ANALYSIS OF SQUAT SHEAR WALL WITH DIFFERENT DIMESNSIONS AND POSITION OF OPENING UNDER DIFFERENT TYPE OF STATIC LOADS

ANG YIP HONG

Bachelor of Engineering (Hons) in Civil Engineering

UNIVERSITI MALAYSIA PAHANG

UNIVERSITI MALAYSIA PAHANG

DECLARATION OF THESIS AND COPYRIGHT

Author's full name : ANG YIP HONG

Date of birth : 04 JANUARY 1991

Title : ANALYSIS OF SQUAT SHEAR WALL WITH DIFFERENT DIMENSIONS AND POSITIONS OF OPENING UNDER DIFFERENT TYPE OF STATIC LOADS

Academic Session : 2014/2015

I declare that this thesis is classified as :

☐ **CONFIDENTIAL** (Contains confidential information under the Official Secret Act 1972)*

☐ **RESTRICTED** (Contains restricted information as specified by the organization where research was done)*

☑ **OPEN ACCESS** I agree that my thesis to be published as online open access (Full text)

I acknowledge that Universiti Malaysia Pahang reserve the right as follows:

1. The Thesis is the Property of University Malaysia Pahang
2. The Library of University Malaysia Pahang has the right to make copies for the purpose of research only.
3. The Library has the right to make copies of the thesis for academic exchange.

Certified By:

(Student's Signature)	(Signature of Supervisor)
910104145611	MOHD ARIF BIN SULAIMAN
New IC / Passport Number	Name of Supervisor
Date : 25 JUNE 2015	Date : 25 JUNE 2015

NOTES : *If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization with period and reasons for confidentiality or restriction.

ANALYSIS OF SQUAT SHEAR WALL WITH DIFFERENT DIMENSIONS AND POSITIONS OF OPENING UNDER DIFFERENT TYPE OF STATIC LOAD

ANG YIP HONG

Thesis submitted in fulfilment of the requirements for the award of the degree of

B.Eng (Hons.) Civil Engineering

Faculty of Civil Engineering and Earth Resources

UNIVERSITI MALAYSIA PAHANG

JUNE 2015

SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Civil Engineering (Hons.).

Signature	:	
Name of Supervisor	:	MOHD ARIF BIN SULAIMAN
Position	:	SENIOR LECTURER
Date	:	25 JUNE 2015

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature	:	
Name	:	ANG YIP HONG
ID Number	:	AA11165
DATE	:	25 JUNE 2015

I would like to dedicate my thesis to my beloved family.

ACKNOWLEDGEMENTS

This dissertation would not have been possible without the help of so many people in so many ways. First of all, I would like to express my sincere gratitude to my supervisor Mr. Mohd Arif bin Sulaiman for his generous, informative and invaluable guidance to support in making this research possible. I appreciate his consistent support from the first day I start my research. I am thankful to him for reading my reports, commenting on my views and helping me to understand and enrich my ideas.

Besides my supervisor, I would like to thank my friends Liang Kai Jun, Tan Hock Hee, Siow Sin Yang, Candra Menan A/L Nagappan, Dushendran A/L Bala Krisnan and Mohd Mustakim bin Azmal Mokhtar for their generous sharing ideas and information about the research. Next, I would like to express my gratitude to my panel who was Dr. Cheng Hock Tian and Mr. Noram Irwan Bin Ramli for their suggestion for me to improve my research.

Most importantly, none of this would have been possible without the love and patience of my family. My family, to whom this dissertation is dedicated to, has been a constant source of love, concern, support and strength all these years. I warmly appreciate the generosity and understanding of my family.

ABSTRACT

Shear walls are usually used in high-rise building or building on high frequency of wind area as the structural element to restrain lateral forces. Openings are created on the shear wall for the architecture, ventilation or mechanical and electrical purposes. With the existence of the opening, the strength of the wall is reduced by the reduction in concrete area and the discontinuity of the reinforcement due to opening which may lead to structural failure. The main objective is to study the effect of size and position of the opening towards the structural behavior of the shear wall under different type of static loads. The analysis is done using the software ANSYS12.0. The samples are SW1, SW2, SW3, SW4, SW5, SW6, SW7 and SW8 where SW1 is solid shear wall while SW2, SW3, SW4, SW5, SW6, SW7 and SW8 are shear walls with different size and position of opening. They are analyzed by using 2 different types of loads which are uniformly distributed axial load and uniformly lateral load. From the same magnitude of loads applied towards the shear walls, they are compared by the cracking pattern and the stress distribution. Under both axial and lateral loads, it shows a significance results that the shear wall with greater opening size shows less efficiency. The position of opening further from the support shows a more significance effect towards the strength of the wall from axial load but opposite from the lateral load. Besides, the closer the position of the shear wall to the load, the less efficient it is. As a conclusion from the results, the most suitable position of the opening on the shear wall is further from the support and the loads and it shows that there is a significance effect even from a smallest opening.

ABSTRAK

Dinding ricih biasanya digunakan di dalam bangunan tinggi atau bangunan pada frekuensi tinggi di kawasan angin sebagai elemen struktur untuk menahan daya sisi. Bukaan yang dibuat pada dinding ricih bagi seni bina, pengudaraan atau tujuan mekanikal dan elektrik. Dengan adanya pembukaan, kekuatan dinding dikurangkan dengan pengurangan kawasan konkrit dan ketakselanjaran tetulang akibat pembukaan yang boleh membawa kepada kegagalan struktur. Objektif utama adalah untuk mengkaji kesan saiz dan kedudukan pembukaan terhadap kelakuan struktur dinding ricih di bawah pelbagai jenis beban statik. Analisis ini dilakukan dengan menggunakan ANSYS12.0 perisian. Sampel adalah SW1, SW2, SW3, SW4, SW5, SW6, SW7 dan SW8 mana SW1 adalah dinding ricih pepejal manakala SW2, SW3, SW4, SW5, SW6, SW7 dan SW8 adalah dinding ricih dengan saiz dan kedudukan pembukaan berbeza. Mereka dianalisis dengan menggunakan 2 jenis beban yang teragih seragam beban paksi dan beban seragam sisi. Dari magnitud yang sama beban yang dikenakan terhadap dinding ricih, mereka berbanding dengan corak keretakan dan agihan tegasan. Di bawah kedua-dua beban paksi dan sisi, ia menunjukkan kepentingan yang menyebabkan dinding ricih dengan saiz bukaan yang lebih besar menunjukkan kecekapan kurang. Kedudukan pembukaan lanjut daripada sokongan menunjukkan kesan signifikan yang lebih kepada kekuatan dinding dari beban paksi tetapi bertentangan dari beban sisi. Selain itu, lebih dekat dengan kedudukan dinding ricih kepada beban, yang kurang berkesan ia. Sebagai kesimpulan dari hasil, kedudukan yang paling sesuai pembukaan pada dinding ricih yang lebih jauh daripada sokongan dan beban dan ia menunjukkan bahawa terdapat kesan yang signifikan walaupun dari pembukaan yang paling kecil.

TABLE OF CONTENTS

CHAPTER 3 RESEARCH METHODOLOGY

CHAPTER 4 RESULTS AND DISCUSSIONS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

%	Percentage
mm	Millimeter
m	Meter
kPa	Kilo Pascal
MPa	Mega Pascal
GPa	Giga Pascal
N	Newton

CHAPTER 1

INTRODUCTION

1.1 GENERAL

Shear wall is a vertical structural element that provides strength to restrain the building from axial load and lateral force such as wind, earthquakes or blast. Shear walls are more preferable in high rise building such as apartment, condominium, office tower or wall of lift and so on. The best position of shear wall were structurally is in the center of each half of the building. However, it is rarely practical. Therefore, the shear walls were usually positioned at the ends Shear walls are usually perforated for architectural purpose like windows. However, the openings of the shear wall has create disturbance against the stress distribution.

Therefore, the shear wall is analyzed by using the finite element analysis with non-linear static analysis to study the changes of the behavior of the shear wall such as stress distribution, cracking position and so on. The finite element analysis is conducted by using ANSYS 12.0 software. With the aids of the software, the structure can be design in a virtual experiment and the materials can be tested. The engineers can analyze the safety, strength, comfort and therefore the result is cost-effective.

1.2 PROBLEM STATEMENT

Squat shear wall is used as structural element to restrain axial load and lateral loads. Unlike slender shear wall, squat shear wall usually failed by shear before by drift effect from lateral forces. These failures are not preferable as it always occurs after elastic deformation and may fail the whole building structure. The stress distribution of shear wall is same as a column when resisting axial load and beam when resisting lateral load. However, with the presence of opening on the shear wall, it has caused disturbance towards the stress distribution. Therefore, the size and positioning of the shear wall shall be considered and analyzed during design phases.

1.3 OBJECTIVE OF STUDY

The main objectives are to study:

i. The effect of different opening size of shear wall to stress distribution and crack pattern under different types of static load.
ii. The effect of different location of opening on the shear wall to stress distribution and crack pattern under different types of static load.

1.4 SCOPE OF STUDY

In this study, the dimensions of all shear walls model are 3.1m width x 3.1m height x 0.300m thick. The concrete and steel reinforcement properties are referred to previous study done by (Musmar 2013). The concrete material properties are listed in the Table 1.1. Smeared steel reinforcement is used and the properties are listed in Table 1.2. The steel plate is used when applying the several types of forces. The Elastic modulus and Poisson’s ratio of the steel plate is same as the steel reinforcement (Kachlakev et al, 2001; Wolanski, 2004. The element selected in this study is SOLID65 for concrete while LINK8 for reinforcement steel. The real constants are set and the cross section of the concrete and steel are to be defined.

All the models are labeled with SW-n where n is the number of sample. The SW1 is the solid shear wall while the other 7 are the shear wall with opening. SW2, SW5, SW6, SW7 and SW8 have the same size of opening but different on different location of the shear wall. SW2, SW5 and SW6 are increased by 0.3 m in both width and height ascendingly. The Table 1.3 has shown the detail dimensions of the shear walls model while the Figure 1.1 shows the model of the shear wall with the dimension. Positive value of horizontal distance represent that the direction is to the right and vice versa. Positive value of vertical distance represent the direction is to the up and vice versa. All the models with different type of opening are also shown in Figure 1.2.

Table 1.1: Material properties of concrete

Material Model	Linear Elastic
Modulus of Elasticity, Es	25743MPa
Poisson's Ratio	0.3
Open Shear transfer Coefficient, βt	0.2
Closed Shear transfer Coefficient, βc	0.9
Unaxial Cracking Stress	3.78 MPa
Uniaxial Crushing Stress f́c	30 MPa

Table 1.2: Material properties of steel

Material model prior to initial yield surface	Linear elastic
Elastic Modulus, Es	200 GPa
Poisson's Ratio	0.3
Yield's Stress, fy	412 MPa
Material model beyond initial yield surface and up to failure	Perfect plastic

Source: Musmar (2013)

Table 1.3: Detail dimension of shear walls model

Sample	Opening height, h (m)	Opening width, b (m)	Horizontal distance from the right, x (m)	Vertical distance from the top, y (m)
SW1	-	-	-	-
SW2	0.9	0.9	0	0
SW3	1.2	1.2	0	0
SW4	1.5	1.5	0	0
SW5	0.9	0.9	-0.5	0
SW6	0.9	0.9	0	0.5
SW7	0.9	0.9	0.5	0
SW8	0.9	0.9	0	-0.5

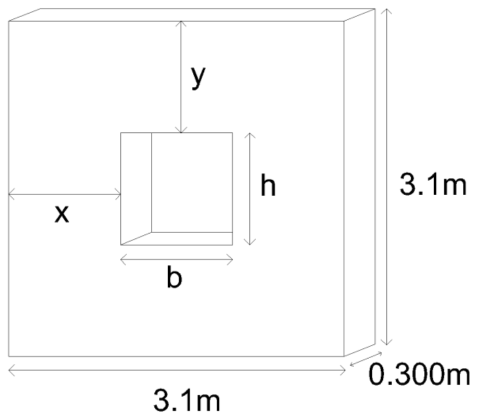


Figure 1.1: Dimension of shear wall

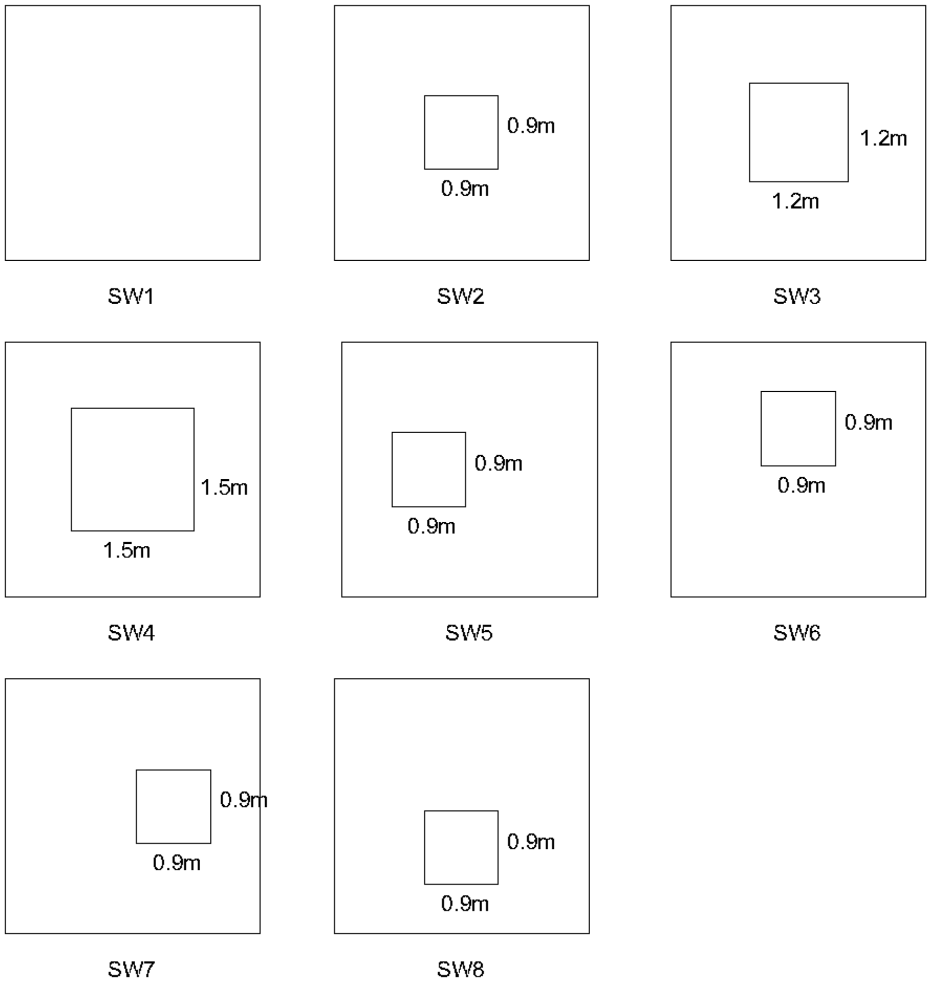


Figure 1.2: Model of Shear Wall

The diameter of the reinforcement steel bar in this study is 12mm for both vertical and horizontal. Both the spacing of the vertical and horizontal reinforcements is 200mm. The main reinforcement arrangement as well as the cross sections of the SW1 as the solid shear wall is shown in Figure 1.3.

The International Residential code specified that extra reinforcement shall be added to the side of opening if the width of the opening exceeds 2 feet which is 0.6m approximately. Since all the samples with opening in this study already exceed 2feet, therefore, extra reinforcement shall be added. The opening reinforcement arrangement is shown in below Figure 1.4. There is 1 reinforcement bar at each side of the opening while 1more extra at top with minimum of 1 inch above the top reinforcement to create lintel for resist the axial force towards the opening. In this case, the unit used in the model is in SI unit; therefore, the distance between the 2 top reinforcement is 0.1m. All the diameter and material properties of the side reinforcements are same as the vertical and horizontal of main reinforcement.

The analysis done in this study is 3-Dimensional finite element analysis. The solid shear wall SW1 was used as the reference for the other remaining models with openings. In this study, SOLID65 provided by ANSYS software is used as the element for concrete while LINK8 is used as the element for reinforcement steel. The material properties of the concrete and steel are referred to the previous study done by (Musmar 2013). The elastic and plastic deformations in concrete and reinforcement can be simulated.

The analysis is initiated by applying low loads and is stepwise increased to study the stress distribution. Different types of static loads include lateral and axial loads are applied on the model to obtain different results. The results are compared to study the changes. The different types of the static load are uniformly distributed axial load and uniformly distributed lateral load. The different types of loads are shown in the Figure 1.5. All the results of SW3 to SW8 are compared to SW1 and SW2 to identify the effect of the made by the changes of the parameter.

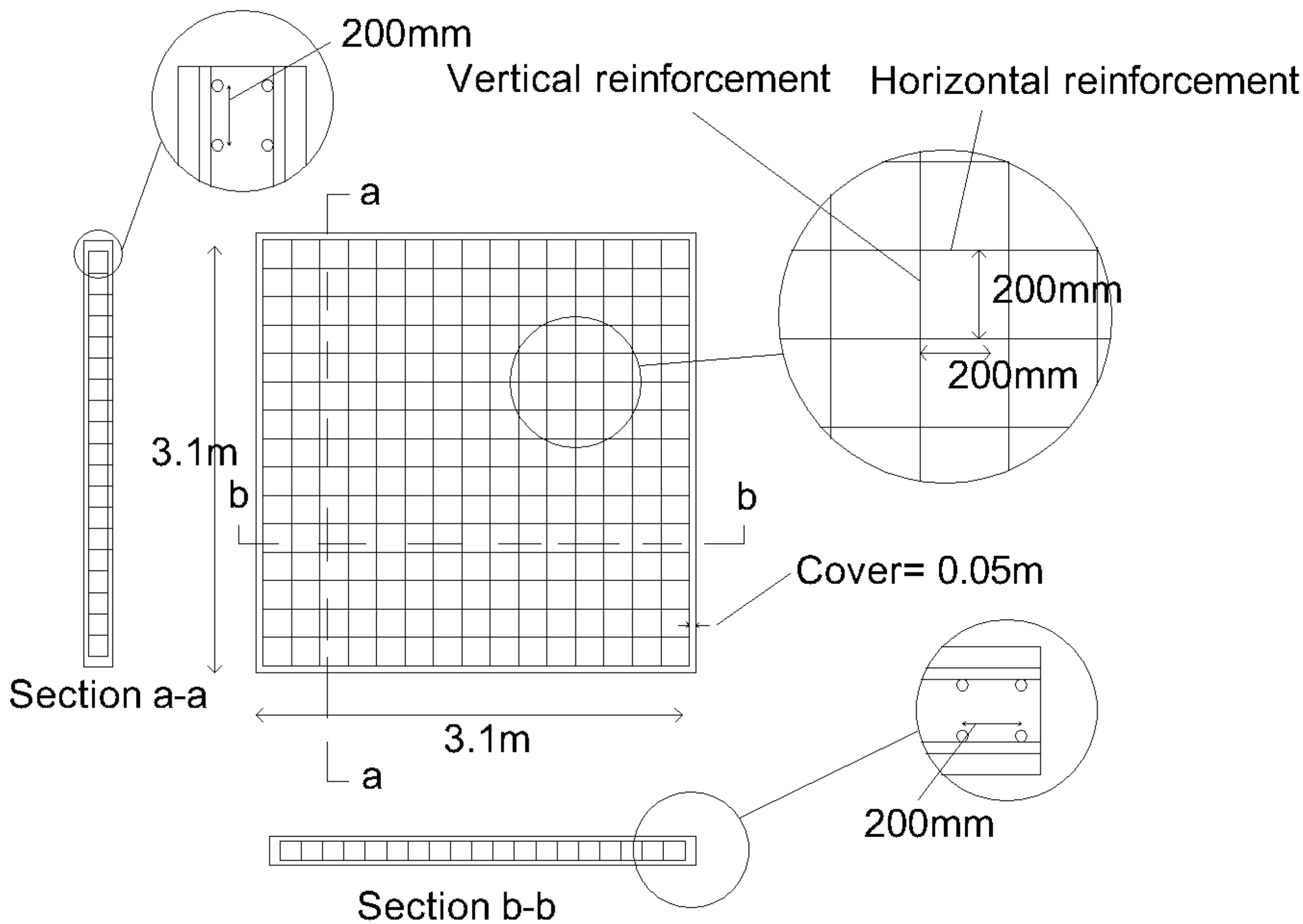


Figure 1.3: Main reinforcement arrangement

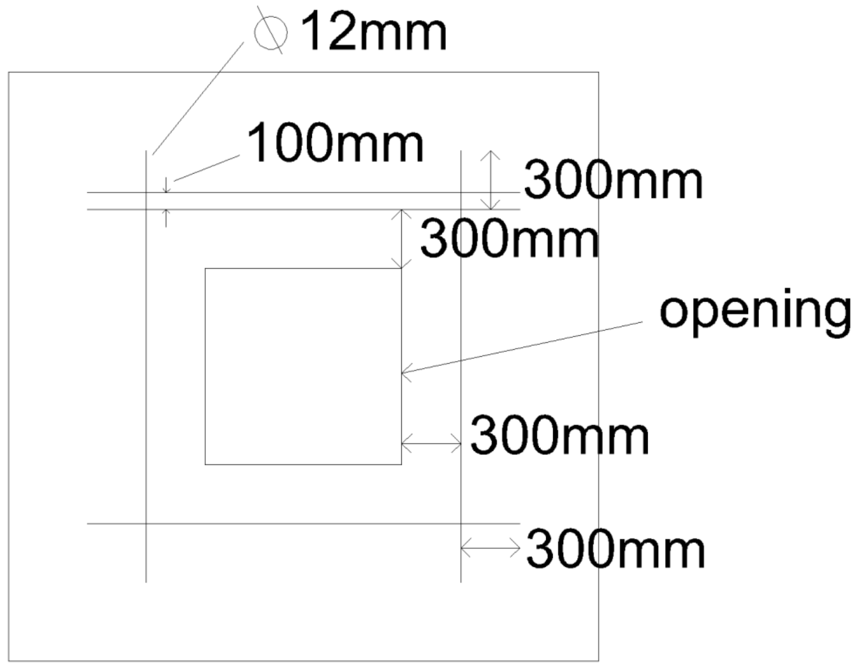
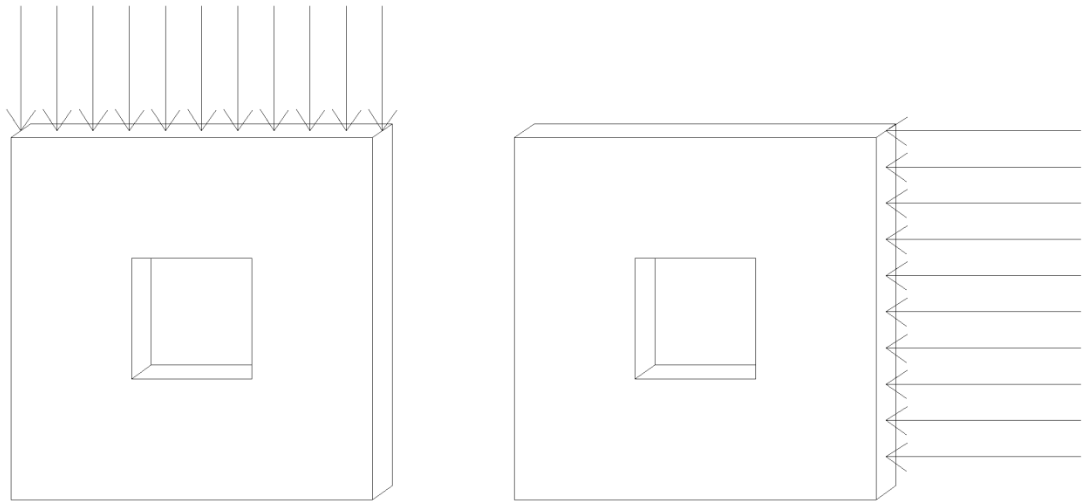


Figure 1.4: Opening Reinforcement



Axial Uniformly distributed load Lateral Uniformly distributed load

Figure 1.5: Different type of static loads

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Shear wall is the vertical component in a building which helps in resisting both axial force and lateral force. Lateral force is much more mainly resisted as the axial forces are already resisted by beam and column. The efficiency of shear wall is referred to the rigidity or stiffness. The solid shear wall appears to be the most efficient and therefore highly desirable. However, most of the shear walls are come with opening as the needs of architecture design such as windows and door.

