# Shaking table examination of the Prothyron monument model

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# Introduction

- Find out the current state of old historic monuments / buildings, both the structure itself and the built-in materials, on the action of natural forces (earthquakes, winds) as well as today's increased dynamic loads (traffic loads) in order to strenghthen and preserve them fot the future.
- We are developing a numerical program / model based on discrete and finite elements connected by connecting means (clamps, anchors, bolts) for 2D and 3D structures and we need the results of the behavior of such real structures (masonry (stone, brick, etc.) structures where the elements are connected with clamps, anchors, bolts, etc.).

This research was supported by the Croatian Science Foundation under the project *Development of numerical models for reinforced concrete and stone masonry structures under seismic loading based on discrete cracks* (HRZZ-IP-2014-09-2319).

# Description of the Prothyron monument

Reconstruction of the possible appearance of Diocletian's Palace (built ca 295 A.D. to 305 A.D.) (according to E. Hebrard, 1912)

View from Hill Marjan (actual situation)

Aerial view of Dicletian's Palace (in white square)

# Description of the Prothyron monument

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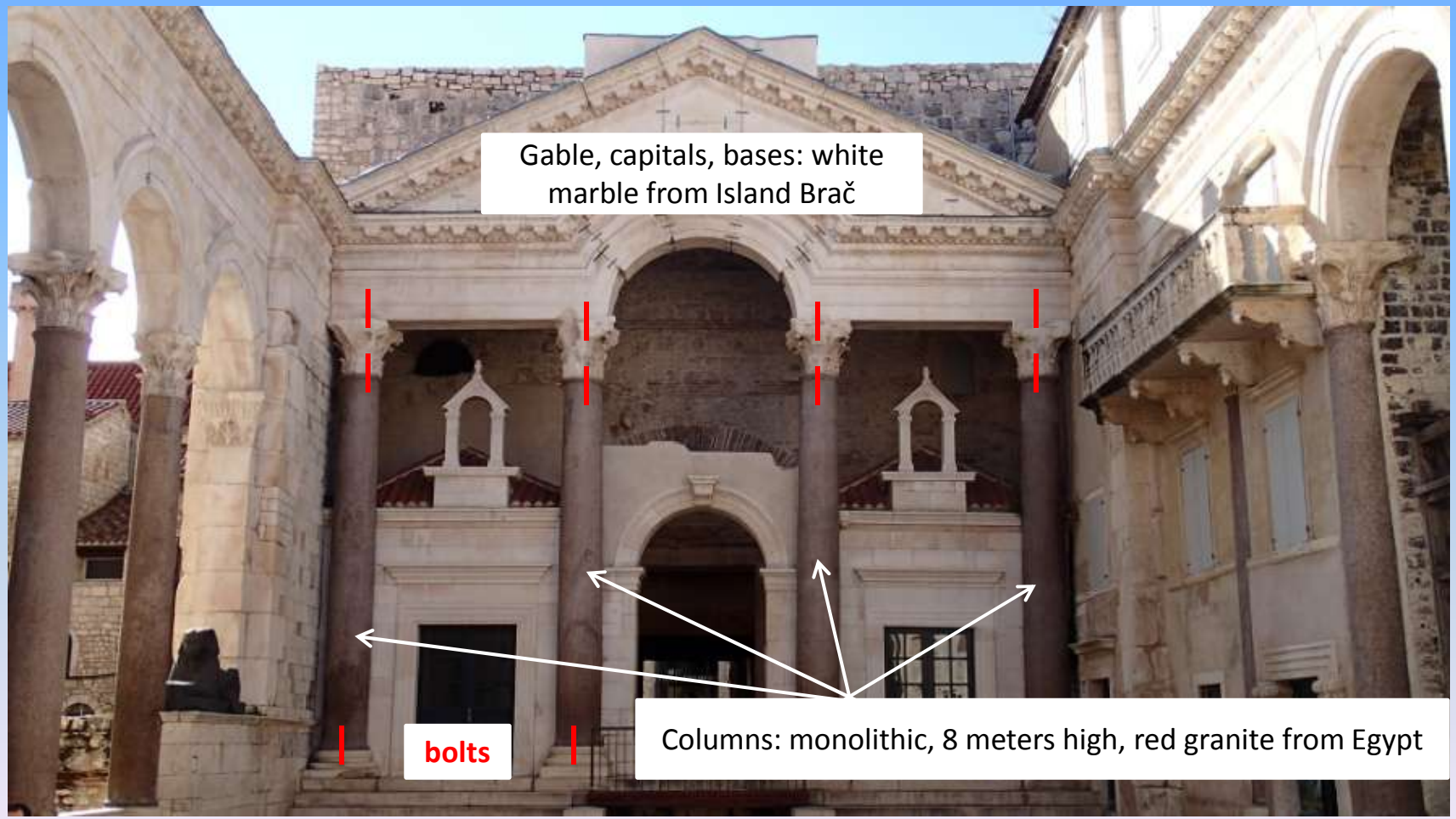
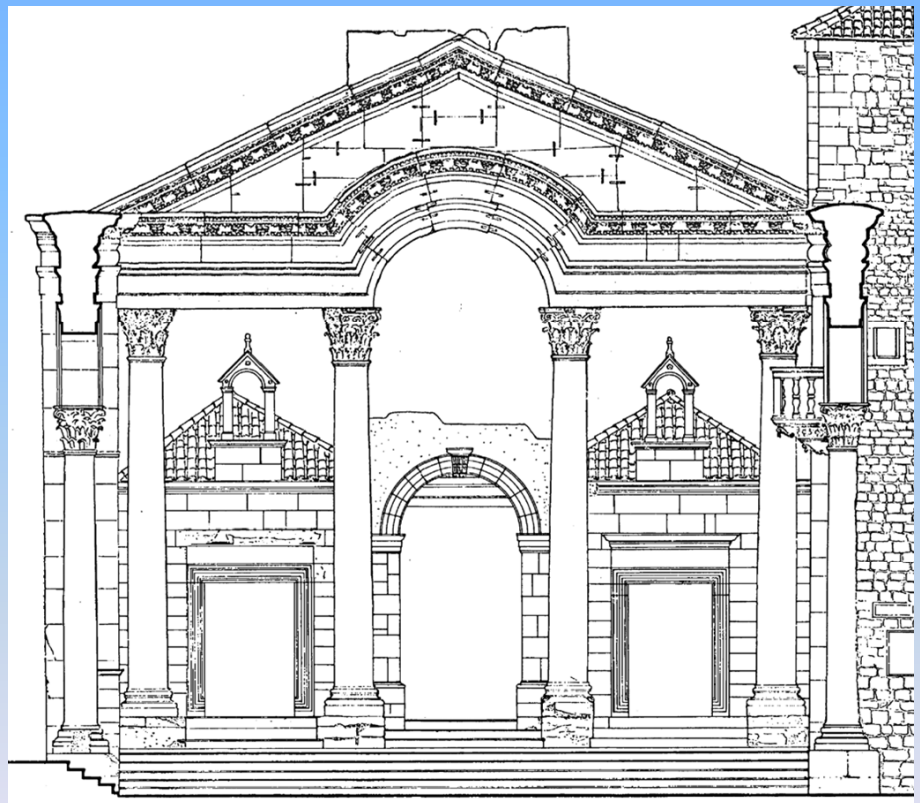


