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The rocking columns of Poreč – archaeoseismology in the Istria Peninsula, Croatia

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Abstract: *The Istria Peninsula in Croatia has a number of monuments from Antiquity, which bear evidence of major earthquakes. The Eufrasius Cathedral of Poreč, built in the 6th century, collapsed in parts due to the 1440 earthquake. Wall of the apse and the nave has been twisted. Nave and aisles supported by 18 monolithic marmor columns. Azimuths of dip directions of chipping planes on tops and bottoms indicate N-S shaking. Floor of the 6th century cathedral is 1.9 m above the mosaic floor of a pre-existing 4th century cathedral. The latter one, being 0.3 m above high tide level, only a few metres away from the sea, suggests that there was major coastal subsidence. This event dates the submergence of marine notches of the Adriatic coast between Trieste and Zadar (a 200 x 80 km area) between 4th and 6th century. Earthquake-damaged Arch of the Sergi in Pula (29-27 BC) testifies to site effects nearby the intact Roman amphitheatre. These findings indicate that Istria's ranking among regions of low seismic hazard in Croatia is to be re-considered.*

Key words*: archaeoseismology, Croatia, Roman age, antiquity, Middle Ages, Porec, Pula*

INTRODUCTION

The Istria Peninsula in the northern Adriatic Sea is considered as low-seismicity area, being external to the active faults of the Dinaric frontal range (Fig. 1). Here we report a preliminary survey of buildings surviving from Antiquity, which bear evidence for major earthquakes.

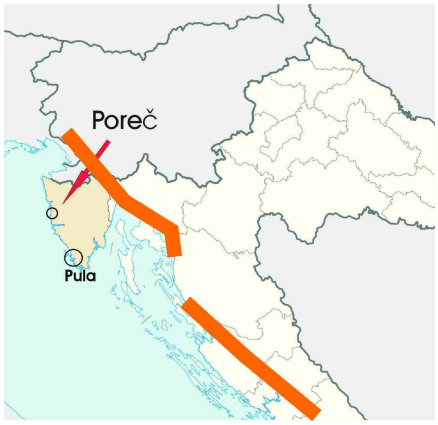

Fig. 1. Istria with studied localities in Croatia. High-seismicity zone of the Dinaric front marked by red (after Markušić & Herak, 1999).

POREČ

Roman Parentium (Italian Parenzo, Croatian Poreč) has been a small coastal city in Late Antiquity. Its episcopal complex, built in 4-6th century, however, is one of a handful of Justinianic monuments to survive essentially intact (Molajoli, 1943). It holds a unique position in the art and architecture of the Early Christian era. The surviving entire cathedral complex – built by bishop Eufrasius in the 6th century – is virtually unparalleled. The complex encompasses a basilica, an atrium, an episcopal palace, and a triconch chapel. The surviving decorative program includes architectural sculpture and furnishings and stucco, along with the superbly preserved wall and floor mosaics (Terry & Maguire, 2007).

In accord with Christian practice, the basilica is oriented east-west. The ground plan forms a slightly irregular rectangle, measuring approx. 19.5 m in width and 38 m in length. Two colonnades, each composed of nine marmor columns, screen the wide central nave from its two narrower, flanking side aisles. At the east, nave and aisles terminate in apses. The main apse projects externally, enclosed by a hexagonal wall; the side apses are inscribed in the masonry of the eastern wall. In elevation the central nave projects above the side aisles. The nave stands ca 18 m tall. The side aisles rise to a height of ca. 11 m (Fig. 2).

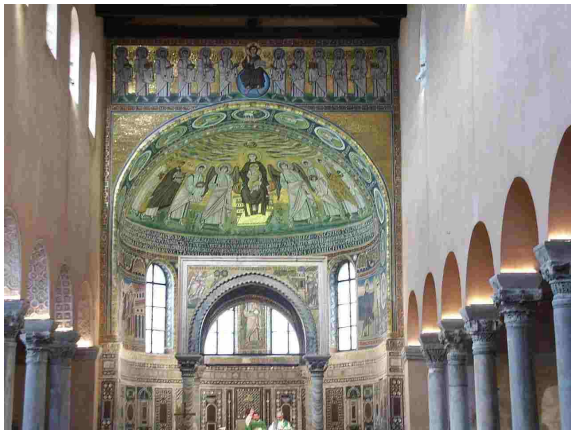

Fig. 2. The Byzantine cathedral of Eufrasius in Poreč, 6th century. Inside view. Note that the left, northern side of the triumphal arch deviates from the vertical. Photo: Loris Romito. http://it.wikipedia.org/wiki/ File:BasilicaMosaici_1.jpg. Accessed 16 June 2013.

