Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2017, 4(12):374-380**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

An Analytical Study of the Effect of Openings in Concrete Shear Walls

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Abstract With the growing use of finite element for structural analysis and the importance of satisfying code design criteria, the need for model reliability and proper interpretation cannot be overemphasized. However, there are alarming reports on the potential of computer errors resulting from user inexperience, size and shape of finite elements, other operating system or hardware related errors. Significant errors may also be created due to opening holes. This paper describes the errors that occur in finite element analysis due to several effects such as size and shape of finite elements, size, shape and positions of opening holes in reinforced concrete structures. The variable parameters in this study are the size and shape of finite elements, size and positions of opening holes. The analysis was carried out using finite element software "Ansys". The problems considered in this study are represented by cantilever shear walls with and without openings. Square and circular shapes located on the center line and near the compression and tension sides were considered. Vertical and horizontal loads were applied to the walls that simulated the gravity and seismic loads in residential buildings with moderate conditions. The effect of size and shape of finite elements, size and positions of opening holes were studied and conclusions in this regard were obtained.

Keywords Finite element, Errors, Analysis, Opening holes

1. Introduction

Concrete structures designed in accordance with the ACI code [1], must satisfy two essential design criteria: the strength and serviceability limit states [2]. For common building structures with regular layout, these criteria may be satisfied without using advanced analytical methods. However, for structures with irregular layout and with opening holes and different geometric properties, advanced numerical methods are required such as finite element elements [3]. Using finite element programs [4, 5] to develop a structural model for a concrete structure, the resulting model and its result's accuracy depend on many factors which are based on the available features in the program, the user knowledge and the modeling procedure. The model results consist of nodal stresses, forces and displacements which in turn depend on the element types, shapes and many other factors. In addition, finite element results are produced in thousands of pages, making it difficult for the user to discover a possible mistake, whether caused by an interior error in the program, or by an inappropriate choice or decision by the user. In an effort to reduce the errors in the analytical model, the Task Committee on Avoiding Failure [6, 7] has identified three main sources of errors:

1. Errors related to operating systems and hardware
2. Errors caused by computer misuse which is related to the user knowledge and experience.
3. Errors related to modeling concepts such as mesh density, opening holes size, shapes and positions and other modeling parameters.

The main objective of this paper is to provide study to investigate the effect of mesh density and opening holes in structural modeling. This objective was achieved by developing three dimensional elastic models of cantilever walls with openings of different dimensions, locations and shapes.

2. Modeling of the walls

In structural engineering, finite element procedures are used in the analysis and design of a variety of structures subjected to different types of static and dynamic loading. A number of decisions and preparatory steps are needed for creating an appropriate mathematical model to compute the required internal forces for design purpose. A number of studies have addressed the modeling process of reinforced concrete walls [8-11]. One of the important factors in modeling is the mesh refinement. The density of the mesh plays a major role in the results accuracy. On the other hand, too fine mesh may complicate the analysis by increasing the size of the model. In this paper, cantilever walls of dimensions 4.0 m width, 20.0 m height and 0.30 m thickness were considered for the analysis. The effect of mesh density was obtained by considering 10 mesh sizes for each wall analysis starting with too coarse mesh to a very fine mesh, size 1 represents the finest mesh and size 10 represents the coarsest mesh. The effects of opening holes were obtained by considering square holes of dimensions 0.5 m, 1.0m, 1.5m and 2.0m and circular holes of diameters 0.5m, 1.0m, 1.5m and 2.0m and these are located at different positions along the width of the walls as shown in figure 1.

