COST C26 Urban Habitat Construction under Catastrophic Events

WG2: Earthquake Resistance

Consolidation, rebuilding and strengthening of the St. Panteleymon church - Ohrid

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OBJECTIVE

Renovation of the church of "St. Panteleymon“, Ohrid

Importance and the specific nature of the structure is reflected through:

1. Historic monument classified in the first category
2. Structure of a particular national interest

Architecture:
Institute for Protection of Cultural Monuments and National Museum - Ohrid

Project on the structural system - static and dynamic analysis:
Institute of Earthquake Engineering and Engineering Seismology,
University "St. Cyril and Methodius", Skopje

Existing State

The St. Clement's church was restored upon the existing foundations from the construction phases dating back to IX to XIV century. The renovation was carried out upon the original remains of the church walls, without damaging the excavated fresco fragments, by previously eliminating the parts of the walls that were added during the conservation of the structure in 1965. During the restoration of the church, the traditional material (stone, brick and lime mortar) was used as construction material, preserving the original walling pattern of each of the different chronological periods of construction of the structure.

Existing state of the church- exacavated materials (2001)

Design Criteria and Analysis

Design Criteria

- To be built from traditional materials as the original church.
- To meet criteria for seismic stability and safety for the expected earthquake acceleration of a_{max}=0.36g whereat the total integrity of the structure will be preserve.

Analysis

- Analysis of the bearing and deformability capacity of the structure and its dynamic analysis by consideration of expected actual earthquake effects of maximum intensity of 0.36 g, using the methodology and computer programmes developed at IZIIS, (MAS-ANL3.1998).
- Static and seismic spectral three-dimensional analysis of the structure by means of the SAP 2000 computer programme, (Wilson & Habibullah. 1998).

Results from Analysis (1)

Bearing and deformability capacity of the structure in longitudinal direction – plain masonry

Storey	Qb,code [kN]	Qy [kN]	Qu [kN]	Δy [cm]	Δu [cm]	Fy	Fu
3	611	386	732	0.04	0.19	0.63	1.20
2	3023	1832	2038	0.16	0.18	0.61	0.67
1	5420	3333	4413	0.10	0.16	0.61	0.81

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Bearing and deformability capacity of the structure in longitudinal direction – confined masonry

Storey	Qb,code [kN]	Qy [kN]	Qu [kN]	Δy [cm]	Δu [cm]	Fy	Fu
3	917	1181	2108	0.13	0.54	1.29	2.30
2	4534	4983	5531	0.43	0.51	1.10	1.22
1	8131	9252	10717	0.28	0.34	1.14	1.32

Results from Analysis (2)

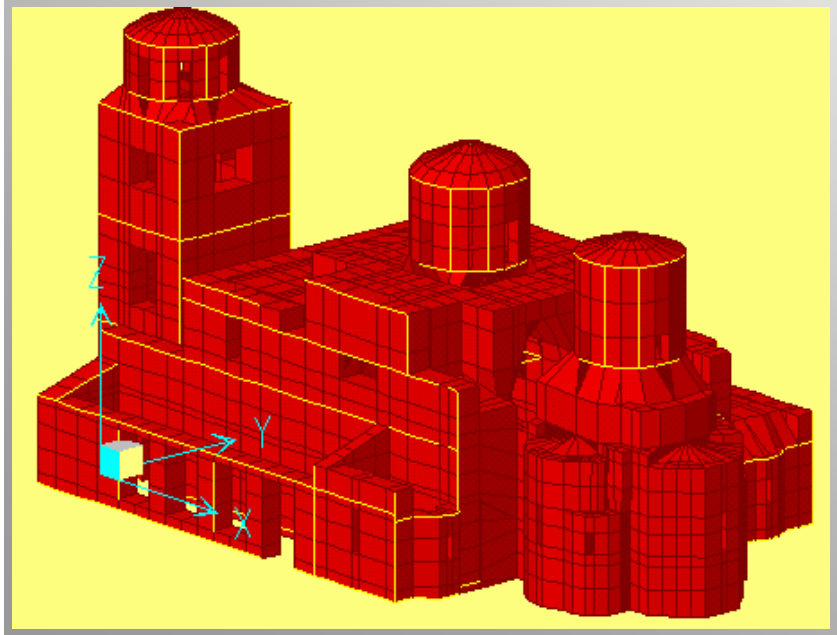
Results from dynamic analysis in longitudinal direction

