Health Monitoring of Masonry Structures in the Rione Terra Archeological Area

O. Corbi and M. Candela

Abstract—In the paper one refers to an archeological area affected by significant tectonic phenomena, i.e. the Rione Terra in Pozzuoli. The task of preserving the standing structures, mainly made of masonry material, or those requiring a partial or total reconstruction, pushes towards the adoption of some effective health monitoring of the masonry, which allows to follow the response of old and new fabrics according to the occurring environmental changes and events. To this purpose some special instrumented masonry elements are referred to able to couple the structural and the monitoring needs.

***Keywords*—** Masonry constructions, Archeological Sites, Tectonic events, Preservation, Monitoring, Vaults, instrumented voussoir.

I. Introduction

Masonry structures usually undergo, during their life, adverse environmental conditions that may result in disease, damage and even collapse.

The understanding of their behavior is not a trivial subject since the complexity of the geometrical shapes of the resistant elements, their reciprocal interactions, the different types of materials composition, textures, apparatus, constructive techniques, the complexity of the material itself in its mechanical behavior and modeling result in a number of uncertainties and non-linearity, which are often hard to be treated.

A wide literature has been developed to this aim, also largely contributed by the research group [1]-[16] which shows that many problems are still far to be solved and that current commercial software adopting some simplified elastic behavior, or reduced approaches to the problem lead to erroneous or misleading results.

Masonry structures mainly rely their structural functioning on the thrust action of its arched or vaulted resistant members.

Anyway, structural elements, in response to environmental or anthropologic changes and actions or external events, may become partially or, even, completely unable to exert their structural function.

The chance of restoring their original role is deeply related to the possibility of adopting the most appropriated consolidation measures (possibly FRP provisions may be introduced [17]-[20]), when failure has not occurred, or most advanced technologies and approaches [21]-[31] with reference also to the expected static or dynamic events [32]-[33].

This objective, in turn, relies on a deep understanding of the behavior of the fabric in relation to the previously experienced events and to the possibility of properly forecasting its future response, which basically require proper theoretical tools, but also a large number of data about the structure.

To this regard one should also emphasize that masonry structures are particularly sensitive to horizontal dynamic actions and foundation subsiding, like in case of seismic events or bradyseismic phenomena.

Health monitoring usually appears necessary for recording the evolution of the behavior of the fabric during its life-cycle, and promptly detecting possible malfunctioning or situations that might evolve towards overall or local crisis phenomena.

Actually a proper monitoring of the masonry construction allows the follow-up of the structure and its response to the loading actions, thus representing an important preservation tool, particularly important when dealing with masonry structures.

It allows to detect possible diseases when they occur, and to undertake the necessary actions for protecting the structure from damage or from the evolution of activated phenomena or, even, prevent, their activation.

Finally health monitoring allows to understand, figure out and forecast, together with the theoretical approaches, the local and overall damage phenomena and mechanisms, and their connections.

Its usefulness then ranges from existing ancient structures, to also the newly constructed structures, that may be then checked in their status during time.

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A proper preservation conception, especially for masonry fabrics, should then embed the monitoring equipment system as mandatory.

Its role it is un-renounceable in geographic areas affected by repeated or continuous environmental phenomena of tectonic type that change the external constraints of the construction, which suffer a continuous redistribution of the internal stresses and force balances in its masses.

In the following, with reference to some collapsed masonry vaults positioned in the Rione Terra archeological area, historically subject to large tectonic events, some reconstruction strategy is reported aimed at pursuing at the same time the structural and monitoring objectives.

II. The Case of Rebuilding of an Ancient Collapsed Masonry Vault in the Rione Terra at Pozzuoli

II.1.The intervention site in the archeological area of Rione Terra in Pozzuoli

The Rione Terra in Pozzuoli, perched on a rock spur jutting out into the Gulf of Naples, was historically subjected to strong tectonic events that deeply changed and damaged its urban structure and caused its evacuation during 70s.

The bradyseism is a environmental adverse phenomenon that has been always characterizing the damage structural scenerios in the Phlegraean area. The most recent disastrous events occurred in the 70s and 80s motivated a number of scientific studies on the topic but were recently completely forgotten.

