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SPECIAL ISSUE: LESSONS FROM THE PAST: THE EVOLUTION OF SEISMIC PROTECTION TECHNIQUES IN THE HISTORY OF BUILDING

PREFACE

“Grecae magnificentiae vera admiratio extat templum Ephesiae Dianae CXX annis factum a tota Asia. In solo id palustri fecere, ne terrae motus sentiret aut hiatus timeret, rursus ne in lubrico atque instabili fondamenta tantae molis locarentur, calcatis ea substravere carbonibus, dein velleribus lanae”. With these words, Gaius Plinius Secundus, better known as Pliny the Elder, in his Naturalis Historia (XXXVI, §95), described the Temple of Artemis at Ephesus, one of the largest temples built by Greeks and one of the seven wonders in the ancient world. Recent historic studies allowed pointing out that the foundations were composed by a continuous stone plate separated from a thin layer of marshland by means of a layer of clay mixed with charcoal and ashes [Carpani, 2017]. Nowadays those layers are interpreted as a pioneering base isolation system.

Actually, several ancient Greek temples were protected by seismic isolation systems. According to Diogenes Laërtius (3rd century AD), this technique was first used by Theodoros of Samos, a great architect of the 6th century BC. He applied also a similar technique to the Temple of Hera at Samos, which had a footing foundation with a thin layer of gravel above a deeper layer of sand. Also the Greek colonies on the Black Sea had foundations made of layers of ash mixed with coal and loess. The Walls of Troy VI (ca. 1300 BC) were founded on a compact “cushion of earth”, as defined by Blegen who excavated them, which separated the foundation from the rock [Blegen, Caskey, Rawson, 1953]. Finally, at Paestum, Italy, three Doric temples, among these the Temple of Athena (6th century BC), have a sand layer between the foundations and the soil.

Anti-seismic techniques were also used in Chinese monasteries, temples and bridges, as well as for some buildings in Anatolia. In Peru the Monastery of Santa Catalina, about 1000 km south of Lima, has foundations on a 1 m deep isolating layer of sand, allowing the structure to settle without damage. It supported devastating earthquakes. Also the great walls of Cuzco, probably built with the same technique, supported very strong seismic events.

The same concept was also used by Frank Lloyd Wright for the Imperial Hotel in Tokyo, whose foundations were placed on a compact soil layer, about 2 m deep, in turn resting on a layer of muddy silts of about 20 m. The construction was completed in 1921 and, probably thanks to this comfortable cushion, supported the 1923 Tokyo earthquake, which caused the collapse of many buildings.

In the structures of the Citadel of Casbah, in Alger, all arches present wooden rollers at their springing. They are in one direction only, so they cannot be interpreted as seismic isolators but just as bearings which cannot transfer horizontal thrusts to the slim columns. Seismic isolators could be those under the foundation plinths, where they are in two orthogonal directions. Similar timber grillage foundations were used in several countries, such as those in vernacular architecture in Iran.

These are just a few examples of how the problem of seismic protection was faced in the past. Base isolation, in particular, is just an example, maybe one of the most interesting, of how the knowledge of the ancient techniques can be useful also in the present [Clemente, 2017]. The ideas of the past, which made it possible to create wonderful structures, which have survived up to our age, can now find even more effective applications thanks to the evolution of technology and the availability of new materials.

The analysis of cultural heritage structures has already been the subject of a previous special issue of this journal [Clemente et al., 2017], as well as other specialized journals [Clemente, 2018]. The papers included in these special issues pointed out that a suitable way to successfully proceed in the preservation effort of monumental structures should be based on the integrated use of different non-invasive diagnostic techniques, aimed at understanding the geological and geotechnical features of the areas where monuments are founded and the structural characteristic of the construction itself. A detailed state-of-the-art on the structural health monitoring of cultural heritage structures is in De Stefano et al. [2016].