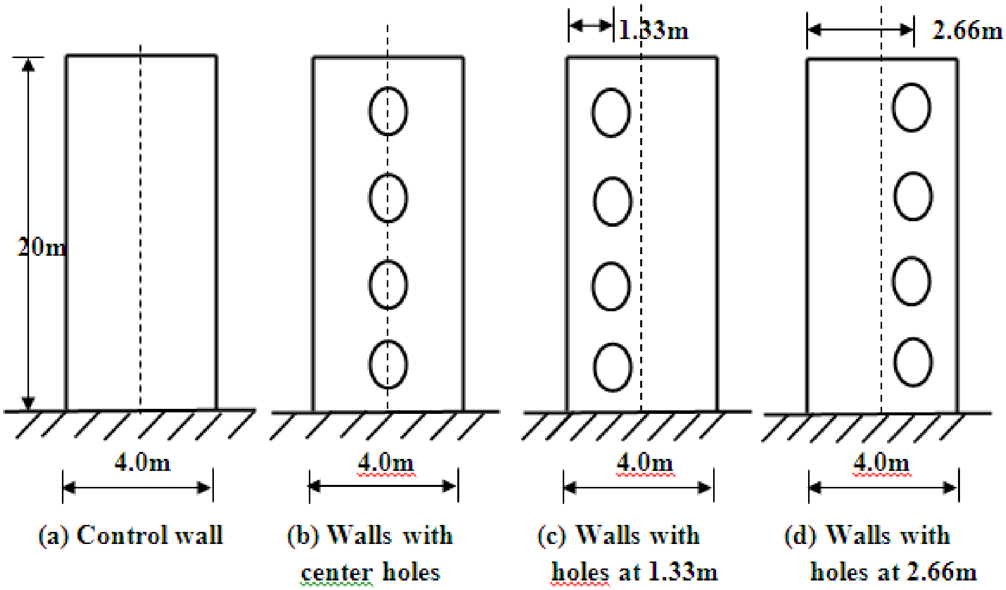


Figure 1: Analyzed walls (Walls with square openings also considered)

In addition, a wall without wholes was analyzed which was considered as a control wall. Vertical and horizontal loads were applied to the walls that simulated the gravity and seismic loads in residential buildings with moderate conditions. Three dimensional solid elements have been used to model the walls with brick and tetrahedron elements to represent the geometry of the model at the positions of the holes.

3. Finite Element Results

3.1. Stress Distribution around Openings

Although it is difficult to describe the different pattern of stress concentrations around the openings, the general visualizations show that both vertical and shear stress concentrations produced visibly different patterns as the opening sizes are increased for both square and circular openings as shown in figures 2, 3, 4, 5, 6 and 7. High vertical stress concentrations were observed around the corners of square openings near the edges which were higher than those obtained using circular openings. This increase is estimated by about 40%. Therefore, the stress distributions and the stress concentrations around the openings were strongly affected by the opening sizes, shapes and positions.

3.2. Strength and Deformation around Openings

The effects of openings on the strength and deformation capacity of the walls are different depending on the opening sizes, shapes and positions. These differences are more evident for square openings at distances 1.33m and 2.66m from the face of the walls which is subjected to lateral loads as shown in the figures. In general, no contra-flexure points occurred above and between the openings. In this study, the parts of the walls between the openings were deflected more in the case of square openings than those with circular openings. Excessive crack development at the base level and around the first opening did not show plastic deformation. However, as the size of the openings is increased, the deformations of the upper parts of the walls were increased significantly leading to a loss of stability. This was observed by the huge increase in the stress which exceeds the strength of concrete material used in practice.

