

Workshop: *Seismic Protection of Monuments*

E.C.P.F.E. – E.P.P.O.

2& 3 December 2013

Seismic actions on the Acropolis Monuments

Scientific and technical choices during the restoration interventions

Maria Ioannidou

Summary

The monuments of the Acropolis, witnesses of a culture that deeply affected today's world, survived standing until our time, preserving most of the features of their incomparable beauty. These unique monuments have been damaged mainly by the incursions of the various occupiers of Athens and by unsuccessful human interventions, the purpose of which was to restore them; far less by natural causes. According to historical facts, the powerful earthquakes that have struck the monuments of the Acropolis caused damage of a restricted kind, which can be recognized only through continuous archaeological, historical and architectural research.

For the future, the only strong mechanical strains are expected to be seismic, since we certainly hope that there will no longer be damage inflicted by mankind. It is therefore imperative to evaluate the efficiency of the monuments in seismic activity, taking into account the damage they have suffered through their long history and with this evaluation as a basis to make the necessary interventions. Analysis of the seismic behaviour of the monuments in their original condition, in any case cannot itself yield conclusions applicable to today's interventions.

And here we may pose the Question: The proven resistance of the monuments to the seismic events is due to the favourable seismic behaviour of the Acropolis hill or it is the way in which the buildings were constructed that enabled them to withstand successfully nearly all the environmental hazards of the past? The answer to that question is exceedingly difficult. The method of building the monuments, the proper formation of the structural system, the choice of materials, the high quality of construction and its details show that the builders had taken into consideration the likelihood of seismic loading.

They are characterized for their clearly defined structural function, for the regularity of their plan, for the symmetrical arrangement of their bearing elements and mass. The great rigidity of the walls together with the diaphragm function of the ceilings and roofs by means of friction, add to the resistance of the building to horizontal stress. Finally, the founding of the monuments for the most part on solid rock and the good quality of construction of the foundations favour their good ant- seismic behaviour.

The monuments of the Acropolis are built of worked stones in the form of rectangular blocks or drums, without mortar, joined to each other with metal clamps and dowels. Extraordinary precision in cutting the surfaces and in fitting the stones together is the basic characteristic of their structure. Joining elements made of iron, placed in sockets specially cut for them in the stones and sheathed in molten lead contribute to the general resistance of the building against seismic load or deformation from violent shifting or foundation yielding.

Of special interest is the seismic behavior of the Acropolis rock. From the geological aspect is a trapezoidal-shaped block of Late Cretaceous grey limestone resting on the marls and sandstones of the Athens Schist rock series. The grey limestone is well exposed on the top of the hill. The top of the hill has been levelled with artificial fill up to 17 m thick which is retained by the Circuit Wall. The artificial fill, that forms the plateau where the monuments stand has a varying composition.

The seismicity of the broader Aegean area is caused by the relative motions of the Africa, Arabia and Eurasia plates. Older studies from many researchers and recent from professor Ambraseys (2010) show that the Attiki peninsula region, in central Greece, is considered as an area of low seismicity. However, recent studies (Ganas et al - 2005) conclude that the centre of Athens can be affected by the possible movements of the Attiki mapped faults.

The structural damage of the standing areas of the Acropolis monuments include geometric distortions, shifts, displacements and cracking of the architectural members, failure of joining elements and openings of the joints. To distinguish the damage caused by seismic events from that brought on by human interventions contributes greatly to the recognition of the problems of construction and anti – seismic planning in the interventions.

In the frame of monitoring the seismic actions that burden the Acropolis monuments a network of 10 accelerographs have been installed on the Acropolis in collaboration with the Geodynamic Institute of the National Observatory of Athens at characteristic locations : in fill, at points where there is limestone outcropping, in the schist bedrock and at specific locations at the Parthenon.

In collaboration with the University MIE of Tokyo and the National Technical University of Athens a research program is in progress in order to study the seismic response of articulated structures, including the installation of two accelerographs on the Parthenon and the investigation of the dynamic properties of the Parthenon with the use of micro- tremor measurement.

Analytical methods for proper simulation of the behavior of classical monuments under seismic loads is in process in order to investigate the response of the anastelosis proposal to the seismic load. Such analytical investigation is already in progress by the Acropolis Restoration Service in collaboration with the Laboratory of Earthquake Engineering of the NTUA. The purpose is the investigation of the structural restoration proposals of the north and south cella walls of the Parthenon with ancient blocks

whose their original position was recognized after research, limiting to the minimum possible, the additions in new marble.

Beyond the results of the contemporary methods of analytical investigations, the structural restoration of the monuments should comply to the basic restoration principles: these stemming from the requirements in the Venice Charter, as well as from the special structural characteristics of the classical monuments. Among these ascendant is the principle of *respect and maintenance during the intervention the original structural system which ensured the sufficient seismic behavior of the monuments*. This respect leads to the choice during the structural restoration of solutions which respect the preservation of the structural autonomy of the architectural members and their original static function during the new intervention.

These requirements lead to specific *scientific choices, technical solutions and construction details* during:

- a) The structural restoration of the architectural members with the joining of their fragments and the filling in with new marble
- b) The joining of the marble blocks after their resetting on the monuments
- c) The restoration of areas of the monuments by resetting the ancient members in their original positions and including also members of new marble

Of special importance is, for the preservation of the authentic structural system of the monuments, the maintenance of the *high quality of construction* in all phases of the work, for both structural and anti-seismic reasons. As in the ancient construction, exceedingly careful working of the contact surfaces and the perfect contact between the blocks insures the development of friction forces between them and through them the cohesion of the building. This concern, quite apart from aesthetic demands, is necessary for purely structural reasons, namely respect for the ancient structural system of the monument, which thus insured the safe transfer of the load to the ground.