DEM modelling of masonry vaults: influence of brick pattern and infill on stability during supports displacements

Claudio BONI*, Daniele FERRETTI[a], Erica LENTICCHIA[b], Alessandro TASORA[a]

* Student of Civil Engineering at University of Parma
via D. Fenulli, 85 - Reggio Emilia - 42123 - Italy
claudio.boni.94@gmail.com

[a] Department of Engineering and Architecture, University of Parma, Italy
[b] Department of Structural, Geotechnical and Building Engineering, Politecnico di Torino, Italy

Abstract

Starting from Ancient Roman architecture, masonry vaults have been built for centuries around the world, with different forms and construction techniques. Although in the past masonry vaults were designed without structural calculations, ancient builders developed practical rules, mainly based on geometrical proportions and empiric observations. Only after the 17th century, the stability of vaults begun to be studied mathematically; currently masonry vaults are analyzed by means of computational methods, such as finite element method (FEM) and discrete element method (DEM). Anyway, It has always been known that brick pattern influences the structural performance of masonry: the optimal design of vaults and orientation of bricks have frequently been one of the main topic in historical treaties, but, till now, this aspect has often been neglected from a scientific point of view. It is also a common knowledge that the main weakness of vaults is due to supports settlements.

The present paper proposes a discrete element method to study both the effects of brick pattern and infill on the stability of masonry vaults subjected to displacements of the supports. On the one hand, brick pattern, thanks to interlocking and friction between blocks, provides an equivalent tensile strength of masonry, which affects the behavior of the vault in terms of failure mode and failure load/settlement. On the other hand, the infill causes additional compression, which affects the thrust line configuration and, consequently, the stability of the vault [1].

In the present work, the discrete element method was chosen, because it allows to model effectively each brick and its interaction with other blocks nearby. ChronoEngine [2] was the software adopted: it is an open source C++ library developed for mechanical engineering but also successfully used to study masonry structures in civil engineering applications [3]. The software is based on a regularized non-smooth contact dynamics approach [3] that reduces the computational burden with respect to other DEM approaches permitting to analyze 3D problems with huge numbers of bodies. Initially, the parameters of the model have been calibrated by studying well-known experimental campaigns. Then, three types of vaults (barrel, cross, pavilion) with different brick patterns, including the herringbone one, were investigated. The infill was modelled by means of thousands of spheres and the support displacements were applied both in horizontal and vertical direction in a quasi-static mode.

The results of the analysis have shown that the static behaviour of a specific type of vault is affected by the brick pattern: for instance, failure displacement goes from 3 to 15 centimetres for barrel vaults. Moreover, in the case of barrel and cross vaults, it turned out that practical rules in handbooks about brick layout not always lead to the best working one. Another interesting aspect is that the presence of the infill is positive, increasing the collapse displacement up to 100%.

References

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