Lateral Strength of Masonry Walls With Openings: Analytical Approach

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Abstract

The study presented herein, summarizes the outcome of an analytical investigation to predict the relation between the lateral load carrying capacity and the dimensions of a possible opening which a masonry wall may have. In this analytical study, the influence of the opening was investigated with three models having concentrically located openings respectively 15%, 30%, 45% of the infill area. The data gathered from these models was compared with the fourth reference model which had no opening. Coupon test of actual materials, such as standard hollow masonry brick unit and ASTM C270 N type mortar, was used in the analytical model. In order to build more realistic three dimensional model, actual brick and bed joint dimensions were adopted. By using Phase2 finite element software, four full scale masonry walls having dimensions of 2040x2100x190 mm were loaded laterally till collapse. Models were considered to be encased with a steel one story, one bay steel frame. Thus local failure of the wall was avoided and more reliable analysis results were introduced. For further stages of this work, an experimental verification study was also planned.

Keywords: Masonry wall; opening; finite element analysis; analytical study.

1.0 INTRODUCTION

Masonry walls are generally used for generating partitions in the living spaces and for non-structural or architectural needs in the buildings. Designers generally never consider these walls as a load carrying members. But in real behaviour masonry infill walls are effective load carrying members. Infill wall has a huge influence on the load and rigidity capacities of bare frame [1,2]. Many researches worldwide have been studying on masonry infill walls both numerically and experimentally in order to reveal realistic seismic behaviour and define material modelling. The outcomes of these studies are still gathered for a more sophisticated seismic code development in foreign countries. In Turkey experimental studies on seismic behaviour of structural

members speed up from late 90's. As a result of these studies TSC (Turkish Seismic Code) has changed twice in last 20 years. Major improvements were made under design and rehabilitation techniques of reinforced concrete buildings. Nevertheless masonry structures and specifically seismic behaviour of walls somewhat go unheeded. The aim of this analytical study is to point out a need of a proper definition of an opening that an infill masonry wall might have. For this purpose three models were developed to point out the effect of the opening on the lateral load carrying capacity of the wall. Models were chosen to have 15%, 30%, 45% of concentrically located square opening. According to TSC, the wall having 15% opening is a safe design, 30% opening is the limit state and 45% opening is 15% unsafe. Load carrying capacities and energy absorption properties of walls with opening are compared to a reference models which has no opening. Sketch of real model and wall and opening dimensions is given in the Figure 1 and Table 1.