2.2 SQUAT SHEAR WALL

The aspect ratio of the wall will determine the behavior of wall dominated by flexure or shear. Aspect ratio of less than 2 is known as squat walls which its behavior is dominate by shear. The shear walls used in this analysis are squat shear wall as its aspect ratio is 1. From a study conducted by Hidalgo et al. (2002), the deformation capacity gets smaller as the aspect ratio decrease and the strength deterioration of wall increased. Therefore, a squat shear wall is preferred in this study for more significance results.

2.3 DESIGN OF SHEAR WALL

Lefas et al. (2010) has done experimental work on 13 structural walls to investigate the cause of failure of shear wall. They found that strength and deformational response of the wall are independent of the uniaxial concrete strength characteristics within a range of 30 to 55 MPa. The reinforcement arrangement of this study is referred to the previous study done by Lefas et al (2010). Besides, the International residential code (R606.12.2.3.3) states that the horizontal joint reinforcement shall be provided at the bottom and top of wall openings and shall be extend not less than 24inches (610mm). The extra reinforcement steel above the top reinforcement is added to create a lintel to support axial force from the top of the opening. Diagonal reinforcement can be added to strengthen the element from cracking at the edges of opening.

2.4 EFFECT OF OPENING

The reinforcement around opening is highly affecting the ductility and shear strength of the shear wall with opening. The shear capacity contributed by the diagonal reinforcement reached 40% of its yield strength while the shear capacity contributed by the horizontal and vertical only reach 20% of its yield strength. This has shown that both the depth and width of the opening are affecting the shear capacity of the wall. (Lin & Kuo, 1988).The larger the size of the opening is, the greater is the stress flow disturbance within the shear wall while in case of small opening; the shear wall will behave as coupled shear wall (Musmar, 2013). From the research done by Vecchio and Chan (1990), they have tested several panels with and without extra reinforcement around the opening. The cracking, yielding of reinforcement can lead to a significant reduction in the overall strength and stiffness. With several tests, they concluded that added reinforcement around the opening can be effectively alleviating the detrimental effects caused by the opening.

2.5 STATIC LOAD

The static load is a mechanical force applied slowly to an assembly or object. The engineers usually use static load tests to determine the maximum force an engineering structure can supports for safety purposes. Besides maximum allowable loads, the static loads also can help to discover the mechanical properties of materials.

2.6 ANSYS MODELING

The ANSYS finite element software is used in this research to model the reinforced concrete shear walls. There are several properties need to be set before start the modeling which is to define the elements, material properties and cross section of the model.

2.6.1 Element

The solid65 finite element is chosen in this as it is a dedicated three-dimensional eight node isoperimetric elements with three degree of freedom at each node, which is x, y and z directions (Musmar, 2013). The figure 2.1 is the geometry of SOLID65 element. The Figure 2.1 is obtained from Saberi et al. (2013). In ANSYS, SOLID65 is also known as 3-D Reinforced Concrete Solid which is capable in tension and crushing in compression. SOLID65 element is able to model the nonlinear response of concrete material based on a constitutive model for the tri-axial behavior of concrete which is capable of plastic deformation and cracking in three orthogonal directions at each integration point (Musmar, 2013). For reinforcement, LINK8 is chosen as the element in the ANSYS. The element is defined by two nodes, cross-sectional area, initial strain and the material properties. The geometry, node locations and the coordinate system for this element are shown in Figure 2.2. The element is oriented along the length of the element from node I to node J.

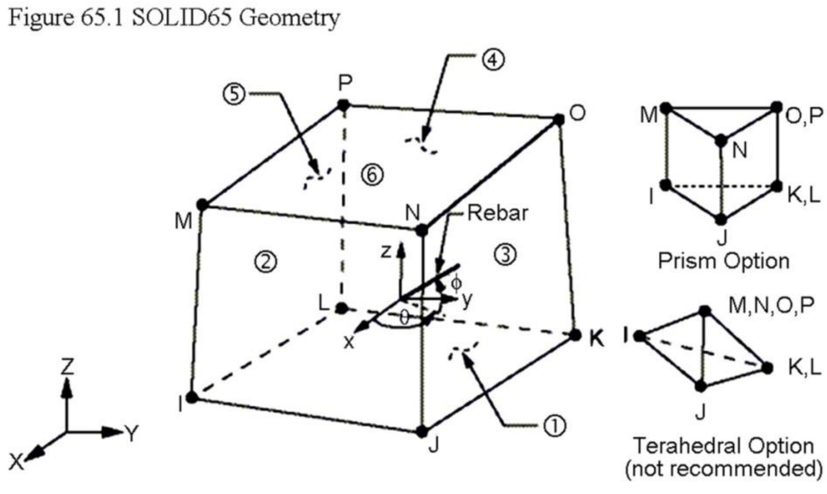


Figure 2.1: SOLID65 3-D Reinforced Concrete Solid

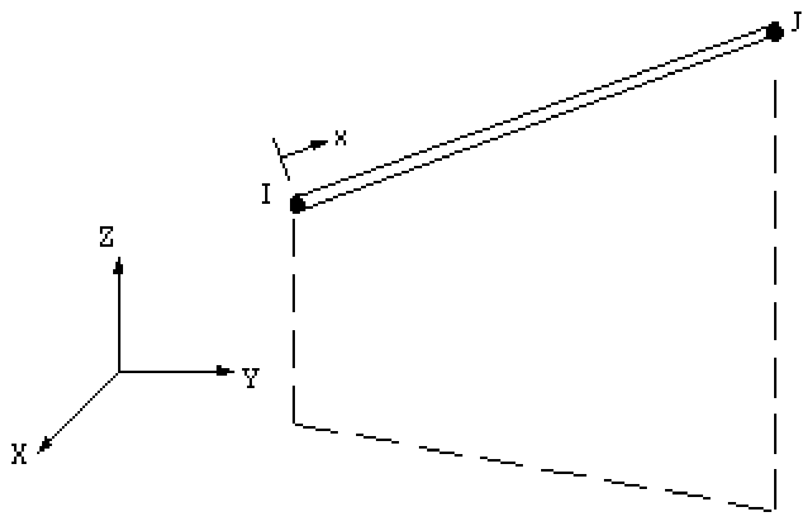


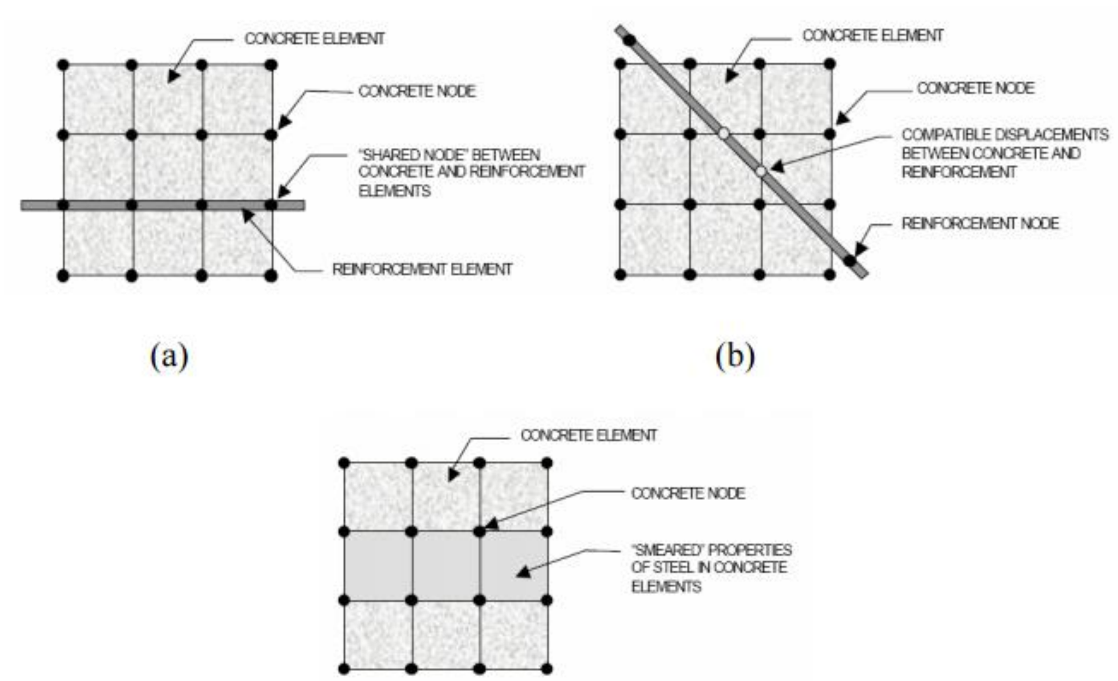
Figure 2.2: LINK8 3-D Spar

2.6.2 Modeling

The key points or nodes are some several of coordinate created to define the body of a structure. They are then connected by lines or element. The properties of element and material are chose before modeling. The real constant of the material can be selected. The size of element can be selected by using meshing. The rectangular mesh is recommended for element SOLID65 to obtain good result (Raongjant and Jing 2008). The boundaries condition shall be specified by giving the location and information of the boundaries.

2.6.3 Steel reinforcement

There are three techniques that exist to model steel reinforcement in finite element models for reinforced concrete. Figure 2.3 shows the three models which are discrete, embedded and smeared model (Tavarez 2001).



(c)

Figure 2.3: Models for reinforcement in Reinforced concrete: (a) discrete; (b) embedded; and (c) smeared

Source: Tavarez 2001

The reinforcement in discrete model as shown in Figure 2.3 (a) uses bar or beam elements that are connected to concrete mesh nodes. Therefore, the concrete and the reinforcement mesh share the same nodes and concrete occupies the same regions occupied by the reinforcement. The embedded model overcomes the concrete mesh restrictions because the stiffness of the reinforcing steel is evaluated separately from the concrete elements. The model is built in a way that keeps reinforcing steel displacement compatible with the surrounding concrete elements. The smeared model assumes that reinforcement is uniformly spread throughout the concrete elements in a defined region in finite element mesh. This approach is used for large- scale models where the reinforcement does not significantly contribute to the overall response of the structure.

Fanning (2001) modeled the response of the reinforcement using the discrete model and the smeared model for reinforced concrete beams. It was found that the best modeling strategy was to use the discrete model when modeling reinforcement.

2.6.4 Meshing

It is necessary to use a fine mesh finite element model for an accurate analysis of a shear wall with openings, but if the entire structure were divided into finer mesh with a large element numbers, it would require significance of computational time and memory. Besides, it is also inconvenient to use inconsistent of grid for the shear wall and frame in modeling the structure

2.6.5 Non-linear analysis

Linear analysis is not preferable as it only able to approximate the real nonlinear behavior of the concrete. Linear assumption sometime differs too much from reality therefore mislead information. The results of linear analysis may lead to over design as the inaccuracy for some materials such as concrete. The linear analysis are using Hooke’s law (linear relationship between stress and strain), while other materials properties are constant and deformation are covered by small deflection theory. On the other hand, nonlinear analysis allows for nonlinear stress-strain relationship and the material properties are dependent. Besides, it also allows the accurate modeling of structure that undergoes large deformation. As concrete is having a nonlinear behavior, nonlinear analysis is preferable in this study. The nonlinear Newton-Raphson approach was utilized to trace the equilibrium path during the load-deformation response. It was found that convergence of solutions for the model was difficult to achieve due to the nonlinear behavior of reinforced concrete material. (Kachlakev 2000).

2.7 CRACKING

Cracking is a major indication of failure in reinforced concrete. There are several types of cracking such as shrinkage cracking, plastic cracking, settlement cracking, structural cracking, tension cracking, rust cracking and thermally-induced cracking. In this research, there are changes in loads on structural element, therefore, structural cracking will occurred and studied. When the tensile strength of the material is exceeded, the concrete will crack. Cracking can be structurally dangerous as the crushing of concrete will occur when the crack reach the ultimate states. The building or structure’s weak point will be the position of cracking especially the edges of the openings such as edge of window and doors.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

In this study, ANSYS 12.0 is used to simulate the shear wall model. They can be divided into 3 steps which is preprocessor, solution and post processor. Under preprocessor, there are several steps needed to be determined in modeling which are element of the model, material properties of the model, cross-section and real constant of the model. After modeling, the boundaries condition of the model need to be added and the load is applied for the analysis. In this case, pressure is used for both the uniformly distributed axial and lateral loads. After that, non-linear analysis is started after the settings are determined. Under post-processor, the results is listed and plotted for each respectively nodes and elements.

3.2 FLOW CHART OF METHODOLOGY

The Figure 3.1 shows the flow chart of the methodology. It consists of 3 different steps which is Preprocessor, solution and post-processor.

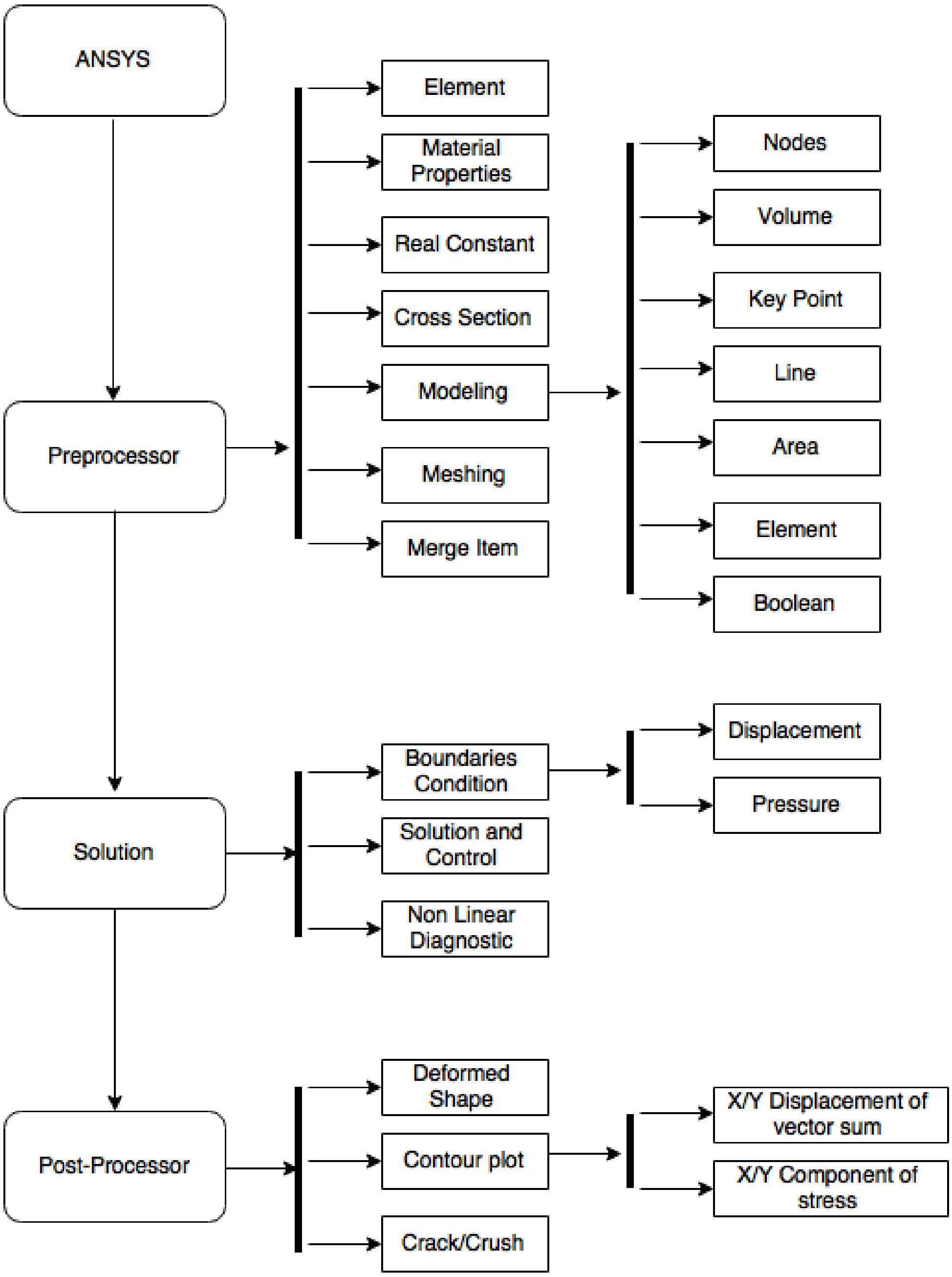


Figure 3.1: Flow chart of Methodology

3.3 PREPROCESSOR

The preprocessor is the preparation before modeling and modeling. It consists of steps to simulate the concrete shear wall by entering the properties, elements and cross section of the shear wall.

3.3.1 Element

The element used in this study was SOLID65 and LINK8 only. The SOLID65 is representing the concrete while the LINK8 is representing the steel reinforcement. Both of the elements is chosen under Preprocessor > Element Type > Add/Edit/Delete. The element types are listed as Figure 3.2 after chosen.

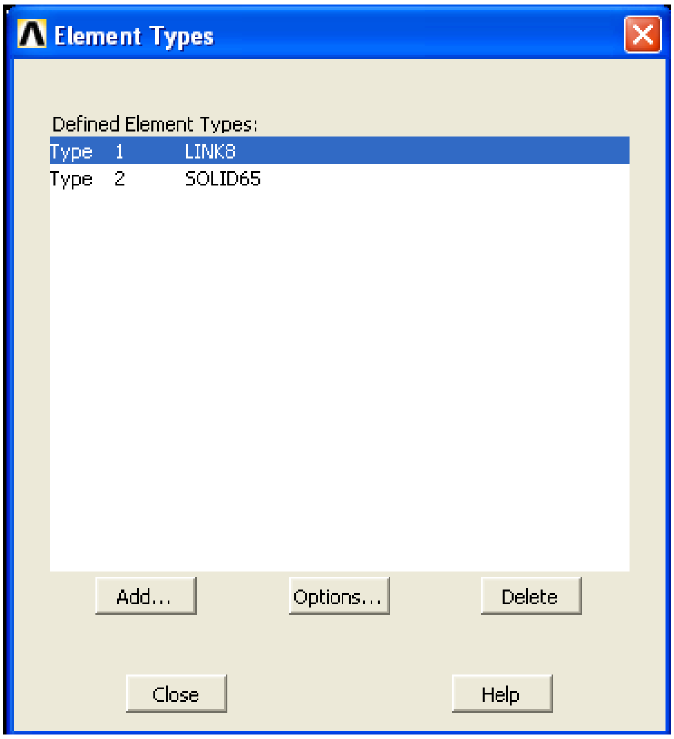


Figure 3.2: Element

3.3.2 Material properties

With the steel and concrete material properties as shown in Table 1.1 and Table 1.2, they are added through Preprocessor > Material Props > Material Models. As shown in Figure 3.3, the material properties of the concrete and steel reinforcement are defined.

