Chapter 14

FEM/DEM Approach for the Analysis of Masonry Arch Bridges

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ABSTRACT

The problem of masonry arch bridges load carrying capacity is studied by means of a coupled FEM/DEM 2D approach. The numerical model relies into a triangular discretization of the domain with embedded crack elements that activate whenever the peak strength is reached. The proposed approach can be regarded as a combination between Finite Elements allowing for the reproduction of elastic strain into continuum and DEM, suitable to model frictional cohesive behavior exhibited by masonry structures even at very low levels of external loads. The aforementioned numerical approach is applied to masonry arch bridges interacting with infill. A preliminary validation of the procedure is addressed for the prediction of the masonry arches limit state behavior where the stones are supposed infinite resistant and plastic hinges can occur exclusively on mortar joints, modeled as cohesive frictional interfaces. The sensitivity of the infill role varying mechanical properties of the infill is extensively discussed.

INTRODUCTION

In this Chapter, the feasibility of the utilization of a combined Finite Element/Discrete Element (FEM/DEM) approach to investigate the behavior of masonry arch bridges is assessed. In particular, the Chapter proposes and discusses a possible approach to FEM/DEM modelling of two existing masonry arch bridges. Attention is paid to the assessment of the load carrying capacity of the structures by means of a suitable coupled FEM/DEM 2D approach.

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As a matter of fact, Finite Element Method (FEM) is the most widely used numerical tool in computational solid mechanics. However, some decades ago, ad-hoc computational methods have been developed to deal with particulates, jointed rock, granular flows and problems where the so called emergent properties of a system are a result of interaction between large numbers of individual solid particles: the most widely used method for a large class of these problems is the so called Discrete Element Method (DEM). This latter approach well adapts to all those non-linear problems characterized by the mutual movement of rigid bodies, eventually interacting by means of both contact and friction, also under large displacement hypotheses. It is therefore quite intuitive to understand why DEM received growing attention in the field of both soil mechanics and masonry modelling, due to the intrinsic capability of the procedure to tackle the most important and distinctive aspects of their behavior, especially in the non-linear dynamic range, but also when limit analysis computations are carried out.

In the early 1990s FEM and DEM methods were combined and the resulting method was termed as combined FEM/DEM method. The first attempts are due, among the others, by Munjiza (2004), who shown how to join the advantages of FEM and the ones of DEM into a single numerical tool. FEM/DEM is in its essence a Discrete Element Method where the Discrete Elements are meshed into Finite Elements. Finite Elements allow to model elastic deformation (but also crushing on blocks when required), while Discrete Element algorithms allow modeling interaction, fracture and fragmentation processes in a very straightforward fashion.

FEM/DEM provides a consistent procedure to study masonry structures, thanks to the possibility of creating models made by separated blocks. In particular, these models result particularly suited to analyze quickly but accurately the behavior of historical masonry constructions (Reccia, Cecchi & Cazzani, 2012; Smoljanović, Živaljić & Nikolić, 2013; Baraldi, Reccia, Cazzani, & Cecchi, 2013; Baraldi, Reccia & Cecchi, 2015).

In the present Chapter, the combination of DEM and FEM provided by the open source code Y2D, developed again by Munjiza (2004), is utilized to study masonry arch bridges behavior interacting with the infill and subjected to increasing static loads up to failure. Typically, the problems show non-linearity at early stages of the application of the external loads. Blocks are usually either clay bricks or stones, showing excellent compression strength and high elastic modulus. As a consequence, they can be conveniently modeled as very stiff elastic bodies, while mortar joints might be idealized as elastic or elastic-plastic zero-thickness Mohr-Coulomb interfaces.

Briefly, the advantages of the coupled FEM/DEM method are:

1. It allows modelling both deformable or rigid bodies – in this chapter this aspect is highlighted modelling the arch voussoirs as a rigid bodies while backfill as a deformable material;
2. Cracks elements are embedded between all the Finite Element of the mesh, therefore joints may be modelled in order to prefigure fixed crack patterns – like in the case of masonry arches, where cracking may occur only between voussoirs – or random crack patterns – like in the case of backfill, where cracks may occur everywhere, according with the mesh geometry and with any orientation.

Masonry arch bridges are among the most ancient and best-preserved historical structures. Their construction dates back to the dawn of the history and their development has gone hand in hand with the technological advancement. Masonry arch bridges are a remarkable evidence of the engineering progress and the technological achievement and skills the mankind has developed over the centuries: they are an essential part of the architectural historical heritage. Their presence is a characteristic feature of the European landscape.
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