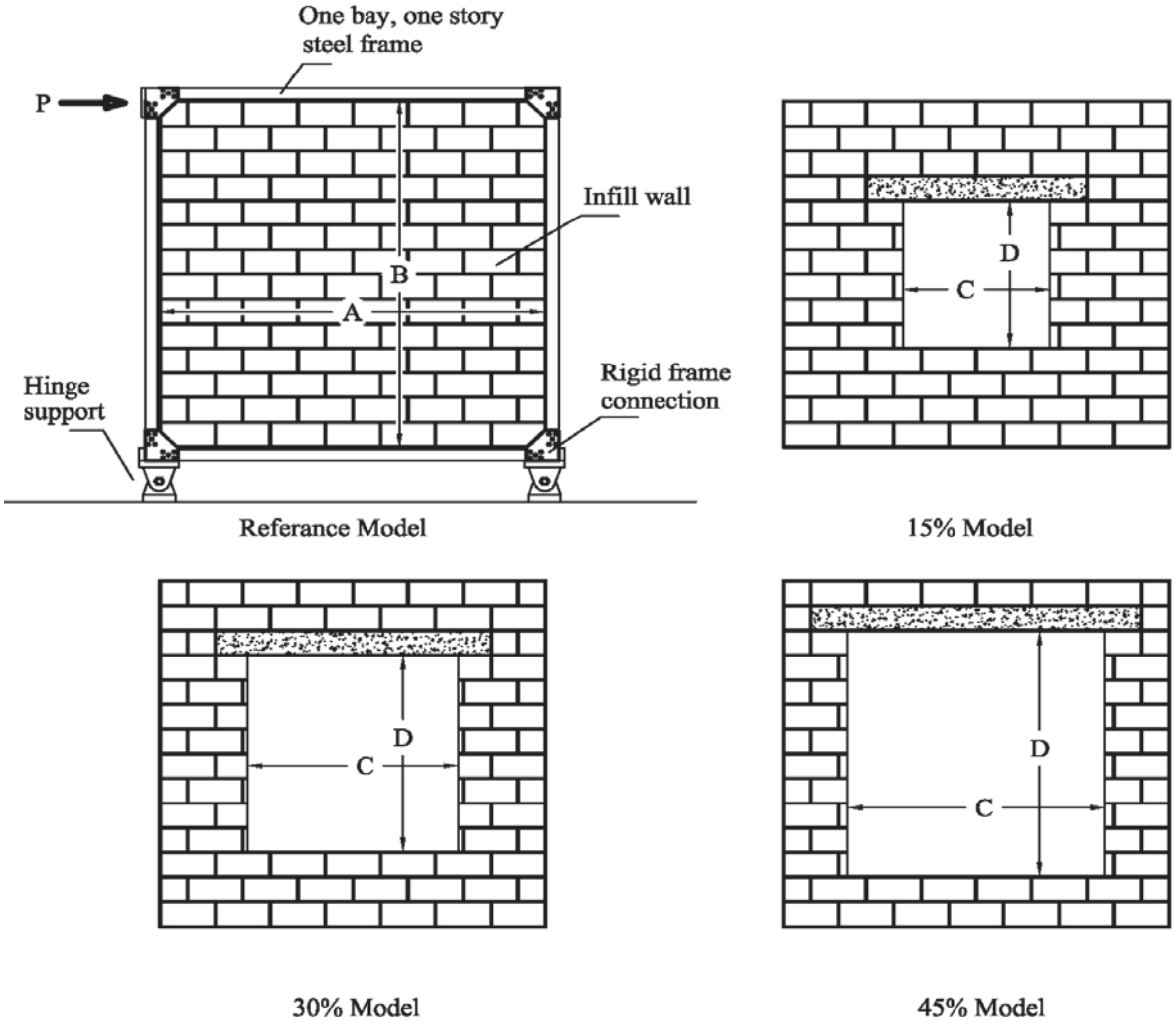


Figure 1 - Sketch of real model and model walls.

Table 1 - Dimensions of model walls.

	A (mm)	B (mm)	C (mm)	D (mm)
Reference model	2100	2040	---	---
15% Model	2100	2040	800	800
30% Model	2100	2040	1150	1150
45% Model	2100	2040	1400	1400

2.0 NUMERICAL ANALYSIS OF MASONRY STRUCTURES

Numerical analysis of masonry structures is not a straightforward task due to the fact that masonry structures which are composed from blocks and mortar joints are heterogeneous and anisotropic. There are several methods for the analysis of masonry structures. These are linearly elastic finite element analysis, non-linear elasto-plastic finite element analysis, discrete (distinct) element analysis and limit analysis techniques. In the limit analysis technique it is assumed that masonry structures are made from perfectly rigid blocks. Finally, the interface between two blocks cannot withstand tensile stresses, can withstand limited compressive stresses, and the shear failure is controlled by the Coulomb's law (Orduna and Lourenço, 2001). Using non-linear elasto-plastic finite element method both deformations and plastic regions of the system can be determined. However finite element method is most suited for continua, therefore discontinuous masonry structure should be treated as a continuum. Discrete Element Method is a numerical method specifically used to solve problems in engineering that exhibit discontinuous mechanical behaviour. DEM explicitly models the motion and mechanical interactions of each object in the physical problem throughout a given simulation and then provides a detailed description of the velocities, positions, and the forces acting on each object at different points in time during the analysis. In this study two dimensional non-linear elasto-plastic finite element method was utilized for analyses of masonry walls with openings.