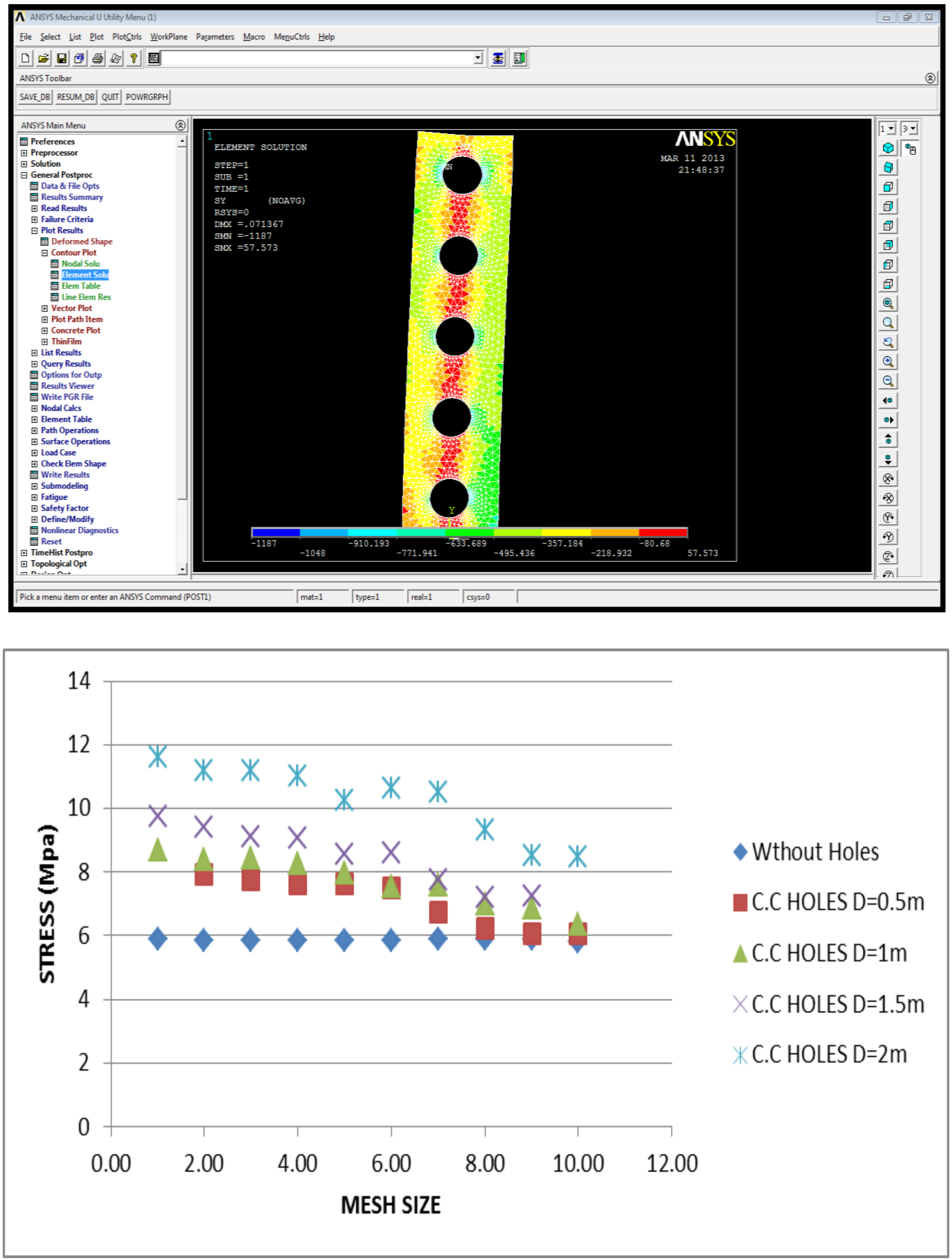
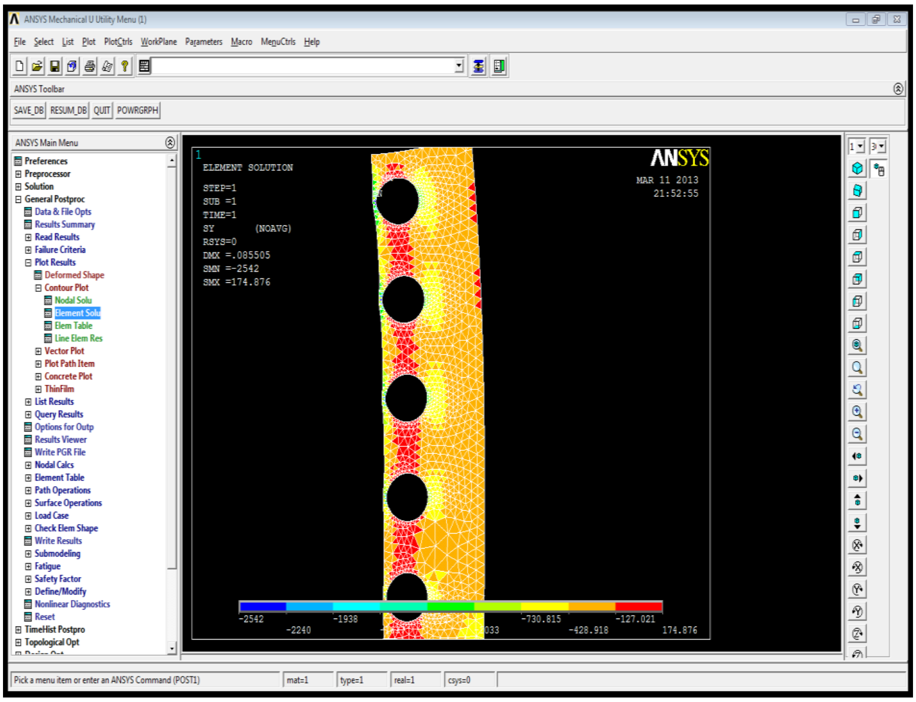