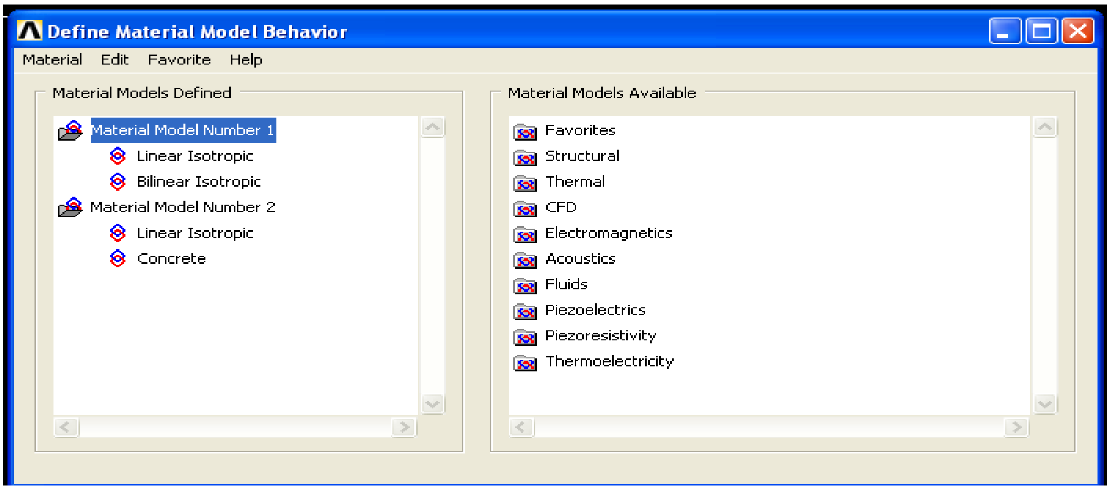


Figure 3.3: Material properties

3.3.3 Real constants

The real constant of the concrete shall be determined. In this study, the real constant of concrete is used with the default option. The real constant of the steel reinforcement is added using the cross-section area. The cross section area of the reinforcement is $\pi d^2/4$ where d is the diameter of the reinforcement bar. They are added using the table through Preprocessor > Real constant > Add/Edit/Delete as shown in Figure 3.4.

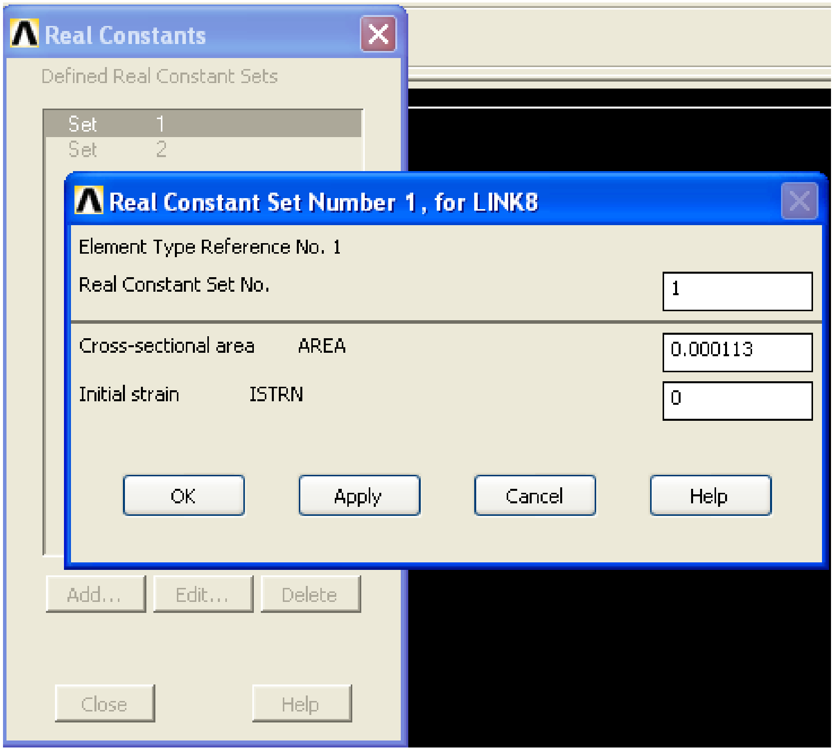


Figure 3.4: Real constant

3.3.4 Cross-section

By using Beam tools from Preprocessor > Sections > Beams > Common Sections, the cross section of the steel and concrete are added. Figure 3.5 shows the beam tools for cross section of steel reinforcement.

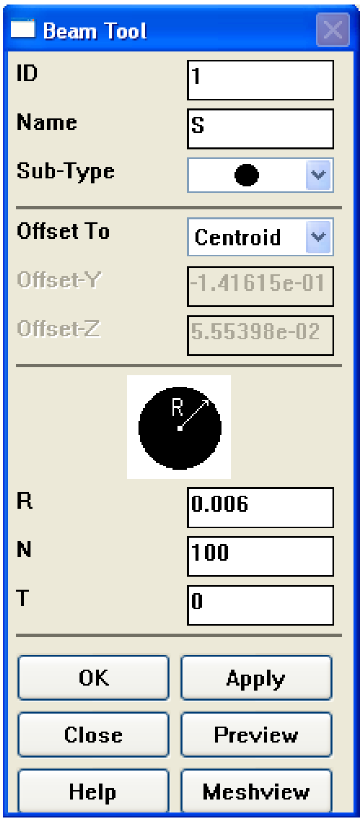


Figure 3.5: Beam tool

3.3.5 Modeling

After all the material properties, element and the real constant are set, the modeling can be started. There are several steps for modeling which are nodes, elements, key point, lines, area, volume, boolean and so on.

3.3.5.1 Nodes

The Nodes can be added through a lot of different method. In this study, I choose to use commands with N, n, x, y, z where x is the coordinate for x-axis, y is the coordinate of y-axis and z is the coordinate for z-axis. The N stands for the command for nodes while the n stands for the number of nodes. For example, N, 1, 3, 5, 6 represent node 1 at coordinate of 3, 5, 6. Figure 3.6 shows the nodes for SW2.

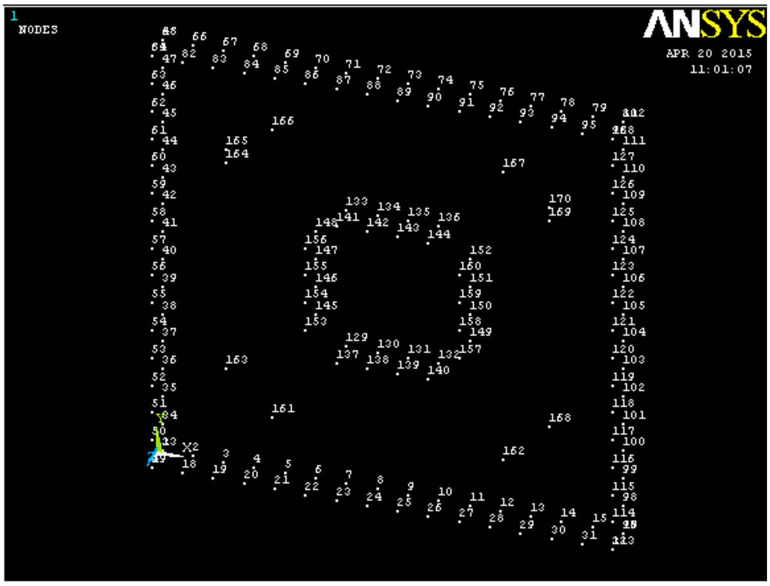


Figure 3.6 Nodes for SW2

3.3.5.2 Volume

There are several types of volumes can be added such as cylinder, block, prism, sphere, and so on. In this study, block is used as the models of SW1 to SW8 are cuboid. The block is added through Preprocessor > Modeling > Create > Volumes > Blocks > By Dimensions. By entering the 2 coordinates of the block, the block can be created. The Figure 3.7 shows the creating of blocks by dimensions for the SW1. Figure 3.8 shows the block added for SW1.

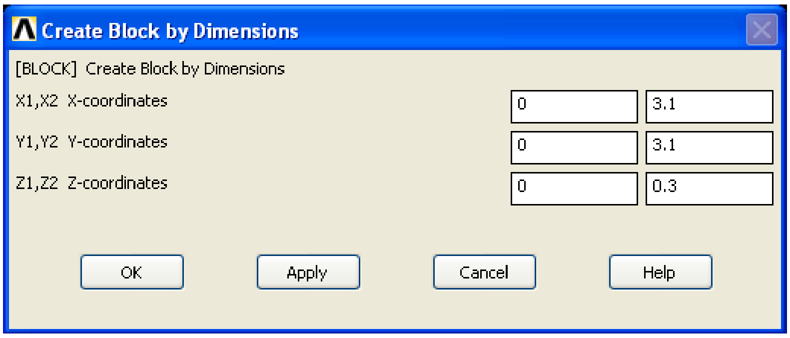


Figure 3.7: Block by Dimensions

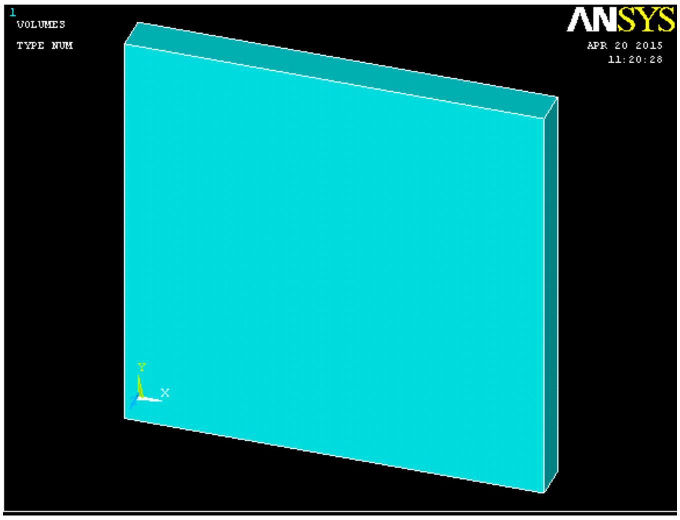


Figure 3.8: Volumes of SW1

3.3.5.3 Key points

Similar to the nodes, key points are added command of k, n, x, y, z. The k represents command for key points while n stands for number of key point. The x, y and z stand for the coordinates of the x-axis, y-axis and z-axis of the key points. Figure 3.9 shows the key points added for SW2.

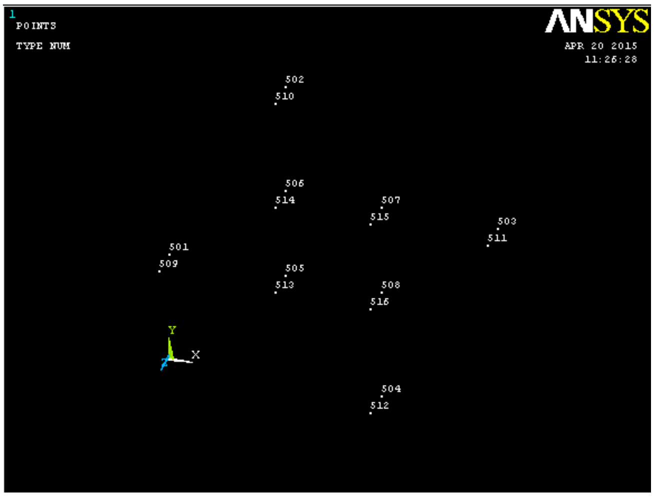


Figure 3.9: Key points for SW2

3.3.5.4 Lines

Lines are added to connect 2 key points. There are several methods to create lines. In this study, I choose to use command by l, k1, k2 where l stands for command for lines while k1 and k2 stands for number of key points. Figure 3.10 shows the lines connected key points of SW2.

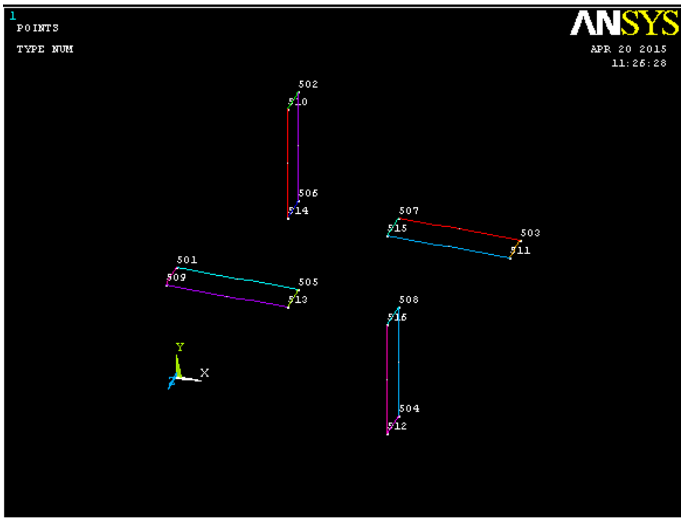


Figure 3.10: Lines of SW2

3.3.5.5 Area

Area also can be added through several methods. In this study, from Preprocessor > Modeling > Areas > Arbitrary > By Lines, I picked the lines created earlier as shown in Figure 3.10 to create area. Figure 3.11 shows the created area for SW2.

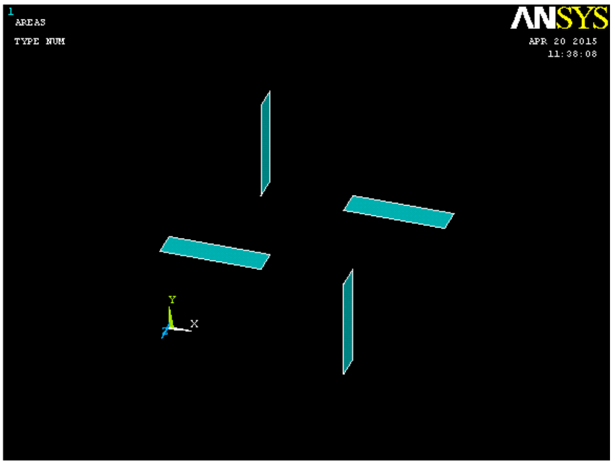


Figure 3.11: Area of SW2

3.3.5.6 Elements

There are also several types of methods to create elements. The Similar to lines, the element is the line connecting 2 nodes by using commands of e, n1, n2. The e represents command for element while n1 and n2 represent the number of 2 nodes connected. Different of element with nodes is the element is line with elements, material properties, cross-section and real constant. The elements are used to create steel reinforcements of the models. Figure 3.12 shows the element of the SW2.

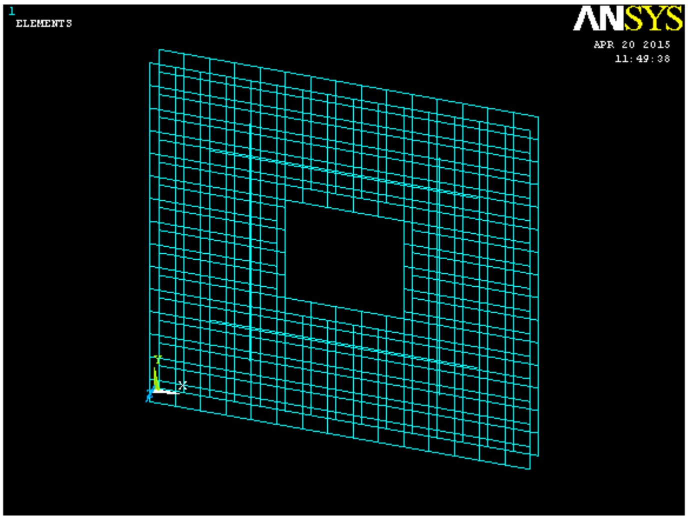


Figure 3.12: Element of SW2

3.3.5.7 Booleans

To create opening of the shear wall, subtract is used by subtracting the volume in the middle of the block. With the creating of 2 blocks earlier, the volume in the middle can be subtracted by Preprocessor> Modeling > Operate > Booleans > Subtract > Volumes. Figure 3.13 shows the volume of the SW2 after subtracts.

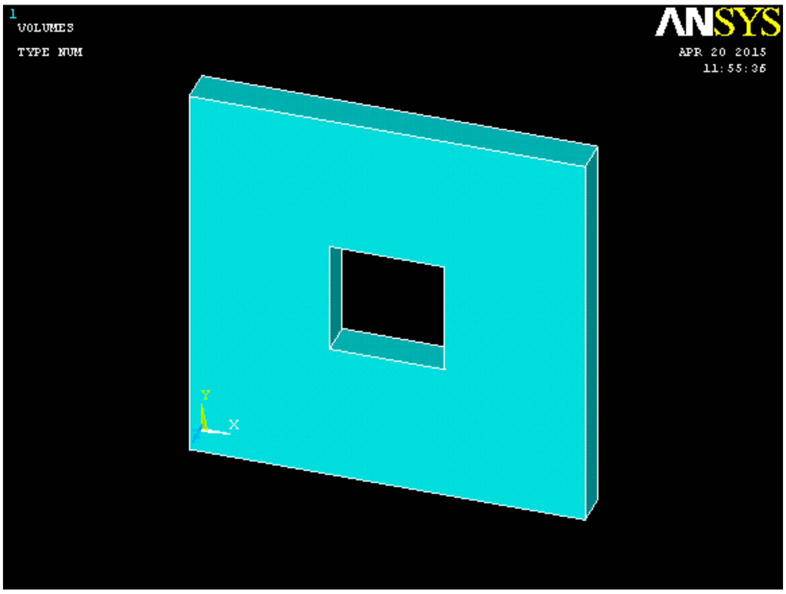


Figure 3.13: Volume of SW2 after subtracts

Divide option is used to create a good rectangular meshing as the SW2 to SW8 are not a cuboid after the volume of middle is subtracted. From Preprocessor > Modeling > Operate > Booleans > Divide > Volume by Area, the solid SW2 can be divide into 4 parts. The divide option is used to create a better rectangular meshing for a more significance results. Figure 3.14 shows the volume of SW2 after divided.

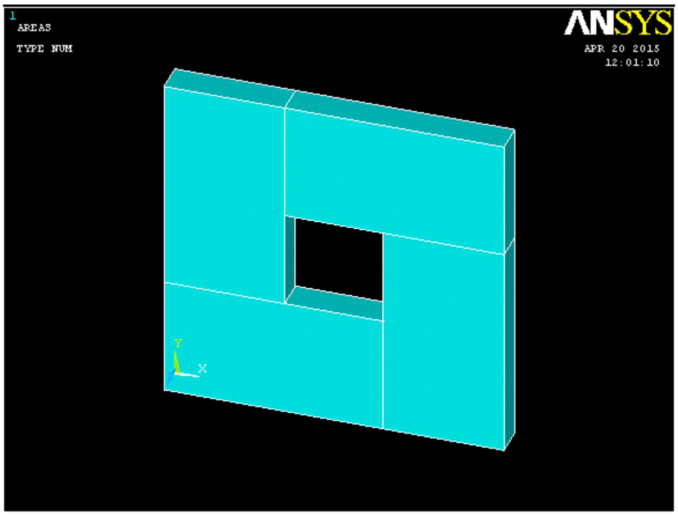


Figure 3.14: Volumes of SW2 after divide

3.3.6 Meshing

As mentioned earlier, meshing is used to divide the volume into small element with element, material properties, real constant and cross-section. Hexahedral meshing is chose for a more significance results. From the Preprocessor > Meshing > MeshTool, the meshing of the solid can be created. First, the size of meshing can be determined by setting the size control. Under the global element sizes table as shown in Figure 3.15, the size of the elements is set as 0.05 which represents 0.05m. Next, as shown in Figure 3.16, the target of mesh is volumes while the shape used in this study is Hex/Wedge > Sweep > Auto Src/ Trg. After the meshing is done, the SW2 will become a solid with a lot of division as shown in Figure 3.17.

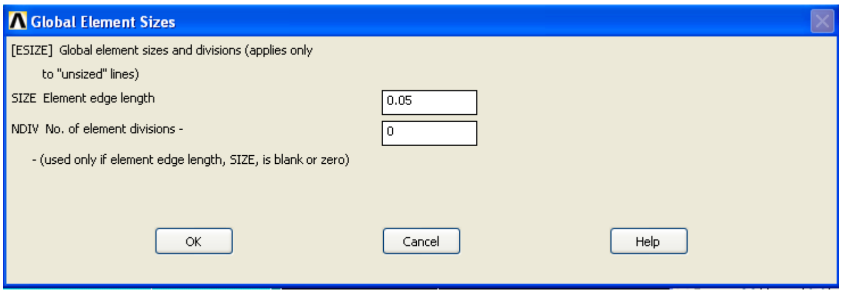


Figure 3.15: Global Element sizes

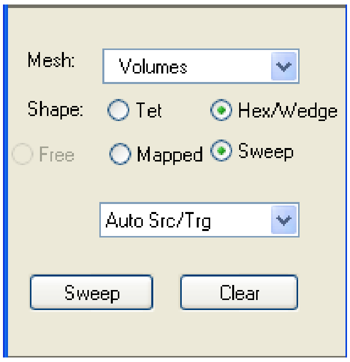


Figure 3.16: Type of Mesh

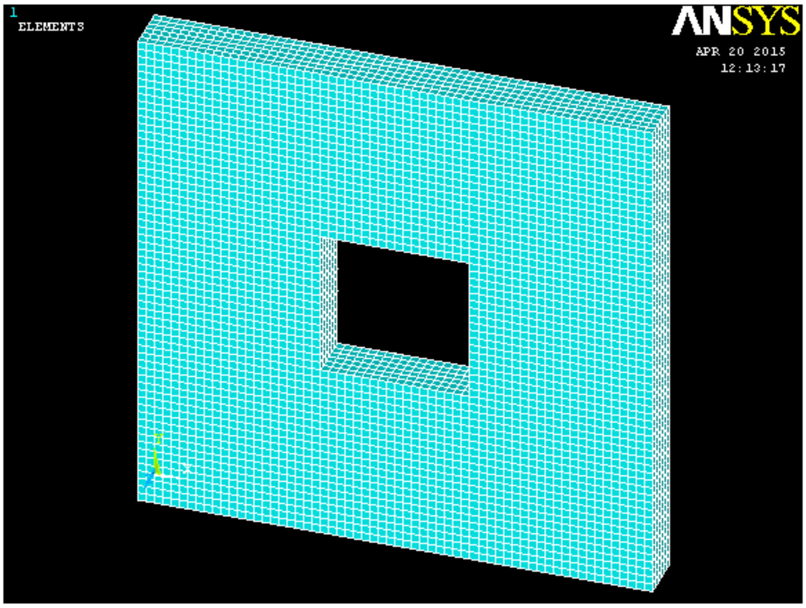


Figure 3.17: Volumes of SW2 after meshing

3.3.7 Merge items

After the meshing is done, all the nodes, elements, key points, lines shall be merged. From Preprocessor > Numbering Ctrls > Merge items, all items are merged with a range of coincidence. In this study the range of coincidence I set is 0.01 as shown in Figure 3.18.It represent that all the same item such as nodes, element, volumes and so on that within the coincidence less than 0.01 will merge as one item.