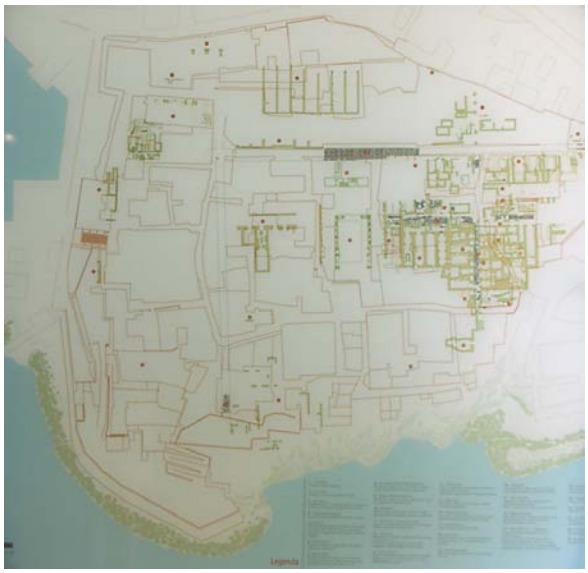

Fig.1 - The plant of the archeological site of Rione Terra in Pozzuoli.

Fig.2 – Picture from the the archeological site of Rione Terra in Pozzuoli.

As well know, the bradyseism is and environmental phenomenon due to slow movements of the upper layers of the earth's crust caused by the pressure of the underlying magmatic mass, thus resulting in uplifting or subsiding motion of the interested geographical area.

The Rione Terra's archaeological underground area of approximately 4,000 square meters characterized by the ancient Roman Acropolis allowed to locate, after the excavations, the two main decumani, i.e. the arteries of the Acropolis, characterized by a number of buildings, mostly warehouses and tabernae (Fig.1).

Actually the interest and uniqueness of the area also lays in its architectural and historical evolution and development, which is witnessed by the urbanistic superpositions dating back from the early Greek and Roman colonization, throughout the middle ages, up to the modern era.

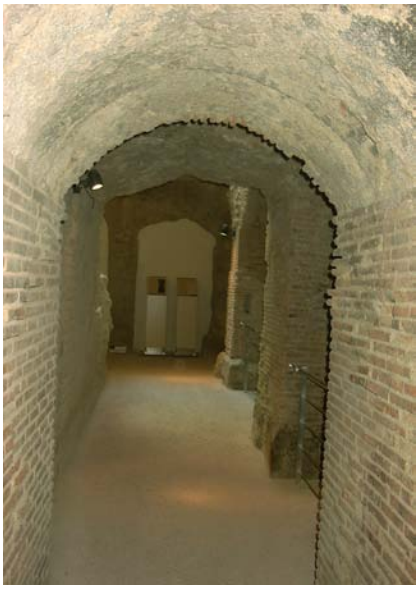

Fig.3 – Picture from the archeological site of Rione Terra in Pozzuoli.

Fig.4 – Picture from the archeological site of Rione Terra in Pozzuoli.

Fig.5 – Picture from the archeological site of Rione Terra in Pozzuoli.

Mostly the constructions either in the underground or in the exterior areas are realized with masonry material, representing an extremely wide and various catalogue as regards masonry material composition and texture, constructive techniques and architectural styles, vaulted and arched surfaces shapes, collapse modes, disease, and so on (Figs 2-5).

In the following one refers to a typical masonry building (Fig.6) placed in the upper external area.

The building under exam experienced, like many other constructions in the same area, the collapse of its intermediate floors caused by the failure of the relevant internal vaults.

The conditions of the building before its restoration may be observed from Figs. 7 and 8.

In the following it is described the description of a special intervention aimed at the re-building of the internal vaults of the building.

In the meanwhile some special devices are realized, able to monitor the behavior of the vaults themselves both during the loading phase and after the conclusion of the reconstruction.

Besides the many structural interventions realized on many of the masonry fabrics, a large part of those in the Rione Terra still needs refurbishment and monitoring.

The proposed intervention represents an alternative way for coupling the structural and the monitoring functions in one single realization, thus allowing to conceive some new structural elements whose behavior may be followed during any phase of the vault life-cycle, and to understand its response to external actions.

One should emphasize that the monitoring objective is even more significant when the intervention, like in the case of Rione Terra, is positioned in a geographic area that is affected by continuous tectonic events. This implies that the masonry structure is continuously or repeatedly subject to environmental changes and solicitations , and need to be preserved also by mean of a deep knowledge of its response to the ongoing external actions.

Under this perspective, such experience represents a significant premise for a different conception of the resistant members, which may embed in the structure itself the way for controlling and monitoring its response at the first stage as well as during time.

Fig.6 - The exterior of the building embedding the collapsed vaults.

II.1. The vault rebuilding and the new monitoring system

An interesting reconstruction of an ancient masonry vault in tuff, which was partially collapsed within the archaeological area of Rione Terra at Pozzuoli, was designed in cooperation with Dr. R. Delgado Estrada.

The original collapsed vault undergoing the special rebuilding intervention, was the one positioned at the first floor of the masonry building referred to in the previous Sect.2.1.

Fig.7 - The standing parts of the building from its interior.

Fig.8 - The standing parts of the building from its interior.

