E - ICES 11

11º Encuentro del "International Center For Earth Sciences", 4-6/05/2016, Malargüe, Mendoza, Argentina

STRUCTURAL MONITORING OF ARCHEOLOGICAL SITES BY LASER MEANS: THE CASE OF THE LAST REMAINING COLUMN OF *HERA LACINIA* AT CAPO COLONNA, CALABRIA, ITALY

Lorenzo Grassi [a], Diego L. Gonzalez [b,c] and Maurizio Conti [d]

[(a)] *ASPER, Ricerca Scientifica e Applicazioni Industriali, Firenze, Italy,* [(b)] *Consiglio Nazionale delle Ricerche - Istituto per la Microelettronica e i Microsistemi (IMM-CNR), Bologna, Italy*
[(c)] *Università degli Studi di Bologna (UNIBO) - Dipartimento di Statistica, Bologna, Italy,* [(d)] *Ecosystems, Firenze, Italy*

E-mail: lorenzo.grassi@asper-fi.it

Introduction

Structural monitoring of archaeological heritage is essential to control the static conditions of historical monuments and their evolution over time. A late survey of static alterations should lead to an onerous intervention of recovery, in the better case, and it can turn out in structure damage in the worst one. A monitoring with traditional instruments fixed to the monument or located in its immediate vicinity highlights the local movements and the effects of repetitive mechanical actions. These movements stress and may affect the structure and its foundations mainly in the case that they are of a macroscopic nature. Examples of the traditional instruments are inclinometers, piezometers, settlement gauges, clinometers, accelerometers, etc. For example, accelerometers detect the first derivative of the speed and allow to highlight the effects of repeated and periodic movements of the monument due to wave motion or wind. In addition to the data collected with the traditional instrumentation it is absolutely necessary for a timely intervention that the monitoring system will be also able to highlight the phenomena before they arrive to compromise the static stability of the monument.

Figure 1: The archeological site of Capo Colonna, Calabria, Italy

The case of the Greek column at Capo Colonna

Of the magnificent Greek temple dedicated to Hera Lacinia, composed of 48 Doric columns 8 meters in high, and located at Capo Colonna, Calabria, Italy, only one column remains. Thus, preventive measures for monitoring such significant remain are mandatory. The main objective of this work is to present a structural monitoring system for continuous non-invasive measurement of the spatial position of the Hera Lacinia column by optical means. Today, the column is threatened by soil movements, due mainly to coastal erosion and subsidence, and to inherent structural weakness, provoked mainly by deterioration of the column structure due to natural ageing. In order to face this issue, the work team has designed, manufactured, and installed, a structural continuous monitoring system based on laser distance meters that are able to detect millimetric displacements of parts of the monument taken as target. The laser distance meters are positioned at a sufficient distance from the monument to ensure a reduced degree of displacement of the ground due to geological phenomena. As the column is placed near the sea, the measuring system has been placed 70 meters from the column, opposite to the sea, and a control reference point was established at 140 meters. Two measurement points are positioned, respectively, on the base and on the capital of the surviving column of the Hera Lacinia temple. For greater security, the system uses in addition a further distance meter as a reference to validate the acquired data. This meter is focused on a target located in almost diametrically opposite position with respect to the monument, that is, at the other side of the measuring station, and far enough to be not influenced by the hypothetical geological phenomena affecting the monument.