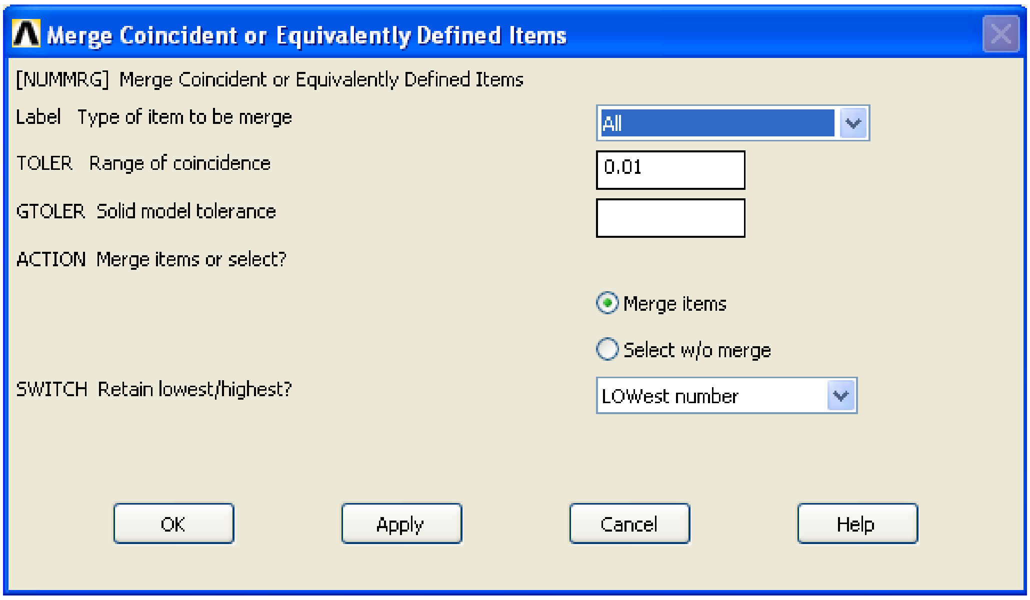


Figure 3.18: Merge coincident

3.4 SOLUTION

The solution is the part of ANSYS where the boundaries conditions and loads are set. The solution control of the ANSYS is set to determine the time and the substep of the analysis. The analysis is started by using nonlinear diagnostics.

3.4.1 Boundaries condition and loads

The shear wall models are set to be fixed at the base of the shear wall and apply 4MPa for axial load or 400kPa for lateral load. In ANSYS, the boundaries conditions are added by fixing the displacement at specific nodes, area, lines or key points.

3.4.1.1 Displacement

In this study, the model is fixed at bottom side; therefore, all degree of freedom of the bottom area shall be fixed. From Solution > Defines Loads > Apply > Structural > Displacements > On Areas, all the bottom area are picked and set as shown in Figure 3.19 to create fix support at the bottom of the model.

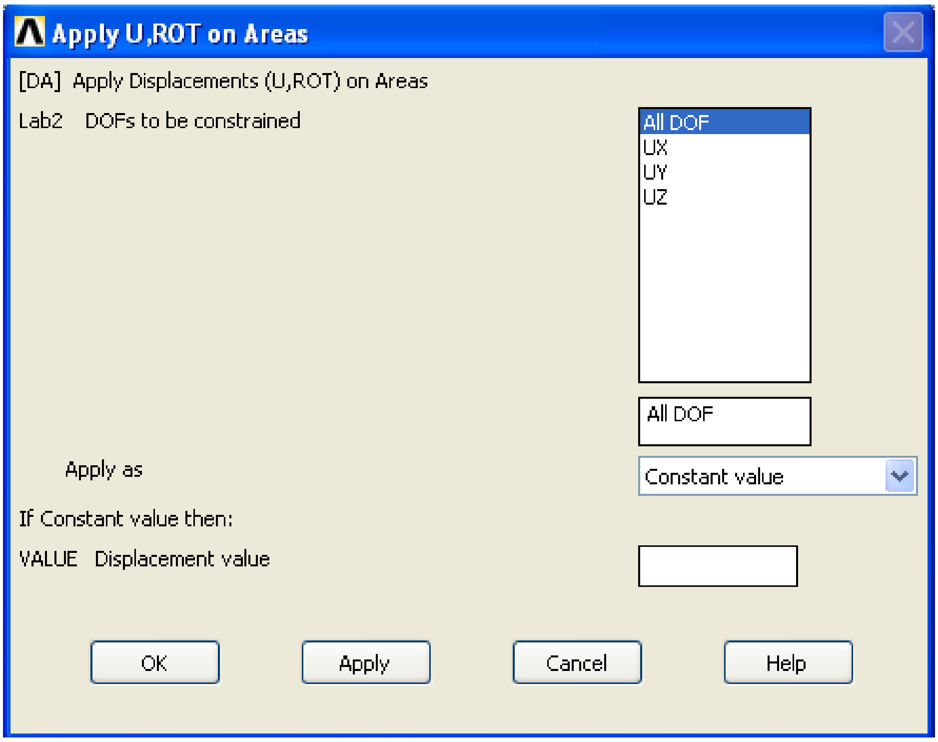


Figure 3.19: Displacement fixed

3.4.1.2 Pressure

Similar to the displacement, the pressure is used on area to create uniformly distributed loads towards the model. For axial load, the pressure is set with 4,000,000 on the top area of the model while 400,000 on the right hand side area of the model for lateral load. From Solution > Define Loads > Apply > Pressure > On Area, the pressure is set with constant value as shown in Figure 3.20. The unit for pressure is SI unit which is in Pascal (Pa).

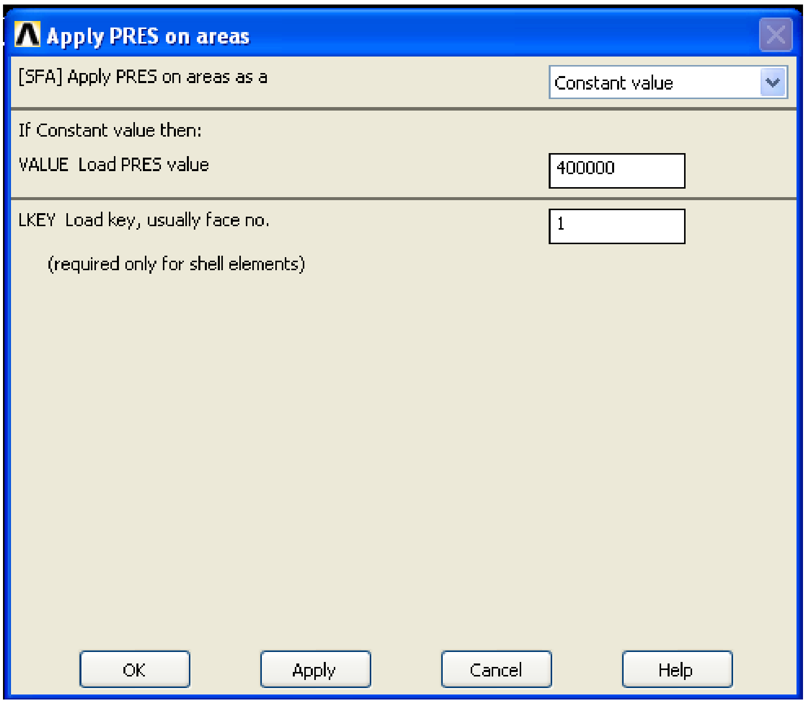


Figure 3.20: Pressure

3.4.2 Solution and control

From Solution > Analysis Type > Sol'n Controls, the solution control shall be set. There are several option shall be set in the Solution controls. First, the Analysis Options shall be set for Small Displacement Static. Time control is set to create the number of substeps of the analysis. All solution items is chosen to write into the results file and the frequency is set with Write every substep. The Solution Controls Basic tab is shown in Figure 3.21. On Sol'n Options tab, the Equation Solvers I used is Program chosen solver while the restart control frequency is Write every substep. On Nonlinear tab, under nonlinear options, the Line search is set as on while the DOF Solution predictor is set as Prog Chosen. On the Equilibrium iterations, the maximum number of iterations in this study is set as 100. Next, the cutback control is set as default option provided by the ANSYS help as shown in Figure 3.22. The convergence criterial is set as shown in Figure 3.23 where F represents force and U represent the displacement.

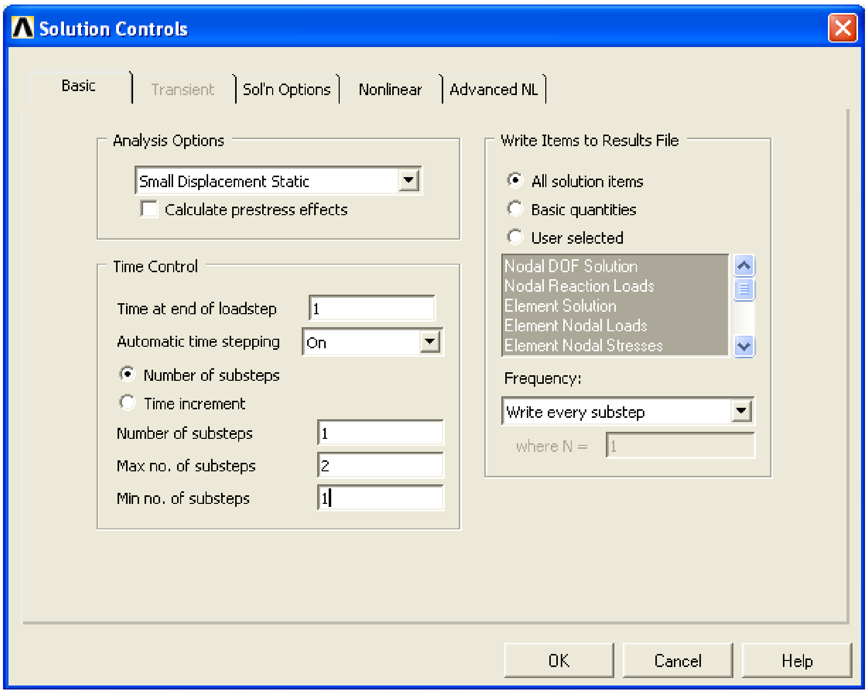


Figure 3.21: Basic Tab of Solution Controls

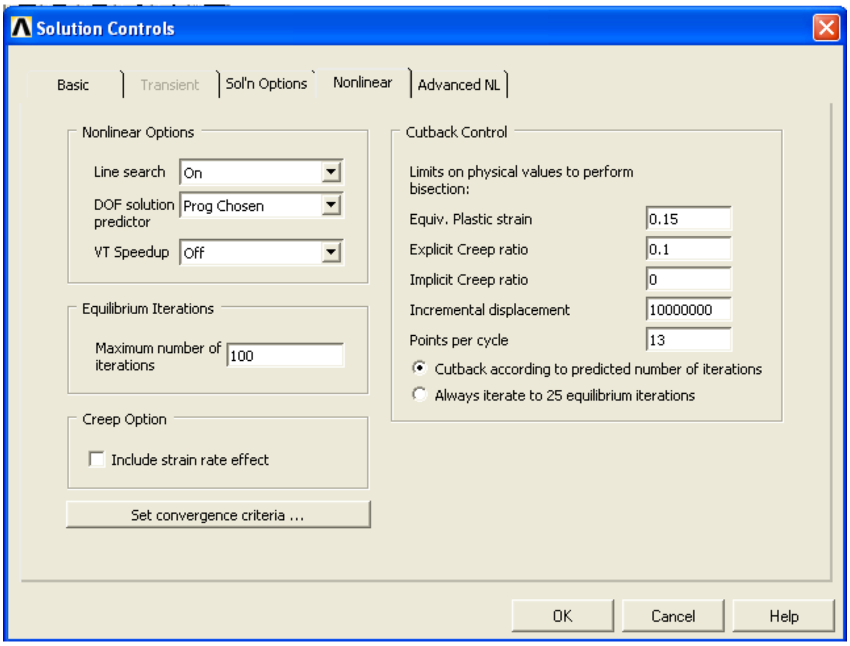


Figure 3.22: Nonlinear Tab of Solution Controls

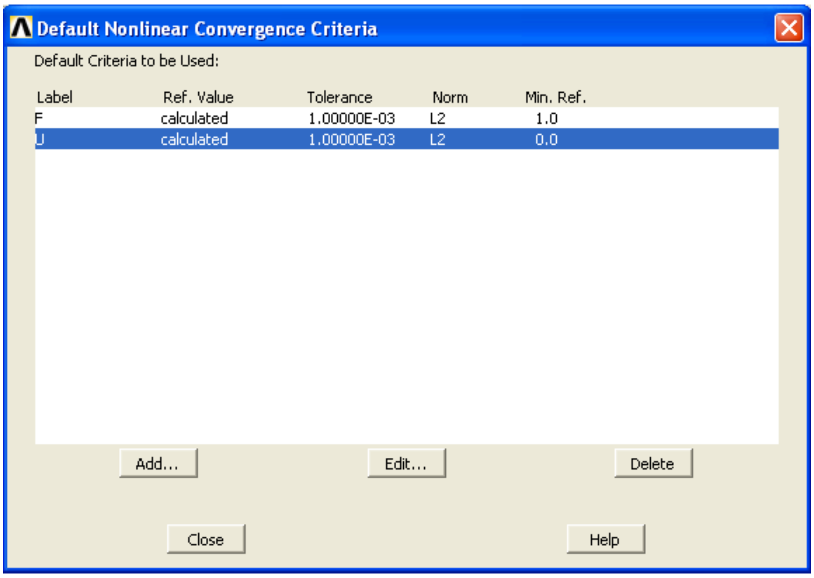


Figure 3.23: Nonlinear Convergence Criteria

3.4.3 Nonlinear diagnostics

The analysis is started after the boundaries condition, loads, and the solution and control is done. From Solution > Diagnostics > Nonlinear Diagnostics as shown in Figure 3.24, the Monitor Newton-Raphson residual information is ticked and the monitor pair-based contact information is based on each substep.

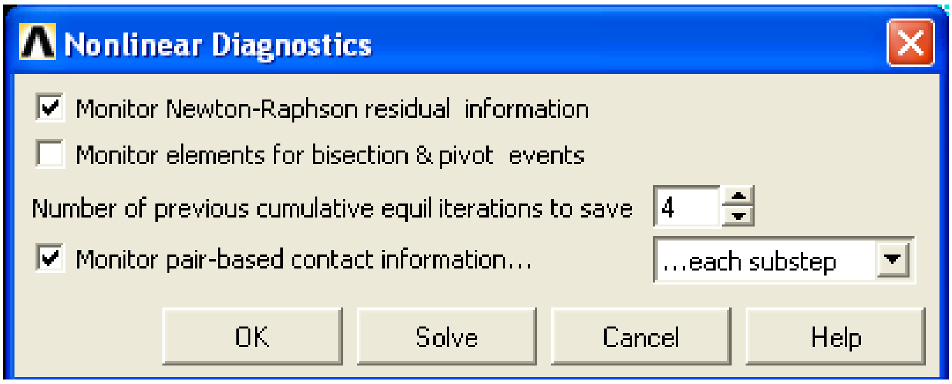


Figure 3.24: Nonlinear Diagnostics

3.5 POST-PROCESSOR

The post-processor is the result of the ANSYS. The deformed shape, contour plot on nodal solution or element and crack/crush can be plotted. The numerical value of the nodal displacement is listed.

3.5.1 Deformed shape

After the solution is done, the deformation shape of model after the analysis is plotted through General Postproc > Plot Results > Deformed shape. As shown in Figure 3.25, the Def + undef edge is chosen to compare the model before and after deformation.

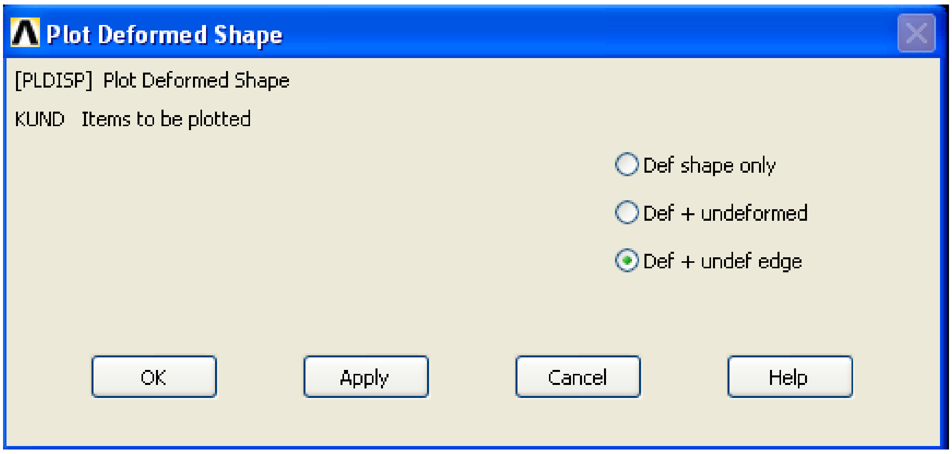


Figure 3.25: Deformed shape

3.5.2 Contour plot

The contour plot is the geometric results displays of element table data or continuous results of nodal solution.

3.5.2.1 Displacement of vector sum

From General Postproc > Plot Results > Contour Plot > Nodal Solu > DOF Solution > Displacement vector sum as shown in Figure 3.26, the nodal displacement of the model after analysis is plotted.

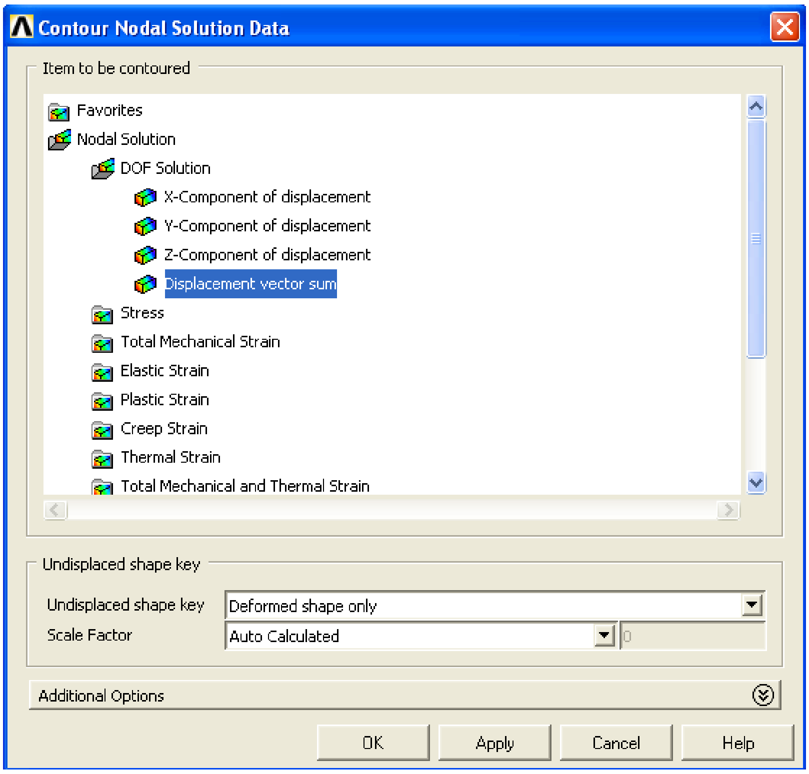


Figure 3.26: Contour Nodal solution Data

3.5.2.2 X/Y-Component of Stress

From General Postproc > Plot Results > Contour Plot > Element Solu > Element Solution > Stress as shown in Figure 3.27, choose either x-component of stress or y-component of stress to plot stress distribution of the model after analysis. X-component of stress is used for lateral load while y-component of stress is used for axial load.