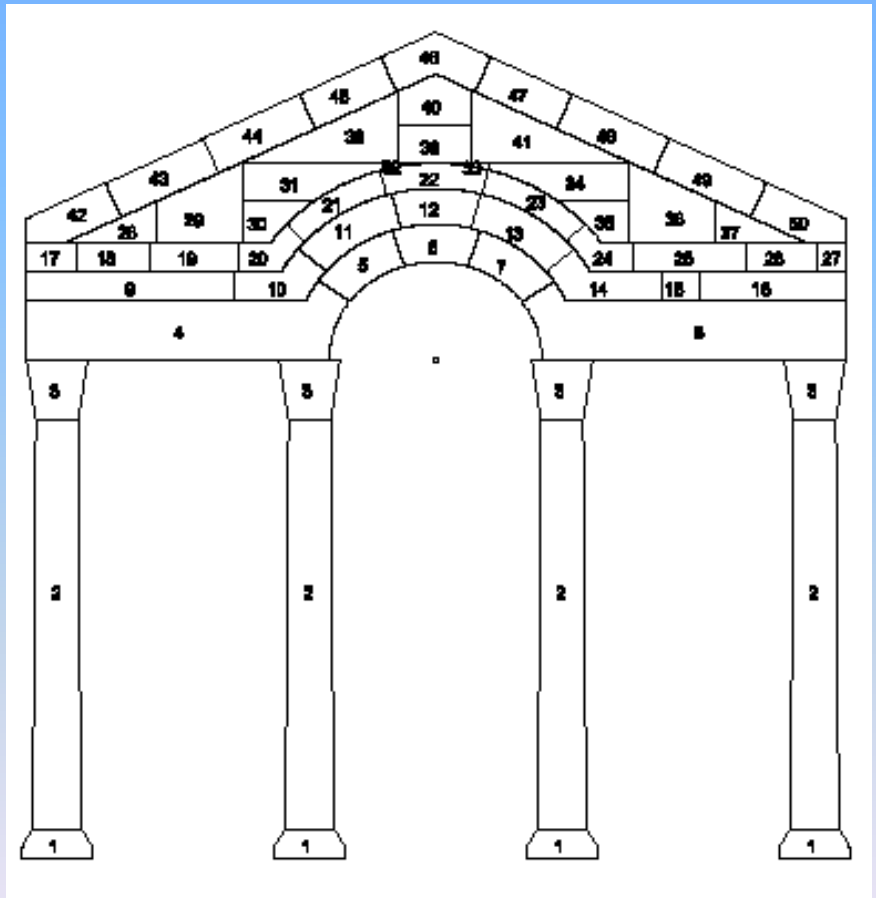
# Description of the Prothyron monument

Photo of the Prothyron (monumental entrance to the Diocletian's private rooms)

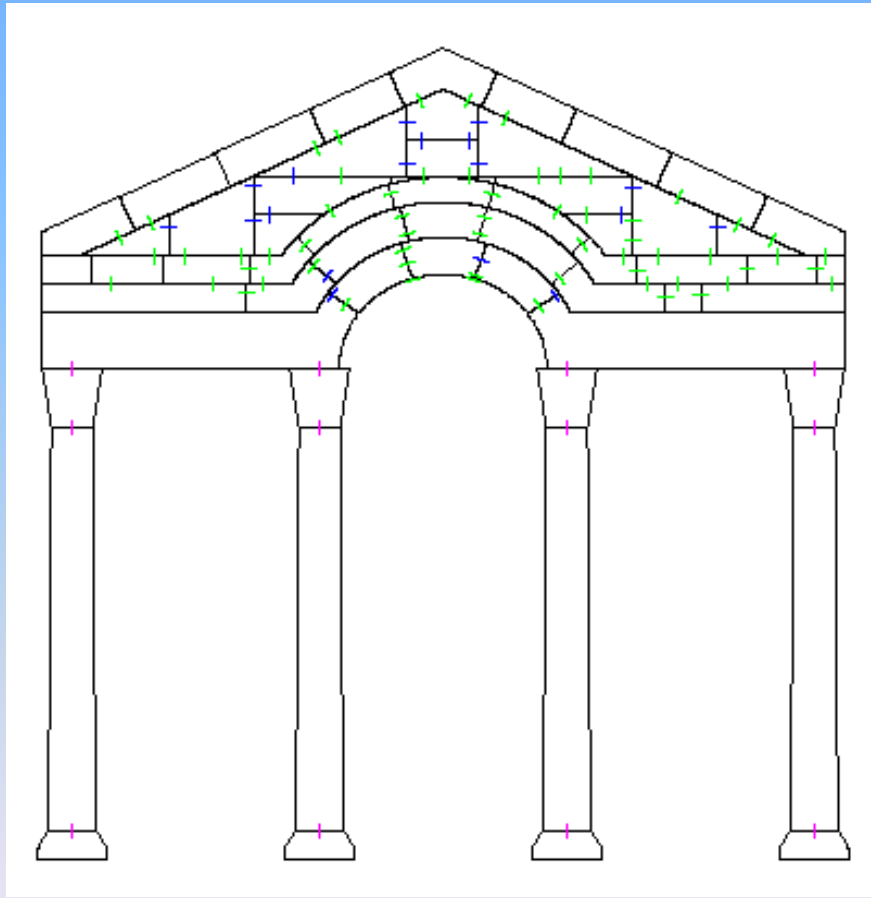


Photogrammetric drawing of the Prothyron

# Making of the Prothyron model



Stone numbering



Position of clamps (green and blue) and bolts (red)

