Chapter 11
Numerical Study of Discrete Masonry Structures under Static and Dynamic Loading

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ABSTRACT

Much of the world’s architectural heritage consists of Unreinforced Masonry (URM) structures whose preservation is a topical subject. To prevent possible collapse of multi-block systems in hazardous conditions, a promising tool to investigate their structural response is represented by numerical modelling with the Discrete Element Method (DEM). Gothic buttresses of trapezoidal and stepped shapes are first analysed comparatively under static loading, defining the optimal configurations. Numerical results are verified against the analytical predictions of overturning and sliding resistances, based on a continuum approximation of masonry. The DEM is then successfully adopted to assess the first-order seismic behavior of arches and buttressed arches with different shapes as compared to predictions based on limit analysis. A systematic investigation on dynamic behavior failure domains and on modes of collapse of URM structures is finally performed for varying input parameters, as needed to gain more confidence on the numerical results.

INTRODUCTION

Among the structural components in masonry building, buttresses, arches, and portals (i.e. buttressed arches) deserve particular attention. They are very widespread in European historical centers, and their preservation as part of the cultural heritage is a topical subject. Because of their ages, or for accidental events as earthquakes, these structural elements can suffer several types of damage. Therefore, a fundamental understanding of their structural behavior has to be evaluated in terms of stability, in order to prevent their brittle collapse in possible future hazardous conditions. In this perspective, the limitations...
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of sophisticated analytical modelling and experimental investigations for complex geometries have increased the use of numerical modelling for structural analyses (Fanning, Boothby, & Roberts, 2001; Raman, 2004; Viola, Panzacchi, & Tornabene, 2005; Gonen, Dogan, Karacasu, Ozbasaran, & Gokdemir, 2013). Although the Finite Element Method (FEM) is widely used for the analysis of problems with discontinuities, this method is not particularly suitable to analyze discrete multi-block systems characterized by continuous changes of their geometry and contact conditions among bodies.

An alternative approach is represented by the Discrete Element Method (DEM), as developed by Cundall (1971), where discontinuous bodies are able to move freely in space and interact reciprocally with contact forces, leading to an automatic updating of contact detection. Based on this approach, a system of multiple bodies may change its position in a time-stepping scheme under the action of external and interaction forces between bodies, which in turn lead to a steady-state configuration when the static equilibrium is reached. For rigid masonry blocks, the contact interaction law is therefore the only constitutive law considered, without including any continuum constitutive law (e.g. elasticity, plasticity, damage, fracturing), as differently occurs for deformable bodies. The DEM features many advantages, e.g. the low storage, simplicity of coding, suitability for parallel processing, adoption of the same algorithm for statics and dynamics. A systematic numerical analysis based on the DEM is herein performed in three parts, in order to evaluate the static, quasi-static, and dynamic response of some bi-dimensional URM structures (see more details in Dimitri, 2009), as implemented in the code UDEC (Universal Distinct Element Code) by Itasca (2004).

More specifically, the first part of the chapter is concerned with the evaluation of the stability of buttresses of different shapes subjected to concentrated lateral loads, accounting for fracturing and sliding before collapse. Gothic buttresses of trapezoidal and stepped shapes, are analyzed comparatively, where numerical results are verified against some theoretical predictions of overturning and sliding resistances, obtained considering masonry as a continuum body without tension resistance.

In the second part of the chapter, the first-order seismic assessment of masonry structures is studied with the discrete modelling in order to estimate the lateral loading they can withstand before collapse. The numerical results are compared with theoretical predictions based on limit analysis. Due to a lack of information about the relative efficiency of different arch shapes, for any possible mechanism of collapse, circular, pointed or basket-handle shapes are analyzed comparatively. This makes clearly interesting a parametric assessment of masonry structure for varying geometry parameters, as herein performed with the DEM.

The last part of the chapter is concerned with the evaluation of the dynamic behavior and resistance of multi-drum columns subjected to simple base excitations. A detailed investigation on failure domains and on modes of collapse is discussed, and the simulations are performed with varying geometry and mechanical parameters. Besides the parametric evaluation of the sensitivity of the response to the input parameters, (i.e. the input properties of the joints, and the damping ratio), a novel aspect of this DEM-based research is pointed out with respect to the available literature, such as the size effect on failure domains.

BACKGROUND

In a context where researchers and engineers differently emphasize the importance of strength or stability in a static or dynamic assessment of masonry structures, the combination of the two aspects should be certainly considered depending on nature and geometry of the specific structure. The structural studies