

# Modeling of in-plane behavior of masonry walls using distinct element method

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**Abstract.** In most of masonry structures, walls are known as the major load-resisting elements. When an earthquake occurs, damage or failure in these elements could lead to total destruction of masonry structure. Due to low flexibility and poor shearing and bending resistance, masonry structures are highly vulnerable. One of the approaches in behavior modeling of discontinuous environments is the distinct element method, which is suitable for blocky structures analysis. This study focuses on the investigation of masonry walls behavior under vertical and lateral loads and verification of the distinct element method results using 3Dec software. The results obtained from distinct element method analysis were compared to the data resulted from experimental tests on two specimens, one with and the other without opening. Acceptable accordance in shearing capacity and failure mechanisms of masonry walls were obtained.

**Keywords:** Masonry walls, Distinct element method, In plane behavior

## 1. Introduction

In recent decades, numerical modeling of masonry structures behavior has been widely considered. Numerical methods used for continuum modeling like finite elements method are not able to simulate the behavior of such structures accurately, because they cannot estimate the dynamic behavior of separated elements and interactions between them [1]. Distinct element method (DEM) could be represented as an ideal alternative to successfully analyze the discontinuous materials such as masonry structures. DEM has been progressively developed over the past two decades. Cundall (1971)[2], first introduced DEM to simulate progressive movements in blocky rock systems and the model has been implemented into computer programs UDEC and 3DEC since then. In DEM method, a solid is represented as an assembly of discrete blocks while joints are modeled as interface between distinct bodies. Similar to the Finite Element Method (FEM), the unknowns in the DEM are also the nodal displacements and rotations of the blocks. However, unlike FEM, DEM is a dynamic process and the unknowns are solved by the equations of motion [3].

## 2. Experimental Studies

In order to verify the modeling of masonry walls using DEM method, results from a Laboratory study in Netherland was investigated. Samples tested in this research include two walls, one with and one without opening. The walls have a width/height ratio of one with dimensions  $990 \times 1000$  ( $mm^2$ ), Built up with 18 courses, from which 16 courses are active and 2 courses are clamped in steel beams to prevent out-of-plane deformation of walls. Bricks dimensions were  $210 \times 52 \times 100$  ( $mm^3$ ) and mortar thickness was 10 mm. Vertical distributed forces are applied to the walls prior to monotonically increasing horizontal force. Test set up and applied vertical load are shown in figure (1).

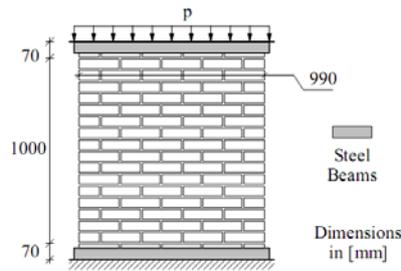


Figure1. Test set up and applied vertical load[4]

For the wall without opening, results show that horizontal tensile cracks develop at the bottom and top of the wall and a diagonal stepped crack leads to collapse, simultaneously with the cracks in the bricks and crushing of the compressed toes (Figure 2). But in the case of wall with opening, diagonal zigzag cracks arise initially from the two corners of the opening which are followed then by tensile cracks starting from the outside of the wall at the base and top of the small piers. Finally, a collapse mechanism is formed with failure of the compressed toes, located at the bottom and top of the wall and at the bottom and top of the small piers (Figure 3).

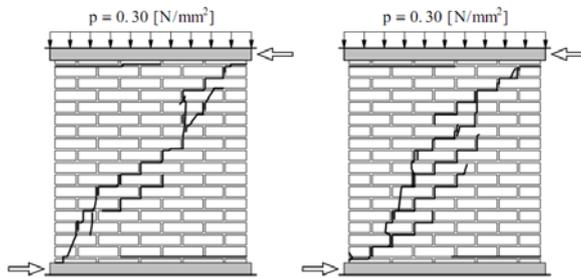


Figure2. Experimental crack patterns for wall without opening [4]

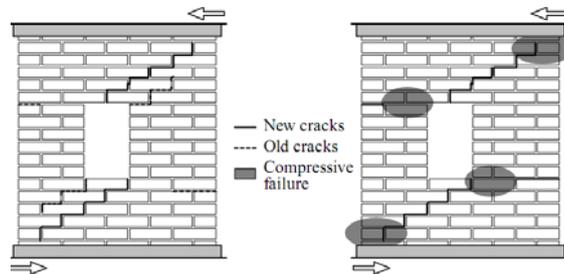


Figure3. Experimental crack patterns for wall with opening [4]

Figure (4) shows the experimental load-displacement diagrams for the two samples.

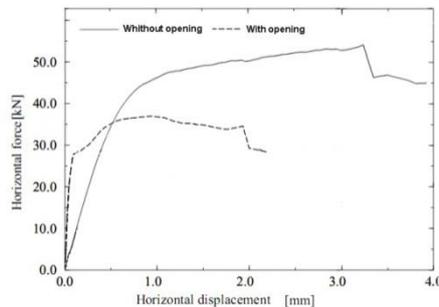


Figure4. Experimental Load-displacement diagrams [5]

### 3. Modeling with Distinct Element Method

For verification of modeling of masonry walls with DEM, two above mentioned specimens were analyzed using 3Dec software. In simulation with 3Dec, mortar joints are deleted from model and their behavior attributed to the discontinuities. 3Dec has predefined behavior models for blocks (bricks) and discontinuities (mortar). Mohr-coulomb plasticity model was used for bricks while for discontinuities

coulomb slip model was employed. In coulomb model, elastic behavior of discontinuities is introduced with normal stiffness ( $k_n$ ) and shear stiffness ( $k_s$ ). Plastic behavior of discontinuities is introduced with cohesion (c), friction angle ( $\phi$ ), dilation angle ( $\psi$ ) and tensile strength (t)[6].