Figure 2: Walls with circular central holes



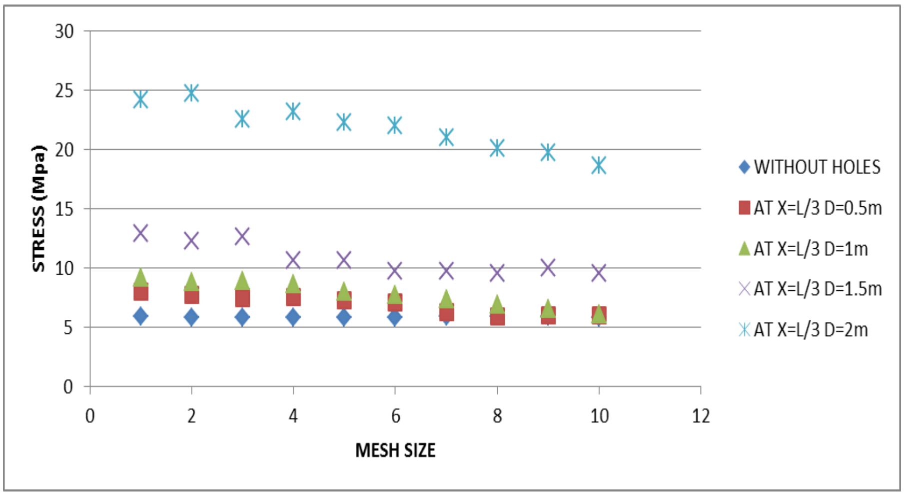
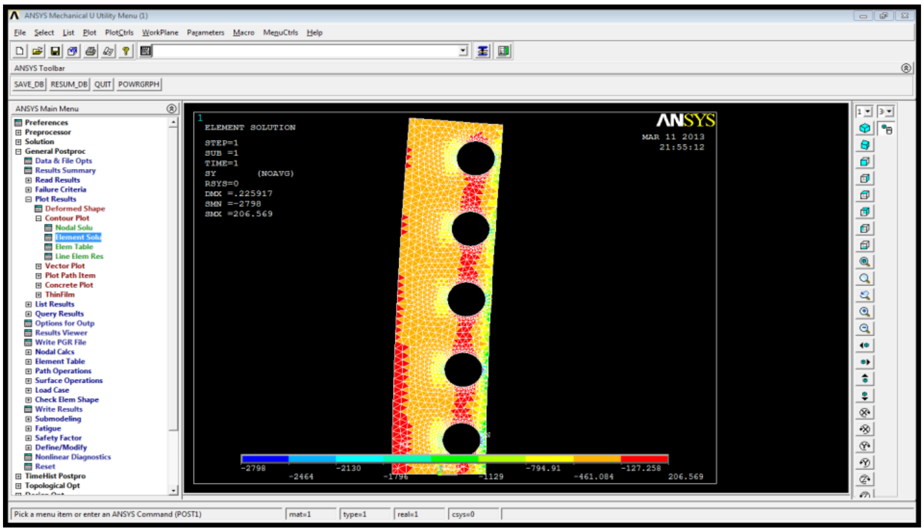