# Making of the Prothyron model

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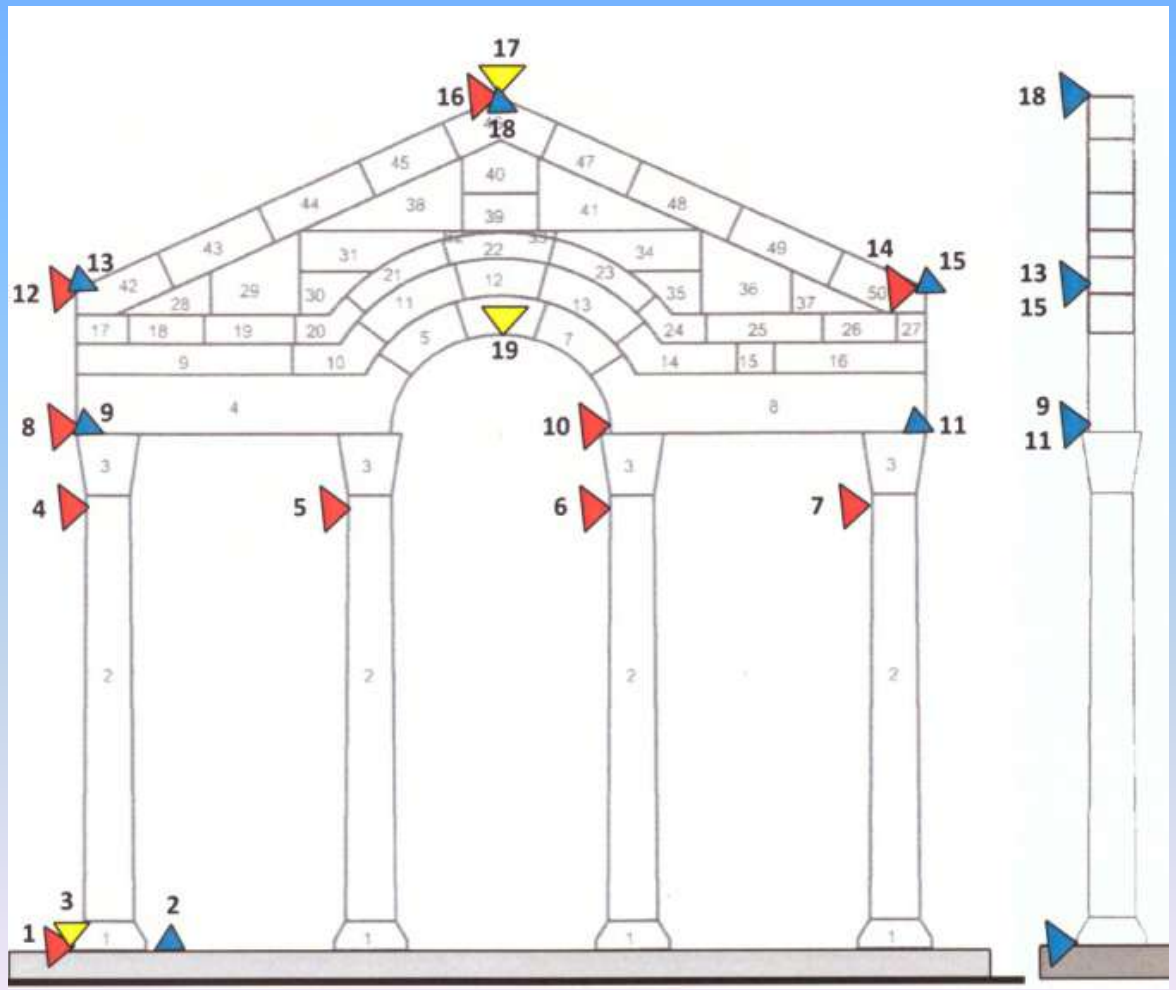
Shaking table in the Laboratory of the Institute for Earthquake Engineering and Engineering Seismolog (IZIIS) in Skopje, North Macedonia (shaking table dimensions: 5 x 5 meters; mass: 33 tons; capacity: 40 tons, max. horizontal displacement: 125 mm; max. horizontal accelaration: 3 g; max. vertical displacement: 60 mm; max. vertical acceleration 1.5 g)

