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SEISMIC RESPONSE OF TROPAEUM TRAIANI MONUMENT, ROMANIA, BETWEEN HISTORY AND EARTHQUAKE ENGINEERING ASSESSMENTS

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The stone structure of triumphal monument Tropaeum Traiani was completed by Romans in 109 A.D in the North-Eastern part of Moesia Inferior, the present land of Romanian Province Dobrudja, between Danube and the Black Sea. It consisted of a stepped base, a large cylindrical drum covered with metopes – sculptured scenes of battle, with a truncated conical part over it, continued with a central hexagonal tower having a platform to support the inscriptions, statues of local prisoners and a tall military trophy, the main symbol of victory of Romans over warriors of Dacia and their allies. The diameter of the drum was some 40…43 m and the total height of monument reached some 37…40 m. It is likely to have been based on a design of Apollodor of Damascus, as it was the symbolic pair of Traian's Column in Rome, with 29.78 m height, erected in 115 AD. The site included a funerary military altar for the Roman soldiers fallen in the battles and a tumulus tomb. A fortified Roman City named also Tropaeum Traiani was settled nearby. (Tocilescu et al, 1895; Florescu, F.B., 1965; Barnea et al, 1979; Sampetru, 1984)

Almost all authors agreed that the upper part of the monument could have been destroyed by an earthquake, within some centuries after erection, while the sculpted metopes were dismantled, most probably by people, in a later age (Tocilescu et al, 1895; Sampetru, 1984); a hypothesis of a reconstruction in the III-rd century was suggested (Dorutiu-Boila, 1987).

In the mid-XIX century, the buried core of the drum and some detached stone remnants of the Adamclisi village attracted the attention of governing Ottoman authorities of the epoch and of some travelers and historians. In 1878 Dobrudja became a province of Romania. Eventually, Romanian archaeologist Grigore Tocilescu uncovered the site in 1882 and all movable remnants were gradually transported to Bucharest in 1885-1902. (Tocilescu et al,1895; Barbu and Schuster, 2006). In the 1960's the stone pieces were taken back in an open air exhibition near the drum core, while in 1977 a Tropaeum Traiani reconstruction was built over the core and all original stone pieces are exposed in a dedicated museum.

Thus, the seismic response of Tropaeum Traiani monument is worth of study because of several reasons:

- the monument was unique and very important in European and Worldwide history and history of art; its structure is the only of its kind in Romanian territory, and the only Roman trophy to survive to such extent, having kept the original core and a large number of stone parts, in a rather good state;
- although the literature about the historical and art significance of the trophy and depicted scenes is very rich, to date there is neither a professional assessment of the seismic source and motion size, nor an engineering assessment of dynamic response, based on the damage pattern of this monument;

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- the past archaeological studies recovered most parts of the upper section and data on the possible detailing of structure, there are some data about the places of unearthing, to be studied in correlation with seismic response and overturning;
- some records of recent Vrancea motions were obtained by INCERC Strong Motion Network, hazard analysis are published (Sandi and Borcia, 2011), while some methods of modeling and assessment of rigid bodies motion under earthquake input evolved since 1980's and are available.

For Tropaeum Traiani site, the overall study of seismic setting is proving that:

- the area is at some 150… 200 km of Vrancea seismogenic intermediate source and at some 50…100 km of local shallow / crustal sources of Black Sea Coast and Northern Bulgaria;
- South-Dobrudja faults caused large earthquakes with damage and tsunami in ancient times (M 7.5 in 545? 543? AD at Dionissopoli, near Shabla-Kaliakra fault) (Guidoboni, 1989; Ranguelov et al, 2008). Some archaeological data are taken as a proof that the Roman Fortress Capidava, built also by Traian on the Danube at some 50 km North of Tropaeum Traiani, was destroyed by a great earthquake or/and an invasion at the end of VI-th or beginning of VII-th century AD. (Florescu, R., 1965 and 2000-2001; Covacef, 1988-1989); www.cimec.ro);
- the Vrancea earthquake of 1802 (Mw = 7.9) caused intensity of 8 MSK, while in 1940 (Mw = 7.7) and 1977 (Mw = 7.4) the intensity was 6 MSK in the area of study;
- there are several major faults crossing Dobrudja, but those of mid-part area were not active in the modern ages; in March 31, 1901, Mw 7.2, Io = X MSK, with I = VII-IX MSK in Romanian Dobrudja; other local faults exist in the area of study;
- using some data arising from NPP Cernavoda safety reassessment of magnitude threshold for Vrancea source (Cernavoda NPP Units 1 & 2), a maximum observed magnitude is Mw =7.7 and maximum possible magnitude is Mw = 7.9 is accepted. For Shabla Cape, the maximum observed magnitude is Mw = 7.1 and maximum possible magnitude si Mw = 7.2. Magnitudes for Dulovo Source, Intramoesic Fault and local earthquakes are lower. The same data source (www.cne.ro) indicated in 2007 the acceleration level as a = 0.2 g for I = VIII MSK (DBE) and a = 0.1 g for I = VII MSK (SDE);
- the Code P100-1/2006 gives a design acceleration PGA of 0.16 g for 100 years recurrence interval, while the new zoning map of Code P100-1/2013 gives a design acceleration of 0.20 g for 225 years recurrence interval (Code P100-1/2006 and P100-1/2013).

The paper will present the preliminary results of the study, aiming at:

- checking how and if the Vrancea or Dobrudja sources would have been affecting the monument; enabling a comparison between seismic sources;
- checking the hypothesis and consequences of a motion with similarities of one of the May 30, 1990 Vrancea earthquakes recorded by INCERC in Cernavoda, having some effects just in Adamclisi Museum, proving a directivity that was different of Vrancea usual motions (Sandi and Borcia, 2011).
- checking data of size, arrangement and detailing and suggesting alternative hypotheses for a structural – dynamic model of base construction and of upper stack of statues and trophy, which may differ of the reconstruction of 1977, based on existing parts and engineering assessment;
- deriving on this background the earthquake resisting capacity of specific sections, and to use a reverse technique to obtain some input accelerations likely to have been able to initiate shearing, oscillation and overturning of specific parts of the monument, and, if possible, correlations with spectral content of motion;
- assessing some patterns of amplification at different heights and the directivity of motion vs. capacity of resistance, direction and place of collapse, in correlation with places of unearthing, and ascertaining, in allowable limits, if the damage could have been man-made;
- deriving patterns and mechanisms of upper parts collapse, the possibility and extent of collision between falling and base parts during collapse.

It is known that the first thousand years AD is not covered by the Romanian Catalogue of earthquakes, as it begins at 984 AD (www.infp.ro). For the period 1100-1973, Purcaru (1974) assessed a specific regularity of great Vrancea earthquakes occurrence, with 3 periods on century, quasicycles of ca. 100 years and supercycles of ca. 300 years; other authors, indicated 3 peaks of activity per century (Enescu et al, 1974). Since the data in the first thousand of years AD are scarce, and a backward assessment of how would have struck Vrancea during the first millennium is not yet available, the study will include an attempt to estimate a range of historical span of time for the event that destroyed the monument. It would be of interest to evaluate whether the physics of the Vrancea source may allow quasicycles or supercycles (as in Purcaru, 1974) but without large events inside a century, while greater events occurred at 100…300 years interval, proving thus a considerable time-gap. Reversely, if the intra-century earthquakes and said cycles existed, as in the last thousand of years, their traces in the life disturbances of ancient civilizations must be investigated.

Thus, the study is bridging the gaps between history, archaeology, seismology, architecture and earthquake engineering, while reinterpreting data gathered separately by each discipline across of over 120 years. Starting from forensic engineering studies, a new insight is possible, with results useful for earthquake design of important facilities in the area, if traces and data are recovered and interpreted (Georgescu, 2004).

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