Figure 3: Walls with circular holes at L/3



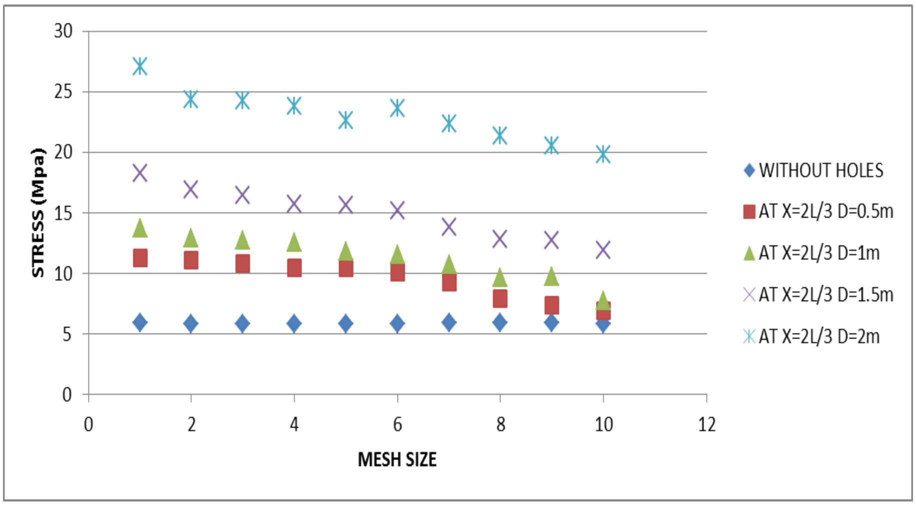
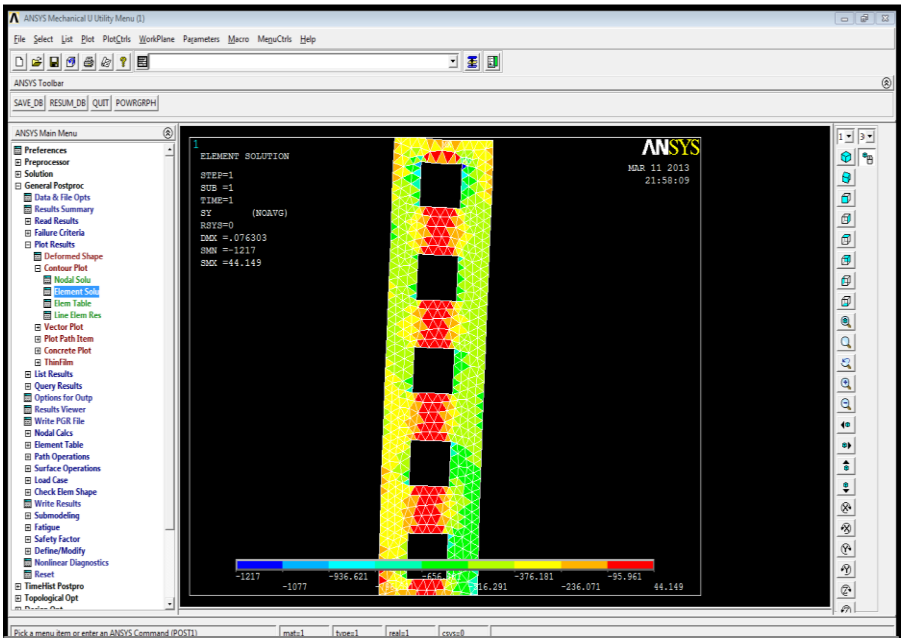