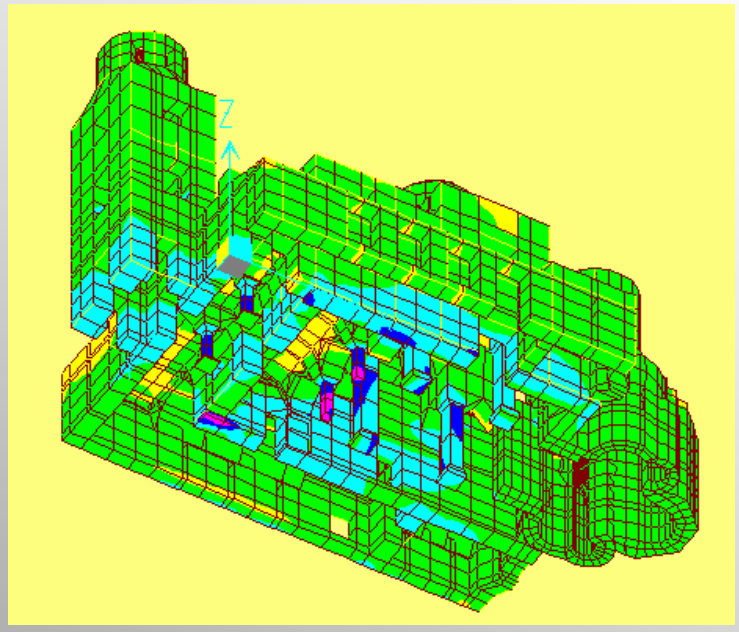
	Storey	Δreq **[cm]**	Δcap **[cm]**	μreq
	3	0.186	0.640	0.372
Petrovac, N-S, 0.36g	2	0.391	0.511	0.891
	1	0.327	0.340	1.088
	3	0.282	0.640	0.563
Ulcinj, N-S, 0.36g	2	0.574	0.511	1.309
	1	0.397	0.340	1.318
	3	0.254	0.640	0.508
El-Centro, 0.36g	2	0.462	0.511	1.082
	1	0.288	0.340	0.957
	3	0.137	0.640	0.274
Parkfield, 0.36g	2	0.261	0.511	0.594
	1	0.215	0.340	0.713

Results from Analysis (3)

RESULTS OF THE 3D ANALYSIS OF THE CHURCH STRUCTURE

1. Forces in the horizontal and vertical steel ties due to vertical loads and seismic loads represented through a design acceleration spectrum;
2. Stresses and deformability states in the SOLID elements, by which the structural elements- walls were modeled, under vertical loads and design acceleration spectra.
3. Stresses and deformability states in the SHELL elements (by which arches and domes were modeled) under vertical loads and design acceleration spectra.





3D view of the structure and distribution of stresses due to the vertical load (SAP2000)

Adopted Structural System (1)

1. The principal structural system of the church consists of massive masonry, stone and brick with incorporated steel horizontal and vertical ties.

2. Stone and brick masonry were constructed in lime mortar of selected characteristics defined through static and dynamic analysis.