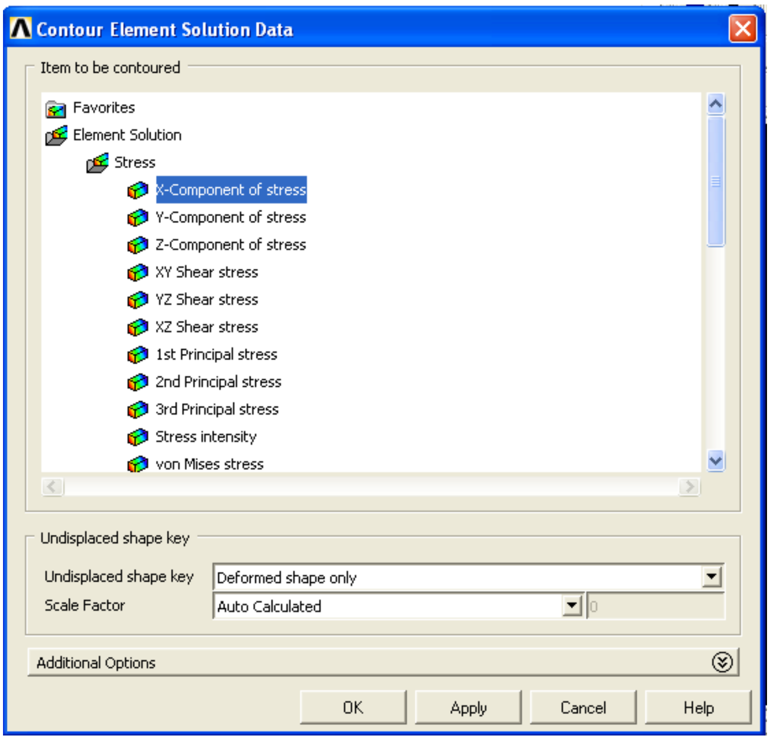


Figure 3.27: Contour Element Solution Data

3.5.3 Crack/Crush

From General Postproc > Plot Results > Concrete Plot > Crack/Crush, the cracking pattern of the model after analysis can be shown. The cracking and crushing locations in concrete elements as shown in Figure 3.28 is used to plot first crack, second crack, third crack and all crack.

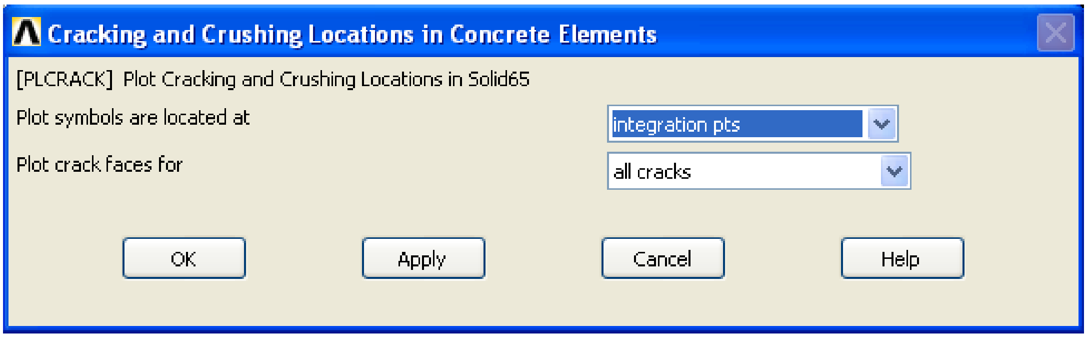


Figure 3.28: Cracking and Crushing Locations in Concrete elements

CHAPTER 4

RESULT AND DISCUSSION

4.1 GENERAL

The result is extracted from the ANSYS 12.0 through post-processor after the solution is done. After applied the axial or the lateral uniformly distributed load, the results are then plotted and to be discussed. The results that can be extracted are deflection which is also known as nodal displacement and the cracking patterns. With the constant applied axial and lateral load, the results under different model are plotted to be compared and discussed.

4.2 DISPLACEMENT OF VECTOR SUM

Excessive deflection can be visually unacceptable that may cause failure; therefore, the deflection behavior of the concrete shall be studied for safety purposes. Nodal displacement in ANSYS is representing the deflection of the reinforced concrete model. The displacement of vector sum is in terms of nodal coordinate system which is Cartesian system. The displacement of vector sum is the square root of the sum of the squares of the displacement to each direction. In this analysis, the units used are in SI, therefore, the units for length is in meter, the area is in meter square, pressure applied is in Pascal and the time is in second. The applied load is in terms of pressure with 400kPa for lateral and 4MPa for axial load. The contour plot for displacement of vector sum of each model under the axial and lateral load after the analysis is plotted in Figure 4.1 to Figure 4.16.

In this analysis, the shear walls have different number of nodes with different value of deflection. Therefore, the results of maximum deflection for each shear wall under both loads are recorded and discussed. The maximum nodal displacement is the DMX value from the contour plot of displacement of vector sum as shown in Figure 4.1 to Figure 4.16.

4.2.1 Displacement for different size of opening

When there is an opening, the red colour area which represents the maximum nodal displacement is more focus on the top of the opening. Besides, the blue colour area which represents the minimum nodal displacement is increased when the opening size or position made the opening closer to the support. Unlike axial load, the red colour area are not focus on the opening but at the top right of the shear wall because of the load applied on the right of the shear wall. By comparing the Figure 4.2, Figure 4.4, Figure 4.6 and Figure 4.8, the increasing of size of the opening has made the maximum displacement area closer to the edges and increases. At the same time, the minimum displacement area is also closer to the bottom left edge of the opening and also increases. Shear wall with smaller opening dissipate more energy compared to the larger opening, whose deformation capacity is higher (Todut et Al. 2014).

The maximum nodal displacements with different size of opening under both axial and lateral load are recorded in Table 4.1. The increasing of the size of the opening has significance results as cracking under axial load. The increment of the displacement is obvious when the size of the opening is increase except until the SW4. The SW4 has been crushed with the same magnitude of axial load applied. On the other hand, the lateral load doesn’t cause much different for maximum deflection for smaller opening. The large opening like SW4 has a increment of 55.75% of maximum displacement. The large opening resulted in significance reduction in lateral resistance as compared to the smaller (Todut et Al. 2014).

Table 4.1: Maximum nodal displacement with different size of opening

Model	Opening Size (m x m)	Axial Load		Lateral Load	
		Displacement (m)	Increment (%)	Displacement (m)	Increment (%)
SW1	-	0.000468	-	0.001930	-
SW2	0.9x0.9	0.000756	+61.54	0.001858	-3.73
SW3	1.2x1.2	0.001151	+145.94	0.001861	-3.58
SW4	1.5x1.5	Failed	-	0.003006	+55.75

4.2.2 Displacement for different position of opening

By comparing the shear wall with different position of opening under axial load, the SW5 and SW6 shows the symmetrical contour with the same range of value of deflections as shown in Figure 10 and Figure 12. The Figure 4.9 to Figure 4.16 is the contour plot of displacement of vector sum of shear wall 5 to shear wall 8 under axial load and lateral load respectively. Under the same magnitude of the lateral load, with different position of the opening, there is not much different deflection on area as the solid shear wall as shown in Figure 4.2. The only different is in Figure 4.16 where the opening is closer to the support, the minimum deflection area increased and closer to the bottom left edge.

The maximum nodal displacements with different position of opening under both lateral and axial load are recorded in Table 4.2. Under axial load, the SW5 and SW6 has the same value of maximum displacement which is 20.90% increment but is still higher than SW2 which the opening size at the center. This shows that center is the better position for horizontal axis under axial load. However, when comparing the SW2 to SW7 and SW8, SW8 has a lower value of displacement of 0.000638 meter which is 15.61% less than the center. This shows that the opening should be further from the applied load for vertical axis of position.

On the other hand, under lateral load, for horizontal axis, the SW5 which is the opening to the left has a lower value of deflection as compared to SW2 and SW6. This shows that the further the position of opening from the applied load, the less the deflection is. For the vertical axis, the SW7 and SW8 have increment of 26.91% and 4.19% respectively as compared to SW2. This shows that the center is the most suitable position for vertical axis to resist lateral load.

Table 4.2: Maximum nodal displacement with different position of opening

Model	Opening Size (m x m)	Axial Load		Lateral Load	
		Displacement (m)	Increment (%)	Displacement (m)	Increment (%)
SW2	0.9x0.9	0.000756	-	0.001858	-
SW5	0.9x0.9	0.000914	+20.90	0.001740	-6.35
SW6	0.9x0.9	0.000914	+20.90	0.002318	+24.76
SW7	0.9x0.9	0.001222	+61.64	0.002358	+26.91
SW8	0.9x0.9	0.000638	-15.61	0.001936	+4.19