Figure 4: Walls with circular holes at 2L/3



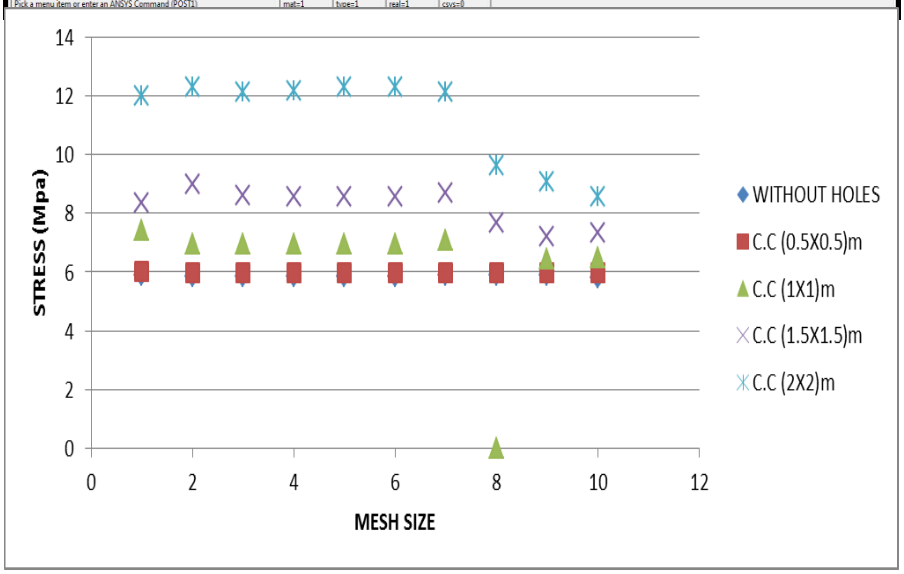


Figure 5: Walls with square central holes

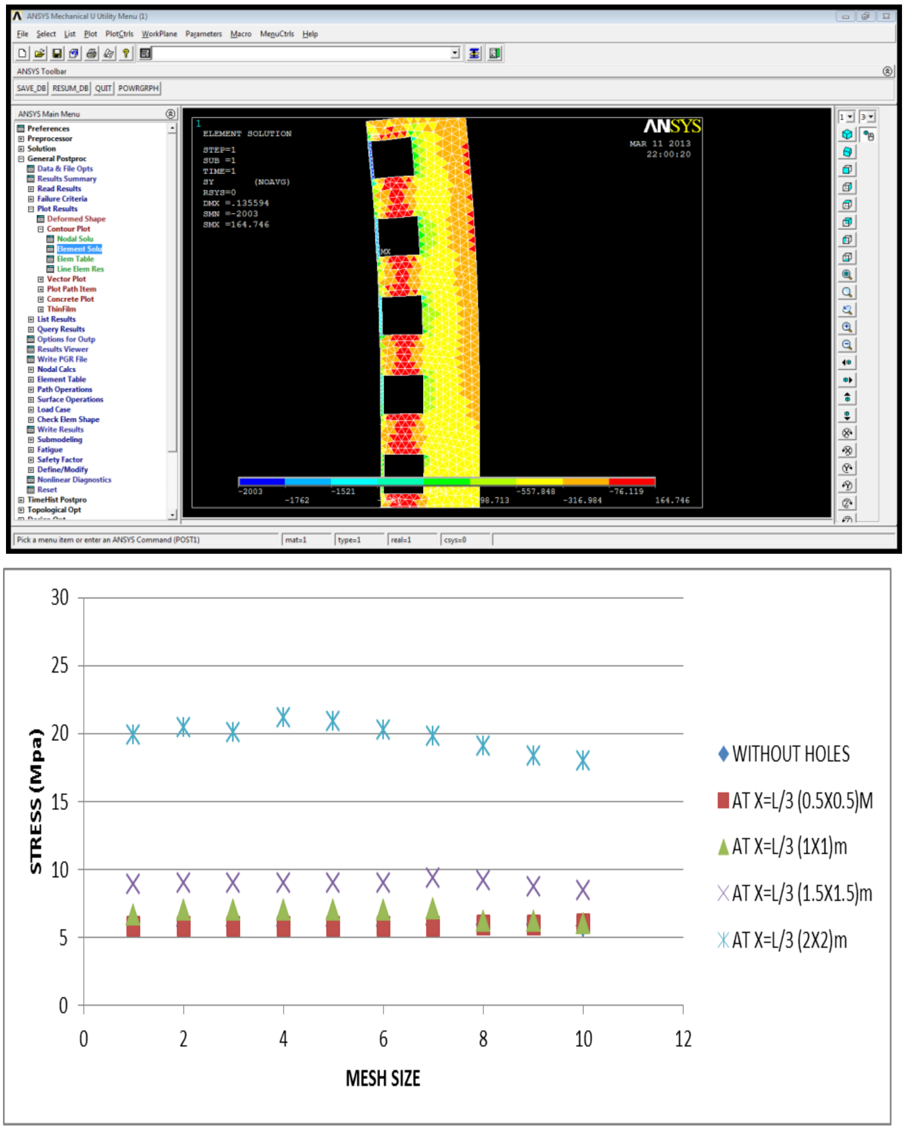
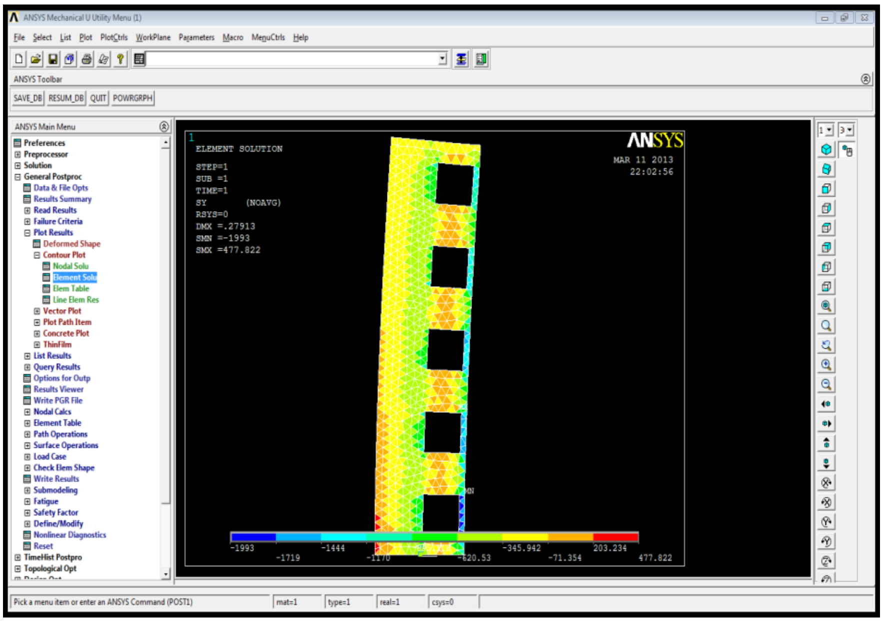


