Testing of Model M-SN-BIC

Steel structure and Isolators

Base isolated model

Isolator in action

Traditional vs. New Technology

Reconstruction, Seismic Strengthening and Repair of St. Athanasius Church

Design Seismic Safety Criteria:

Level I – elastic behaviour, $\mu<1$;

Level II – limited nonlinear deformations of individual elements,

$\mu<1.5$, tp=500 years, amax=0.20g

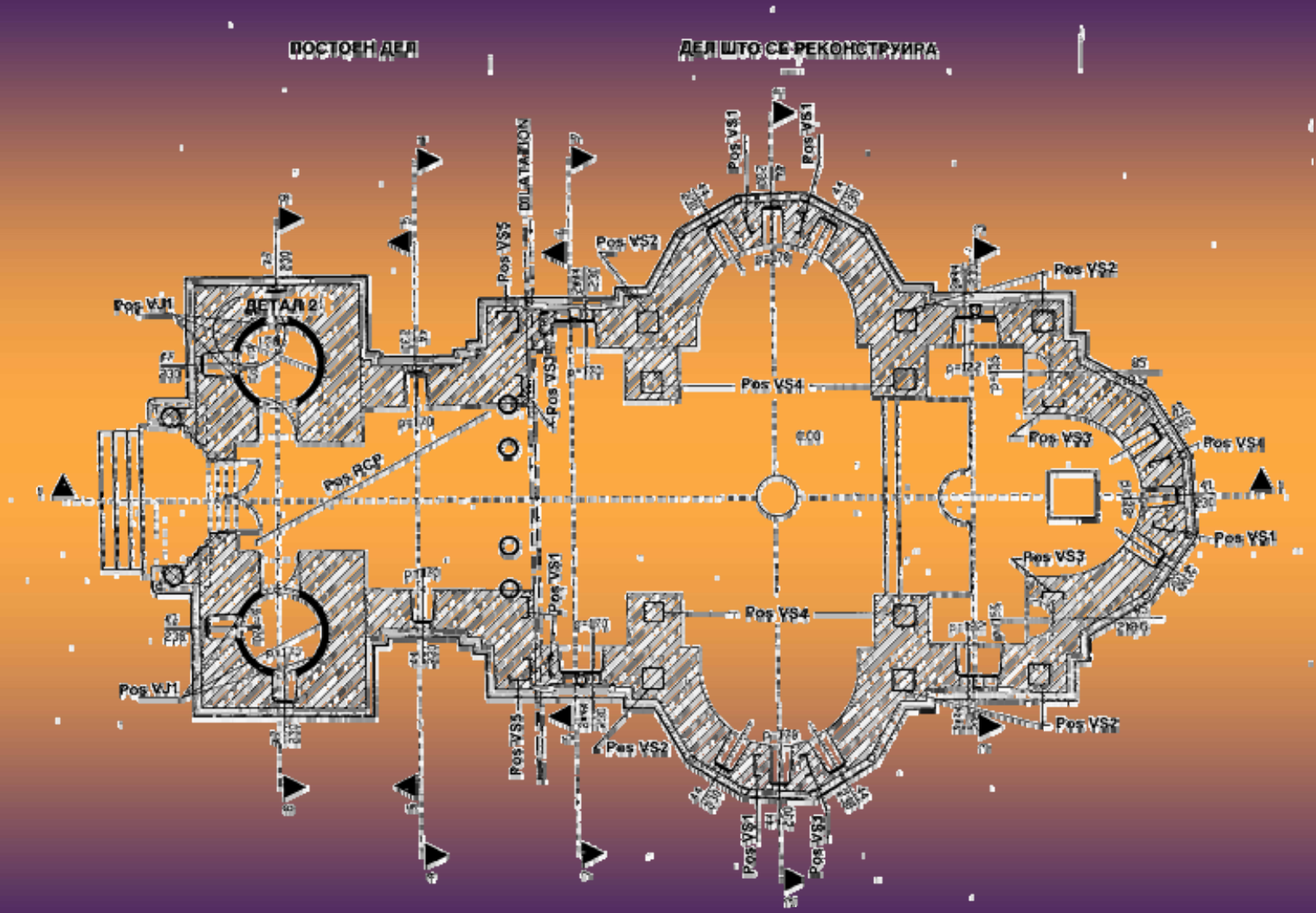
Level III – deep nonlinearity, but non-disturbed stability,