3.0 FINITE ELEMENT ANALYSES OF MASONRY WALLS WITH OPENINGS

In this study the influence of the opening was investigated with three specimens having concentrically located 15%, 30%, 45% of the opening. The data gathered from these specimens was compared with the fourth reference model which had no opening using Phase2 software. Phase2 is a non linear elasto-plastic finite element stress analysis program (Rocscience, 2013). In order to use finite element method for the analysis of masonry walls, continuum equivalent parameters (modulus of elasticity and Mohr Coulomb failure criteria

parameters cohesion and friction angle) are needed. Mohr – Coulomb failure criteria are used for masonry modelling. For example Lourenço (2002) and Orduna and Lourenço (2003) used Coulomb type failure criterion between masonry blocks. Mojsilovic (2012) represented shear strength of masonry walls using Mohr Coulomb failure parameters. Mojsilovic (2012) performed shear tests on masonry elements with and without damp-proof course membrane. According to shear test performed on normal masonry element by Mojsilovic (2012) (without damp-proof course membrane), 0.3 MPa cohesion and 0.87 friction coefficient (41° friction angle) were obtained. Similarly Kanit and Işik (2007) performed three dimensional finite difference analyses of brick masonry arch models. They used, 400 kPa cohesion, 40° friction angle and 200 kPa tensile strength to match predicated failure load from finite difference model to laboratory model tests.

By considering these information, 350 kPa cohesion, 40° friction angle and 1.825 GPa modulus of elasticity values were used for the two dimensional finite element analyses of masonry walls.

Finite Element Meshes for Model Walls

Figures 1 – 4 present the finite element and boundary conditions for model walls. In finite element analysis increasing point load is applied from upper right corner as shown in figures 1 to 4 and corresponding maximum displacement is calculated as well as stress – strain distributions within the model.

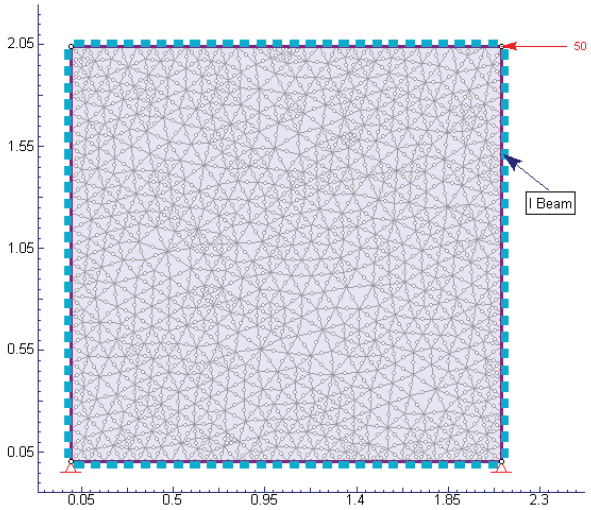


Figure 2 - Boundary conditions and finite element mesh for model wall with no opening.

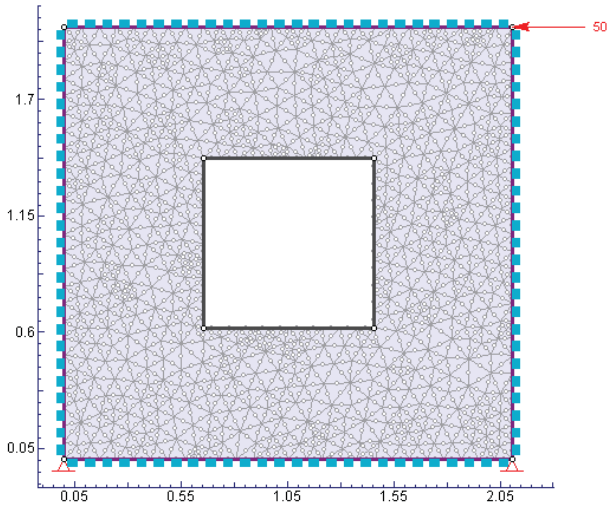


Figure 3 - Boundary conditions and finite element mesh for model wall with 15 % opening.