# Instrumentation



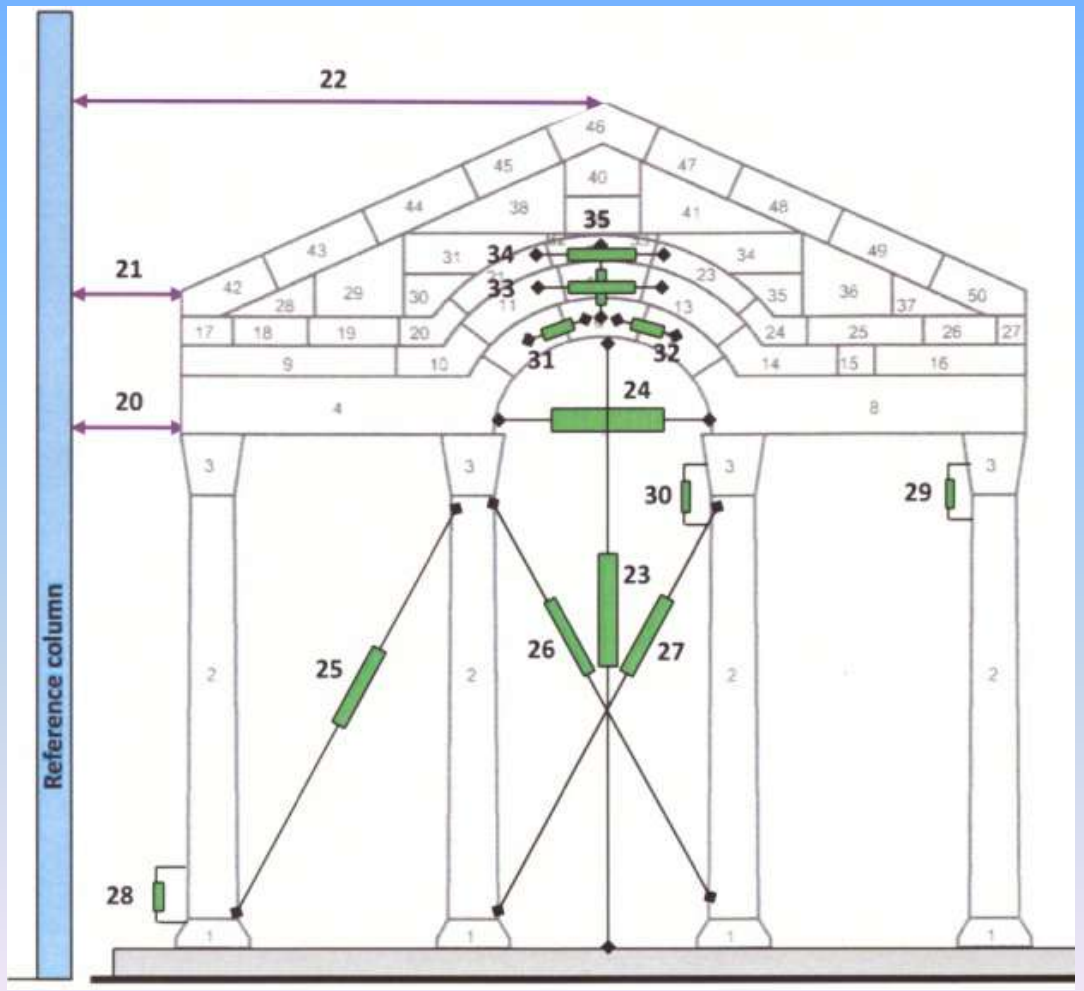

Accelerometer positions (19):

red: horizontally in plane (no. 1, 4-8, 10, 12, 14, and 16);

blue: horizontally out of plane (no. 2, 9, 11, 13, 15, and 18);

yellow: vertikally in plane (no. 3, 17, and 19)

# Instrumentation



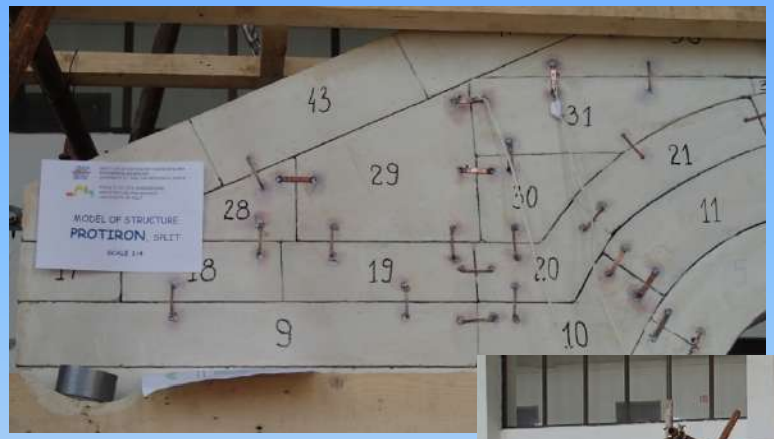

Positions of LP (3) and LVDT (13):

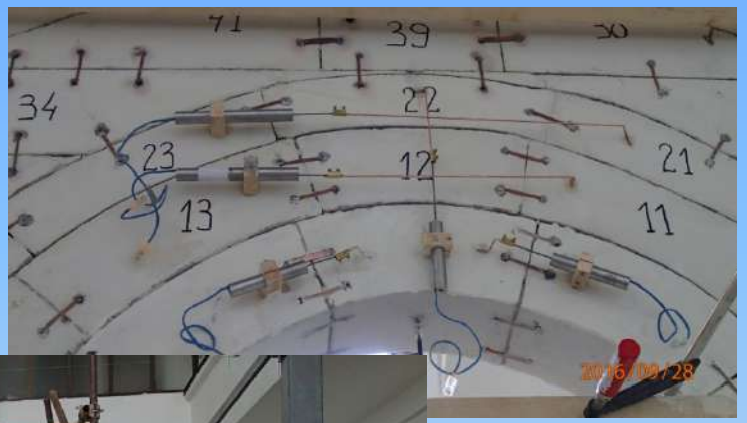
blue: absolute displacements (LP) (no. 20, 21 and 22);

