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## PREFACE

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### 1. Introduction

The preservation of cultural heritage is a crucial issue in areas prone to seismic and other natural hazards. The major challenge in pursuing such an important objective is related to the extreme fragility of ancient monuments and buildings exposed for centuries to the ravages of time.

A suitable way to successfully proceed in the preservation effort of monumental structures should be based on then 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.

In this perspective a team composed by researchers of ENEA, INGV and Sapienza University of Rome has recently carried out geophysical and structural investigations on the Amphitheatrum Flavium in Rome, better known as Colosseum, which is the symbol of monumental heritage in Italy and well-known all over the world. The experimental campaign was only a preliminary analysis of the very famous archaeological site that allowed outlining the state of knowledge about the characteristics of the site and the structure and should be considered as a starting point for an in-depth investigation of the monument vulnerability. In our opinion, the benefits of such an integrated approach can steer the political and social choices related with the preservation of the cultural heritage at National or European level.

The results obtained were very interesting and induced the authors to propose their publication in a special issue of an international journal. The scope of this choice was twofold: ensuring both a wide audience with these activities and a serious review process of the studies. Therefore, we selected the most interesting results of the experimental campaign and invited a number of researchers involved in the field of “Monitoring and Seismic Characterization of Archaeological Sites and Structures” to contribute to this special issue.

The relevance of this volume has been emphasized by the occurrence of the recent seismic sequence in Central Italy, whose mainshocks of August 24th and October 26th and 30th, 2016, caused 298 victims, hundreds of injured and the damage to most of the cultural heritage in the area. Symbol of the open wound left by the seismic sequence on the monumental patrimony is the San Benedetto Cathedral in Norcia. The morning of October 30th only the façade of the church, which is dedicated to the Patron Saint of Europe and represents the emblem of the medieval architecture in Central Italy dating back to XIII century, was still standing. It is worth noting that the mainshocks were clearly felt in Rome, at distance of about 100 km.

### 2. Volume contents

The issue includes twelve papers regarding both geophysical and structural topics, pointing out the importance of a multidisciplinary approach when studying archaeological sites and structures.

In the first paper, Bozzano et al. [2017-this issue] present the evaluation of the Local Seismic Response (LSR) along the ancient Roman Road Laurentina, which has been exhumed in several areas of south-west Rome over the last decade during the construction of new structures. It is an example of LSR analysis applied to ancient and archaeological sites resting on alluvial valleys with some methodological inferences for the design of infrastructure and urban planning.

The next four papers are dedicated to the Amphitheatrum Flavium.

In the first one, Cardarelli et al., [2017-this issue] present the results of non-invasive geophysical investigations carried out on the subsoil below the archaeological site. The new experimental results contribute to link the reference geologic model to the specific conditions of the anthropic layer and the seismic bedrock at the monumental site, as well as the foundations and the buried parts of the monument below the former arena, providing key input data for the assessment of the response of the Colosseum under dynamic loading.

In the second one, Orlando et al., [2017-this issue] report the results of the non-invasive investigation of the foundations, carried out by georadar surveys along the so called "Passage of Commodus", dug in the foundation. They demonstrate that the foundations of the Colosseum are characterized by a heterogeneous multi-layer structure, with the presence of a cavity network and of buried anomalies, likely due to the extension of load-bearing structural elements underground.

Hailemikaël et al. [2017-this issue] with the aim of understanding the seismic response of the area and investigating the soil-structure interactions, performed seismic experiments based on ambient vibration recordings. Measurements were performed at the original ground level, on the foundations and at different floors of the monument. Data were analysed in terms of standard Fourier analysis (FAS) and horizontal-to-vertical spectral ratio technique (H/V).

Finally, Bongiovanni et al. [2017-this issue] studied the effects of ambient and traffic-induced vibrations on the external northern wall of the Amphitheatrum Flavium, with the two objectives of analysing the amplitudes of such vibrations and extracting the dynamic characteristics of the structure as part of preservation effort. Data processing consisted in the time domain and frequency domain analyses, in which Fourier transform, power spectral density and cross spectral density were used to extract resonance frequencies, modal shapes and damping.

The successive papers deal with new methods and proposals aimed at the preservation of structures of historical importance, which are tested with other very important archaeological sites and monuments.

Sboras et al. [2017-this issue] propose a GIS-based data-base, developed to collect and combine all necessary data about the monuments and their regional geological and seismotectonic conditions, and to assess seismic hazard for each and every monument using the most modern techniques. In the paper the structure and development of the data-base is presented, and a methodological procedure for estimating seismic hazard in Greece for the structural assessment of historical structures is presented.

Azzara et al. [2017-this issue] report on a vibration measurements campaign performed on the medieval Maddalena Bridge, over the Serchio River in Borgo a Mozzano (Italy), one of the most fascinating in Italy. A monitoring system has been installed on the bridge and the natural frequencies and mode shapes of the structure and the corresponding damping ratios have been obtained by analysing the recorded data using different techniques of Operational Modal Analysis.

The paper by Masciotta et al. [2017-this issue] deals with the dynamic characterisation of a historical masonry chimney aimed at identifying the structural damage and assessing its seismic performance. The structure was severely damaged by a lightning accident and in-depth repair works were executed to re-instate its sound configuration. The case study is fully detailed, including the aspects of survey, inspection, diagnosis, and evolution of the dynamic properties of the system throughout the structural intervention.