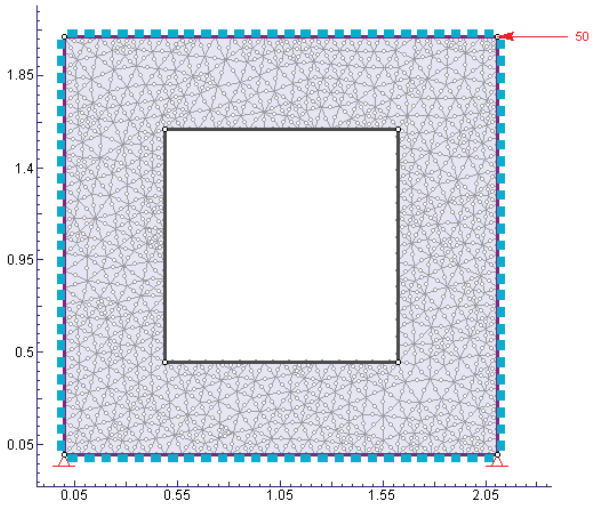


Figure 4 - Boundary conditions and finite element mesh for model wall with 30 % opening.

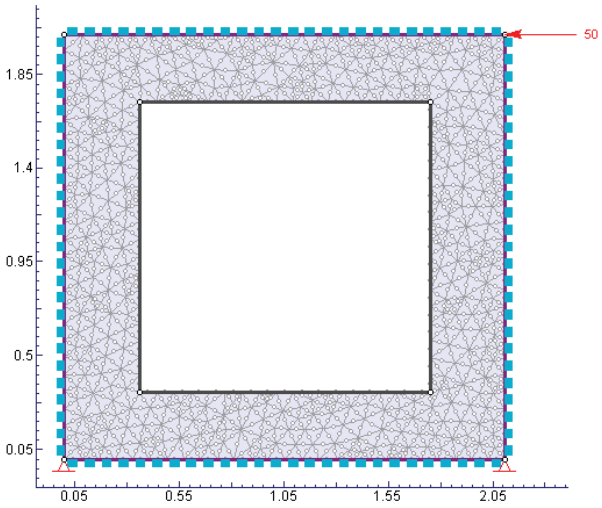


Figure 5 - Boundary conditions and finite element mesh for model wall with 45 % opening.

4.0 RESULTS OF NUMERICAL ANALYSES

Point load at the upper right of the model increased at each step corresponding displacements and stress distribution within the model was calculated. Figures 6-9 show the displacement vectors and shear strain distribution in wall models. Shear strain distribution is an indication of shear crack s that may occur in walls.

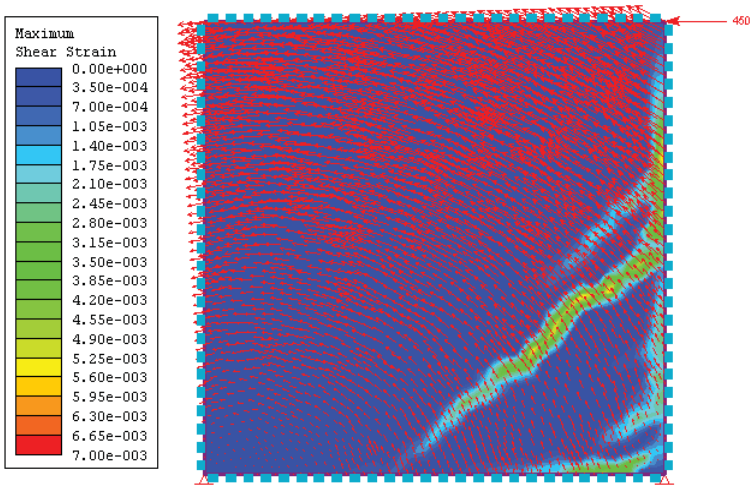


Figure 6 - Displacement vectors and shear strain distribution in the model wall with no opening.

