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ANCIENT CONSTRUCTIONS AS MARKERS OF TECTONIC DEFORMATION AND OF STRONG SEISMIC MOTIONS

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Abstract

Many ancient structures such as temple were constructed on the basis of a very strict plan and excellent workmanship. For this reason, even their slight deformation due to various effects (ground instability, earthquake oscillations, etc.) can be identified, and it is possible to discriminate between different types of deformation due to earthquakes and those due to other natural causes or to anthropogenic effects. Two study cases are presented here: the Propylaia on the Acropolis and the temple of Hephaistos (Hephaisteion) in the Agora at Athens. In both buildings deformation was produced by earthquakes.

1. Introduction

Various ancient buildings have suffered damage over the centuries, chiefly due to human intervention such as fire, military and wartime destruction, explosions etc. but also due to natural causes as falling rocks, thunderstorms, earthquakes etc. Unfortunately, only a few of these constructions are still standing and preserve traces of seismic deformation, while other buildings that were completely destroyed in the past or have been recently restored do not preserve any evidence of seismic deformation.
In Athens, the historical and instrumental seismic data indicated that it is an area of low-seismicity. In fact only a few earthquakes are documented in the period between the fifth century BC and the seventeenth century AD. The earliest known earthquake occurred in 427 BC and from the historical reports seems to have caused some minor damage to the Acropolis at Athens. Some times later, before the Frankish occupation (AD 1200) a stronger earthquake struck the city producing some dislocation in the NE corner of the Parthenon (Korres, 1996). Many other earthquakes have hit this region over the course of years but only a few were recorded, while others, such as the earthquake that caused damage in the temple of Hephaistos, have been recently discovered (Galanopoulos, 1956).
In this article we summarize some of the earthquake deformations observed at ancient monuments of Athens showing that the town was not aseismic in the past and that through the study of earthquake damage we can improve our knowledge of past seismic activity.

2. Cases in study

2.1 Hephaisteion

This Doric temple was built by the Greeks between 449 and 415 BC on the *Kolonos Agoraios*, the 66 m high Hill of the Agora. It has been known as Theseion but the temple was probably dedicated to Hephaistos, the god of metalworking, and it is the best preserved temple in the Greek world. It is a rectangular building measuring 31.8 m long and 13.7 m wide, with 13 columns on the long sides and 6 on the short sides. The superstructure is made of Pentelic and Parian marble while the foundations are built from limestone. The lowest step of the temple, built from poros limestone, stands directly on dressed bedrock with the exception of the southwest and southeast corners, which stand on foundation courses of a different kind of poros (Dinsmoor, 1941). During Byzantine times (around the seventh century AD), the temple of Hephaistos was transformed into a church and the entrance was moved in the west side. Later it was used as a cemetery.

According to Galanopoulos (1956) the temple suffered an earthquake, which probably occurred after the Byzantine restorations (Stiros personal communication). The seismic event was not strong enough to cause the collapse of the building, but the southern side of the temple suffered a deformation that is still preserved today (fig.1). The sinusoidal offset of the column drums is indicative of seismic deformation. This was caused by the different mechanical behavior of the two types of limestone in the substructure during the seismic shaking.

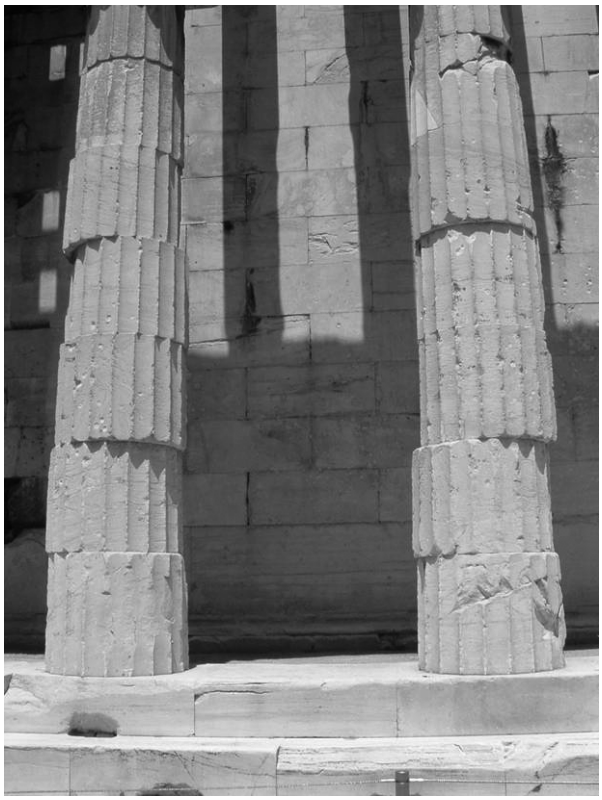

Fig.1 - Sinusoidal offset of the column drums indicative of seismic deformation in the Hephaisteion (Theseion), Athens according to Galanopoulos (1956).

Fig. 2 - Characteristic rotation in the column drums of the Propylaia after the 1999 Athens earthquake.

2.2 The Propylaia

The gate building of the Acropolis was designed by the architect Mnesikles and built shortly after the construction of the Parthenon, between 437-432 BC. Two different types of stone were used: one Eleusinian blue and the other Pentelic white. It was intended as a façade for the Acropolis and the end-point of the most important festival in ancient Athens, the Panathenaia. The building was never finished and it had three different kinds of columns, small Doric, large Doric and Ionic columns. Six large Doric columns on the front were flanked by two asymmetrical porches. Between the large Doric columns was a wide passageway with a central ramp flanked by six Ionic columns, three on each side (fig.2; Lawrence, 1957). From the twelfth to the fifteenth century AD the building was transformed to host the Dukes of Athens and at the same time a quadrangular Frankish tower was added at the east wing to reinforce the defence of the Acropolis. The military superstructure was afterwards demolished in the nineteenth century.

On September 7th, 1999 an earthquake caused an offset in the drums of the columns on the central ramp. This seismic event was not stronger than the average earthquake recorded in Athens -- in fact the calculated M was around 5.5-5.9 -- but the peak ground acceleration was high enough (0.30 g) to produce a rotation of the drums (fig.2).

3. Conclusion

The offset of column drums of ancient Greek or Roman buildings, when their base is stable, is indicative of the seismic oscillations produced by high acceleration seismic motion. The ground acceleration of the 1999 earthquake (with its epicentre about 15 km from Acropolis) was high enough to produce a rotation of the drums of the Propylaia while the previous studies on seismic risk for Athens had estimated a maximum acceleration of 0.16 g (Anastasiadis et al., 1999). Another very strong earthquake that caused damage at Athens was the 1981 Corinth earthquake, with M_s=6.7, PGA= 0.29g and with an epicentral distance of about 77 km (Anastasiadis et al., 1999). This earthquake produced no damage in the nearby archaeological site of Corinth while in the Parthenon at Athens it opened joints (around 1 cm between the blocks) in the western part of the S wall (Korres, 1996).
In conclusion, through the study of the deformation of the ancient buildings we can improve our knowledge of the seismic history of an area under study and in the specific case of Athens we can affirm it had experienced earthquakes throughout its history as the above mentioned evidence shows. Furthermore, the study of seismic deformation provides opportunity to collect additional information, qualitative and quantitative that can serve as a marker in the studies on the seismic behaviour of monuments.

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