$\mu<2.0$, tp=1000 years, amax=0.24g

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 seismic safety for the *demolished part*
3. Dilatation (not less than 3 cm) between the structural units, concentration of future damages

Plan of the church, Level +1.90 m



Cross section 1-1

Analysis of the structure

Static and Equivalent Seismic Analysis by the Finite Element Method

Bearing and Deformability Capacity and Nonlinear Dynamic Analysis

INPUT:

Shear base K = 0.30

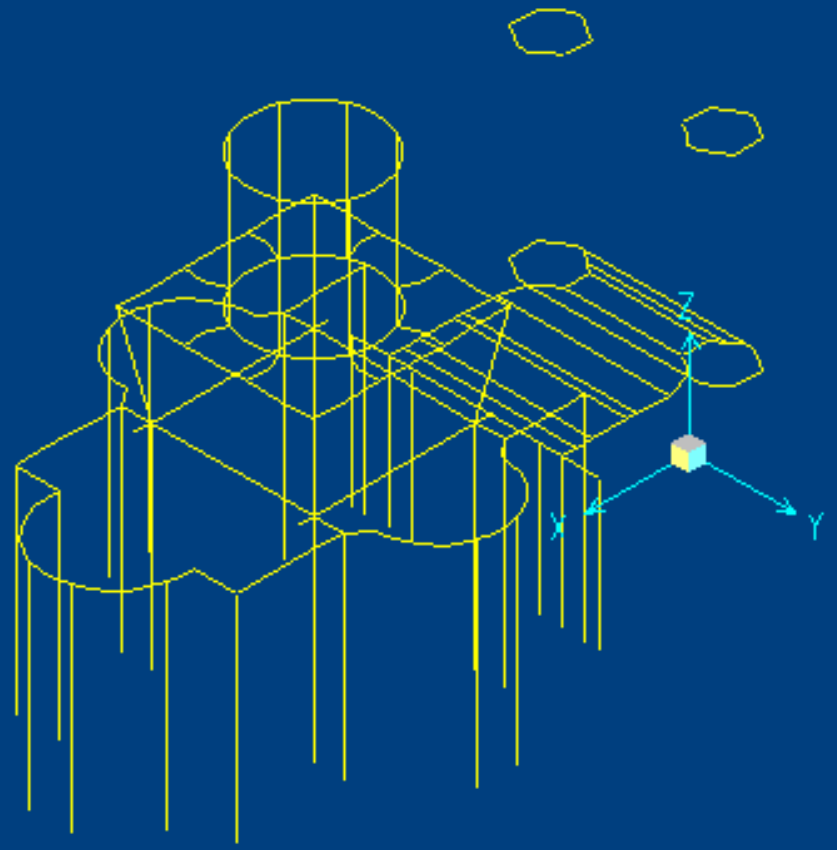
E = 1200000 kPa; G = 460000 kPa;

fc = 1000 kPa; ft = 100kPa;

