Chapter 3

The Basis for Masonry Analysis with UDEC and 3DEC

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ABSTRACT

The “distinct element method” was proposed by Peter Cundall in 1971 for the analysis of rock slopes by means of rigid block or circular particle models. This method led to the UDEC and 3DEC codes, presently in wide use in rock engineering. Their application to masonry structures started in the 90’s, as researchers found that they were also excellent tools to approach the highly nonlinear behavior of masonry, in particular the collapse processes of stone block structures under static or seismic loads. This chapter reviews the essential assumptions of UDEC and 3DEC, relating them to other methods and codes, and stressing the features that make them suitable for masonry analysis. Rigid and deformable blocks, contact mechanics, contact detection, and solution algorithms are examined. Key issues in the modelling of masonry are addressed, including: irregular block models; determination of collapse loads; large displacement analysis; computational efficiency issues in dynamic analysis. Practical examples taken from the published literature illustrate these issues.

INTRODUCTION

The development of the finite element method and its wide acceptance by the engineering community during the 1960’s supplied a powerful tool for structural analysis. Joint elements were proposed by Goodman et al. (1968) to represent joints or other thin discontinuities, which play a key role in the behavior of rock or masonry. Cundall (1971) proposed a different approach to the study of discontinuous systems, by viewing them as an assembly of blocks in mechanical interaction through sets of point contacts. He employed an explicit solution algorithm based on dynamic relaxation instead of the common matrix methods. With these tools, he was able to simulate the full evolution of collapse processes of blocky media taking into account the changes in geometry and contact due to large displacements, including total block separation. The initial aim was the analysis of rock slopes, but this approach was soon recognized to be of interest in many other engineering fields dealing with complex, discontinuous structures with...
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strongly nonlinear behavior. Papastamatiou and Psycharis (1993) and Psycharis et al. (1993) showed the potential of this method for the study of the dynamics of block masonry structures, in their analysis of the drum columns of the Apollo temple at Bassae. Extensive application to other types of masonry constructions would follow.

Cundall named his approach the “distinct element method”, but the designation “discrete element method (DEM)” is nowadays more common, encompassing not only the codes derived from Cundall’s work, such as UDEC (Itasca, 2014) and 3DEC (Itasca, 2013), but also many other formulations and codes currently used in masonry analysis (Lemos, 2007a). It is interesting to note that Cundall’s 1971 paper already included an example of a circular particle model, a class of DEM models which became quite widespread after the work of Cundall and Strack (1979).

In this chapter, the essential features of UDEC and 3DEC are reviewed, with an emphasis on clarifying differences and similarities with respect to the alternative approaches within the family of discrete elements. The key ingredients required to model the discontinuous nature of masonry will be stressed. A discussion of the main types of problems for which these codes are suitable follows, illustrated by examples taken from the literature. While the present chapter refers mainly to UDEC and 3DEC, the discussion of their application to masonry is based on general concepts so that it is also relevant for users of other DE formulations and codes. The practical issues examined, such as the choice of a rigid or deformable block representation, the generation of complex geometries, the simulation of reinforcement elements, or the specific requirements for an efficient seismic analysis, are encountered by all those using DE models in this field.

THE EVOLUTION OF UDEC AND 3DEC

Early Rigid Block Codes

The original DEM codes developed by Cundall (1971) allowed the analysis of systems of rigid bodies in mechanical interaction, either polygonal blocks or circular particles. The intended application was the analysis of the stability of slopes in jointed rock, taking into account the possible separation between the rock blocks during the failure process. The key requirements were the proper simulation of the nonlinear behavior of the joints, assuming no tensile strength and frictional sliding. The main assumptions were:

- Polygons behave as rigid bodies.
- Mechanical interaction represented by point contacts.
- Contact behavior characterized by: normal stiffness, shear stiffness, and friction angle.
- Solution based on the integration of the equations of motion by means of an explicit algorithm.
- Static solutions obtained by dynamic relaxation using artificial damping.
- Large displacement analysis, including automatic contact detection and update.

Many of the features in this list would be retained in the future codes, as they proved to be very effective in the study of many other types of discrete systems.