In this issue, different construction techniques for the seismic protection used in the past are presented, as well as studies on the materials used and a state-of-the-art and new trends in the static and dynamic monitoring of cultural heritage structures. The issue includes twelve papers regarding both geophysical and structural topics, pointing out the importance of a multidisciplinary approach when studying ar-

chaeological sites and structures. Three main lines can be identified. The first is the historical analysis and includes five papers, the second the evaluation of the historical construction and monuments with six papers, and the last paper is about the trends for the future.
The paper by Alberti [2019] introduces this special issue, reminding that earthquakes were a well-known phenomenon in antiquity, which inspire myths and require the creation of apotropaic cults. In Aegean Bronze Age architecture, a series of anti-seismic practices were early developed. In Minoan palaces in particular, lighter walls were superimposed on stone ones built at basement or ground floor levels. Using vertical, horizontal and cross timbers they put up wooden frames into which stone and mudbrick elements were integrated and bonded, and over which clay and plaster were later applied (Figure 1). The paper investigates how extensively these techniques are spread in the Mediterranean basin and elsewhere, both in ancient and modern times, and how they can be applied to contemporary architecture in a more sustainable way.

FIGURE 1. On the left reconstruction of a wall in Tylissos with stone socle, timber frame and rubble filled interior [Shaw, 1971]; on the right timber traces in the Hagia Triada villa [Tsakanika and Theohari, 2009].

Fiandaca and Lione [2019] analyse the pre- and post-1908 earthquake situation of Messina city. It is well known that the tragic earthquake of 1908 affects the area of the Messina Strait already strongly proved in previous centuries. With the reconstruction, which followed the destroy of the city, Messina became a building site of verification of previous construction solutions and experimentation of "innovative" technique, new methods of calculation and ad hoc regulations. The article analyses the pre- and post-earthquake situation of 1908, with particular attention to the composition of lands, sub-layers, foundations and of the structures in elevation. In particular, it lingers on the Via Risorgimento area, which has a rich palimpsest of techniques and shrewdness of that period (Figure 2).

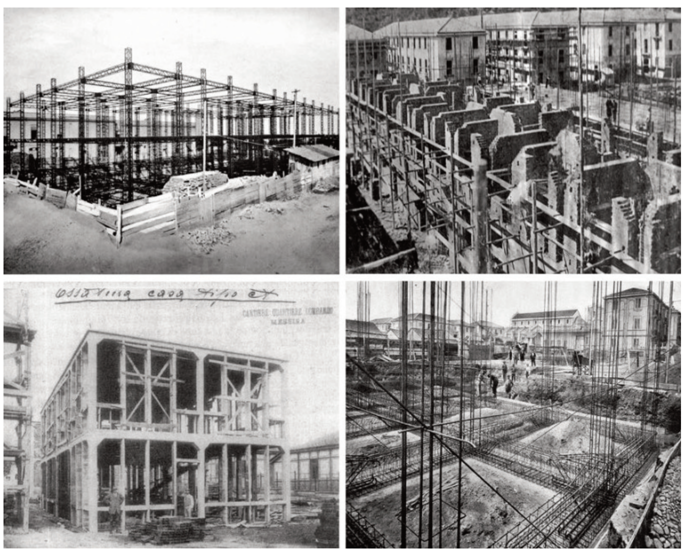

FIGURE 2. Construction systems for "anti–seismic" structures permitted after 1908 Messina earthquake: frames of steel (1909 et seq.); reinforced masonry (from 1912 to 1924); reinforced concrete frames with diagonal bracings (1909); frames in reinforced concrete with rigid knots (1909 and then since 1924).

The contribution of Arrighetti and Minutoli [2019] outlines a methodological program designed with the purpose of offering an innovative and multidisciplinary analysis of seismic protection techniques in historical architecture of Mugello, a medium-high risk seismic area between Tuscany and Emilia Romagna. This analysis can allow the breaking up and dating of the single construction and destruction actions present in a building, leading to the identification of some uncommon elements in respect to traditional construction techniques, being able to interpret a specific function (Figure 3).