γ_{stone} = 22.5k /m^3; γ_{brick} = 18.5kN/m^3

SAP2000

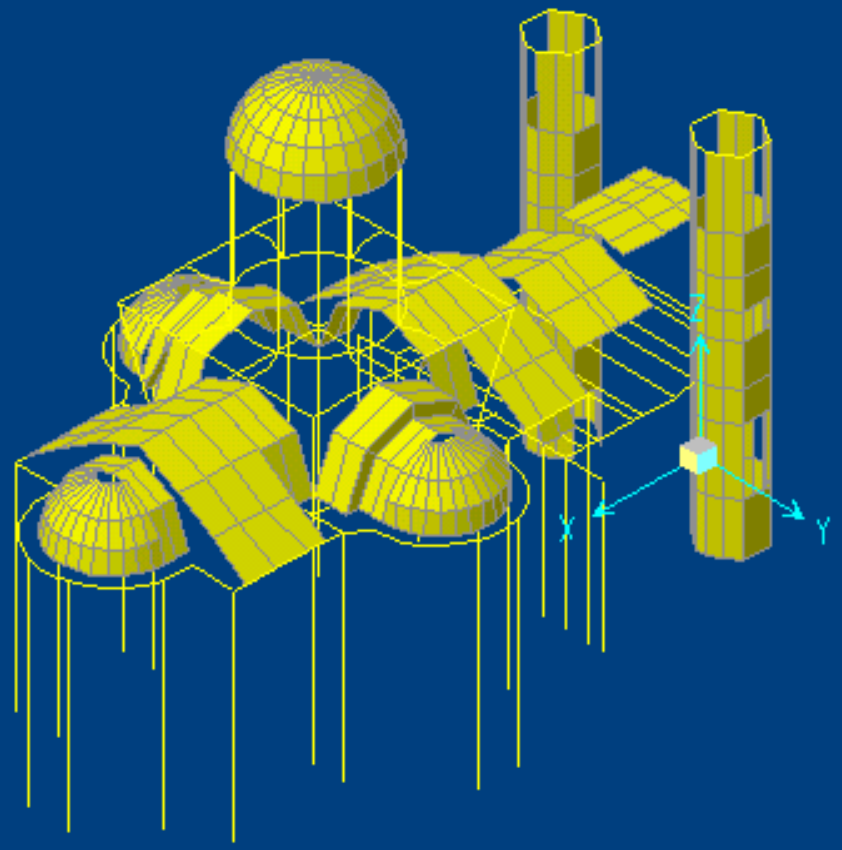
362 FRAME



SAP2000

362 FRAME

601 SHELL

