RESTORING STONE MONUMENTS OF CULTURAL HERITAGE: CRITICAL ASPECTS FROM THE ENGINEERING POINT OF VIEW

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1. General

Restoration of monuments is a multi-disciplinary field demanding harmonious cooperation between archaeologists, architects and engineers and the decisions made arise, usually, as compromises between de facto conflicting approaches. From the engineering point of view, the key issue is the restoration of the structural integrity of the monument, keeping in mind that any intervention should be restricted to the minimum possible and, also, that it should be implemented according to a reversible approach. Moreover, any intervention should respect and protect the authentic structural elements while the materials used should be compatible (from both the mechanical and the physicochemical aspect) to the authentic building material. The extent of acceptable interventions is outlined in the "Venice Charter" [1]. In the present study attention is focused to the restoration of stone monuments of classical Cultural Heritage, taking advantage of the experience gathered from the restoration project of the monuments of the Acropolis of Athens and mainly from the Parthenon Temple.

2. Experience from the restoration of the Acropolis monuments: The Parthenon project

Ancient Greek temples were built using natural building stones quarried from the near vicinity of the place of the temple. Among the very few exceptions are the monuments of the Acropolis of Athens, which were built using marble quarried from mount Pentelicus, more than 30 km away from the Acropolis hill. It is a fine-grained white marble consisting of calcite (~98%) and very small amounts of muscovite, sericite, chlorite and quartz. It is a bimodular, slightly nonlinear, anisotropic material, usually, modelled as transversely isotropic [2].

Given that quite a few structural elements of the Acropolis monuments are damaged, an ambitious restoration project is in progress under the auspices of the "*Committee for the Conservation of the Acropolis Monuments*". The technique adopted for restoring fragmented members is based on the use of metallic reinforcements placed either in holes drilled in the marble body (threaded bars, Fig.1a) or in grooves sculptured on their surface (e.g., "I"-shaped beams, Fig.1b). Both holes and grooves are then filled with a cement-based material [3].

3. Modelling the response of restored structural elements. Detecting pre-failure indicators

The restoration technique described above generates a three-material-complex (marble-cement-titanium) with two "hidden" interfaces (i.e., marble-to-cement and cement-to-titanium). Given that damage mechanisms are firstly activated along these interfaces, any attempt to model the mechanical response of the restored elements necessitates data from these interfaces. Such data can be only obtained with the aid of novel sensing techniques,

Figure 1: (a) In-situ restoration of one of the longest epistyles of the Acropolis Propylaea using threaded titanium bars; (b) Inter-connecting epistyles of the Parthenon Temple using "I"-shaped titanium beams.

like, for example, Acoustic Emissions (AE), Pressure Stimulated Currents (PSCs) [4], Optical Fibers etc. In addition, the unique cultural value of these monuments renders continous Structural Health Monitoring (SHM) a pressing demand. The relative data required must be obtained with the aid of cheap, reliable and very small sensors, since they should not destroy the aesthetic splendor of the monuments. In the direction of providing some answers to the above open problems, various experimental protocols are implemented in the Laboratory for Testing and Materials of the National Technical University of Athens. Both traditional and innovative sensing techniques are used in a combined manner, for validation reasons and, also, in order to properly calibrate the outcomes of the novel techniques, which in most cases are of qualitative rather quantitative nature.

As an example, results of an ongoing project related to the response of the restored connection of marble epistyles are here discussed. The specimens consisted of two marble blocks, joined together by means of an "I"-shaped connector and suitable cementitious material. Loading/gripping were achieved by an in-situ improvised set-up assuring pure shear loading of the connection, a challenging task, taking into account the asymmetries of the specimens (Fig.2). The specimens were monitored by a system of eight R15α AE sensors, two electric sensors (recording the PSCs with the aid of sensitive electrometers) and a 3D-Digital Image Correlation (DIC) system. In parallel, traditional sensing tools (electrical strain gauges, LVDTs and dial gauges) were also used.

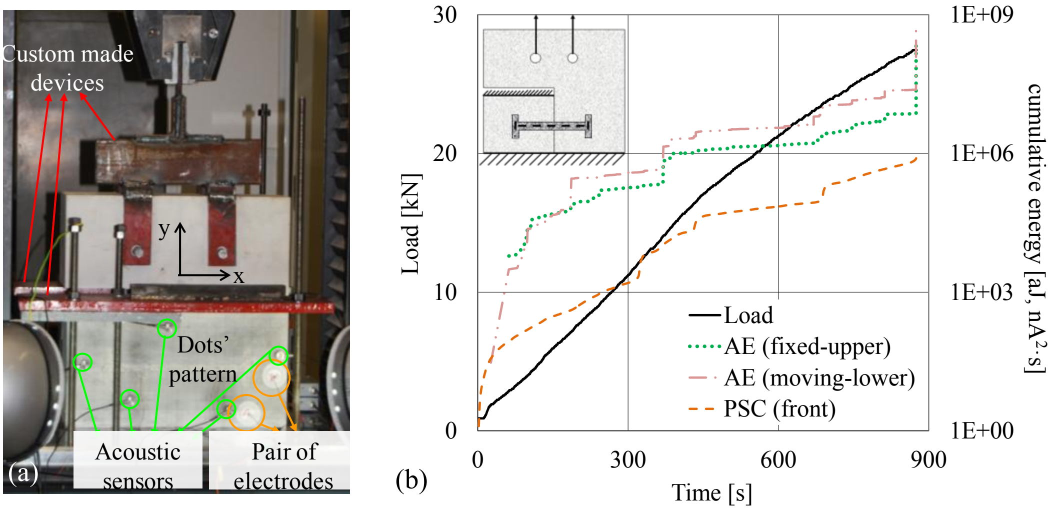

Figure 2: (a) The experimental set-up; (b) Time evolution of the load induced, in juxtaposition to that of the cumulative energy of the Acoustic Emissions and of the Pressure Stimulated Currents.

4. Some concluding remarks

The data gathered during the tests (see, for example, Fig.2b, in which the time evolution of the cumulative energy of the AE and the PSCs is plotted in juxtaposition to that of the load imposed) indicate that both the AE and PSC techniques "follow" the mechanical response of the restored epistyles according to a satisfactory manner. Moreover, both techniques provide early signs concerning the entrance of the system to its "critical stage", i.e., clearly distinguishable pre-failure indicators. Taking into account the low cost of the sensors of the PSC-technique and, also, their small size, it appears that this technique is an attractive alternative for SHM of restored elements of ancient monuments. The fact that the PSC data are in excellent accordance to those of the AE technique [5] provides a reliable calibration tool for the PSC technique (given that the AE technique is based on a well founded scientific basis and it is nowadays considered as a mature sensing system).

References

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