The vault was a sail type vault, made of local tuff bricks, with approximately square plant, with a special masonry texture that was completely reconstructed during the executive phase according to the ancient constructive techniques, in the respect of the original apparatus.

The position of the vault within the archeological area is represented in Fig.9.

Actually the particular set up of the reconstruction was conceived in such a way to incorporate in the thicknesses of the vault some special instrumented masonry elements, built on purpose, and able to monitor the most stressed areas of the vault, where those were inserted according to a prefixed overall arrangement.

The single structural elements, consisting of some differently shaped tuff voussoirs embedding some strain gauge rosettes, were then incorporated in the vault, at different locations, during the re-building phase in order to provide the continuous monitoring of masonry during the loading phase (Fig. 10).

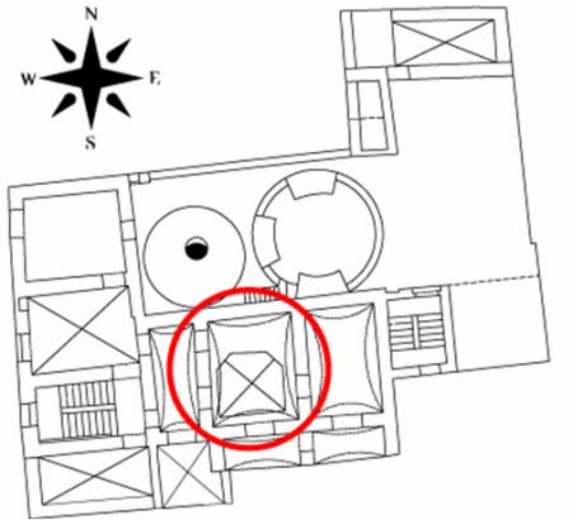

Fig. 9 - Planimetric position of the rebuilt vault in the Rione Terra.

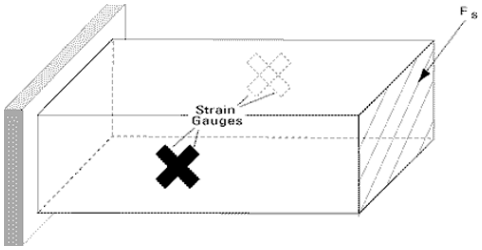

Fig. 10 - Instrumented ashlar element.

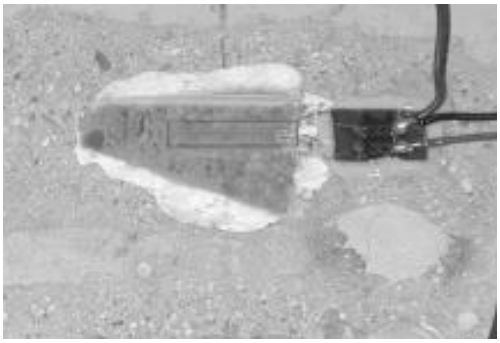

Fig. 11 - Strain-gauge.

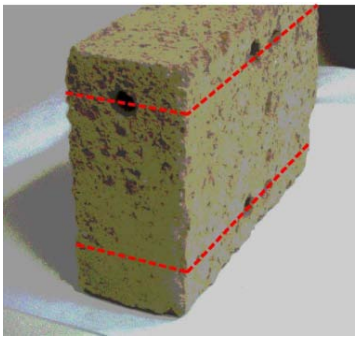

Fig. 12: The prototype of the tuff instrumented voussoir.

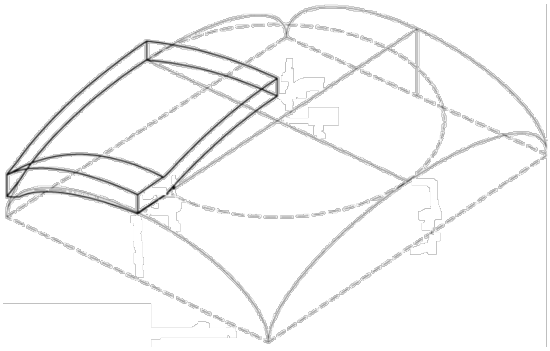

Fig. 13 - The geometric shape of the re-built sail vault.

Fig.14 - Detail of the collapsed vault.

Usual strain gauges generally adopted in monitoring deformation measurements were inserted to this purpose, thus realizing some special instrumented masonry elements, in the meanwhile accomplishing the double objective of structural operation and monitoring action (Figs 10-12).

In particular, the sail vault under consideration, whose geometry is represented in Fig.13, had practically entirely collapsed as shown in the picture of Fig.14 with the relevant scheme in Fig.15, where the standing parts are visible that just consist of the peripheral supports of the vault.