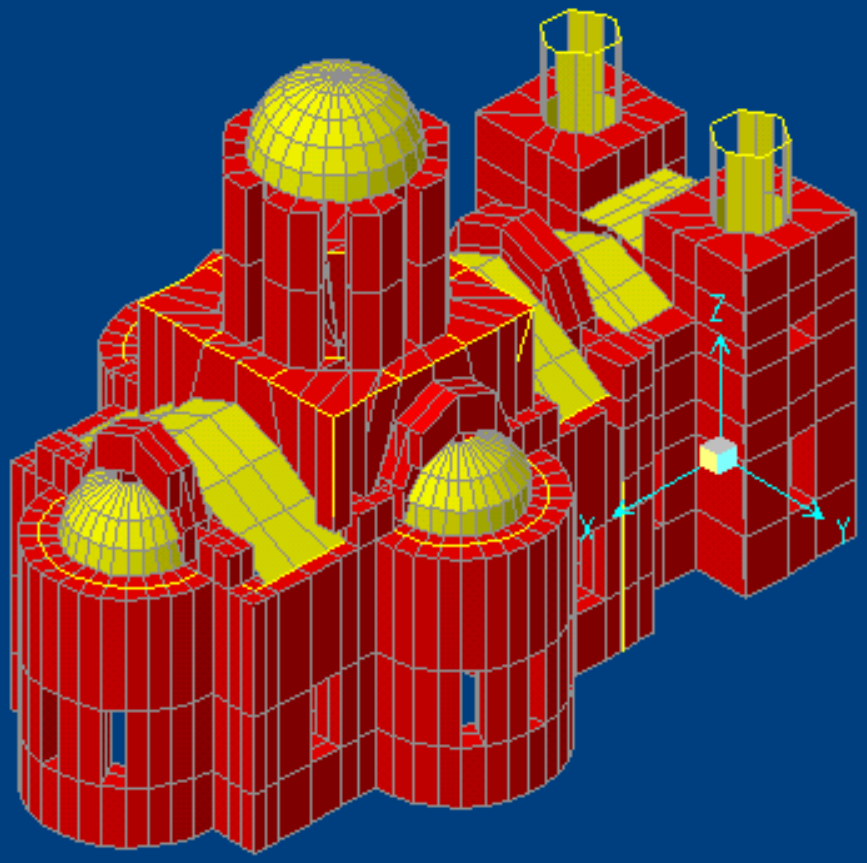


SAP2000

362 FRAME

601 SHELL

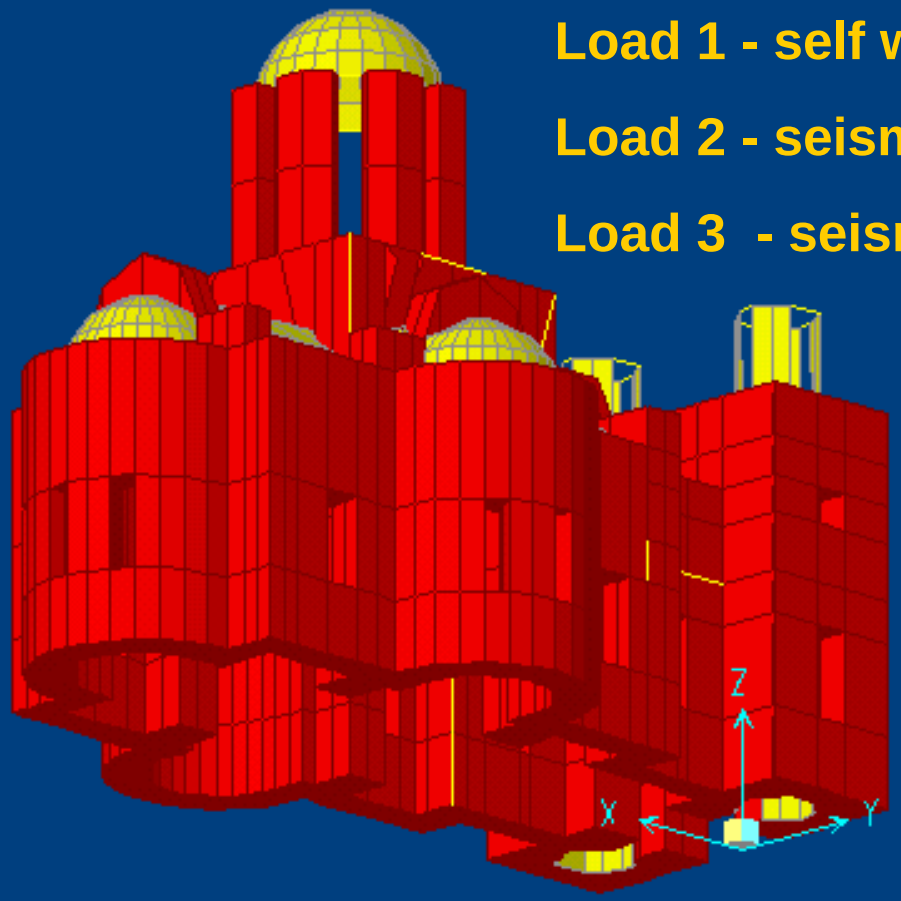
938 SOLID



SAP2000