Material properties used for modeling with distinct element method and 3Dec software are shown in table (1) and table (2).

Table1. Elastic and inelastic properties for the blocks [4]

Block properties					
Elastic		Shearing			Tensile
$(\text{N}/\text{mm}^2)$ E	$\nu$	$C$ ( $\text{N}/\text{mm}^2$ )	$\tan \phi$	$\tan \psi$	$f_t$ ( $\text{N}/\text{mm}^2$ )
16700	0.15	2.8	1.0	0.0	2.0

Table2. Elastic and inelastic properties for the joints [4]

Joints properties					
Elastic		Shearing			Tensile
$k_n$ ( $\text{N}/\text{mm}^3$ )	$k_s$ ( $\text{N}/\text{mm}^3$ )	$C$ ( $\text{N}/\text{mm}^2$ )	$\tan \phi$	$\tan \psi$	$f_t$ ( $\text{N}/\text{mm}^2$ )
82	36	$1.4f_t$	0.75	0.0	2.0

Results from simulated models seem to be in good agreement with the results from laboratory works in the case of shearing capacity and failure mechanisms. Figure (5-a) shows the stress distribution at the failure stage in the wall without opening. Compressive stress concentration causing a failure in compressive toe can be observed. For wall with opening, stress distribution is shown in figure (5-b). In this case stress concentration in corners of opening and compressive toe can be observed. Figure (6) shows cracking patterns in the walls. Stepped cracks in the wall without opening are illustrated in figure (6-a). In the case of the wall with opening, as shown in figure (6-b), stepped cracks begin from corners of opening and extend towards the corners of the wall.

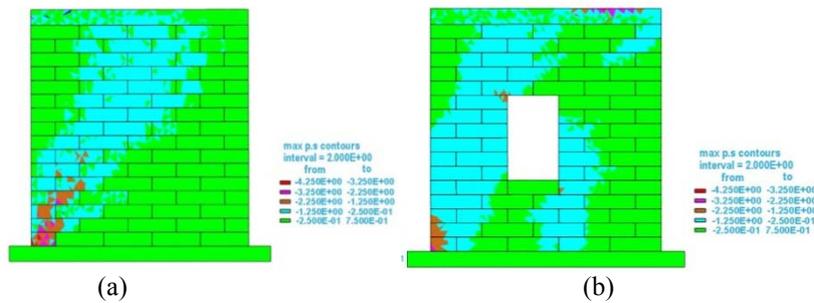


Figure5. Stress distribution in walls

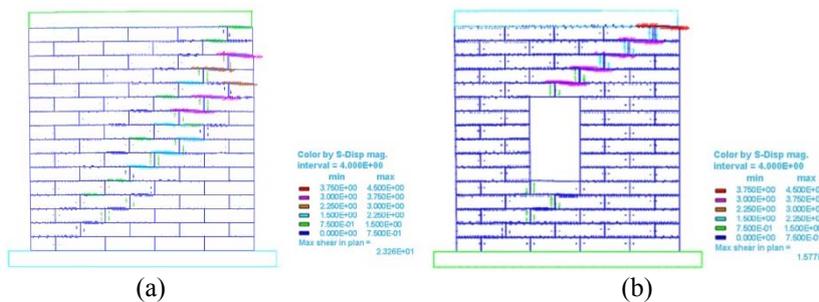


Figure6. Crack patterns in walls

A comparison has been made between the shearing capacity data resulted from laboratory tests and data obtained from numerical method. As shown in table (3), values obtained from numerical method for walls without and with opening, are 3% and 17% higher than experimental results respectively [7]. It should be noted that in numerical modeling of structures, due to the reducing degrees of freedom, obtained models for

structures are stronger. This can attribute to the difference between the experimental and numerical results. Figure (7) shows the numerical load-displacement diagrams for the two walls.

Table3. Shearing capacity resulted from experimental and numerical studies

walls	experimental (KN)	3DEC (KN)	Ratio(3dec/exp)
Without opening	51	59.5	1.17
With opening	36	37.5	1.03

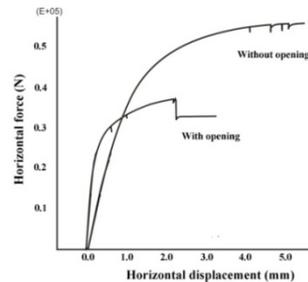


Figure7. Numerical load-displacement diagrams

#### 4. Summaries

Masonry structures due to inherent weakness in flexibility and shear strength are at risk of failure under lateral earthquake forces. Therefore detailed studies are needed to determine the behavior of these structures. Laboratory studies generally need high amount of time and cost and sophisticated equipments. Such limitations can be minimized by using a numerical analysis that simulates the behavior of these structures with sufficient accuracy. In this study numerical modeling of masonry structures using distinct element method and 3Dec software was investigated. Numerical results and experimental results for shearing capacity and failure mechanism were compared. Comparative studies confirmed a good agreement between the data obtained from both methods. It can be concluded that the distinct element method and simulating technique by 3Dec software could be reliably used for behavior prediction of masonry walls.

#### 5. References

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