Chapter 10

Vulnerability Assessment of Damaged Classical Multidrum Columns

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ABSTRACT

Multi-drum columns are articulated structures, made of several discrete bulgy stone blocks (drums) placed one on top of the other without mortar. The multi-drum column is a typical structural element of temples of the Classical, Hellenistic and earlier Roman period. Despite the lack of any lateral load resisting mechanism, these columns have survived several strong earthquakes over the centuries. The Chapter focuses on the effect of past drum dislocations on the vulnerability of classical columns and presents a performance-based framework for their seismic risk assessment. The vulnerability is numerically calculated through response estimations using detailed three-dimensional models based on the Discrete Element Method. Conditional limit-state probabilities are calculated and appropriate performance criteria are suggested. The proposed methodology is able to pinpoint cases where past damage affects the vulnerability of such structures and can serve as a valuable decision-making tool.

INTRODUCTION

Classical monuments are particular masonry structures made of bulgy stone blocks. Major structural members of these ancient structures are their columns, which consist of bulgy discrete drums that lie one on top of the other without mortar (Figure 1). During earthquakes, the columns respond with intense rocking, wobbling and, depending on the magnitude of the induced accelerations, sliding of the drums. In rare cases, steel connections (dowels) are provided at the joints, which restrict sliding without, usually, affecting rocking.

Several investigators have examined the seismic response of classical monuments and, in general, of stacks of rigid bodies analytically, numerically or experimentally, mostly using two-dimensional models (Allen et al., 1986; Sinopoli, 1991; Psycharis, 1990; Konstantinidis & Makris, 2005; Lemos, 2007; Papaloizos & Komodromos, 2009; Sarhosis V., Lignola G.P. & Asteris P., 2014). Three-dimensional studies are less, e.g. Psycharis et al. (2003), Dasiou et al. (2009b), Stefanou et al. (2011a, 2011b). These studies have shown that:

- Owing to rocking and sliding, the response is nonlinear. The nonlinear nature of the response is pronounced even for the simplest case of a rocking single block (Housner, 1963; Makris & Zhang, 2001). In addition, multidrum columns can rock in various ‘modes’, which might alternate during the response increasing thus the complexity of the problem (Psycharis, 1990). The word ‘mode’ denotes the pattern of rocking motion rather than a natural mode in the classical sense, since rocking structures do not possess such modes and periods of oscillation.

- The dynamic behaviour is sensitive to even trivial changes in the geometry of the structure or in the base-motion characteristics. The sensitivity of the response has been verified experimentally, since ‘identical’ experiments produced significantly different results in some cases (Yim et al., 1980; Mouzakis et al., 2002; Dasiou et al., 2009a). The sensitivity of the response is responsible for the significant out-of-plane motion observed during shaking table experiments for purely planar excitations (Mouzakis et al., 2002).

- The vulnerability of the structure greatly depends on the predominant period of the ground motion, with earthquakes containing low-frequency pulses being in general much more dangerous than high-frequency ones (Makris & Roussos, 2000; Psycharis et al., 2000). The former pulses force the structure to respond with intensive rocking, whereas the latter produce significant sliding of the drums, especially at the upper part of the structure.

- The size of the structure affects significantly the stability (Psycharis, 1985; Makris & Roussos, 2000; Psycharis et al. 2000), with larger structures being much more stable than smaller ones of the same slenderness.
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