1901 elements

5190 nodes



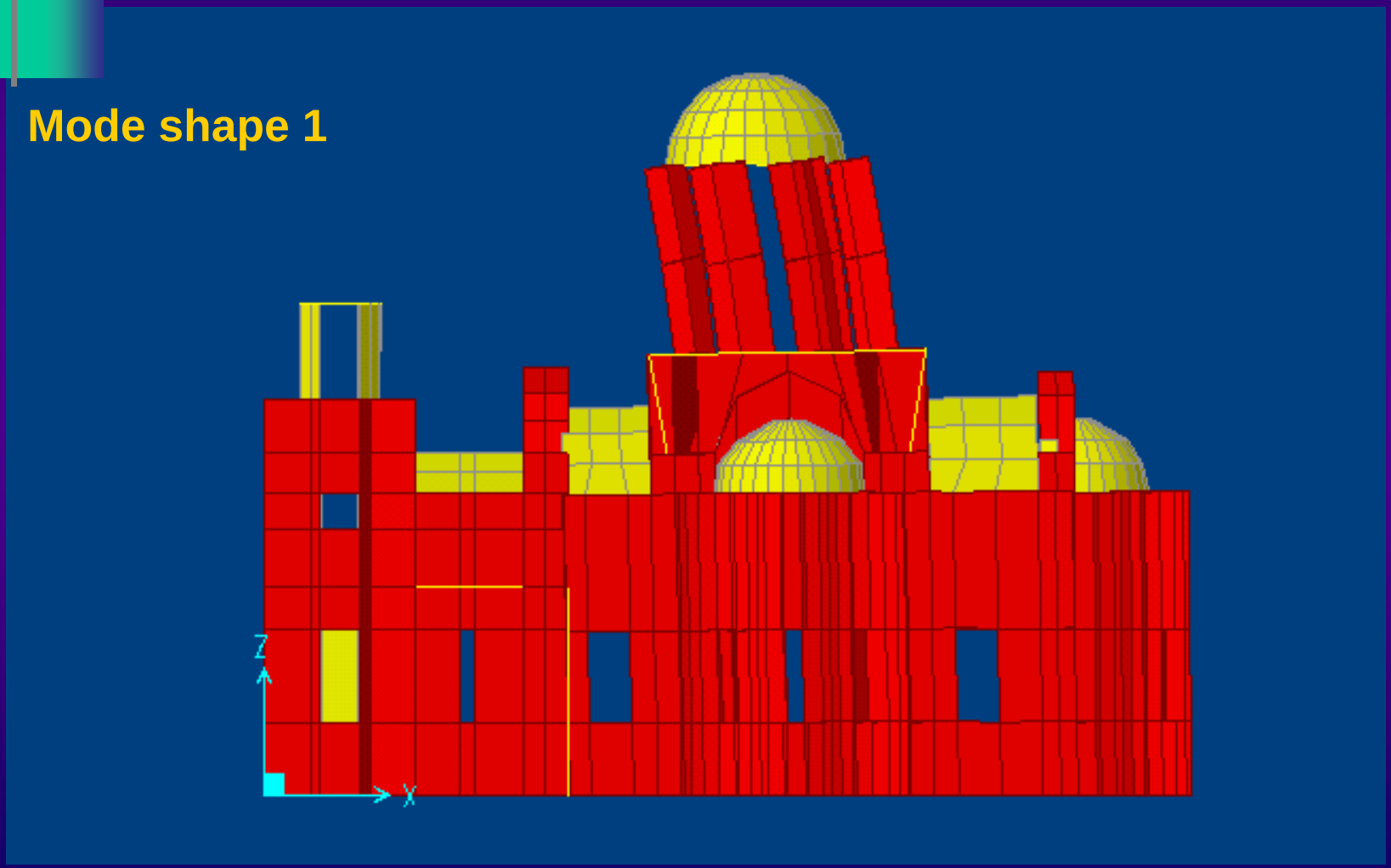
Load 1 - self weight

Load 2 - seismic X-X dir.

Load 3 - seismic Y-Y dir.