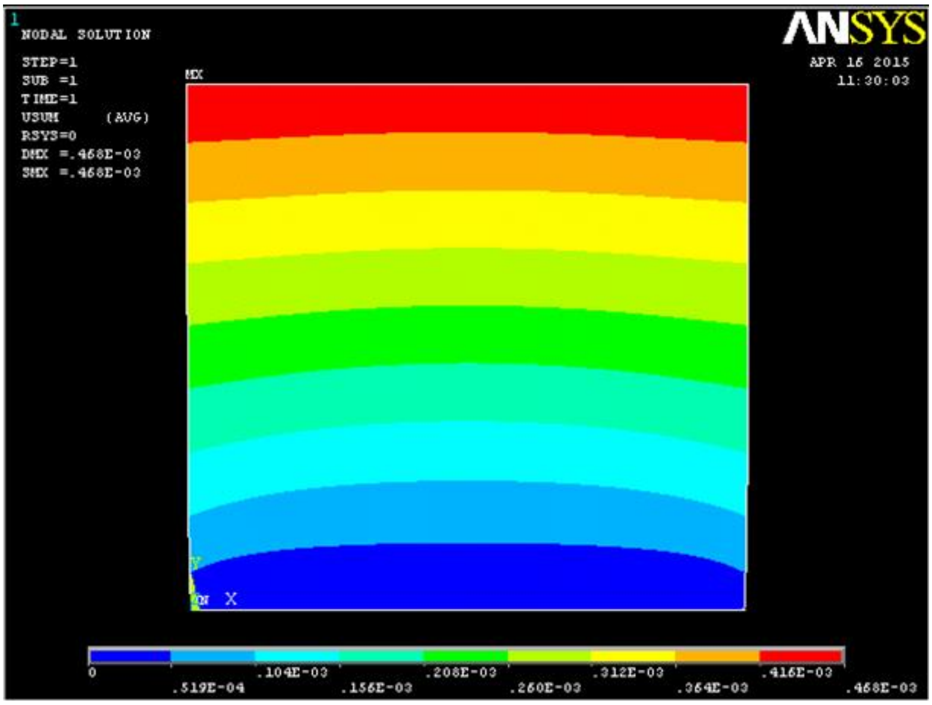


Figure 4.1: Displacement of vector sum of SW1 under axial load

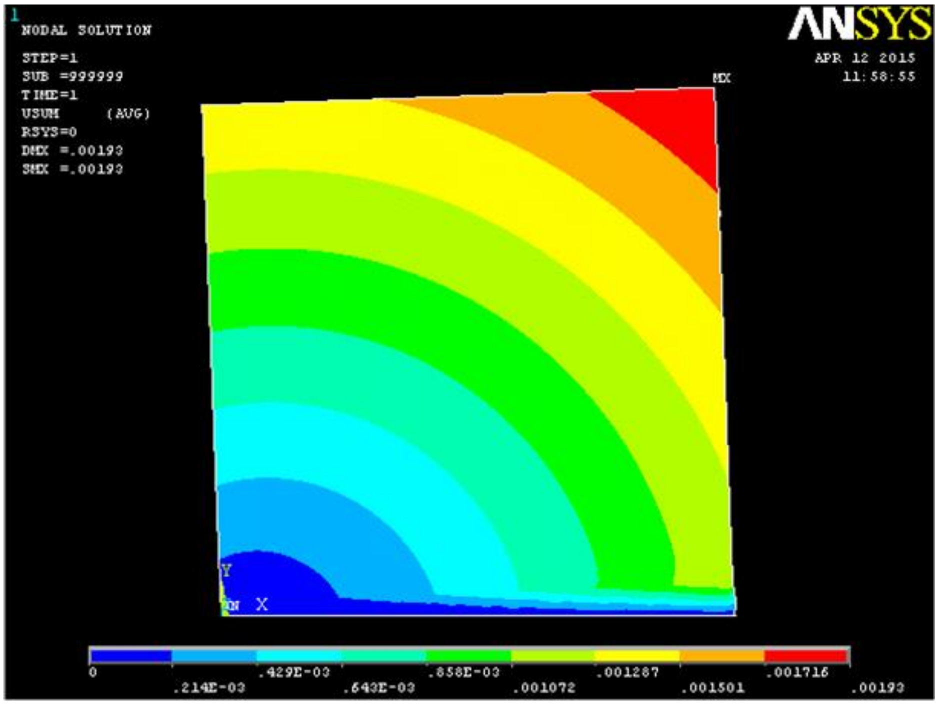


Figure 4.2: Displacement of vector sum of SW1 under lateral load

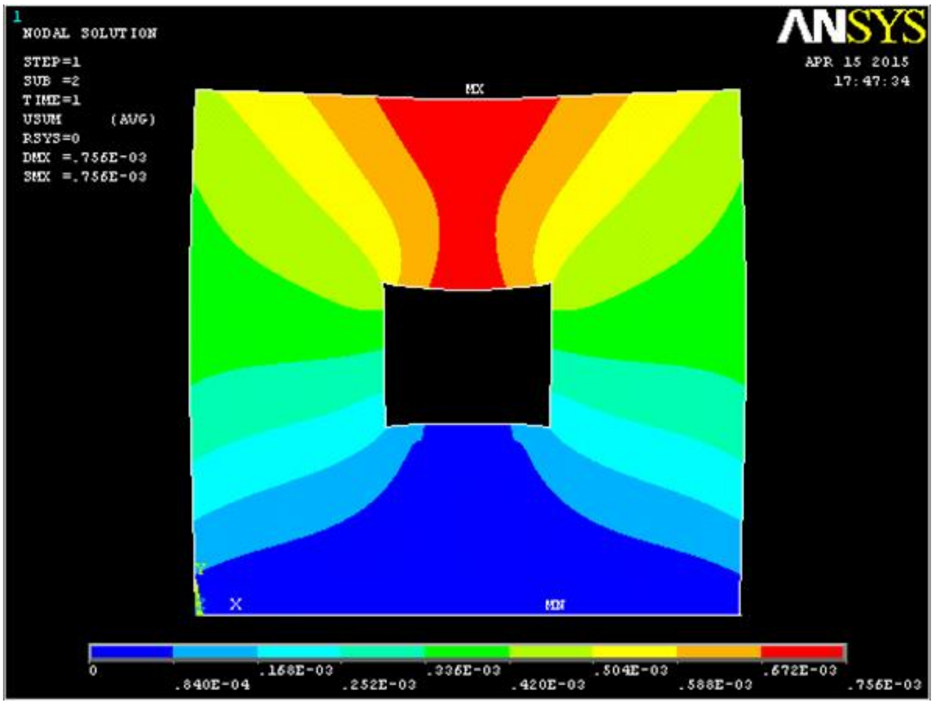


Figure 4.3: Displacement of vector sum of SW2 under axial load

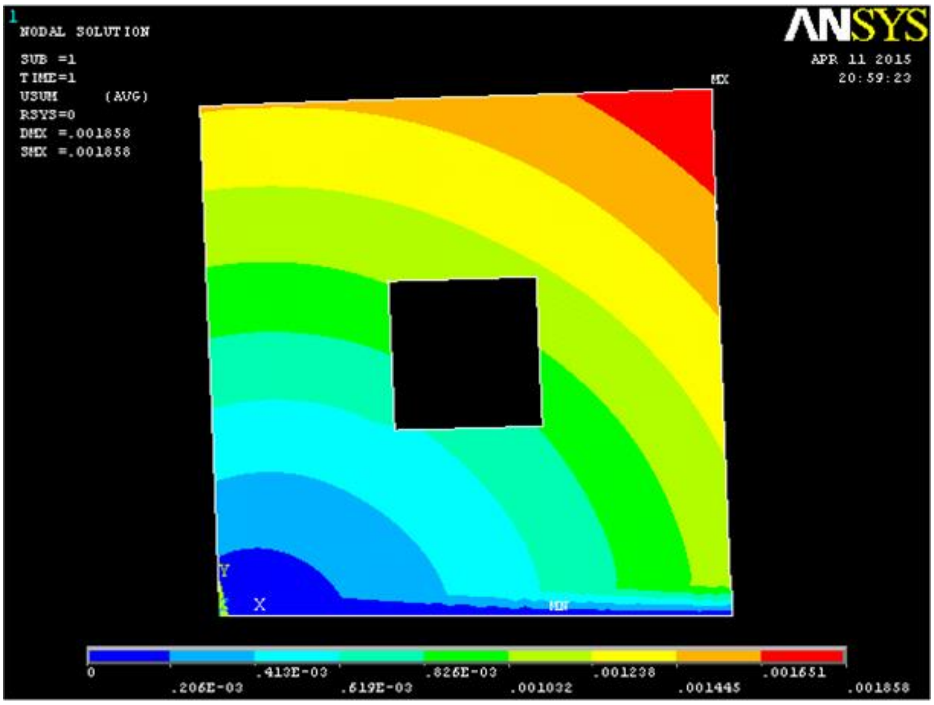


Figure 4.4: Displacement of vector sum of SW2 under lateral load

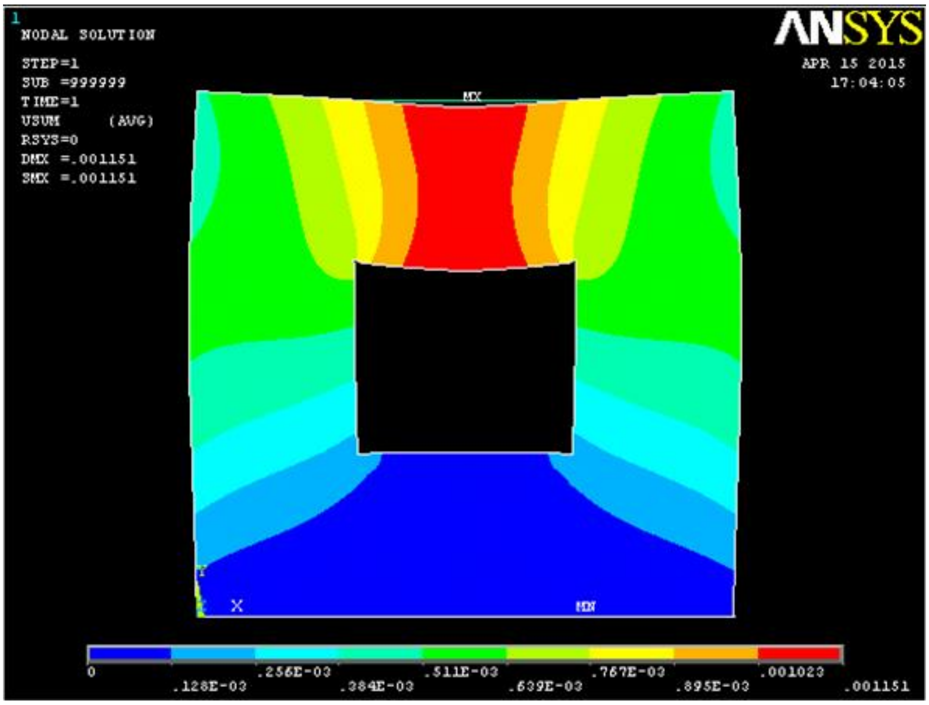


Figure 4.5: Displacement of vector sum of SW3 under axial load

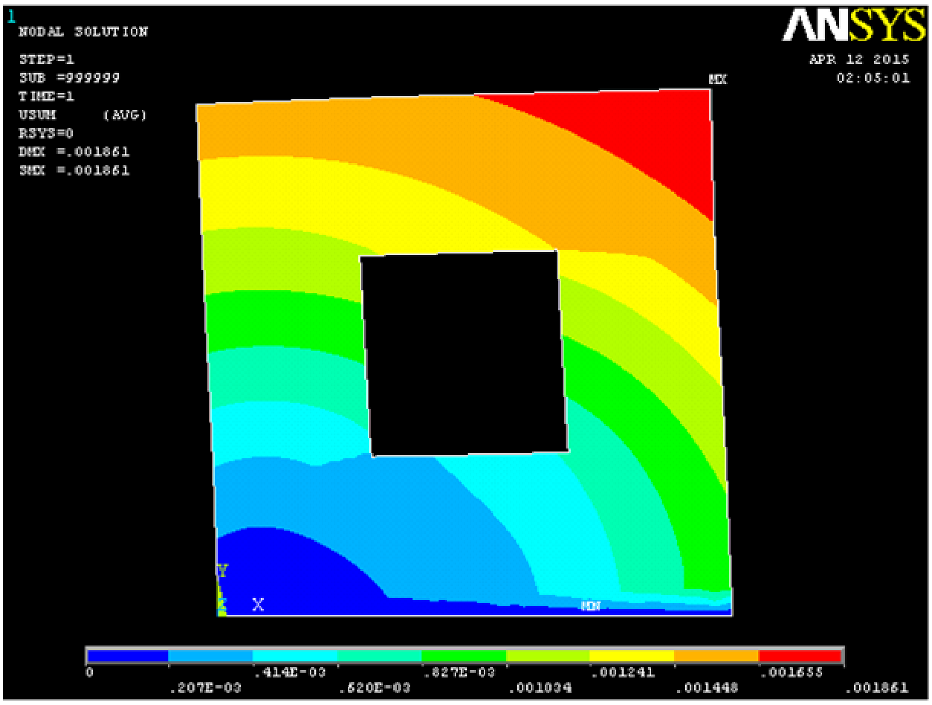


Figure 4.6: Displacement of vector sum of SW3 under lateral load

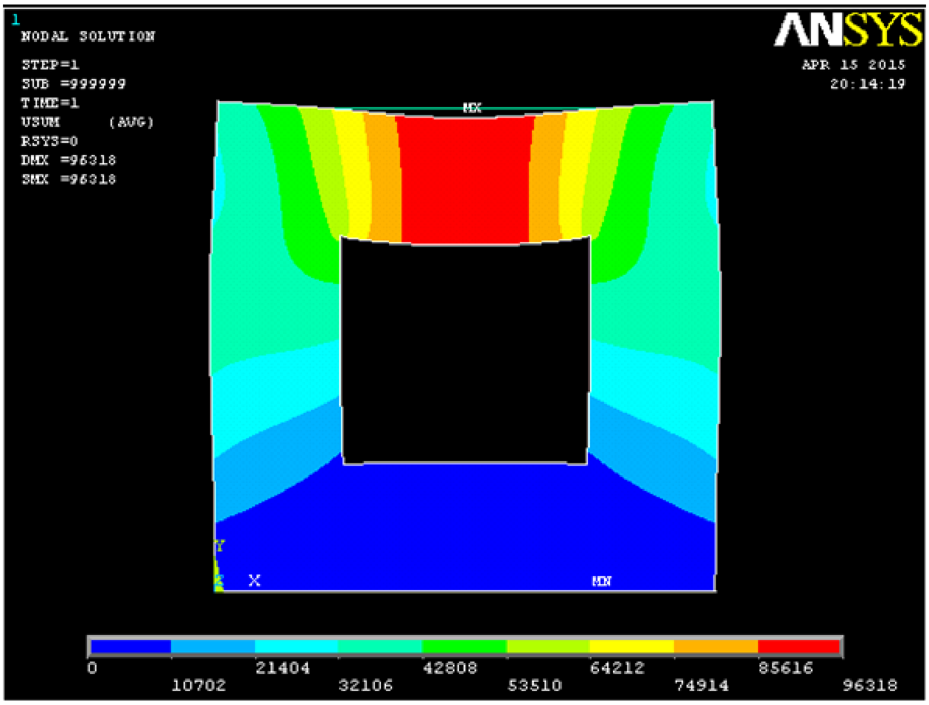


Figure 4.7: Displacement of vector sum of SW4 under axial load

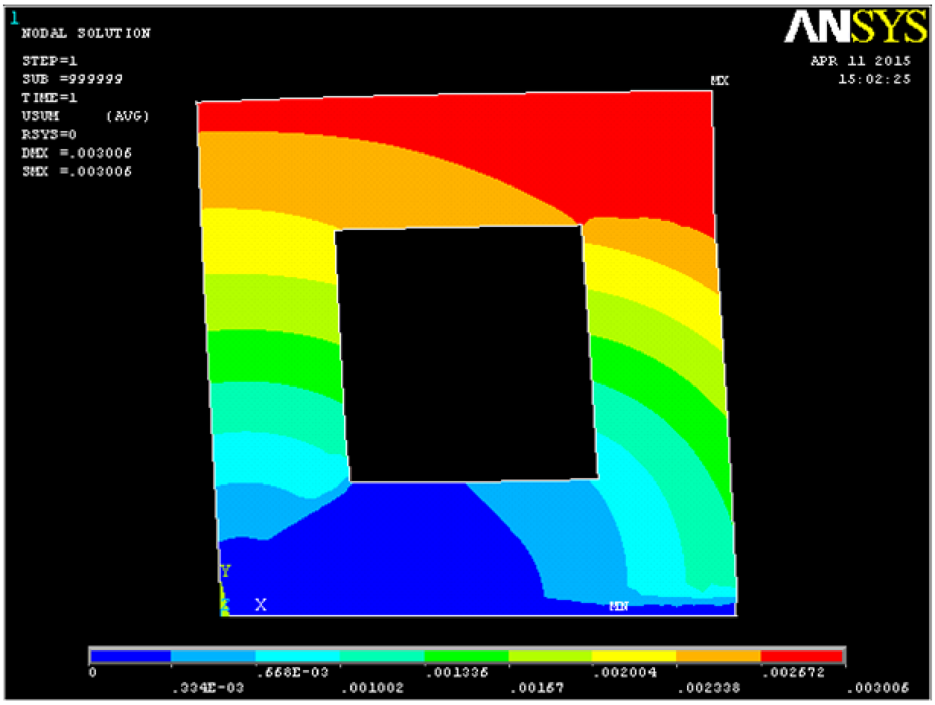


Figure 4.8: Displacement of vector sum of SW4 under lateral load

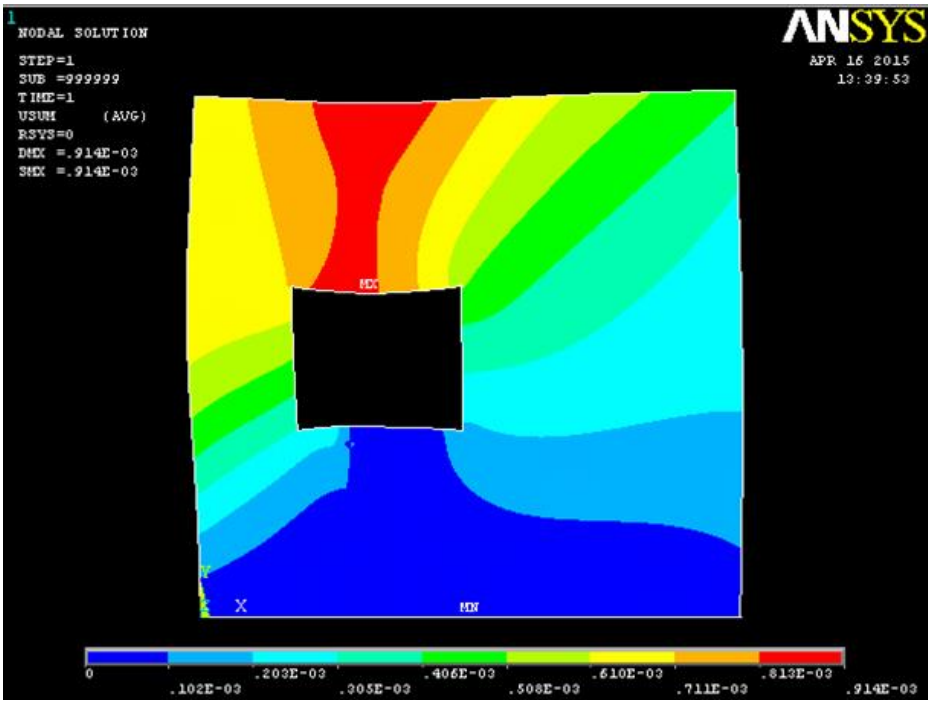


Figure 4.9: Displacement of vector sum of SW5under axial load

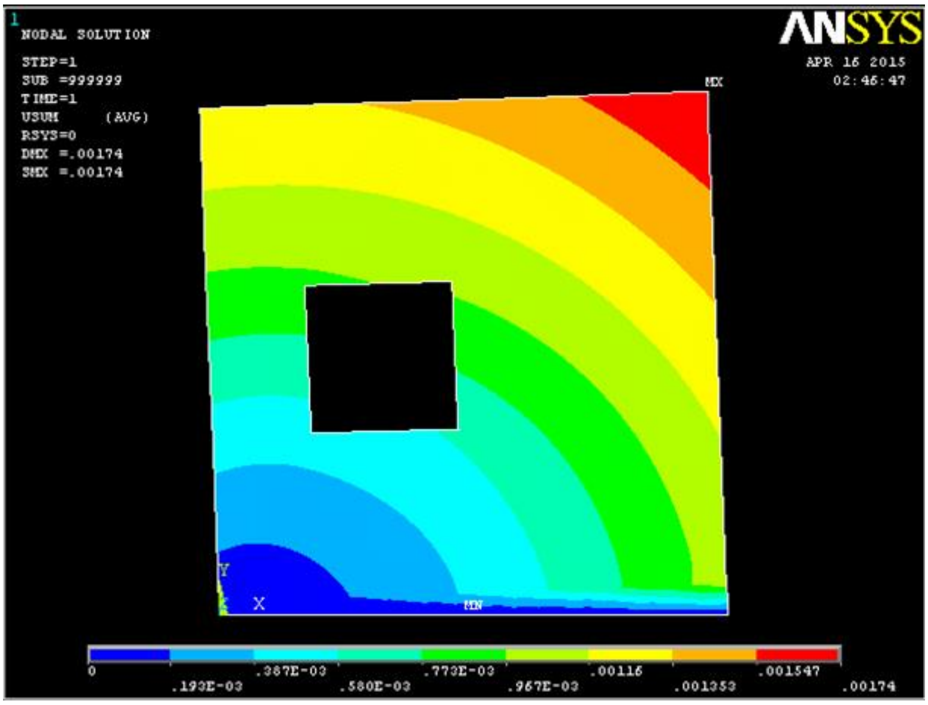


Figure 4.10: Displacement of vector sum of SW5 under lateral load

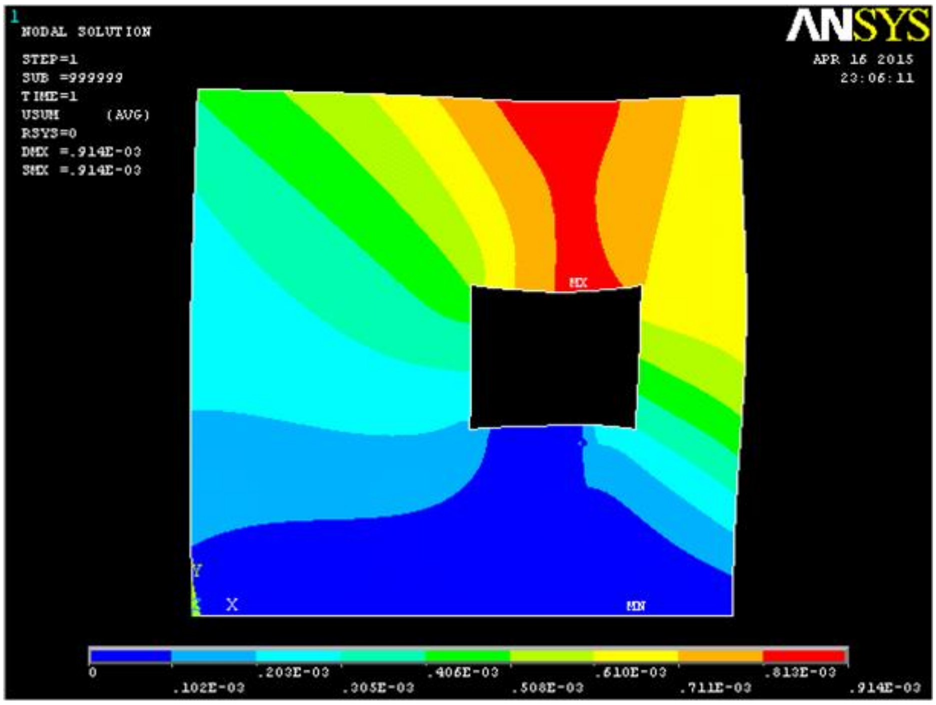


Figure 4.11: Displacement of vector sum of SW6 under axial load

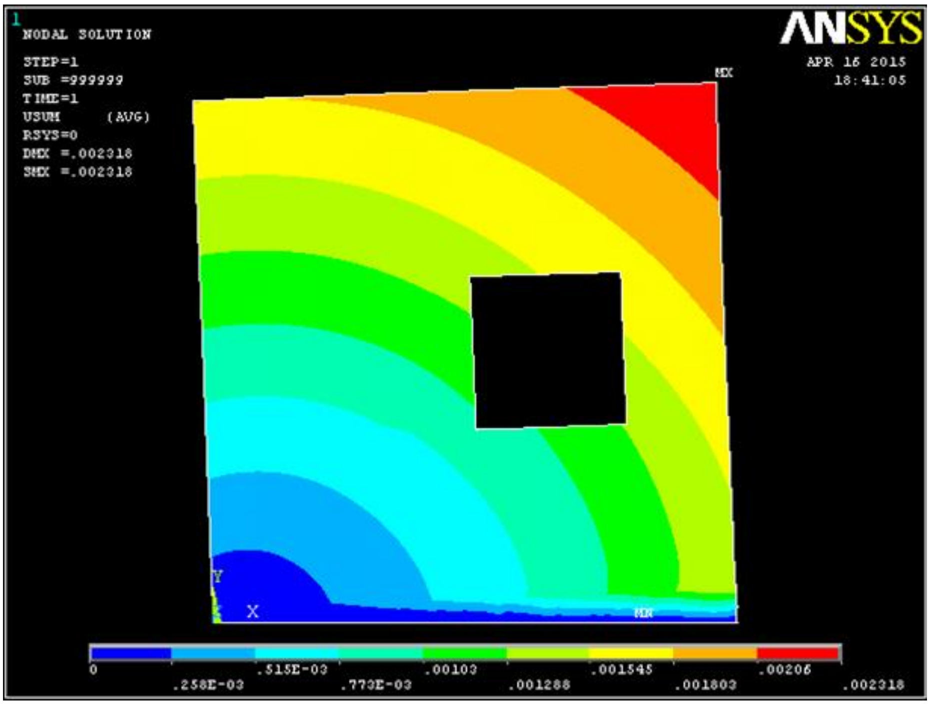


Figure 4.12: Displacement of vector sum of SW6 under lateral load

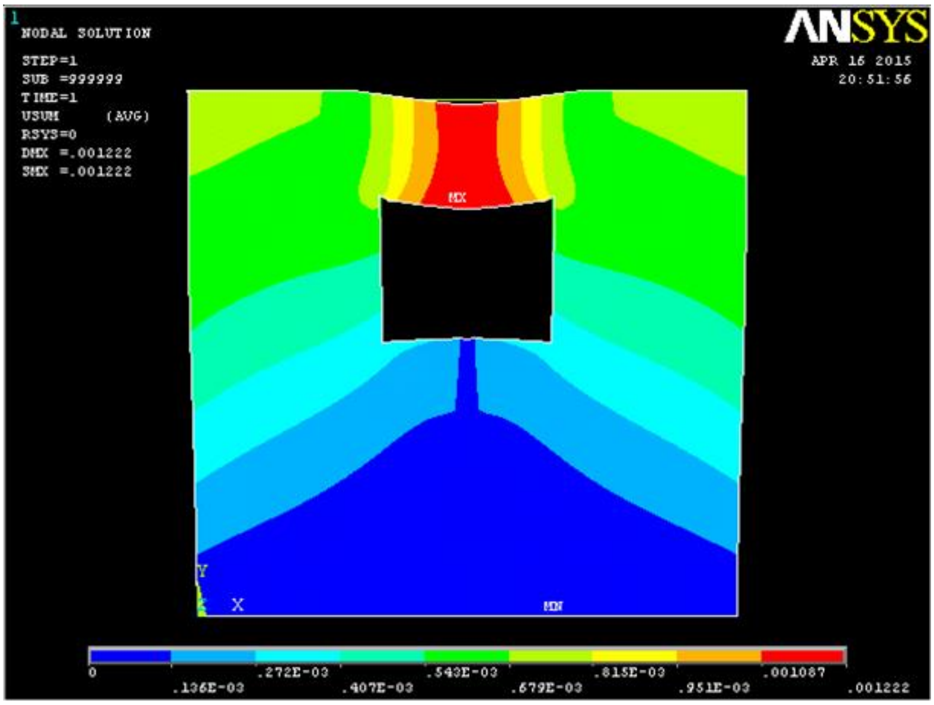


Figure 4.13: Displacement of vector sum of SW7 under axial load

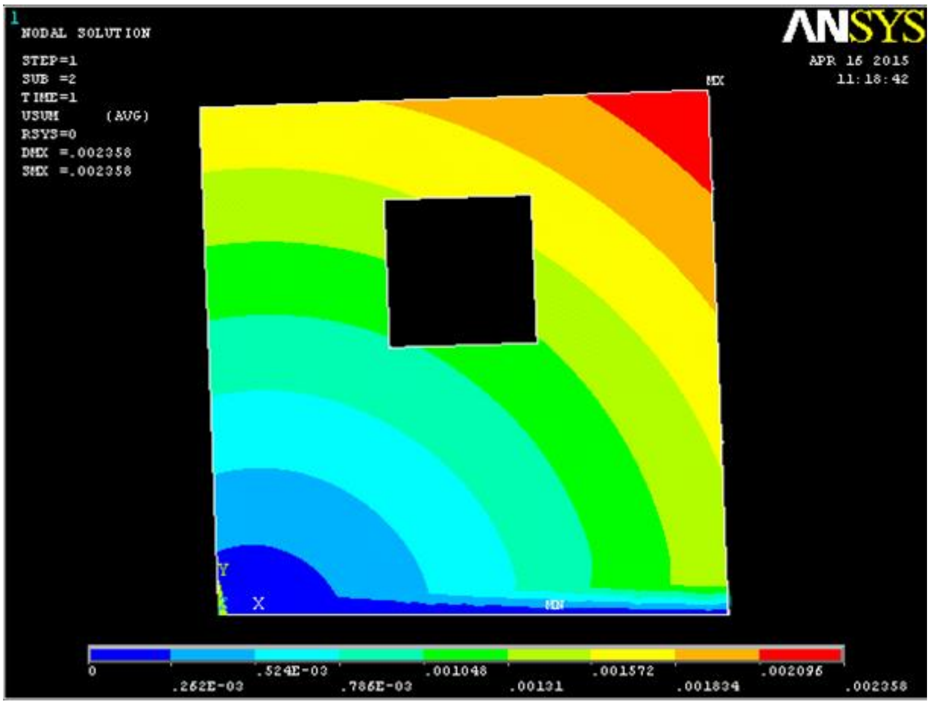


Figure 4.14: Displacement of vector sum of SW7 under lateral load

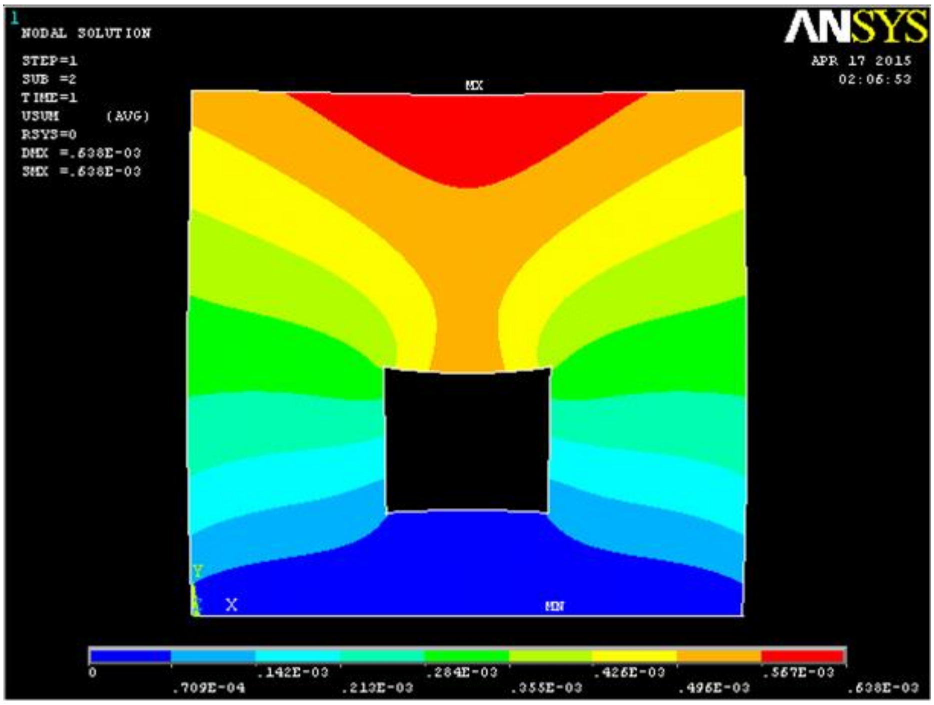


Figure 4.15: Displacement of vector sum of SW8 under axial load

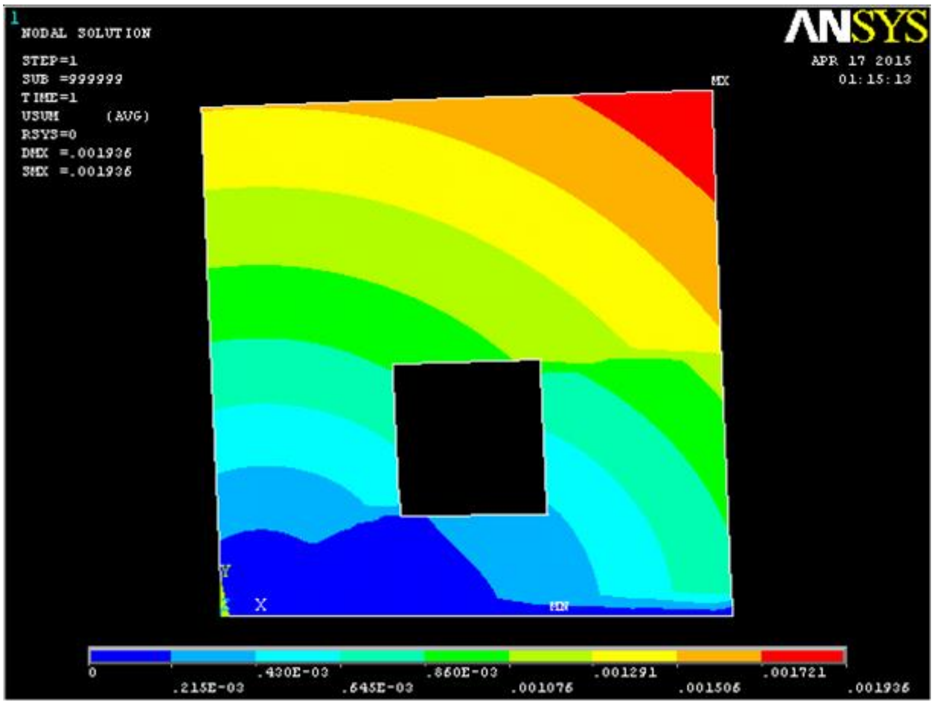


Figure 4.16: Displacement of vector sum of SW8 under lateral load

4.3 CRACKING PATTERN

Cracking is a major indication of failure in reinforced concrete. Crack can be caused by a lot of different reason and may result in different type of cracking pattern. With the simulation by ANSYS, the cracking occurred is mostly caused by the overloading. Under this 2 different type of loads, the different type of cracking patterns had occurred are the reentrant cracking, base cracking and overloading cracking. With the using of SOLID65 element in ANSYS as concrete, the element which have cracked and/or crushed can be shown and plotted by using the plot command. With the vector mode of display on, the cracking pattern of each model under different loads are plotted in Figure 4.17 to Figure 4.32.

