MULTISCALE APPROACH TOWARD THE ASSESSMENT AND CONSERVATION OF ARCHAEOLOGICAL HERITAGE AT POMPEII

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Curriculum: Ingegneria dei Materiali e delle Strutture

The protection and valorization of heritage structures must be addressed following fundamental principles of compatibility, reversibility, distinguishability, and minimum intervention for the protection of both the material asset and intangible values. To this aim, conservation, reinforcement, and restoration interventions of architectural heritage require multi-disciplinary approaches. Indeed, the achievement of comprehensive and detailed knowledge of the structural behavior and material characteristics of heritage structures is an essential part of the conservation and restoration process. The archaeological site of Pompeii was listed as a World Heritage Site for the outstanding universal value of its tangible and intangible heritage. The protection of this exceptional site set special challenges related to its great extension, the fragility of its built asset, and a large number of visitors hosted every day. Moreover, from a structural point of view, technical and conservation restrictions limit the possibility to perform extensive and in-depth investigation campaigns for the achievement of basic mechanical properties.

This PhD thesis aims at supporting the conservation and valorization of heritage assets of immeasurable value, by contributing to achieving adequate knowledge from a structural point of view. This involves the development of investigation approaches that are: i) compatible with conservation requirements; ii) repeatable and comparable with experimental campaigns carried out in other contexts; iii) representative of the vast built heritage of the site. The achieved information could represent a useful tool for the definition of appropriate choices and new methodologies for the design and planning of suitable interventions on the heritage structures. The research was developed in cooperation between the Department of Structures for Engineering and Architecture (DiSt) of the University of Naples Federico II and the authority of the Archaeological Park of Pompeii (PAP), whose representatives have been Prof. Massimo Osanna, Arch. Annamaria Mauro, Arch. Bruno De Nigris, Dr. Alberta Martellone. The main scopes of the research were: i) development of integrated diagnostic approaches; ii) implementation of specific databases for the Pompeian asset; iii) critical analysis and processing of the acquired data; iv) analysis of past restoration interventions; v) addressing future investigations and structural interventions at the site toward uniform and guided approaches.

Since the archaeological site of Pompeii contains a wide and varied range of construction types, building techniques and materials, this research focused on selected typologies of elements, that were deemed among those most representative and vulnerable of the site. For that, rubble stone masonries, traditionally known as *opus incertum*, and multridrum tuff columns were selected for the study. Besides, a part of the research focused on the definition and characterization of a suitable mortar for interventions on the archaeological structures. A wide experimental program has been implemented through extensive field activities, laboratory work, archival analysis and data processing. In particular, the whole research involved: i) different regions of the site (especially *Regio* V, *Regio* VI and *Regio* VIII); ii) different types of building (private and public); iii) the execution of destructive and non-destructive tests, in the laboratory and situ; iv) the execution of tests on archaeological and reproduced materials and structures. In particular, new archaeological excavations at *Regio* V provided a unique opportunity to study masonry structures that emerged for the first time since the Vesuvius eruption of 79 A.D. and to perform standard tests on archaeological materials.

The study of rubble stone masonry involved three main stages, developed over the entire course of the PhD: i) the mechanical characterization of typical building materials through destructive tests and non-destructive tests; ii) the characterization of archaeological masonry structures through on-site non-destructive tests, particularly sonic pulse velocity tests; iii) the construction and characterization through non-destructive and destructive tests of masonry panels reproducing the archaeological *opus incertum*. As regards the panels, they were realized following the ancient technique with the use of original rock units and new mortar compliant with the ancient ones. This latter was realized with precious volcanic sand coming from the same volcanic region where the ancient builders collected their *pulvis puteolanus*, i.e. the Phlegrean area, next to the Bay of Naples. The characterization of the panels involved sonic tests, three diagonal compression tests conducted at the Pompeii site and axial compression tests conducted in the laboratory.

The study of the multidrum columns focused on the analysis of their state of preservation and seismic response and was mainly developed over the second and third years of PhD. The study involved an extensive campaign survey for the definition of the mean geometrical properties affecting the dynamic behavior of the columns and the recognition of the most common forms of degradation. This also involved a critical analysis of past interventions performed on the columns, specifically focusing on the most degraded ones. Moreover, a numerical analysis based on the Finite Element Method of the seismic behavior of columns from the Casa del Fauno was performed, to assess the seismic capacity of these elements.