In 1440, the basilica was seriously damaged by an earthquake which toppled the upper wall of the nave and most of the south aisle (Babudri, 1913). The columns of the south aisle sustained some damage, while the stucco relief work on the intrads of the south colonnade was completely destroyed.

Columns supporting the nave are of Proconnesian marble imported from the island of Marmara in the Marmara Sea (Terry, 1988: 27). The columns are of approximately uniform height: they range from 3.39 m to 3.58 m. The circumferences at the base of the shafts vary from 1.52 m to 1.77 m. A number of columns are damaged (Figs 3-4) (Terry, 1984; Terry, 1988: 27-28).

Fig. 3. Adjacent chipping both in pillar and capital. Pillar F. #0080

Fig. 4. Chipping in pillar. The adjacent fracture to the right outlines a second chip. Pillar A, plinth. #0076

EARTHQUAKE DAMAGES

Various damages have been observed on the columns: chipped tops and bottoms are common. These were formed when seismic excitation and torsion made the columns rock on the plinth (see Stiros, 1996, fig. 6a).

Chipped parts are either lost, replaced, or repaired with concrete. There are fractures in various dimensions (closed fractures are from geological ages, open fractures are from the site). Part of them are filled. Major fractures are reinforced with old-looking metal rings, now joined with new screws. A detailed list of damages is available in Terry (1988, footnote 71).

The walls of the southern aisle were rebuilt with Gothic windows, while the remainders are in Roman style. It is clear that the south arcade has sustained serious damage, probably from the 1440 earthquake (Terry, 1988, footnote 71).

In addition we measured the azimuth of the chipped and fractured damages by compass and plotted them on Fig. 5.

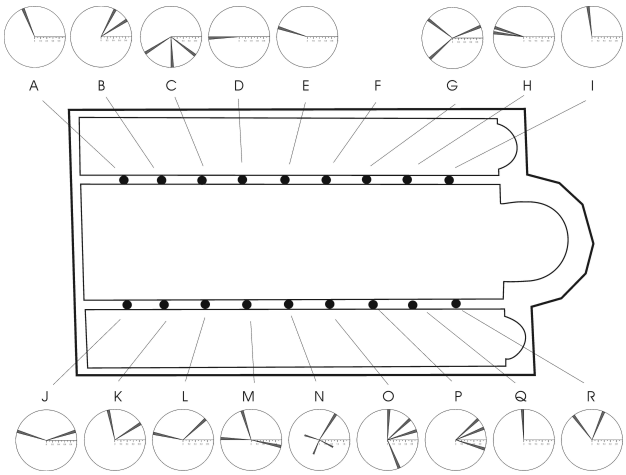

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Fig. 5. Floor plan with azimuths of dip directions of the chipping planes as observed on pillars. Most of them are of no special direction, supporting the conviction that columns are not suitable to determine the direction of earthquake epicentres (Hinzen, 2009). We should note, however, that the Eufrasius columns are fixed both at the base and at the top, therefore bound to move with the rest of the building as long as collapse does not occur. We noted that many directions are towards the north, rather than to the south. Another, prominent direction is more or less parallel with the church axis. Were these free-standing columns, one would account them to N-S strong motion, while it is not necessarily the case here. N-S is the easiest way of significant free vibration of the building, perpendicular to the main axis of the cathedral. Northern row F: this is the only column without chipping.

We noted that walls and columns of the cathedral deviate from the vertical. Northern part of the triumphal arch is clearly tilted outwards (Fig. 2), and top of the adjacent column has shifted about 10 cm to the north as well. Northern wall of the nave is mildly twisted, tilted outwards together with the triumphal arch. An earthquake origin is suggested for similar features, among others, by Kamh et al. (2008). It is noted that the cathedral is not rectangular! Whether it is due to fault dislocation (for an example see Karakhanian et al., 2008) or not, we cannot tell at the moment.

Earthquake parameters

An earthquake occurred in 1440 (Babudri, 1913), which can be responsible for most of the damages visible in the cathedral. We suggest the earthquake intensity is IX on the Rapp scale (Rapp, 1986): IX – good masonry damaged seriously. It yields a M 6.6-7.1 event on the Richter scale.