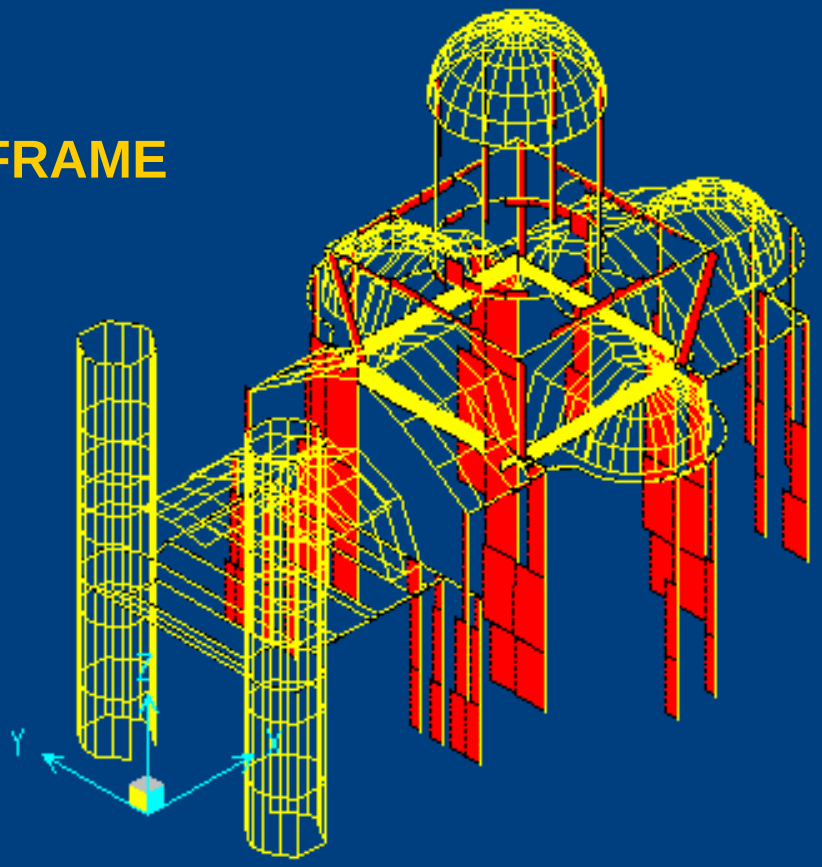
SAP2000 – dynamic characteristics

Mode shape 1



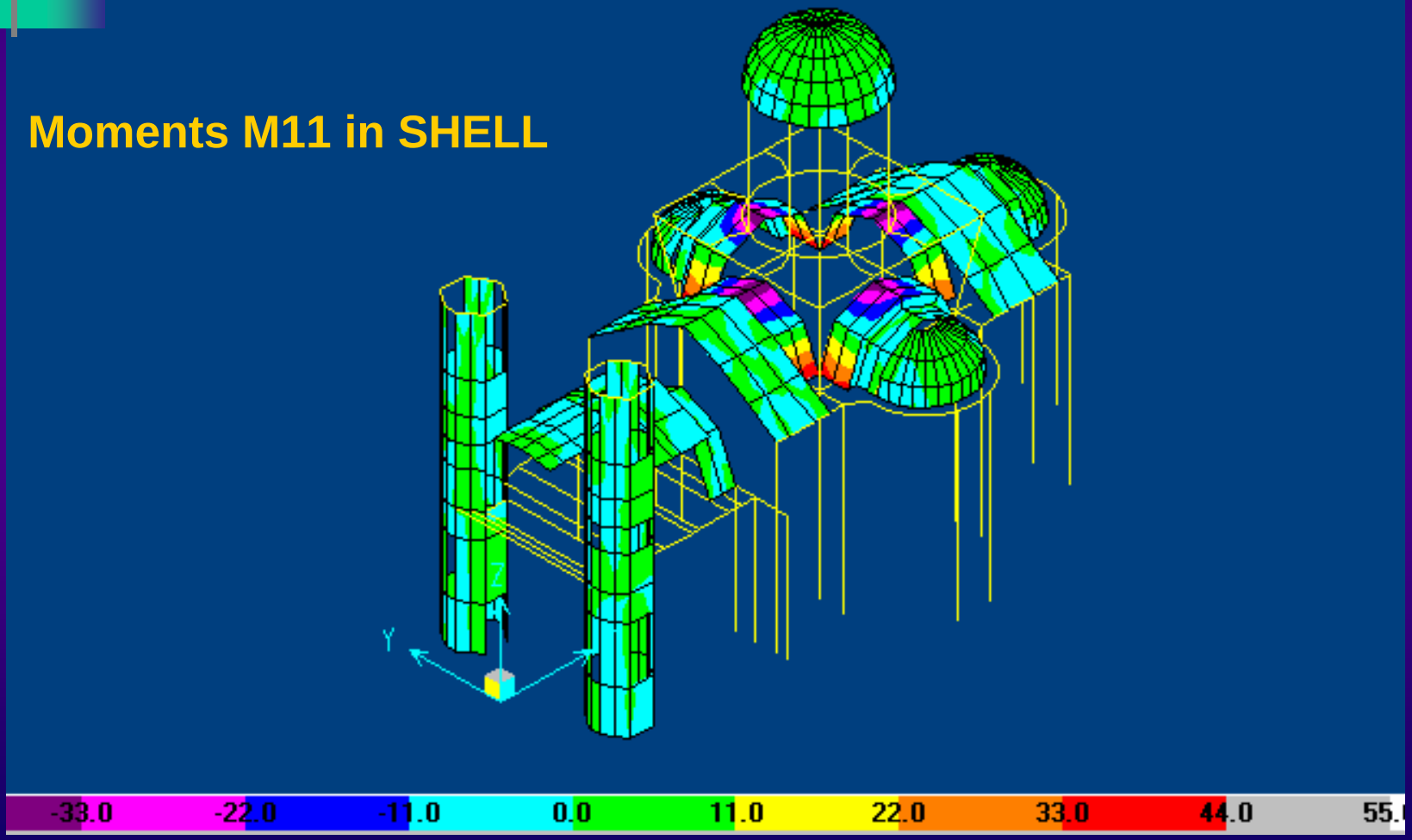
SAP2000 – stress state

Axial forces in FRAME



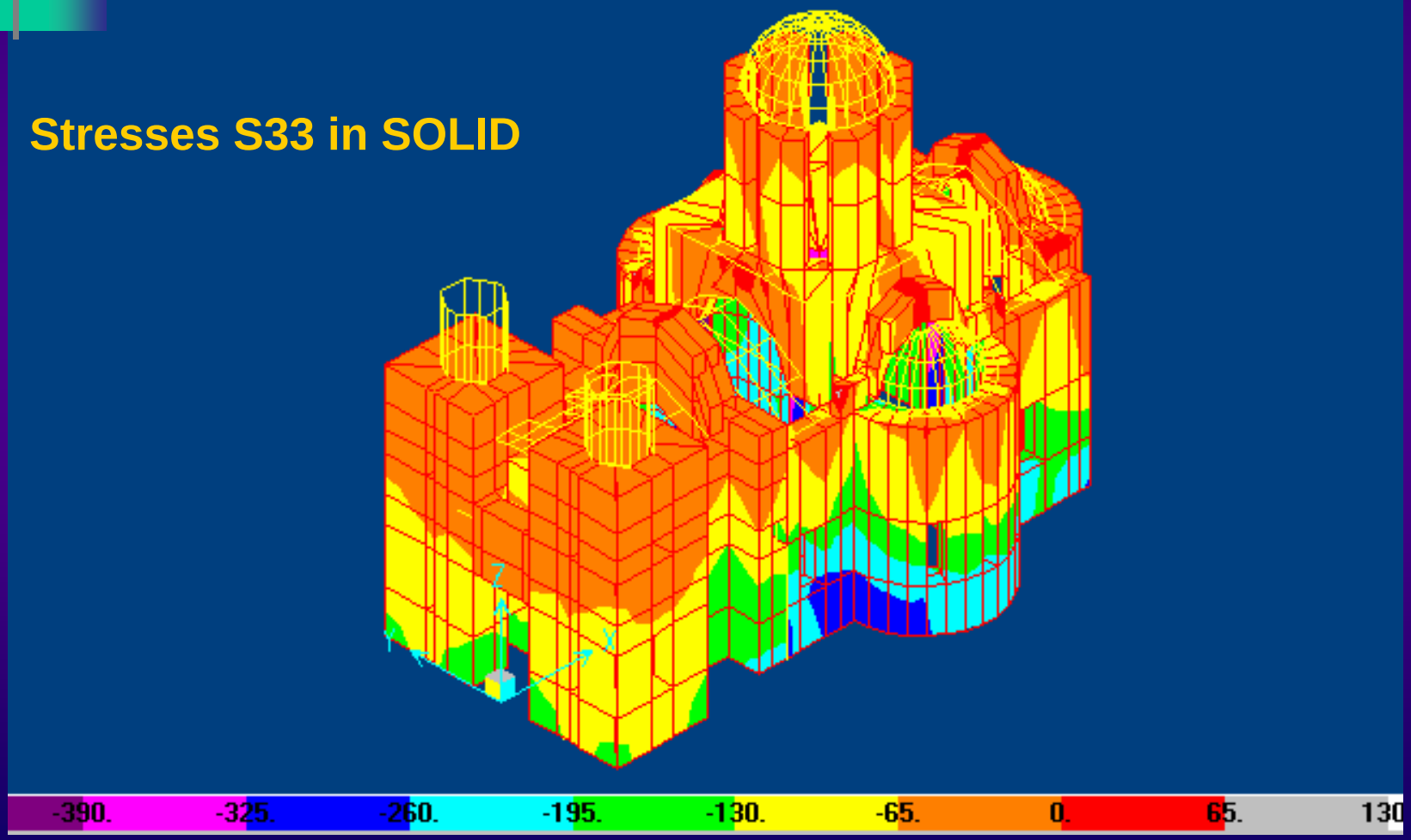
SAP2000 – stress state

Moments M11 in SHELL



SAP2000 – stress state

Stresses S33 in SOLID



Bearing and Deformability Capacity

Existing part

	Ki (kN/cm)		Qu (kN)		F=Qu/S	
	x-x	y-y	x-x	y-y	x-x	y-y
kat 3	1283	1283	496	496	2.21	2.21
kat 2	14386	14072	2567	2502	2.57	2.51
kat 1	10148	10640	3249	3407	1.56	1.63

Reconstructed Part

	Ki (kN/cm)		Qu (kN)		F=Qu/S	
	x-x	y-y	x-x	y-y	x-x	y-y
kat 2	1158	1158	1323	1058	2.86	2.29
kat 1	16498	5448	4439	4283	1.36	1.31

Nonlinear Dynamic Analysis

$\mu < 1.5$ for tp=500 years, $a_{max}=0.20g$

$\mu < 2.0$ for tp=1000 years, $a_{max}=0.24g$

Such designed structure satisfies the prescribed requirements and criteria for this type of historic structures

July – December 2003

realization

April - September 2004

realization

June 2005

CONCLUSIONS

When damage or destruction of cultural historic monuments is considered, the reason does not play a primary role anymore!

We must not allow that either the globalization or any other social, political, economic or technological process take place in the world ignoring the genesis of development of the human environment and the achievements of the human civilization!

Acknowledgement

THANK YOU !

- Council of IZIIS and all the collaborators in the project realization
- European Agency for Reconstruction
- Ministry of Culture of Republic of Macedonia