Under Axial load, the over loading cracks are all around the opening. As the name of the cracking, over loading cracking are the occurred when the structure could not restrain the applied load. The cracking occurs under lateral loads are the base cracking and the reentrant cracking at the edges of the opening. All the shear walls experienced the similar base cracking which is caused by the overturning moment by the lateral loads. The reentrant cracking shows the similar pattern in direction as the result in the study done by Musmar 2013. The reentrant cracking which is the cracking at the edges of the opening is mostly caused by the settlement and movement around the opening.

4.3.1 Cracking pattern for different size of opening

By comparing the Figure 4.17, Figure 4.19, Figure 4.21 and Figure 4.23, the increasing size of the opening has a very significance results. As the size of the opening increase, the crack increase. When the same magnitude of axial load, the SW4 which has the biggest size of opening could not restrain the loads and result in crushing of the structure as shown in Figure 4.23.

By comparing the model under lateral load, the reentrant cracking has shown different magnitude when the size of the opening is different. Similar to the results in axial load, when the size of the opening increases, the reentrant cracking become bigger.

4.3.2 Cracking pattern for different position of opening

Similar to the result of nodal displacement, the SW5 and SW6 have the symmetrical cracking pattern to each other. Similar to the result in nodal displacement, the SW7 in Figure 4.24 shows more cracking as compared to the SW2 and SW8 as the position of the opening closer to the support which is the bottom of the shear wall. This shows that the closer the opening to the support, the more effective the shear wall is. Therefore, the better position for opening to restrain axial load is closer to the base support which is to the bottom.

Since the lateral load applied on the right of the shear wall, the reentrant cracking increase when the opening closer to the applied load which is SW6 as shown in Figure 4.28. Unlike axial load, the lateral load caused a bigger cracking when the opening is closer to the support as shown in Figure 4.32. Therefore, the better position for opening to restrain lateral load is away from the base support which is to the top.