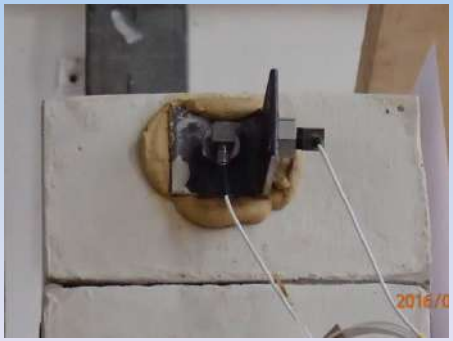
green: relative displacements (LVDT) (no. 23 up to 35)

Strain gages (11) on clamps (not shown)

# Instrumentation

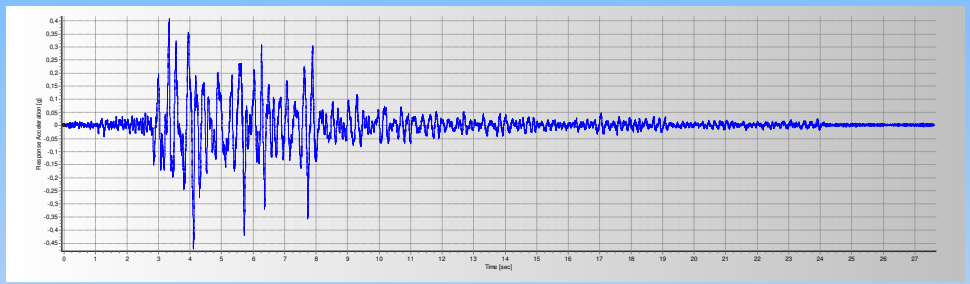


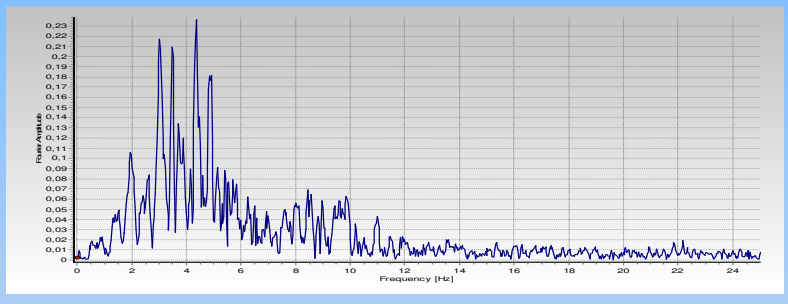




# Examination and results

Selected earthquake: Petrovac (Montenegro) 1979 direction N-S



Condensed earthquake record of Petrovac earthquake (Montenegro) 1979 direction N-S

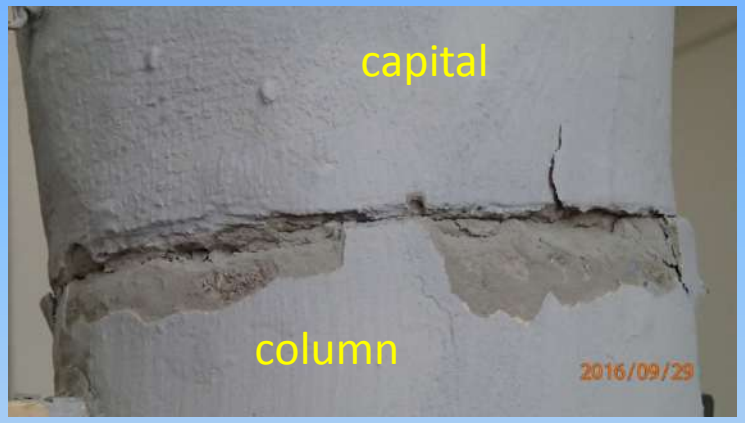


Corresponding Fourier amplitude spectrum (FAS)

A total of 19 seismic tests of input acceleration intensity (excitation acceleration) from 0.017 g to 1.9 g were conducted.

The expected peak ground acceleration of earthquake in the City of Split for return period T = 475 years is $a_g$ = 0.22 g.