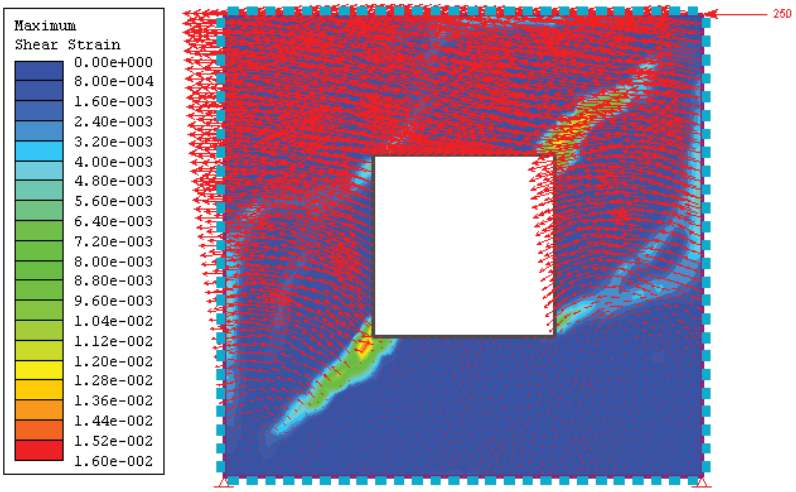


Figure 7 - Displacement vectors and shear strain distribution in the model wall with 15 % opening.

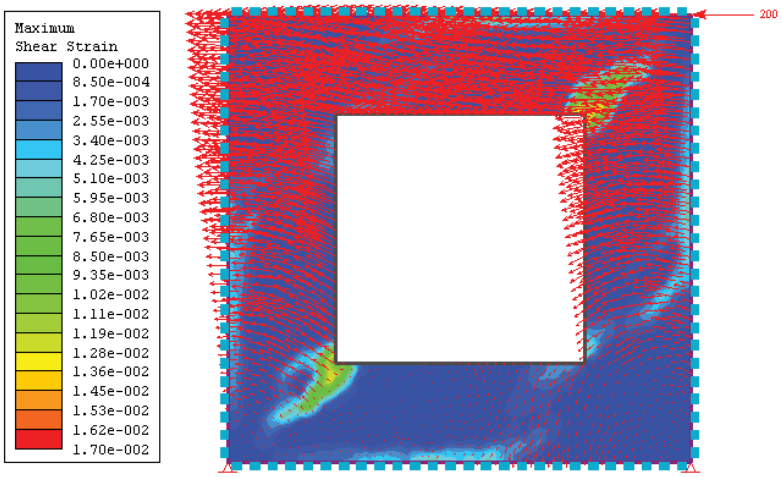


Figure 8 - Displacement vectors and shear strain distribution in the model wall with 30 % opening.

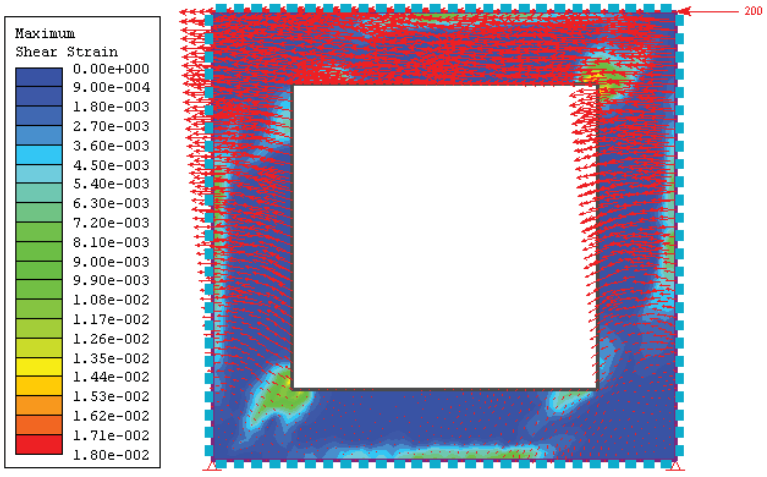


Figure 9 - Displacement vectors and shear strain distribution in the model wall with 45 % opening.

From figures 6 to 9, it is evident that shear cracks are likely to form around the corners of the openings. Figures 10 to 13 show the mean stress distribution in wall models. Positive values of mean stress indicate compression whereas negative values of mean stress indicate tension.