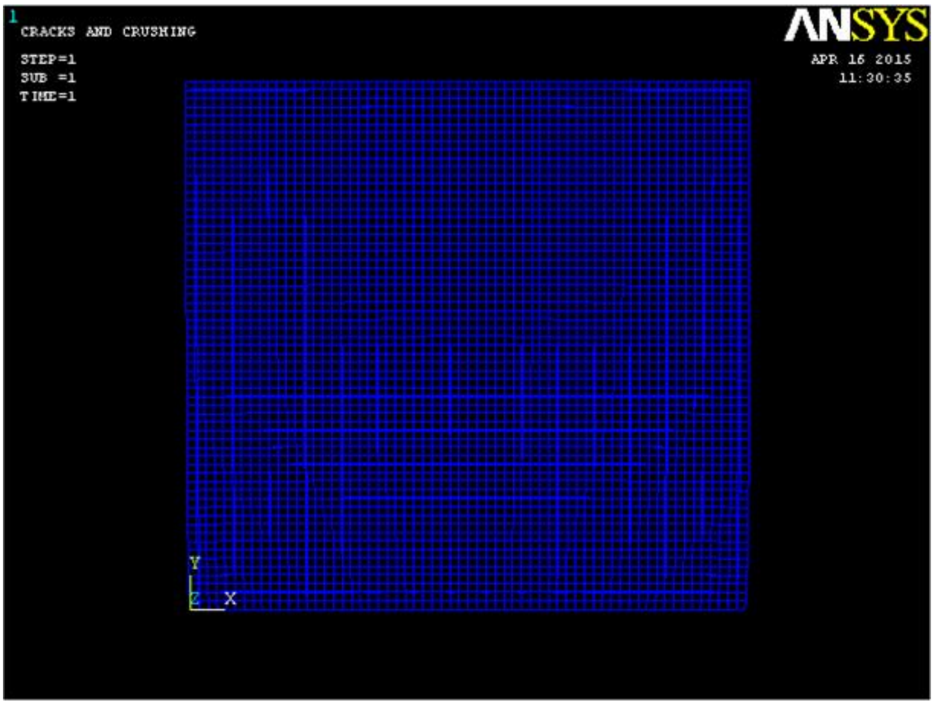


Figure 4.17: Cracking Pattern of SW1 under axial load

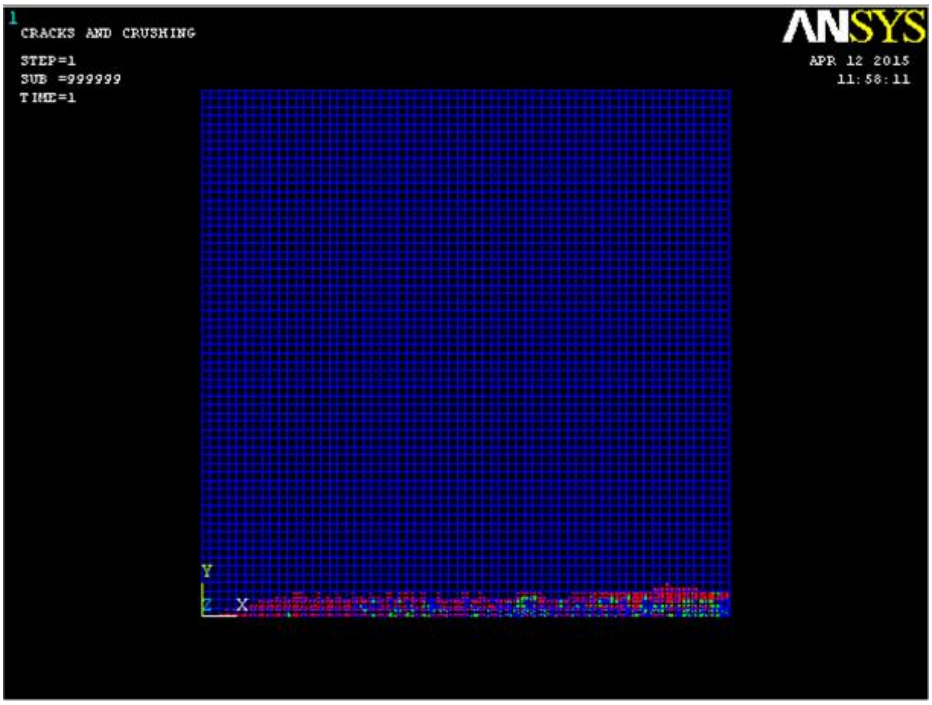


Figure 4.18: Cracking Pattern of SW1 under lateral load

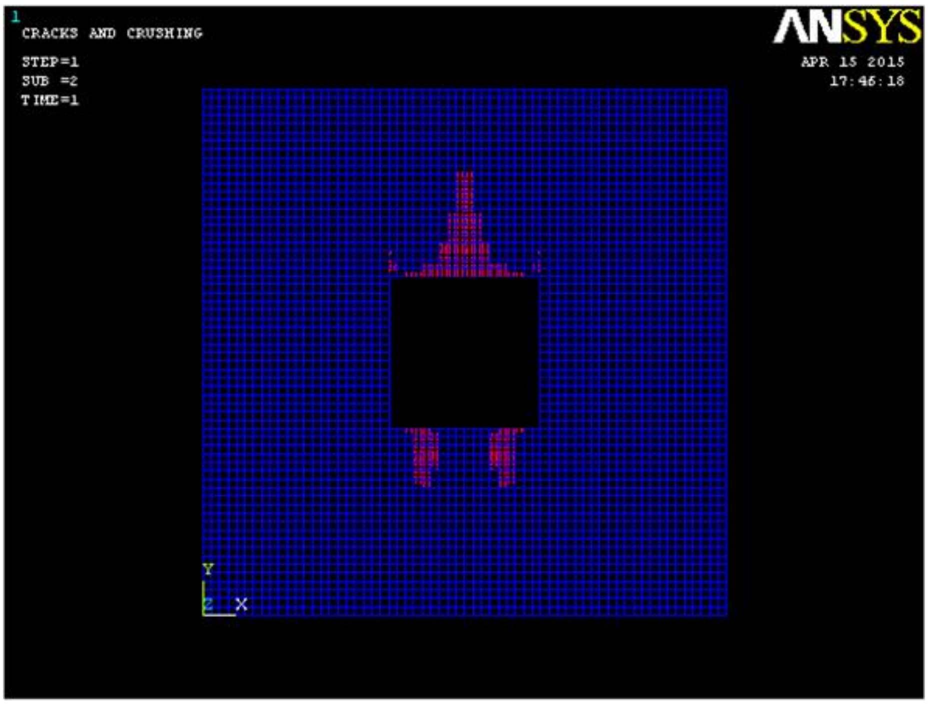


Figure 4.19: Cracking Pattern of SW2 under axial load

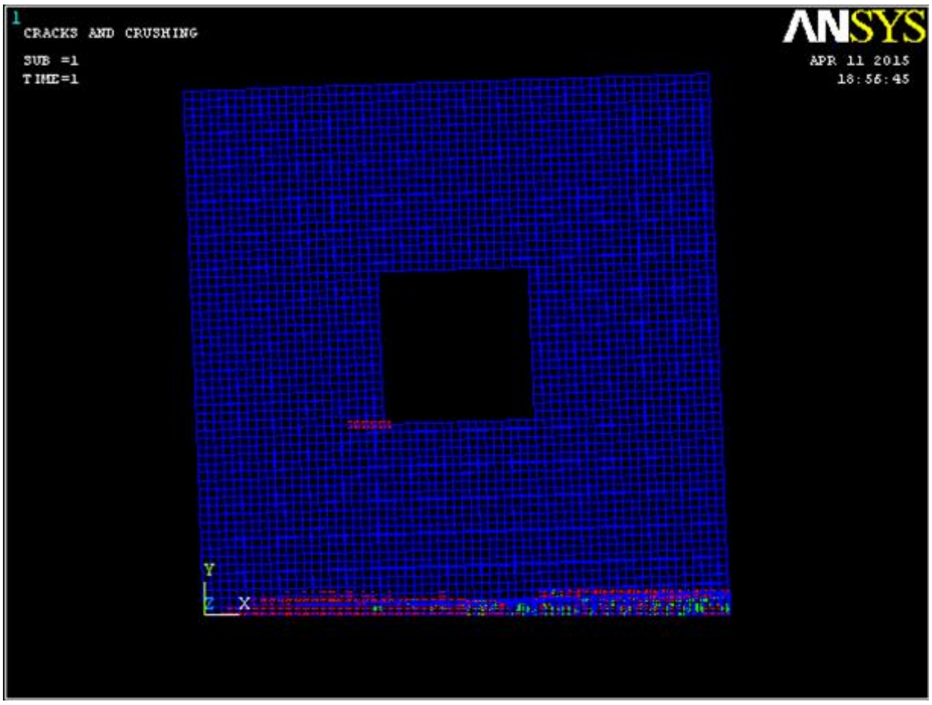


Figure 4.20: Cracking Pattern of SW2 under lateral load

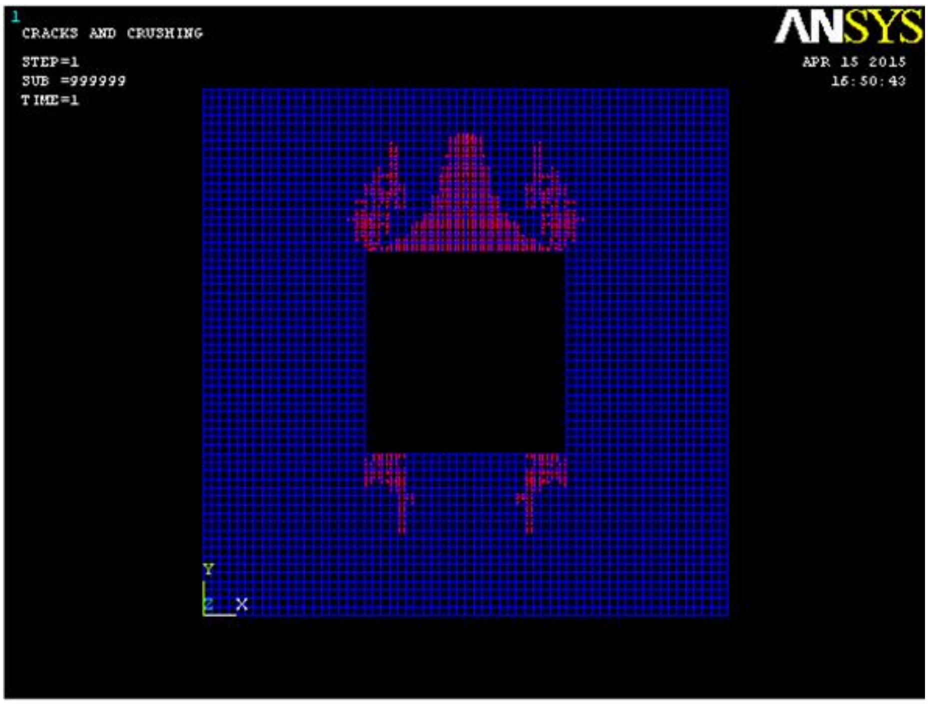


Figure 4.21: Cracking Pattern of SW3 under axial load

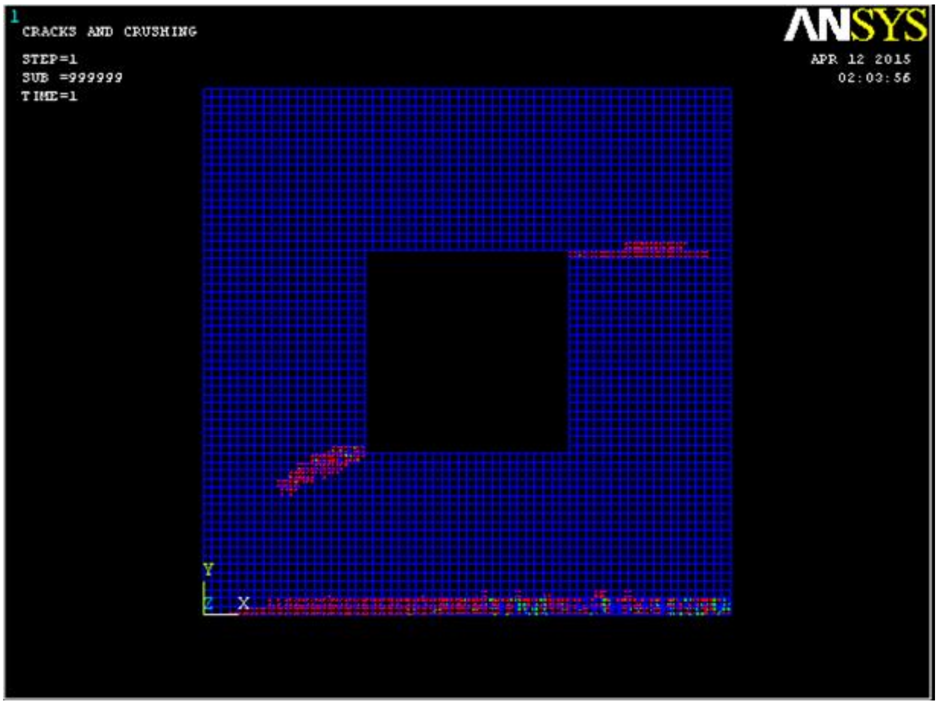


Figure 4.22: Cracking Pattern of SW3 under lateral load

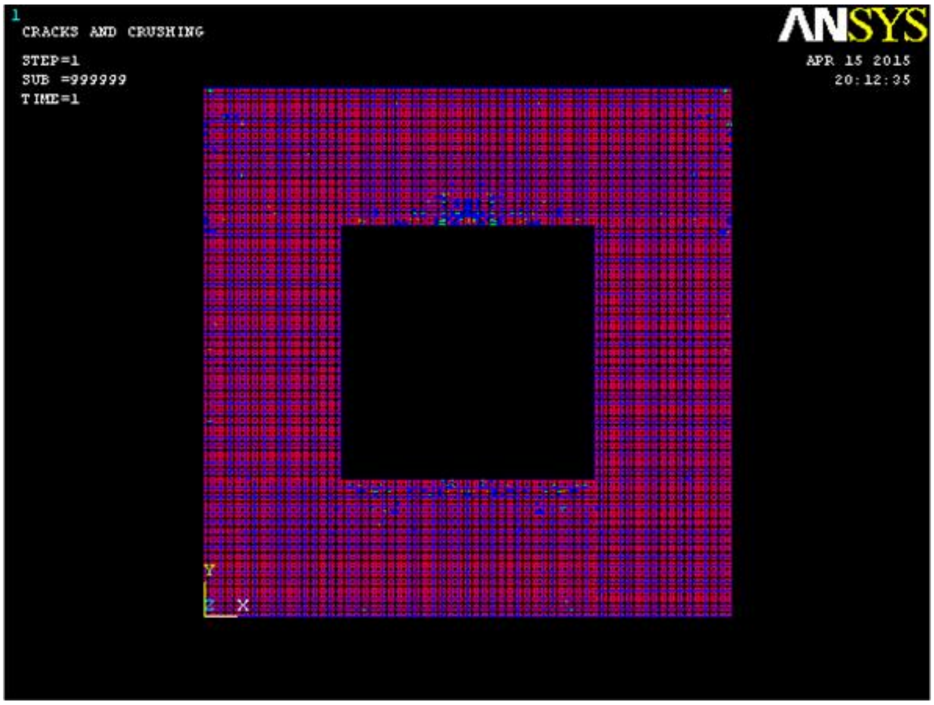


Figure 4.23: Cracking Pattern of SW4 under axial load

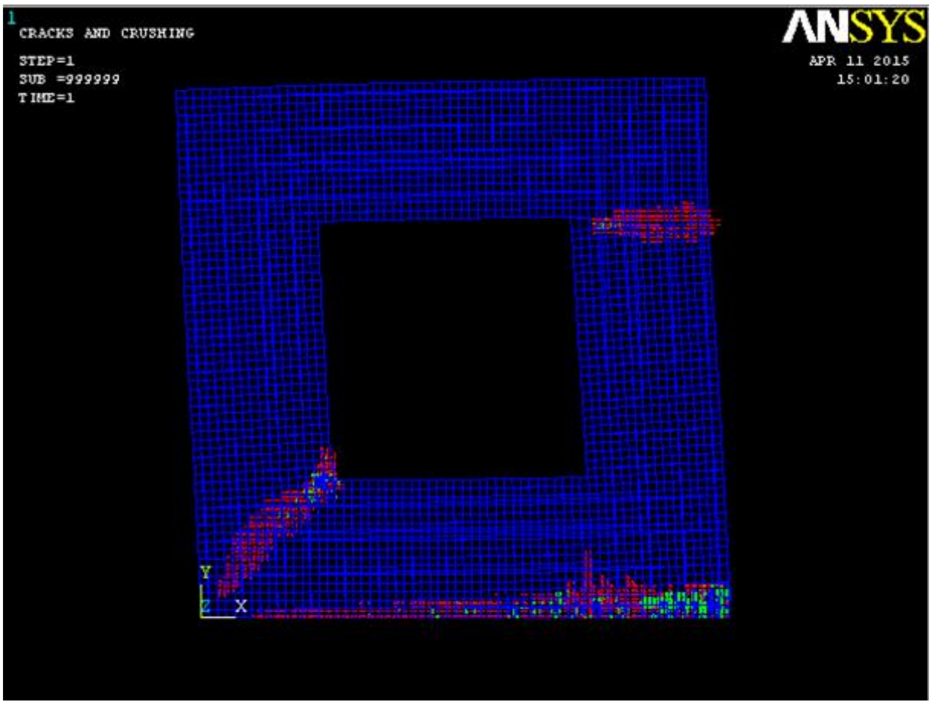


Figure 4.24: Cracking Pattern of SW4 under lateral load

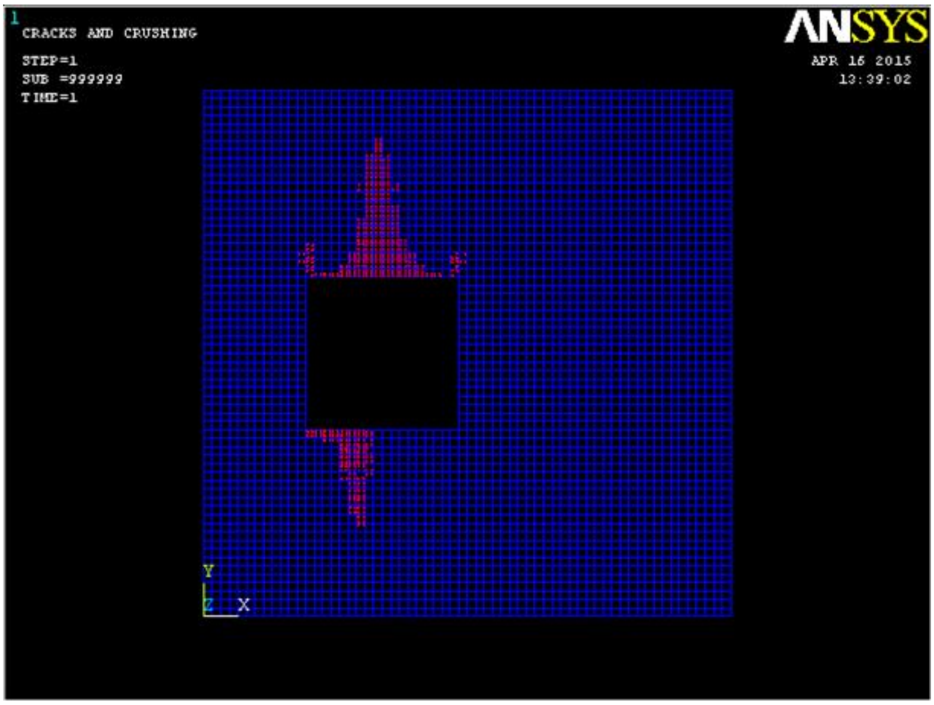


Figure 4.25: Cracking Pattern of SW5 under axial load

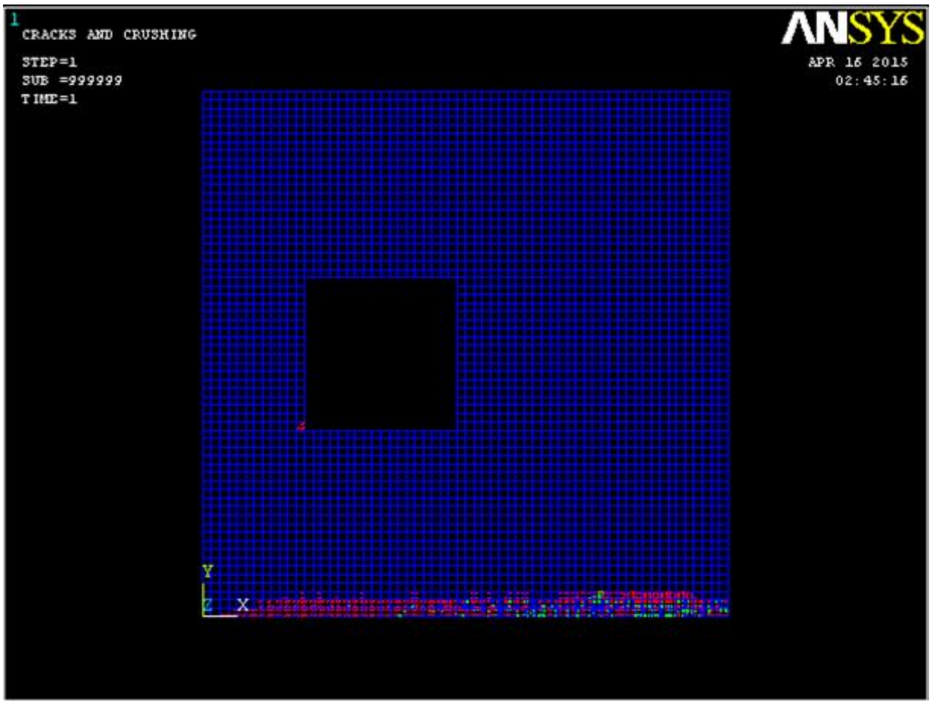


Figure 4.26: Cracking Pattern of SW5 under lateral load

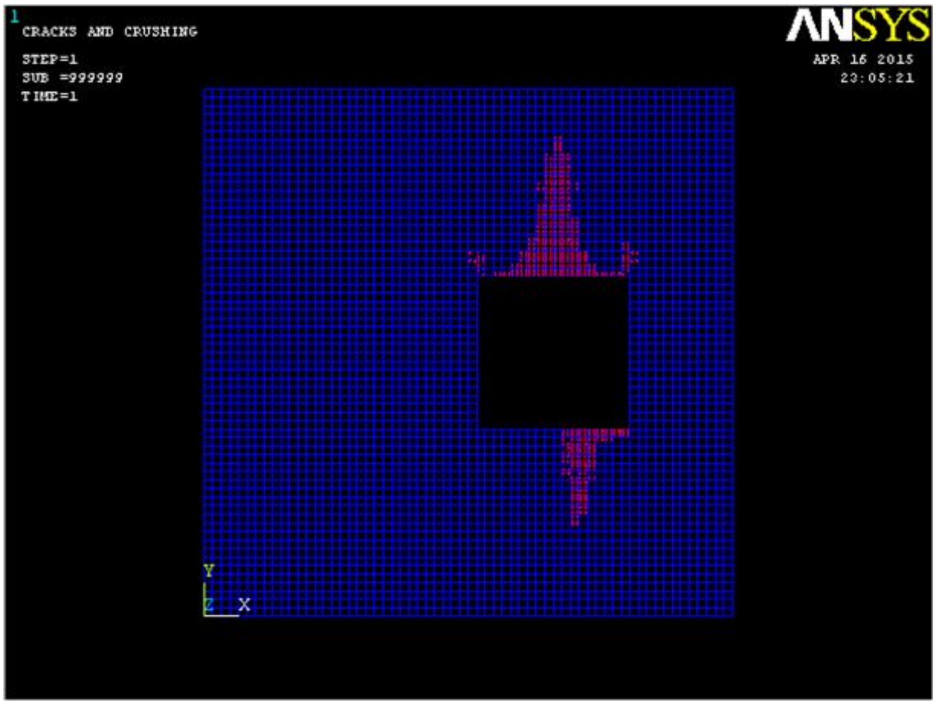


Figure 4.27: Cracking Pattern of SW6 under axial load

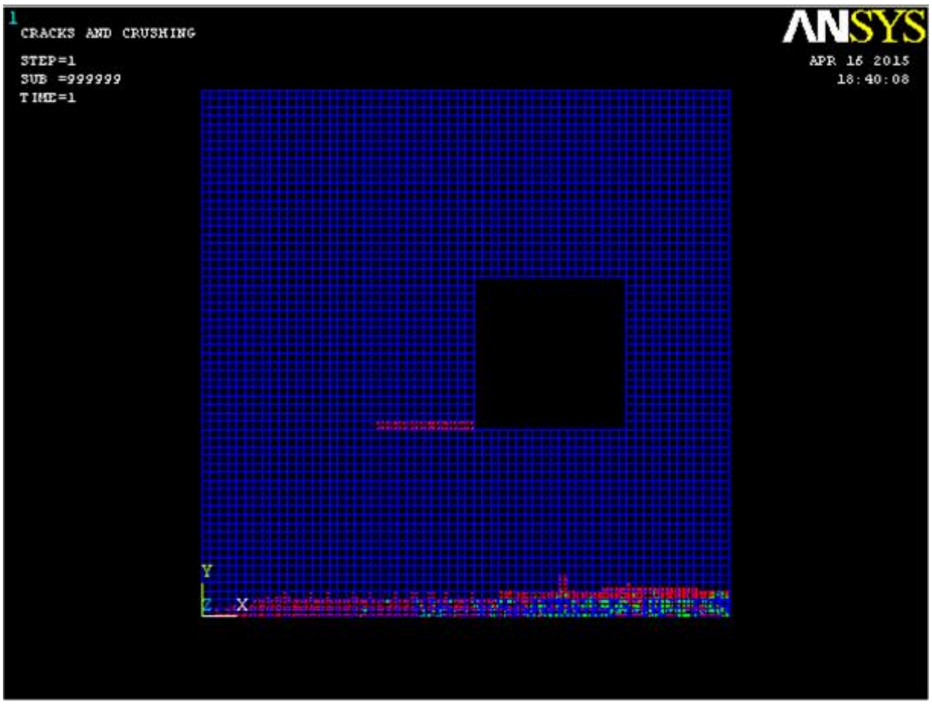


Figure 4.28: Cracking Pattern of SW6 under lateral load

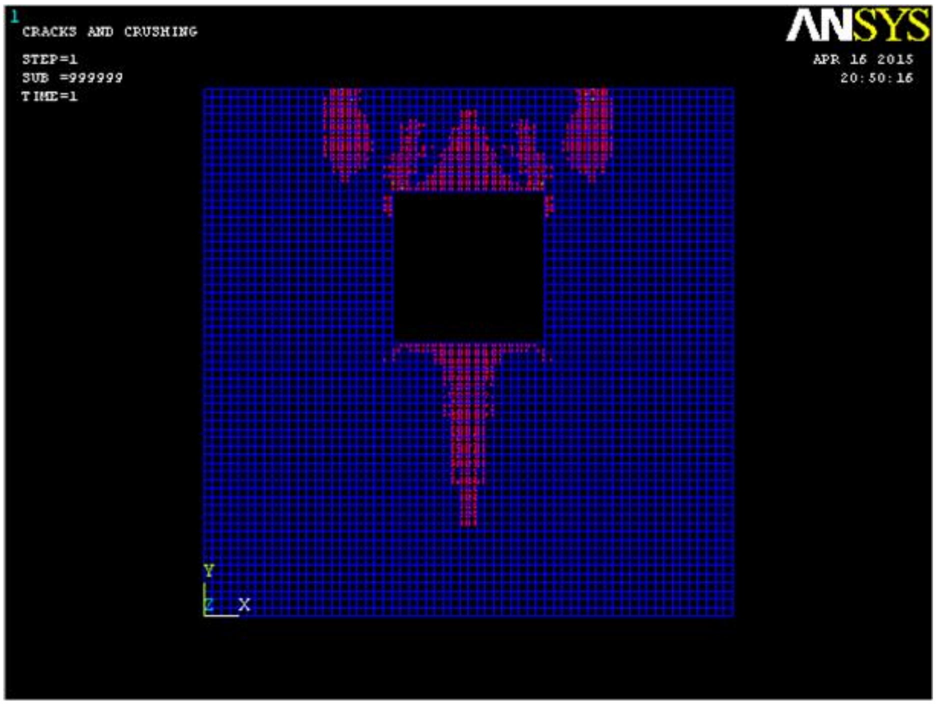


Figure 4.29: Cracking Pattern of SW7 under axial load

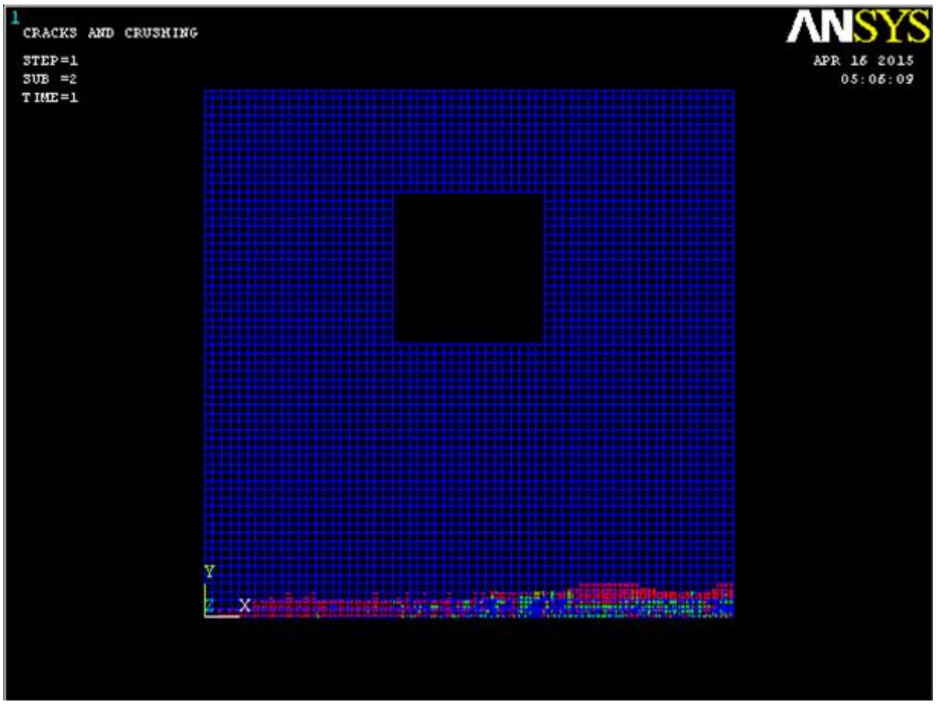


Figure 4.30: Cracking Pattern of SW7 under lateral load

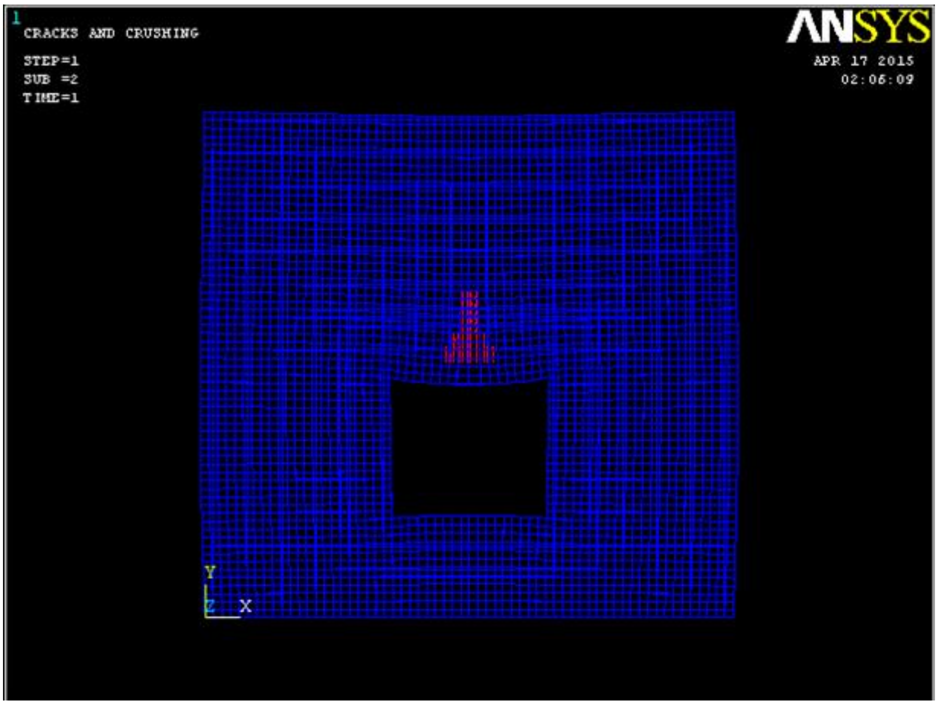


Figure 4.31: Cracking Pattern of SW8 under axial load

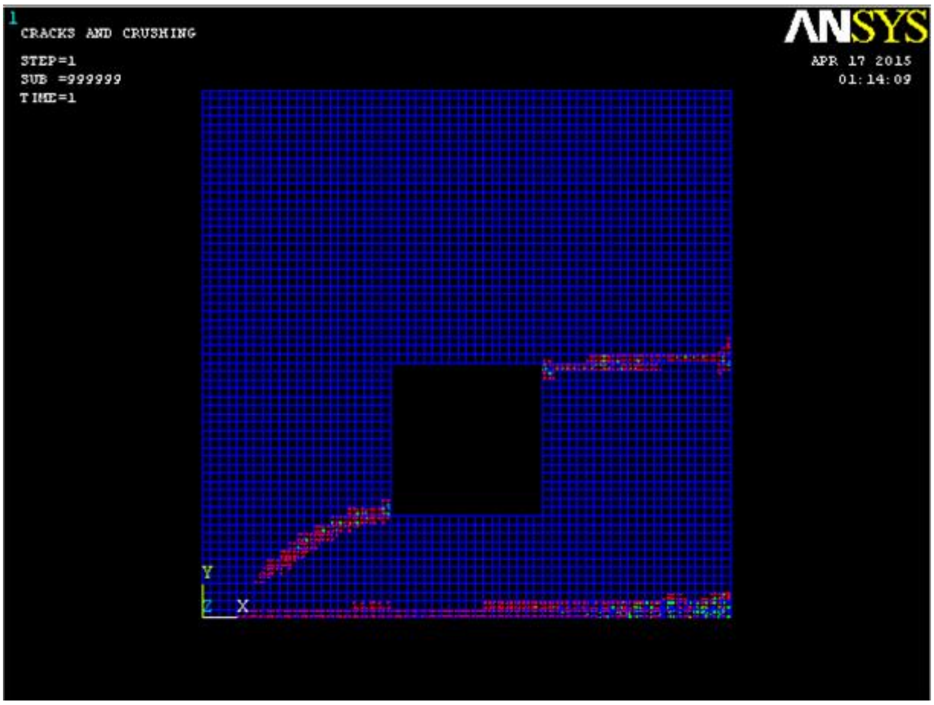


Figure 4.32: Cracking Pattern of SW8 under lateral load

CHAPTER 5

CONCLUSION AND RECOMMMENDATION

5.1 GENERAL

With the aids of ANSYS, the simulation of the concrete shear wall is analyzed. The analysis demonstrated that the shear behavior of the shear wall with different sizes and positions of the opening.

5.2 CONCLUSION

Based on the results and the discussion obtained, there are several conclusions can be drawn.

i. Load carrying capacity is lower under both lateral and axial load for shear wall with opening.
ii. The reduction in concrete area and the discontinuity of the reinforcement have created a significance effects towards the strength of the shear wall to restrain axial load.
iii. By using the appropriate opening size, the deflection and the cracking of the shear wall from the lateral load does not have much effect but it still has a critical size of opening.
iv. When the size of the opening exceeds a limit, there is a significance increase in deflection under the applied lateral load.
v. The further the position of the opening from the applied load, the more efficient the wall is.

vi. The best position of opening of shear wall is in the center as lateral load in real practice shall be not in only 1 direction.

5.3 RECOMMENDATION

The size and position of the opening under uniformly distributed static load is focused in this analysis. There are several of recommendation were made for further research with improvement.

i. The other types of loading such as cyclic load, seismic load or dynamic loads can be applied on the model to be compared with static load.
ii. The model can be rescaled, cast and test it in laboratory.
iii. Diagonal reinforcement is usually used in real practice, it should be added in the model to get a more accurate result
iv. The analysis can be done by using other software like LUSAS, STAAD PRO and so on.
v. CivilFEM in ANSYS 12.0 consists of some actual model with respective properties according to EC2, EC3, ACI and so on. The code checking and element structure can be checked whether it is critical if the model is created by using CivilFEM.

REFERENCE

Fanning, P. (2001), Nonlinear Models of Reinforced and Post-tensioned Concrete Beams, Electronic Journal of Structural Engineering, University College Dublin, Earlsfort Terrace, Dublin 2, Ireland, Sept.12.

Hidalgo, P., Ledezma, C., & Jordan, R. (2002). Seismic Behavior of Squat Reinforced Concrete Shear Walls. *Earthquake Spectra*, *18*(2), 287-308. doi:10.1193/1.1490353

Kachlakev D., Miller T., Yim S.,(2001) Finite Element Modeling of Reinforced Concrete Structures Strengthened with frp Laminates. Oregon Dept. of Transp., USA, Res. Group, Final Report SPR, 316, May 2001.

Lefas L. D., Kotsovos M. D. and Ambraseys N. N.(1990). Behavior of Reinforced Concrete Structural Walls: Strength, Deformation Characteristics, and Failure Mechanism. (1990). *ACI Structural Journal*, *87*(1). doi:10.14359/2911

Lin, C. Y. and Kuo, C. L. (1988). Behavior of shear wall with opening. *Proceeding of Ninth World Conference on Earthquake Engineering*, August 2-9, 1988, Tokyo-Kyoto, Japan (4), 535-540

Musmar, A. M. (2013). Analysis of shear wall with opening using solid65 element. *Jordan Journal of Civil Engineering*, 7(2), 164-173.

Rahman.A. (2012). Drift analysis due to earthquake load on tall structures. *J. Civ. Eng. Constr. Technol.*, *3*(5). doi:10.5897/jcect11.055

Raongjant W., Jing M., Finite Element Analysis on Lightweight Reinforced Concrete Shear Walls with Different Web Reinforcement. The Sixth Prince of Songkla Univ. Engng. Conf., Hat Yai, Thailand, May 8-9, 2008, 61-67.

Saberi, H., Saberi, V., Kheyroddin, A., & Firouzi, A. (2013). Numerical Evaluation of Symmetric Prism Method to Analyze the Splitting Forces Due to TBM Jack Loads. *Open Journal Of Safety Science And Technology*, *03*(03), 51-58. doi:10.4236/ojsst.2013.33006

Tavarez, F.A., (2001), Simulation of Behavior of Composite Grid Reinforced Concrete Beams Using Explicit Finite Element Methods, Master’s Thesis, University of Wisconsin-Madison, Madison, Wisconsin.

Todut, C., Dan, D., & Stoian, V. (2014). Theoritical and experimental study on precast reinforced concrete wall paneles subjected to shear force. Engineering Structures, 80, 323-338. Doi: 10.1016/j.engstruct.2014.09.019

Vecchio, F., & Chan, C. (1990). Reinforced Concrete Membrane Elements with Perforations.*Journal Of Structural Engineering*, *116*(9), 2344-2360. doi:10.1061/(asce)0733-9445(1990)116:9(2344)

Wolanski J.A.,(2004) Flexural Behavior of Reinforced and Prestressed Concrete Beams Using Finite Element Analysis. M. Sov. Diss., Marquette University, Milwaukee, Wisconsin, USA, 2004.