SEA LEVEL

The 6th century Eufrasius cathedral has been built on top of at least three previous churches, each marked by a buried mosaic floor (Molajoli, 1940; Terry, 1995; Matejčić & Chevalier, 1998). The mosaic floor of the lowermost one, constructed in the 4th century, is 1.9 m below the 6th century cathedral. The lower one, being a mere 30 cm above high tide level, standing no more than 10 m from the sea, is subject to inundations several times a year. It is an impossibly low elevation above sea level for a church as important as this one.

The Istria coastline is known to have been subsided significantly since Roman times, marked by submerged marine notches and submerged Roman ports and other buildings along the coastlines (e.g. Faivre et al., 2010). Suggested dates for submergence range from 361 AD (Benac et al., 2004) to 1500 AD (Faivre et al., 2011). The anomalously low position of the lowermost mosaic level indicate that subsidence occurred between the construction dates of the first and the last cathedrals, i.e. between the 4th and 6th century. Whether the intercalated two mosaic-covered floor levels are related to one or more subsidence events, can be a matter of discussion. We suggest that the subsidence, which lowered all Istria by about 0.5 to 1 m, occurred between 4th and 6th century. Flat top of most submerged marine notches is evidence for single, rapid, seismic subsidence event (Pirazzoli & Evelpidou, 2012).

PULA

Good preservation of the Pula amphitheatre, better preserved than the Colosseum in Rome, suggested to most that that there was no major earthquake in the region during the last two millennium. The amphitheatre's foundation is lying on solid Cretaceous limestone, therefore site effects were probably minimal.

The triumphal Arch of the Sergi at the former city gate of Pola (Porta Aurea) was built between 29 and 27 BC (Dzin, 2009). Apart from minor modern restoration it did not change any during the last two millennia (Fig. 6). Close observation of the masonry revealed various damages attributable to seismic activity. Shifted stones of the arch (Fig. 7) are clearly of the dropped keystone type, described by various authors (e.g. Marco, 2008) as foolproof evidence of earthquake shaking. Broken corners of blocks are further evidences of seismic shaking (Caputo & Helly, 2005; Rodriguez-Pascua et al., 2011).

As the Porta Aurea stands on soft soil, certainly site effects yielded a much higher level of damage than in the virtually undamaged amphitheatre.

IMPLICATIONS FOR SEISMIC HAZARD

Druing the last two milennia Porec and the rest of the Istria peninsula were a seismically quiet area – this is the general understanding, expressed by the seismic zonation scheme of Croatia (Markušić & Herak, 1999). An M 5.1-6.0 seismic event offshore Porec is indicated in the earthquake map of Croatia. However, there are frequent earthquakes above M 6.0 along the various faults of the Dinaric front, 60-70 km to the NE both from Poreč and Pula (Markušić & Herak, 1999)

Fig. 6. Western facade of the Porta Aurea in Pula.

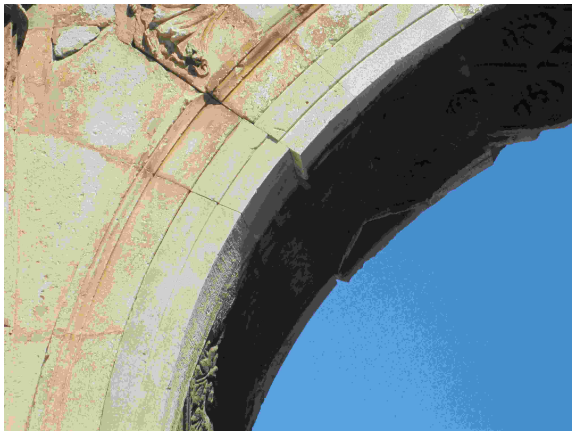

Fig. 7. Porta Aurea, western façade, dropped ashlar in the arch.

The AD 1440 earthquake, which damaged the Poreč cathedral, is not listed in historical catalogues (Herak et al., 1998; Ambraseys, 2009). It was certainly larger than the M 5.1-6 offshore event nearby, which is listed. Whether active faults of the the Dinaric front, those of the Čičarija-Učka range (Prelogovic in Markušić & Herak, 1999), or a suspected fault offshore Istria is responsible, is a matter of further considerations.

The even larger earthquake, which made the old cathedral of Porec and all of Istria submerge by about 0.5-1 m, is a mystery at the moment. All we know is that the area from Trieste in the north to Zadar in the south (about 200 km long and 80 km wide) has been submerged (Faivre et al., 2010). As the mechanism is unknown as yet, we cannot offer any clues for magnitude. It was a big shock anyway, bigger than any other during the last 2000 years.

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