FIGURE 3. Wooden chain inserted in an internal corner of the belfry of the Church of San Lorenzo in Borgo San Lorenzo (FI).

It is thus only through the analysis of this complex mechanism that is established over time that identification of anomalies within the building becomes possible. Applying this research methodology to a building, or even better to a whole area, allows the identification and dating of the potential presence of safeguards related to earthquakes.

Diskaya [2019] investigates the earthquake-resistant timber constructions and the use of wooden material as an absorbing element for seismic actions in Anatolia. Proven to be safe due to their lightness and ductile nature, wooden buildings have gained importance in the course of time in Turkey, which suffered numerous severe and destructive earthquakes. The seismic structure, forests and timber residential placements of Turkey have been studied in relation with each other at first. The structural characteristics that render a traditional timber building earthquake-resistant were researched according to the regional distribution, material and structural features and the most advanced structural systems used in both timber and timber-masonry composite systems were demonstrated as living examples today (Figure 4).

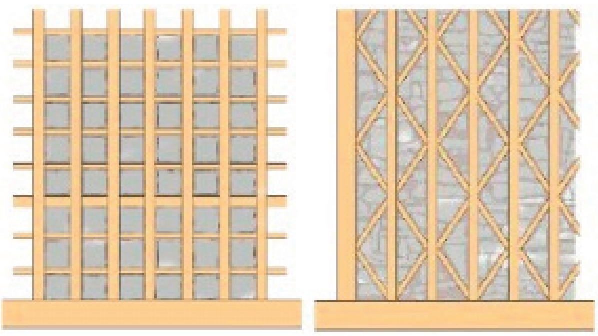

FIGURE 4. a) "Göz dolması technique" and b) "Muska dolgu technique" in the Black Sea Region.

Codes are a fundamental part of the overall strategy for the reduction of seismic risk. Marotta et al. [2019] gave a historical analysis of the seismic codes after the 1859 Norcia (Central Italy) and 1883 Ischia (Southern Italy) earthquakes, both of them a remarkable attempt to improve the performance of ordinary unreinforced masonry structures by regulating architectural configuration and structural details (Figure 5).

Both documents represent a codification of earthquake-resistant techniques used in seismic zones in accordance with best practice, still extraordinarily relevant when compared with both recent standard recommendations about structural details and with the performance observed during the 2016 and 2017 earthquakes.

Braga et al. [2019] present the analysis of the structural performance of the Armenian Church in Famagusta, Cyprus (Figure 6).

FIGURE 5. Example of damage occurring in: a) Norcia, after the 2016 earthquake and b) Ischia, after the 2017 earthquake.

FIGURE 6. The Armenian Church view from the southwest.

FIGURE 7. Views of the Stylite Tower at Umm ar–Rasas.

Visual and photographic survey, non-destructive testing and numerical evaluation, using a tridimensional finite element model, are included. Results has been studied in terms of capacity curves and damage patterns. The influence of the church mass-distribution has also been evaluated. The analysis has estimated an adequate safety level of the building, while various real damage features of the church have been justified and attributed to seismic actions. The Stylite Tower, which is part of the UNESCO archaeological site of Umm ar-Rasas (Figure 7), Jordan, is the subject of the papers by Cozzolino et al. [2019] and Clemente at al. [2019]. The monument, a symbol and emblem of Jordan's history and culture, has evident signs of deterioration. In the first paper, a high-detail analysis of the state of conservation of the Tower has been achieved through the realization of 3D geometrical survey (Photogrammetry and Laser Scanner) and non-invasive geophysical surveys (using Ground Penetrating Radar Technique). In the second one, the stability and vulnerability analyses carried out on the Tower are presented. The soil and the structural material have been analysed by means of in situ experimental tests, as Schmidt-hammer tests on stone blocks and passive seismic measurements. The stability of the tower has been first analysed, assuming an elastic – perfect plastic behaviour in compression for masonry. Then the push-over seismic analysis has been carried out, which has been based on a single-mode approach and a finite solid element modelling with a Drucker-Prager yield criterion for masonry. The analysis is propaedeutic to the design of a retrofit intervention.

