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Case study

Seismic evaluation and strengthening of nemrut monuments

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ABSTRACT

Nemrut Dağ Tumulus and Monuments, constructed during the Commagenian Kingdom approximately 2000 years ago on the peak of Mount Nemrut, is a UNESCO World Heritage Site in Turkey. The region is about 5 km away from the East Anatolian Fault, therefore, this paper focuses on dynamic testing and earthquake simulations carried out within the framework of the Commagene Nemrut Conservation Development Program in order to explain monuments' current condition. The simulations showed vulnerability of cut-stone blocks separating from one another under seismic action, and simple strengthening solutions were proposed.

1. Introduction

Nemrut Dağ Tumulus is a UNESCO's World Heritage Site in Turkey since 1987 [1]. The tumulus, located in Kahta, in the province of Adıyaman, was placed in an important location in the Upper Euphrates Valley during the Commagenian Period. The monuments were constructed during the reign of King Antiochus I. (69–36 BC) [2–11].

The Hierothesion of Nemrut Dağ is approximately 2.6 ha wide and was constructed around the 2.206 m high tumulus with 30–35° of inclination. The tumulus is surrounded by three terraces at east, west, and north. The east and west terraces are remarkable for the presence of 8–10 m high limestone sculptures representing five deities seated together with King Antiochus I (Fig. 1).

Commagene Nemrut Conservation and Development Program (CNCDP) was set up in 2006 by Middle East Technical University in order to identify the problems and to devise necessary interventions [12,13]. This paper presents the seismic evaluation studies, carried out by the structural team, who also investigated effects of snow, wind, vandalism, and blast [14]. Since the site is located only 5 km away from East Anatolian Fault (EAF), in a 1st grade seismic zone, the investigation also included research into whether earthquake loading might be responsible for the current damaged state of the monuments. The results showed vulnerability of cut-stone blocks to seismic action, separating considerably from one another during a large earthquake and therefore simple strengthening solutions were proposed.

2. General assessment

The Nemrut monuments are approximately 8–10 m high, and made of 7 layers of limestone blocks placed on top of each other without mortar, shear key/metal clamps. Therefore, they are free to move under lateral loading (excepting frictional forces). The lower three stone layers form a square base which is currently filled with rubble-earth mix up to the lower third stone layer and represents a throne. The upper three layers form the torso. The uppermost single piece stone represents the heads of the deities.

East and west terrace statues are almost identical; however, the thickness of the stones forming the west terrace monuments is less than that of the east-terrace monuments (approximately 20 and 40 cm, respectively). The statues in the east-terrace have kept their physical integrity to a large extent, except for the stone blocks forming the heads, while the west terrace statues are almost completely torn down.

The tumulus is located only 5 km away from the EAF. The direction of scatter observed in the west terrace is in line with the fault. The partially standing statues are composed of blocks moved relative to one another, which makes the statues more vulnerable to future disturbances.

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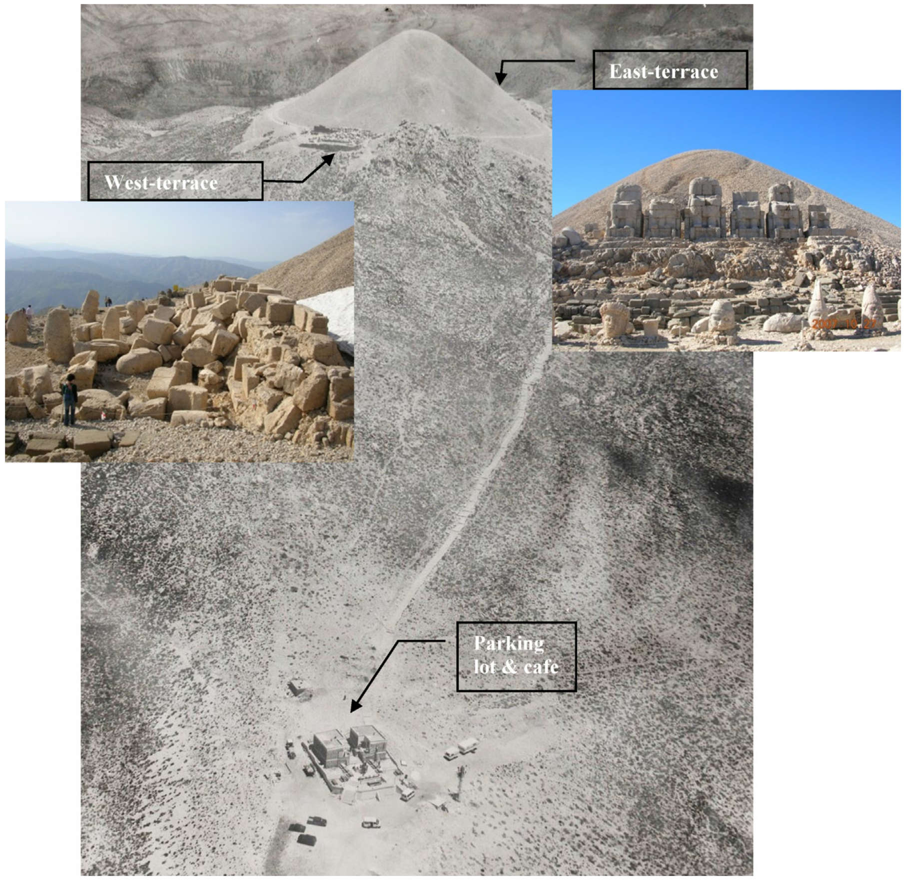

Fig. 1. General view of Nemrut site.

3. Dynamic testing and FE modeling

For dynamic testing, triaxial wireless G-Link accelerometers with ±2 g range and 10 mg resolution were used on 2 monuments (Fig. 2). However, the high noise level of 10 mg combined with low ambient vibrations on massive Nemrut monuments led to poor results. The obtained data were processed using Ambient Response Testing and Modal Identification Software (ARTEMIS). The measurements were obtained by both naturally-induced forces (microtremors and high winds) and striking the ground with wooden logs. However, these actions were insufficient to produce a detectable level of acceleration on the monuments.

Following this, another round of dynamic tests was carried out using low-noise sensors, with 0.5 g and 2.5 g ranges. In this case, the obtained results had better resolution. The obtained data was processed manually by using the following equation:

$$a = a_m * e^{(-f_n * 2\pi * \zeta * t)} * \sin(f_d * 2\pi * t + \phi) + DC_{shift} \quad (1)$$

where, a and a_m are acceleration and amplitude, while f_n and f_d are natural and damped frequencies respectively, ζ is damping (%), t

Fig. 2. Tested monuments and triaxial wireless accelerometer.