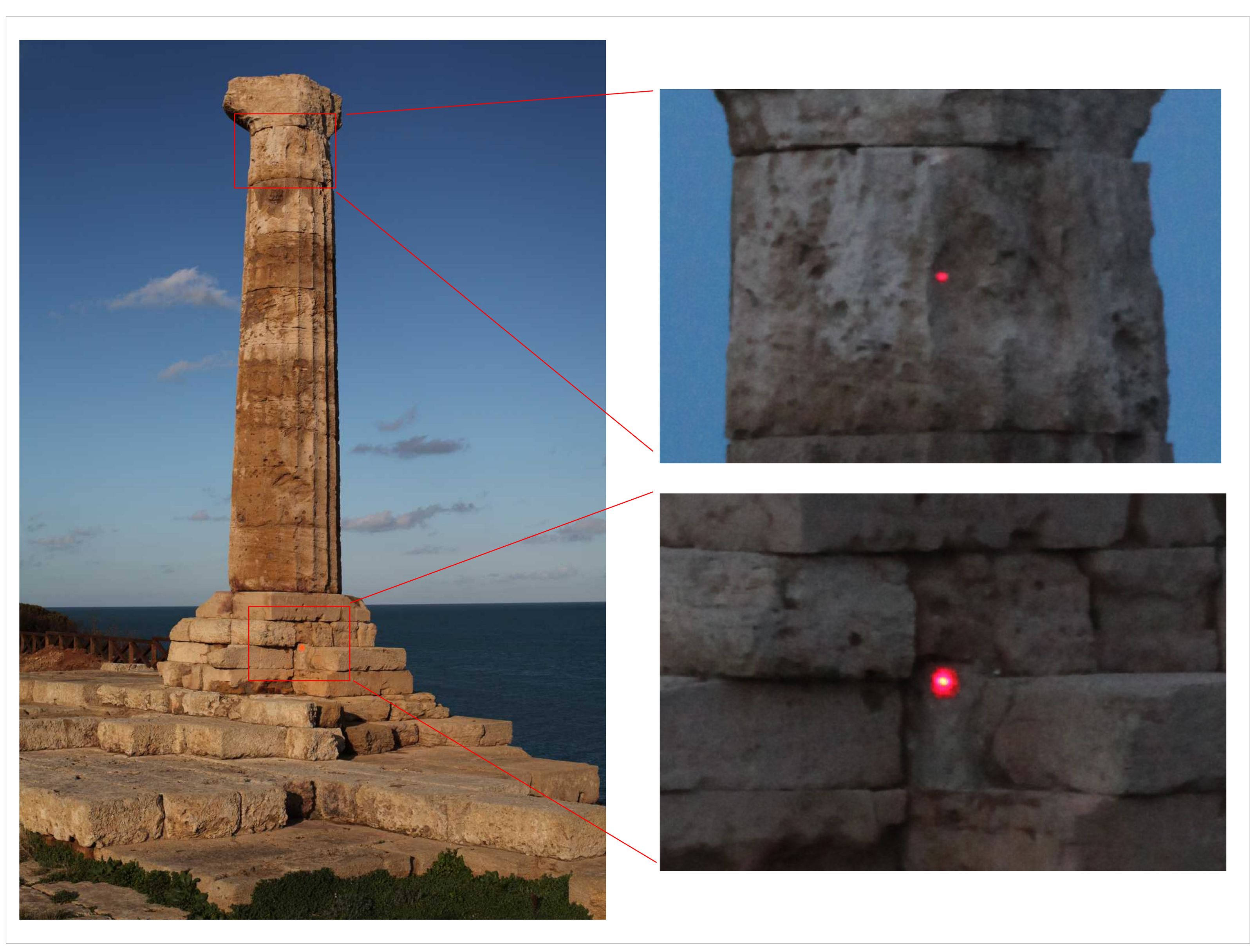

Figure 2: The column (on the left) and the two laser spots at night (on the right)

The optical monitoring system

The developed monitoring system determines in real time the position of the column and logs the data to a secure server through the Internet. The heart of the implemented system consists of three industrial laser distance meters, model FLS-C 10 of Dimetix, and a real-time control unit, model cRIO-9022 of National Instruments. The FLS-C distance meter can measure on a natural surface with an accuracy of one millimeter over distances that under optimal conditions can reach 80-100 meters in outdoor conditions.

The cRIO-9022 controller, equipped with real-time operating system, ensures the reliability required for controlling the entire system and for continuous measurement, 24 hours a day and 365 days a year, on the long run. On board of the cRIO-9022 unit, an application manages the distance meters configuration, and the collection, processing and logging of the measurements. For each distance meter, the application captures a number of measurements at close intervals and processes aggregated data, statistical indicators and measurement quality. The processed data are so logged on file along with some of the control unit status indicators. The application developed is fully configurable in terms of the parameters and frequency of measurement. Through configuration it is possible to access the different measurement modalities of distance meters FLS-C. This feature was particularly useful during installation and tuning of the system service to determine the best mode of distance meters. In order to allow a complete management and remote maintenance, the application can be also controlled from remote.

The entire system was designed to work outdoors under unfavorable environmental conditions such as strong winds, salt spray, strong sunlight, rain, etc. The system was conceived for attaining robustness to climate threats, vandalism, and also to energy and communication fails while maintaining an efficient and cheap implementation. Each of the three distance meters is mounted on a two axes micrometric pointing system; all pointing systems are fixed on a robust common platform, made of stainless steel AISI 316 and anchored to a reinforced concrete plinth rooted in the soil. The pointing system is designed around commercial rotary tables and was designed and built by a precision machine shop. The metal components not made of stainless steel were protected against oxidation with specific surface treatments. A box made with frame in L-profiled, also in stainless steel AISI 316, and closed by wafer panels of composite material, protects distance meters and the support structure from weather attacks. The box is equipped with ventilation mouths with protective filters and the cover is similar to a ventilated-roof in order to reduce, in the interior, the irradiation due to the exposure to the sun on the outer cover. The box is mechanically and spatially separated from the platform on which the distance meters are mounted in order to decouple the latter by the mechanical action of the weather, such as the wind or the thermal expansions, which act on the outer protection structure. On the walls of the box some holes have been made for the passage of the laser beams. The holes are also provided with the necessary protection from wind and rain.

Figure 3: The tree laser distance meters on the two axes micrometric pointing system. Two of them (central and right) are pointing the column and the third one (left) is pointing the control target on the opposite side

Figure 4: The protection box

Conclusion

After a period of testing, the system is at present continuously monitoring the position of the column and allows to forecast any abnormal movement. The system is working for 2 years, acquiring a distance measurement from each laser every 15 seconds. This information can be used for preventive intervention in the case of serious danger for the integrity of the remain. The acquired data, that include relevant meteorological parameters, pose interesting challenges because different kinds of noise are superposed to the data of the column position. It is planned to develop a statistical approach for the analysis of the structural stability of the column in presence of this background noise. This technological system and the analysis algorithms would also be very useful for the monitoring of similar threatened archaeological or historical sites of relevance for the cultural heritage. Thanks to this system it is possible to operate a complete monitoring where the conservation of an archaeological monument is put at risk, in particular for the monuments which after excavations are subjected to the action of surface atmospheric dynamics, either by the action of local phenomena of geological/geomorphological origin, which could also be present at the time of realization and which became dangerous in future periods, or that were subsequently developed, such as movements of faults, openness of diaclase, erosion conditions (just think of the coastal cliffs), landslide, of changes in the water table level (which can induce bradyseism phenomena), subsidence, etc.