# Examination and results





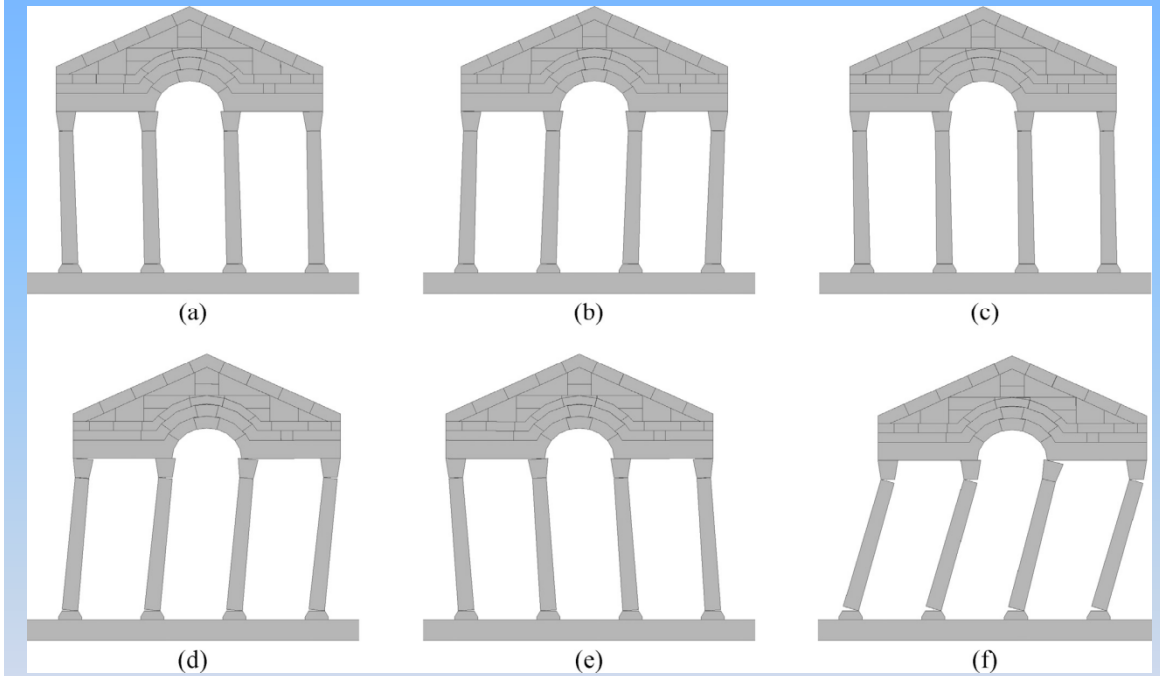

# Examination and results

Separation of the stone blocks in broad gable

Current damage of the real structure


Deformation of the clamps on the model

# Examination and results




Combined finite-discrete element simulation of dry structure with steel bolts and copper clamps

Shaking table examination

# Conclusions

- **For the maximum actually possible earthquake in the region of intensity 0.47 g, the model vibrated stably.** Some joints between stone blocks have opened, but without endangering the stability of the structure. Clamps maintained the connection between the stone blocks as well as the bolts.
- **The earthquake of 1.9 g, which caused the collapse, is far above what can be expected in the City of Split** (an earthquake with an intensity of 0.22 g).
- **The collapse occured due to excessive opening of the contacts at the tops and bottoms of the columns and the los of geometrical stability of the structure.** Namely, the large mass of gable with a large horizontal displacement caused a complete break in the connections of the columns both with the bases and with the gable itself. Clamps kept the stone blocks of the gable in one unit.
- **The obtained results will be used to verify the numerical model** that is being developed so that a more realistic numerical analysis of various real masonry structures connected with clamps and bolts will be possible.