Mirabile Gattia et al. [2019] analysed the historical masonry mortar from sites damaged during the Central Italy 2016-2017 seismic sequence, with particular reference to the village of Arquata del Tronto. It is well known that the mortar quality is a fundamental parameter that influence the structural behavior of masonry, especially under seismic actions (Figure 8).

The authors carried out both diagnostic techniques and mechanical test, in order to correlate the obtained values with the performance of the original masonry. The results of the analysis could be useful as support for future research, supplying information for establishing priorities of intervention for repairing, consolidation and reconstruction activities.

The experimental and numerical investigations on the seismic response of the San Frediano Bell tower in Lucca (Figure 9) is the subject of the paper by Azzara et al. [2019]. During a monitoring campaign for about one year, many seismic events were recorded. The most relevant turned out to be the Amatrice earthquake, which struck Central Italy on August 24th, 2016. A review of the experimental results obtained has first been shown.

Then, a finite element numerical model of the tower has been presented and validated via model updating, by assuming the hypothesis of no tensile strength for the material. The experimental records of the Amatrice earthquake have been also included and a numerical simulation of the tower subjected to the Lunigiana earthquake, recorded at Fivizzano (Tuscany) on June 21st, 2013, has been performed. The results pointed out the sensitivity of the tower to seismic actions.

Cozzolino et al. [2019] present the results of the surveys carried out on the Abbey of Santa Maria a Mare at San Nicola (Tremiti Islands, Italy, Figure 10), a monument in a significant state of degradation. In order to define the restoration interventions, the structure has been analysed through the realization of 3D metric surveys (photogrammetry and laser scanner) and non-invasive geophysical surveys (Ground Penetrating Radar Technique). The use of non-destructive testing techniques allowed a proper representation of the conservation status of the abbey, which constitutes a key element of knowledge in order to guarantee the success of a restoration project, the valorisation and the fruition of the monument itself.

Catalano [2019], finally, posed the attention on the introduction of nanotechnologies in concrete band composite structures. These allowed to increase significantly the strength of concrete and to introduce the ductility due to the tensile strength. Furthermore, they are consistent with the capacity design and the formation of plastic hinges. The author underlines also that the behaviour of such structures in seismic zone should be beater investigate as well as the influence of the creep.

The variety of the issues presented in the papers testifies the importance of studying deeply the historical constructions and the anti-seismic techniques used by the ancient peoples. Furthermore, Structural Health Monitoring is a must to extend the life span of historical constructions, with light and preventive maintenance.

FIGURE 8. Mortar sampling campaign in Pretare – St. Rocco Church (Arquata del Tronto).

FIGURE 9. The San Frediano Bell Tower in Lucca.

FIGURE 10. Laser scanner Focus 3D MS120 (FARO) (a), mesh visualization of the model (b), RGB visualization of the cloud points (c, d).

REFERENCES

Alberti L. (2019). Lessons from the past: some Greek Bronze Age responses to natural disasters and their modern counterpart. Annals of Geophysics, This issue, doi: 10.4401/ag-8143.

Arrighetti A. and G. Minutoli (2019). A multidisciplinary approach to document and analyze seismic protection techniques in Mugello from the Middle Ages to Early Modern Time. Annals of Geophysics, This issue, doi: 10.4401/ag-7991.

Azzara R.M., M. Girardi, C. Padovani, D. Pellegrini (2019). Experimental and numerical investigations on the seismic behaviour of the San Frediano bell tower in Lucca. Annals of Geophysics, This issue, doi: 10.4401/ag-8025.

Blegen C.W., J.L. Caskey, M. Rawson (1953). Troy: Excavations conducted by the University of Cincinnati 1932–1938. Vol. III - The Sixth Settlement. Princeton.