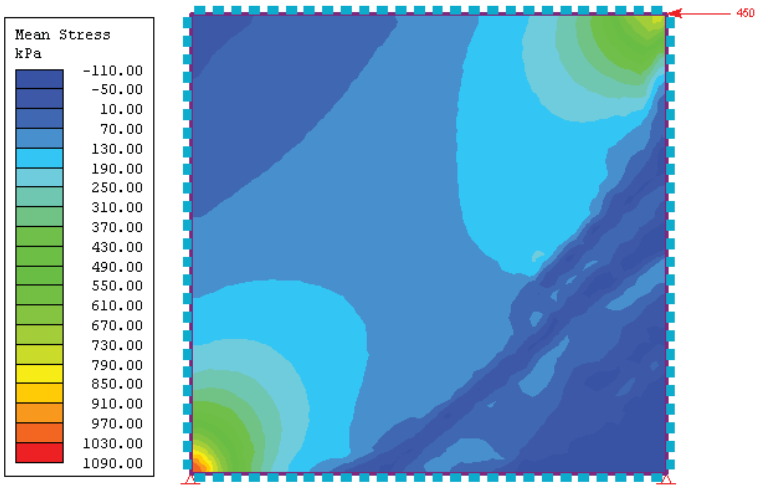


Figure 10 - Mean stress distribution in the model wall with no opening.

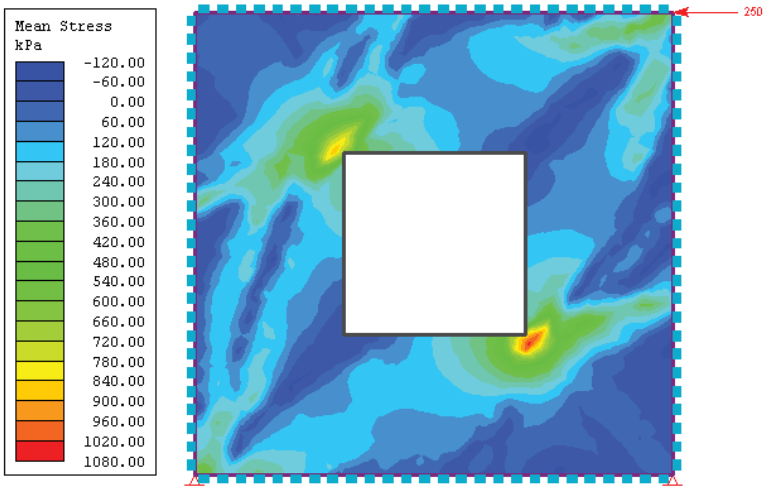


Figure 11 - Mean stress distribution in the model wall with 15 % opening.

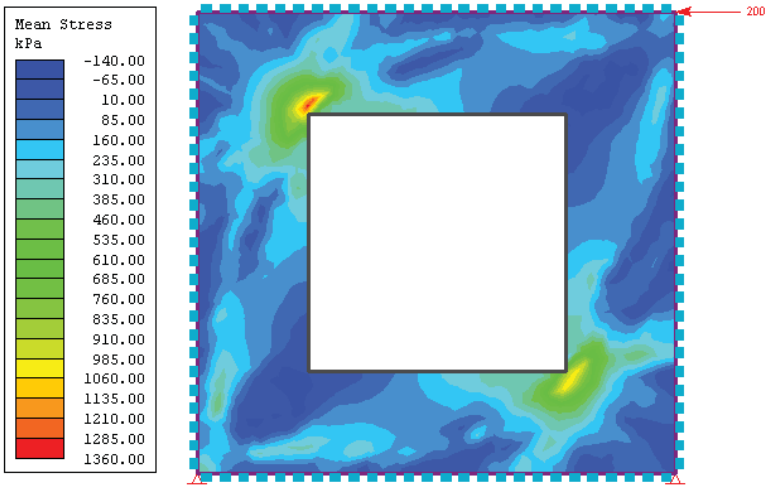


Figure 12 - Mean stress distribution in the model wall with 30 % opening.