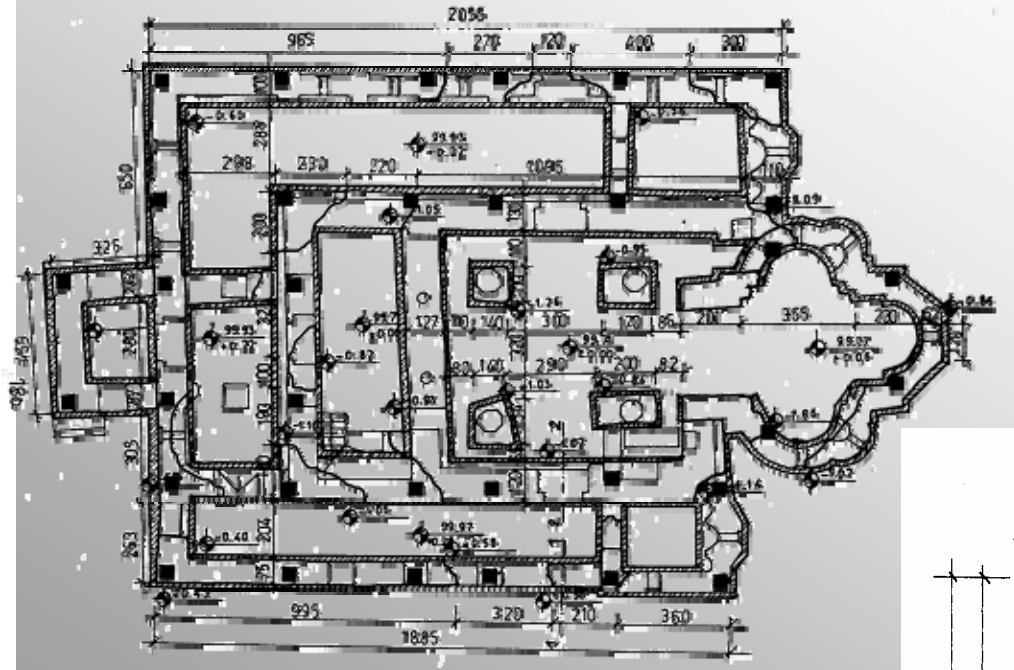
3. The existing walls below the level of the floors were systematically injected based on cement emulsion. The injection of the walls over the floor level that contain remains of fresco-paintings was done by use of emulsions that are not based on cement.

4. During the injection of the foundation walls, the problem of elimination of humidity was solved.

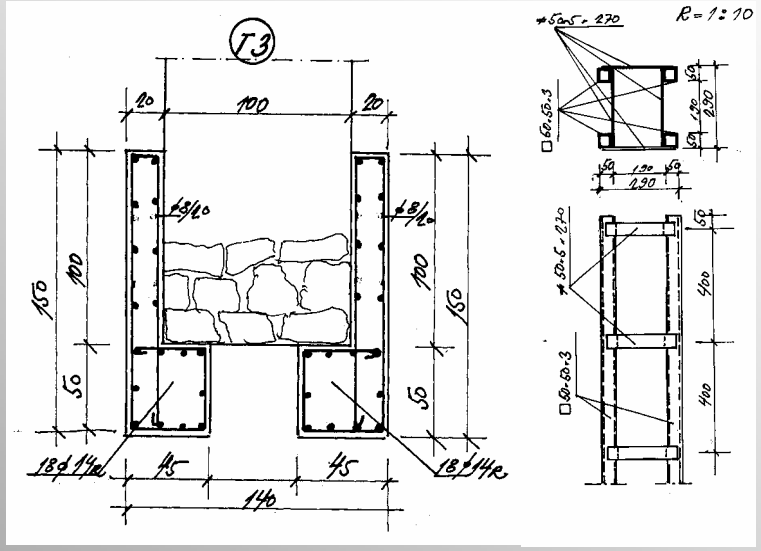
5. The contact between the existing and the restored walls was made at certain levels, depending on the level of the existing walls.

6. The strengthening and the consolidation of the existing foundation walls down to level 0.00 (to the slab) consisted of the following: beside the existing walls, from the inner and the outer side, a RC belt course is formed. It is pulled under the existing wall within a length of $\approx$ 50 cm and, at height, it runs beside the existing wall with d=20 cm to the floor slab. The RC belt course is appropriately reinforced and connected to the RC slab with d=20 cm.

Adopted Structural System (2)



Plan of the structure at level +0.22m



Detail of the foundation and of the vertical steel ties

Conclusions

- The structural system of "St. Panteleymon" church in Plaoshnik - Ohrid consisting of bearing walls strengthened by horizontal and vertical ties has a sufficient bearing and deformability capacity.
- During the expected design earthquake level, the structure is expected to behave elastically, while the maximum expected earthquake is expected to induce cracks in the nonstructural elements of the structure.
- It is generally concluded that the structure satisfies all the prescribed requirements and criteria of design of such type of structures, also satisfying at the same time the conservation aspects and requirements for the construction heritage.

Present appearance of the church, (2003)