During the re-building, the instrumented tuff elements were placed according to the arrangement presented in the scheme of Fig.16, inside the wall reconstructed masses.

Loading tests were then carried on, on site, by burdening the reconstructed vault with gradually increasing masses.

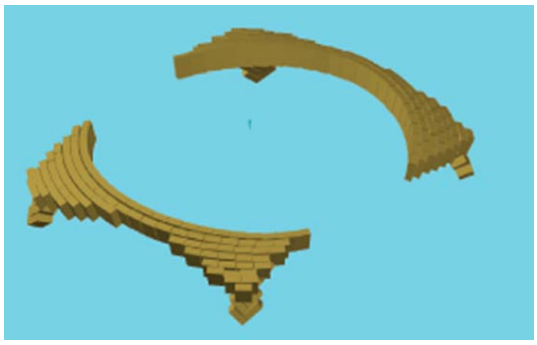

Fig. 15 - Scheme of the collapsed vault, and its standing parts.

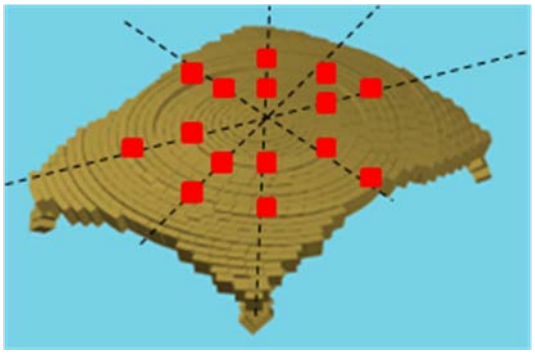

Fig. 16 - Scheme of the rebuilt vault with the positioning of the instrumented monitoring ashlars as placed in the vault thickness.

The loading scheme followed an asymmetric pattern, according to Fig.17, where the first and the last loading steps of the loading process are reported, by recording at any stage for the different stress levels the measurements provided by means of the special instrumented voussoirs incorporated in the vault.

III. Conclusion

In the paper one addresses the problem of monitoring of masonry fabrics. Different new types of health monitoring systems may be conceived in relation to the special case under examination and to the final desired objective. With reference to the case of reconstruction of vaulted structures within archeological sites, the aim of acting in the respect of the original apparatus, texture and material composition may be successfully coupled to the need of preserving the new structures from future events, which may lead to damage and collapse. This task is even more significant when the structure is placed within a geographic area which is subject to relevant tectonic events, which requires and pushes towards a practically continuous or repeated monitoring of the behavior of the structure during its life-cycle and in response to the occurrence of external events and environmental actions.

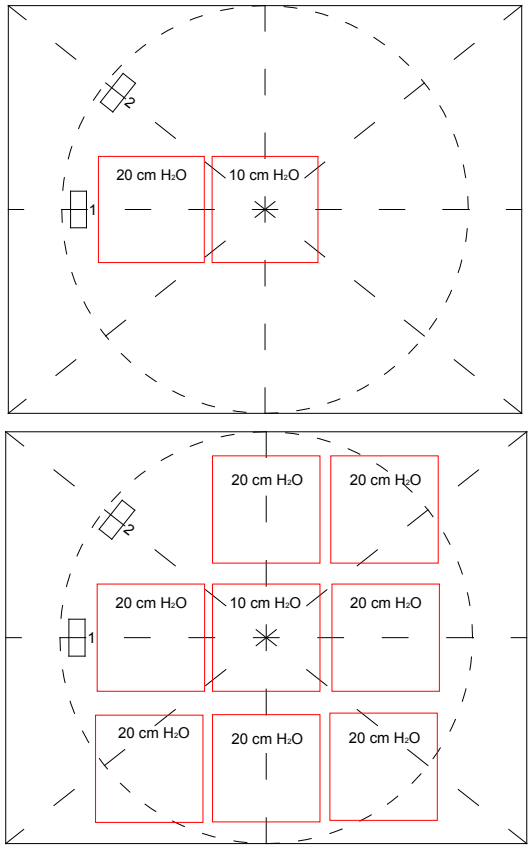

Fig. 17 Load tests for the re-built masonry vault: load pattern at the 1st and last step.

In the paper a new monitoring technique is presented which is supposed to come together with the restoration of the structural operation of ancient masonry vaults.

The proposed techniques still needs to be investigated and wide experimental campaign are necessary as well.

The reconstruction of ancient vaults according to the original construction techniques, materials and masonry apparatus is then re-interpreted by introducing and strictly relating the structural function of the single tuff element within the vault with the possibility of following its behaviour during time. This is accomplished by special instrumented masonry voussoirs whose monitored response allow to figure out the phenomena occurring in the overall structure.

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