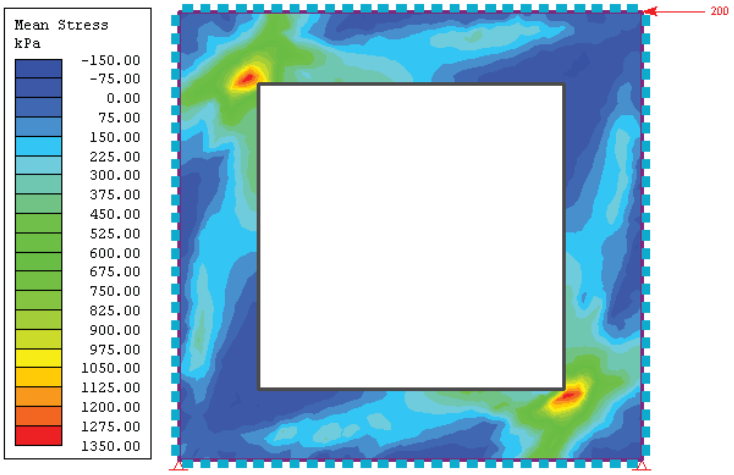


Figure 13 - Mean stress distribution in the model wall with 45 % opening.

In the model wall with no opening maximum compressive mean stress concentrates around the wall corners, tensile mean stresses are concentrated around opposite corners to compressive stresses. However in walls with openings tensile and compressive mean stresses are concentrated around openings. In Figure 14 load displacement graphs of model walls is presented.

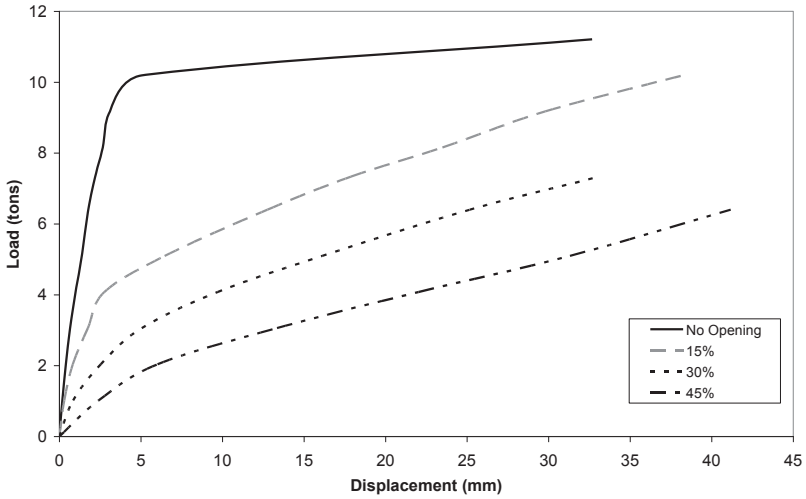


Figure 14 - Load displacement graphs of model walls.

It is clear from Figure 14 that rigidity of the wall with no opening is much larger and retains its load carrying capacity till further displacement levels. As the opening within wall increases collapse displacement is postponed, initial stiffness decreases rapidly and load carrying capacity decreases accordingly. After collapse, gain in the load capacity with the increasing displacements for the models having openings is a handicap for finite element models authors also aware that this is not a realistic behaviour.

5.0 CONCLUSIONS

This study summarizes the outcome of an analytical investigation to predict the relation between the lateral load carrying capacity and the dimensions of a possible opening which a masonry wall may have. The influence of the opening was investigated with three numerical specimens having concentrically located 15%, 30%, 45% of the opening. The data gathered from these specimens was compared with the fourth reference model which had no opening using Phase2 non-linear elasto-plastic finite element software. Analyses results indicate that shear cracks are likely to form around the corners of the openings; in the model wall with no opening maximum compressive mean stress concentrates around the wall corners, tensile mean stresses are concentrated around opposite corners to compressive stresses. However in walls with openings tensile and compressive mean stresses are concentrated around openings.

Wall with no opening shows more rigid behaviour, also as the opening within wall increases load bearing capacity of the masonry walls decreases rapidly.

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