Finally, a comprehensive and accurate experimental program involving the design and characterization of a suitable repair mortar for structural interventions on archaeological structures was carried out particularly in the second and third years of PhD. This part of the research was developed within a research visit at the University of Minho (Guimaraes, Portugal), Institute for Sustainability and Innovation in Structural Engineering (ISISE). The mission was coordinated and supervised by Prof. Eng. Miguel Azenha and Prof. Eng. Paulo B. Lourenco for ISISE. The mortar was prepared with lime putty and pozzolan sand from the Phlegrean region following traditional techniques typically encountered in the ancient Pompeii and Vesuvius surrounding area. The evolution of the main mechanical and physical properties of the mixture has been monitored for up to 200 days, based on standard procedures. Moreover, the hardening process was monitored through Differential Thermal Analysis for up to 90 days, considering different depths from the external surface of the mortar.

The outcomes of this research led to essential mechanical information related to typical structural elements of Roman archaeological sites. The characterization of traditional building materials showed heterogeneous mechanical properties and different levels of degradation. The non-destructive tests were found to correlate with a good matching the results of the destructive tests representing a sound tool to provide preliminary information on the mechanical properties of the materials. Non-destructive investigation of the archaeological masonry structures through sonic tests led to a unique set of information for their qualitative structural assessment and the enrichment of the existing available dataset on different typical ancient masonry typologies. Taking into account the impossibility of carrying out destructive tests on the archaeological masonry structures, the tests performed on the reproduced masonry panels allowed obtaining exceptional mechanical information at the scale of the masonry assemblage. Moreover, preliminary correlations with the results of sonic tests certainly represent a useful tool for an indicative assessment of the ancient masonry structures. As regards the study of the columns, systematic and detailed knowledge provided a useful tool for the identification of the elements being potentially more vulnerable than others, related to geometric characteristics and state of conservation. Moreover, numerical analyses led to deriver important general conclusions on the dynamic response of such elements and interesting approximate formulations for a simplified estimation of their stability towards the seismic risk. Finally, an exclusive repair mortar, which is very similar to the archaeological ones, was designed. The achieved mechanical properties were found to be particularly suited for the use of this material for structural interventions on ancient structures. Moreover, the systematic and carefully controlled procedures adopted for its production and characterization led to obtaining important information, most of which were still not available in the literature.

References:

Autiero, F., De Martino, G., Di Ludovico, M., Mauro, A., and Prota, A. (2020). “Multidrum Stone Columns at the Pompeii Archaeological Site: Analysis of Geometrical Properties and State of Preservation.” Heritage, 3(4), 1069–1082. DOI: 10.3390/heritage3040059

Autiero, F., De Martino, G., Di Ludovico, M., and Prota, A. (2020). “Mechanical performance of full-scale Pompeii-like masonry panels.” Construction and Building Materials, Elsevier Ltd, 251, 118964. DOI: 10.1016/j.conbuildmat.2020.118964

Autiero, F., De Martino, G., Di Ludovico, M., and Prota, A. (2019). “Mechanical properties of rock units from the Pompeii archaeological site, Italy.” Structural Studies, Repairs and Maintenance of Heritage Architecture XVI, P. De Wilde, ed., 341–350. DOI: 10.2495/STR190291

Autiero, F., De Martino, G., Di Ludovico, M., and Prota, A. (2019). “Mechanical behavior of ancient mortar specimens from Pompeii site.” Proceedings of the 7th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering (COMPDYN 2019), Institute of Structural Analysis and Antiseismic Research School of Civil Engineering National Technical University of Athens (NTUA) Greece, Athens, 1251–1262. DOI: 10.7712/120119.6994.18836

De Martino, G., Covolan, M., Autiero, F., Filocamo, F., Prota, A., Dessales, H., and Munzi, P., (2019). ...“alterno pulsu renitente (Plinio, Nat. His., II, 197). Interventi di consolidamento statico e riparazioni tra Baiae e Puteoli.” Construire face au risque naturel dans les sociétés anciennes, Naples. HAL Id: hal-02876966

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