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Numerical study on the dynamic behavior of masonry columns and arches on buttresses with the discrete element method

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ABSTRACT

Earthquakes represent one of the major threats to the stability of the world architectural heritage, which is mostly constituted by unreinforced masonry (URM) structures. The dynamic behavior of these structures is complex and highly non-linear, as it involves sliding and rocking of the component blocks. As a result, numerical modeling seems to be the most appropriate predictive approach and, in particular, the Discrete Element Method (DEM) has recently emerged as a very promising tool for this purpose. Although multi-drum columns and arches on buttresses are typical components of historic URM structures, their modeling with the DEM has been the subject of relatively limited research. Moreover, a set of input parameters is required for the definition of the numerical model and, due to the uncertainty and difficulty in their experimental evaluation, these parameters are usually set in an arbitrary way.

In this paper, a systematic parametric study based on the DEM is adopted to evaluate the dynamic behavior and resistance of multi-drum columns and arches on buttresses subjected to two different base motions, i.e. step and harmonic impulses. A detailed investigation on failure domains and modes of collapse is presented. The main features of the dynamic response of masonry structures and the sensitivity of the response to changes in the excitation, geometry and mechanical parameters are discussed.

1. Introduction

The study of the dynamic response of unreinforced masonry (URM) structures to horizontal ground motions is crucial to understand the possible effects of a seismic event, and therefore to ensure their preservation. Ancient URM structures have been exposed to a large number of seismic events throughout many centuries of their life span. Yet, most of them still survive. Therefore, it is important to understand the mechanisms that allowed them to avoid structural collapse and destruction during strong earthquakes, as well as to develop tools for the assessment of the safety of URM structures threatened by seismic events.

The analysis of the dynamic response of URM structures is very complex because of their non-linearity and sensitivity to small changes in the excitation, geometry and mechanical parameters. An analytical investigation of the dynamic response would be impractically complicated or even unfeasible, as the structures change their modes of vibration during the excitation, with each mode being governed by a different set of equations of motion. Laboratory tests are difficult and costly to perform, although they are obviously needed for validation purposes. It seems that the most convenient way to investigate the dynamic response of multi-block systems is by numerical modeling. With appropriate numerical tools, the sensitivity of the response to changes in the input parameters can be readily evaluated, and the most significant parameter values can be identified to carry out selected experimental tests.

The discrete element method (DEM) is particularly effective to model masonry structures as an assemblage of distinct rigid or deformable blocks, interacting through unilateral deformable contact elements. This method allows for fully dynamic analysis with large displacements, governing the independent motion of the component blocks caused by rocking, hinging and sliding. An increasing attention has been recently given in the literature to the dynamic analysis of masonry structures based on the DEM. A brief state-of-the-art review is reported as follows.

Winkler et al. [1] applied the DEM to simulate the response of rigid single blocks and block assemblies subjected to harmonic base motion. They found a good agreement between the numerical results and those obtained from laboratory tests and analytical modeling. Papantonopoulos [2] demonstrated the existence of a good correlation between the results of the numerical modeling by the DEM and rigid body dynamics of a rigid block subjected to a real earthquake ground motion. Also, Peña et al. [3] examined the seismic response of a single rocking block to both harmonic and earthquake ground motions by modeling the problem with the DEM.

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