Hinzen [2017-this issue] faces the problem of rigid blocks under seismic input. He uses simply structured

discrete element models of four walls with different block geometries, perfect rectangular, an Inka-type structure and two polygonal designs, to test their dynamic behaviour. He also uses measured strong motion signals as boundary conditions for the 3D wall models with varying height to width ratios.

Schwepe et al. [2017-this issue] propose to use ancient manmade structures, delicate in terms of stability and particularly those that have survived earthquake ground motions intact, for a rough estimation of the ground motion that has not been reached or exceeded at the site. They suggest using them as local seismoscopes for determining maximum upper ground motion bounds. They applied this concept to the ruin of the Roman temple of Kedesh, located in close proximity to a branch of the Dead Sea Transform Fault.

In the paper by Minos-Minopoulos et al. [2017-this issue] an indicator-based method for assessing the vulnerability of archaeological sites to earthquakes is presented and tested, which is based on the definition of two indices, the Spatial Susceptibility Index and the Temporal Vulnerability Index, whose sum give the Archaeological Site Vulnerability Index. The method is applied to 16 archaeological sites across Greece, allowing an assessment of their vulnerability. This then allows the establishment of a regional and national priority list for considering future risk mitigation strategies.

Riccio et al. [2017-this issue] carried out a vibration study experiment on a masonry building, using six-channel stations equipped with three-component velocity-transducers and accelerometers and running in continuous modality. The analysis of weak motions from several local earthquakes, together with the 3D numerical modelling of the structure, allowed identifying the first three vibration modes of the target building.

### 3. Conclusions

The variety of the issues presented in the papers testifies the complexity of the analysis of the behaviour of archaeological sites and structures under dynamic loading and the evaluation of their seismic vulnerability, we believe that the monitoring represents an effective tool to improve significantly our knowledge towards the definition of seismic risk mitigation plans.

### References

- Bozzano, F., Buccellato, A., Coletti F., Martino, S., Marra, F., Rivellino, S., Varone, C. (2017). "Analysis of the seismic site effects along the ancient via Laurentina in Rome", *Annals of Geophysics*, 60, 4; doi: 10.4401/ag-7140.
- Cardarelli, E., Cercato, M., Orlando, L. (2017). "Geometry and seismic characterization of the subsoil below the Amphitheatrum Flavium in Rome", *Annals of Geophysics*, 60, 4; doi: 10.4401/ag-7124.
- Orlando, L., De Donno, G., Di Giambattista, L., Palladini, L. (2017). "Investigating the foundation of the Amphitheatrum Flavium through the passage of Commodus", *Annals of Geophysics*, 60, 4; doi: 10.4401/ag-7183.
- Hailemikaël, S., Milana, G., Cara, F., Vassallo, M., Pischiutta, M., Amoroso, S., Bordoni, P., Cantore, L., Di Giulio, G., Di Naccio, D., Famiani, D., Mercuri, A. (2017). "Sub-surface characterization of the Amphitheatrum Flavium area in Rome through single-station ambient vibration measurements", *Annals of Geophysics*, 60, 4; doi: 10.4401/ag-7359.
- Bongiovanni, G., Buffarini, G., Clemente, P., Rinaldis, D., Saitta, F. (2017). "Dynamic characteristics of the Amphitheatrum Flavium northern wall from traffic-induced vibrations", *Annals of Geophysics*, 60, 4; doi: 10.4401/ag-7178.
- Sboras, S., Dourakopoulos, J.A., Mouzakiotis, E., Dafnis, P., Palantzas, T., Karastathis, V., Voulgaris,

- N., Tselentis, G.A. (2017). "Seismic hazard assessment for the protection of cultural heritage in Greece: methodological approaches for national and local scale assessment (pilot areas of Aigio, Kalamata and Heraklion)", *Annals of Geophysics*, 60, 4; doi: 10.4401/ag-7154.
- Azzara, R.M., De Falco, A., Girardi, M., Pellegrini, D. (2017). "Ambient vibration recording on the Maddalena Bridge in Borgo a Mozzano, Italy: data analysis", *Annals of Geophysics*, 60, 4; doi: 10.4401/ag-7159.
- Masciotta, M.G., Ramos, L.F., Lourenço, P.B., Vasta, M. (2017). "Damage identification and seismic vulnerability assessment of a historic masonry chimney", *Annals of Geophysics*, 60, 4; doi: 10.4401/ag-7126.
- Hinzen, K.G. (2017). "Rectangular blocks vs polygonal walls in archaeoseismology", *Annals of Geophysics*, 60, 4; doi: 10.4401/ag-7127.
- Schweppe, G., Hinzen, K.G., Marco, S., Reamer, S.K., Fischer, M. (2017). "The ruin of the Roman Temple of Kedesh, Israel: example of a precariously balanced archaeological structure used as a seismoscope", *Annals of Geophysics*, 60, 4; doi: 10.4401/ag-7152.
- Minos-Minopoulos, D., Dominey-Howes, D., Pavlopoulos, K. (2017). "Vulnerability assessment of archaeological sites to earthquake hazard: an indicator based method integrating spatial and temporal aspects", *Annals of Geophysics*, 60, 4; doi: 10.4401/ag-7157.
- Riccio, G., Cogliano, R., Di Giulio, G., Fodarella, A., Pucillo, S., Rovelli, A. (2017). "A study of building vibrations induced by weak motions: effects of earthquake excitation, cultural noise and wind speed", *Annals of Geophysics*, 60, 4; doi: 10.4401/ag-7149.

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