Figure 6: Walls with square holes at L/3



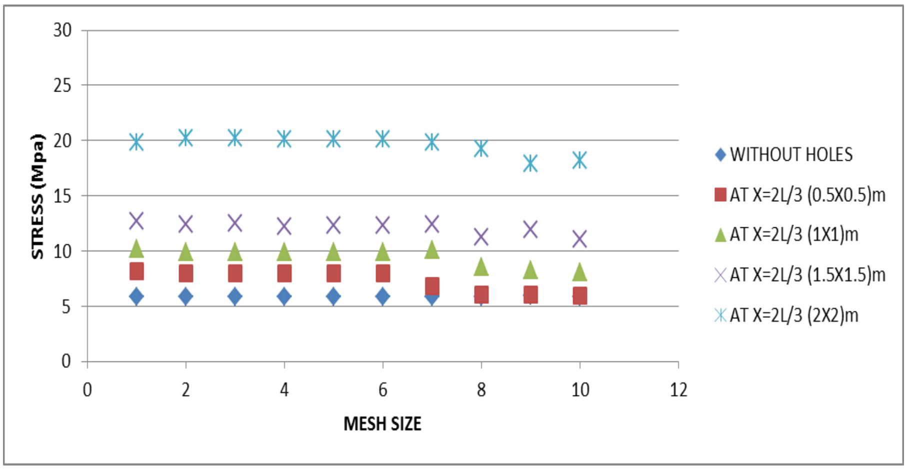


Figure 7: Walls with square holes at 2L/3

4. Conclusions

The results of this investigation show that show that the analytical studies using three dimensional finite element models conducted on walls without considering the opening effects will yield inaccurate results. In this study, the stress concentrations and its pattern around the openings were found to be drastically different and increased with the opening sizes and shapes as high as 40%. The mesh density did not seem to have a significant effect on the stress concentrations with maximum increase of 10%. However, due to the nature of high stress concentrations around the openings, use of certain kind of reinforcement around the openings such as diagonal shear reinforcement in addition to edge reinforcement, may lead significant contribution for retarding and slowing down the crack propagation. The observation gained from this study for wall openings and their impact on the overall behavior may help to accomplish more accurate design and analysis for structures with medium and significant wall openings such as tunnel form buildings as well as to expose their weak and strong points that may remain hidden in the conventional analysis of such structures.

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