Braga A.B., P.B. Lourenco, N. Mendes (2019). Seismic assessment of the medieval Armenian church in Famagusta, Cyprus. Annals of Geophysics, This issue, doi: 10.4401/ag-7076.

Carpani B. (2017). Base isolation from a historical perspective. In: Proceedings of 16th World Conference on Earth. Engineering (16WCEE, Santiago del Chile, Jan 9-13), IAEE & ACHISINA.

Catalano A. (2019). Nanotechnologies for concrete and composed structures for seismic safety, Annals of Geophysics, This issue, doi: 10.4401/ag-7981.

Clemente P. (2017). Seismic isolation: past, present and the importance of SHM for the future. J. of Civil Structural Health Monitoring, Springer, Vol. 7, No. 2, 217-231, doi: 10.1007/s13349-017-0219-6.

Clemente P. (2018). Extending the life span of cultural heritage structure, Foreword to Structural Health Monitoring of Cultural Heritage Structures, Special Issue of J. Civil Structural Health Monitoring, Springer, 8, 2, 171-179, doi: 10.1007/s13349-018-0278-3.

Clemente P., G. Delmonaco, L.M. Puzzilli, F. Saitta (2019). Stability and seismic vulnerability of the Stylite Tower at Umm Ar-Rasas. Annals of Geophysics. This issue, doi: 10.4401/ag-8004.

Clemente P., S. Hailemikael, G. Milana, L. Orlando (2017). Monitoring and Seismic Characterization of Archaeological Sites and Structures. Preface, Foreword to Special Issue "Monitoring and Seismic Characterization of Archaeological Sites and Structures" of Annals of Geophysics, Vol. 60, No. 4, S0447; doi: 10.4401/ag-7480.

Cozzolino M., A. Di Meo, V. Gentile (2019). The contribution of indirect topographic surveys (photogrammetry and laser scanner) and GPR investigations in the study of the vulnerability of the Abbey of Santa Maria a Mare, Tremiti Islands (Italy). Annals of Geophysics, This issue, doi: 10.4401/ag-7987.

Cozzolino M., R. Gabrielli, P. Galatà, G. Gentile, G. Greco, E. Scopinaro (2019). Combined use of 3D metric surveys and non-invasive geophysical surveys for the determination of the state of conservation of the Stylite Tower (Umm ar-Rasas, Jordan). Annals of Geophysics, This issue, doi: 10.4401/ag-8060.

De Stefano A., E. Matta, P. Clemente (2016). Structural health monitoring of historical heritage in Italy: some relevant experience. J. of Civil Structural Health Monitoring, Vol. 6, No. 1, 83-106, Springer, doi: 10.1007/s13349-016-0154-y.

Diskaya H. (2019). The evolution of earthquake-resistant timber constructions in Anatolia, based on archaeological data. Annals of Geophysics, This issue, doi: 10.4401/ag-7996.

Fiandaca O., R. Lione (2019). Messina: story of a town "expert" on earthquakes Via Risorgimento, a palimpsest of "anti-seismic" building system. Annals of Geophysics, This issue, doi: 10.4401/ag-7961.

Marotta A., D. Liberatore, L. Sorrentino (2019). Historical Building Codes issued after the strong Italian earthquakes of Norcia (1859) and Ischia (1883). Annals of Geophysics, This issue, doi: 10.4401/ag-7986.

Mirabile Gattia D., G. Roselli, O. Alshawa, P. Cinaglia, G. Di Girolami, C. Francola, F. Persia, E. Petrucci, R. Piloni, F. Scognamiglio, L. Sorrentino, S. Zamponi, D. Liberatore (2019). Characterization of historical masonry mortar from sites damaged during the Central Italy 2016-2017 seismic sequence: the case study of Arquata del Tronto. Annals of Geophysics, This issue, doi: 10.4401/ag-8019.

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