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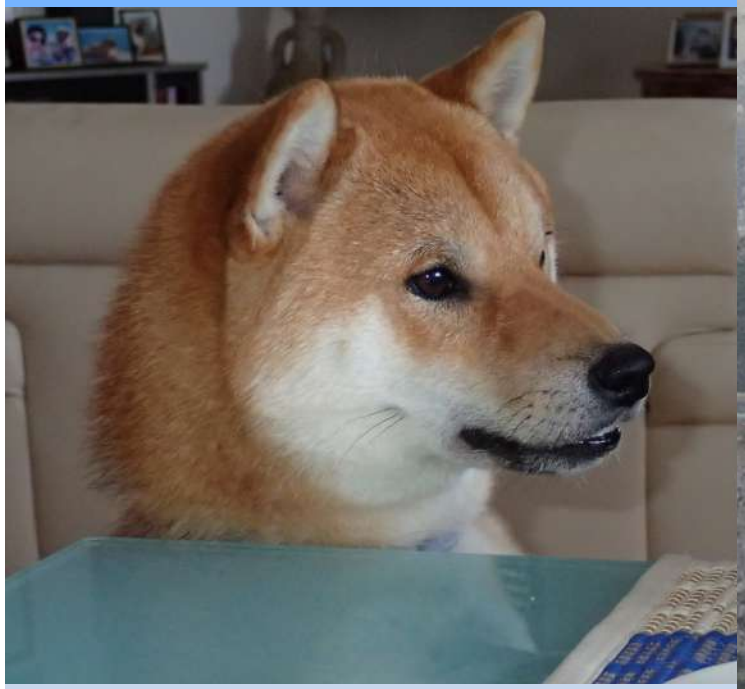

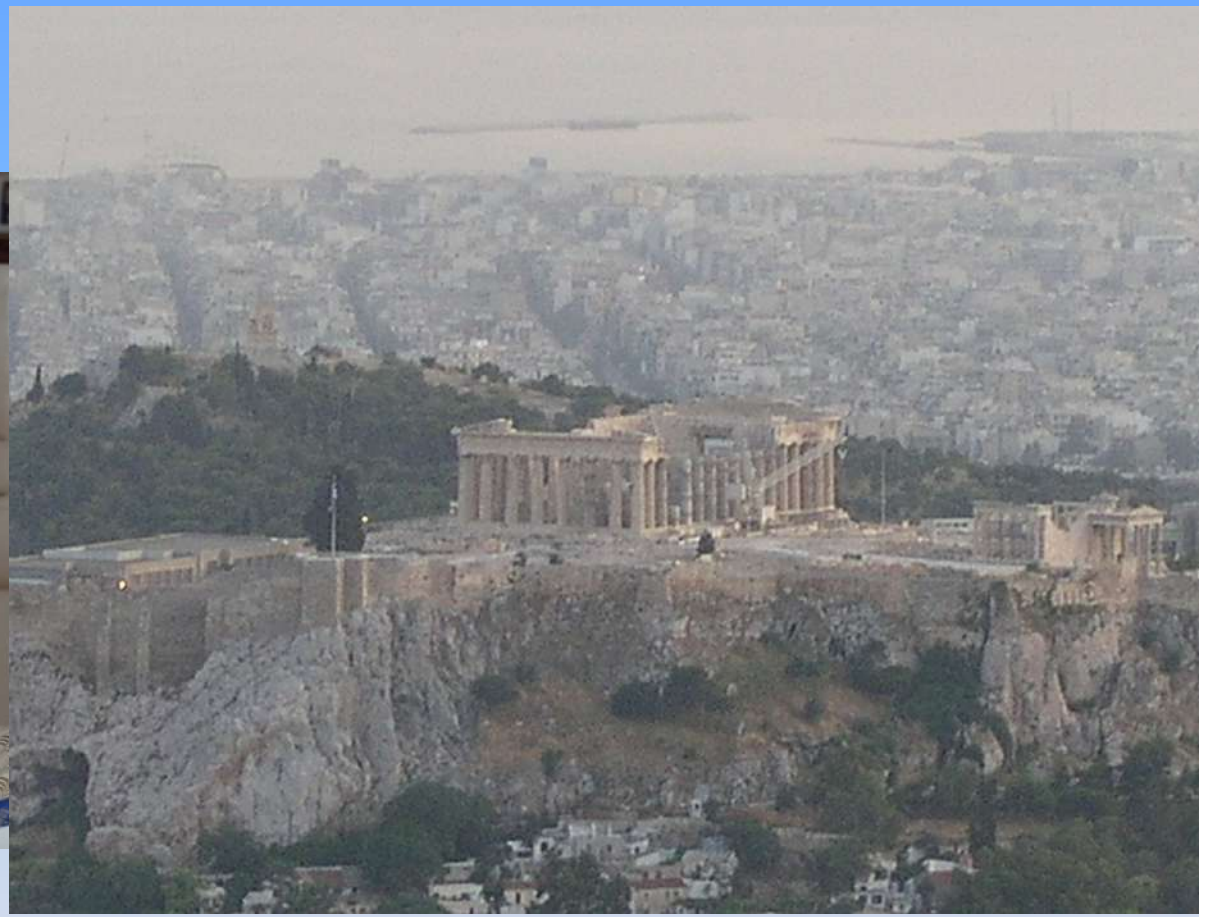

***Thank you for your attention!***