SIMULATION STUDY ON REINFORCED CONCRETE BEAM WITH VARIATION OF SHAPE AND SIZE OF OPENING

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Thesis submitted in fulfillment 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 2017

ACKNOWLEDGEMENTS

I would like to take this golden opportunity to thank my university, University Malaysia Pahang for providing me the good condition of facilities and equipment to complete this study.

I would also like to express my sincere appreciation to my supervisor, Mr. Mohd. Arif bin Sulaiman, who has been very patient and supportive in guiding and providing me helpful discussion and recommendation throughout the study. His consistent encouragement and motivation allowed me to perform my capabilities in this final year project. Besides, I also like to thanks Dr Cheng Hock Tian and Dr Gul Ahmed Jokhio for their guidance and knowledge sharing throughout the study.

In addition, I would like to appreciate my panel, Dr Chin Siew Choo and Mr Noram Irwan Bin Ramli for their comments and recommendations on my work to allow me to improve my research outcome and meet the objectives of this study.

Finally, I am also grateful to my parents for their love and encouragement all the way to the completion of my task in this final year project. Special thanks to my friends, Loo Kian Loon, Wong Chee Yean, Tan Woon Han, Tan Keen Hong and Kwan Hui Yee for sharing their precious knowledge and resources with me in completing this final year project.

ABSTRAK

Penyediaan pembukaan akan memberi kesan kepada kemuluran dan ketegaran rasuk RC kerana penumpuan tegasan sekitar pembukaan. Kesan peruntukan pembukaan di RC rasuk normal adalah besar kerana ketinggian yang terhad. Dalam kajian ini, 8 sampel segi empat tepat RC rasuk dengan bentuk dan saiz bukaan yang berbeza akan dianalisis menggunakan FEM. Satu rasuk pepejal (Beam S1) telah digunakan sebagai sampel kawalan, RC rasuk dengan pembukaan berbentuk empat segi (Beam S2), pembukaan bulat (Beam S3), pembukaan segi empat tepat (Beam S4) dan rasuk dengan dua pembukaan bulat (Beam S5). 3 sampel yang disediakan adalah berbeza daripada saiz bukaan iaitu, 60mm x 40mm, 100mm x 48mm dan 100mm x 80mm yang dinamakan Beam S6, S7 dan S8 masing-masing. FEM perisian yang digunakan untuk menjalankan analisis adalah ANSYS 12.0. Beban yang dikenakan kepada semua sampel adalah sama. Kesan pembukaan dengan pelbagai bentuk dan saiz telah dikaji dari segi pertengahan span pesongan dan retak corak. Daripada keputusan ujian, pembukaan bulat adalah bentuk yang terbaik kerana memberi kesan pertengahan span pesongan yang paling minumum bandingkan dengan geometri pembukaan lain. Hal ini demikian kerana sudut ortogon pembukaan segi empat tepat akan menyebabkan retak pekat di sudut dan mengakibatkan keretakan awal. Ketika pembukaan telah disediakan, ia menyebabkan penumpuan tegasan sekitar pembukaan. corak retak menjadi lebih serius dan jelas ketika saiz pembukaan bertambah.

ABSTRACT

Provision of opening will affect the ductility and rigidity of the RC beam due to stress concentration around the opening. The effect of provision of opening in normal RC beam was significance due to its limited height. In this study, 8 samples of rectangular RC beam with different shape and size of opening were analysed using FEM. One solid beam (Beam S1) was used as control sample, RC beam with square opening (Beam S2), circular opening (Beam S3), rectangular opening (Beam S4) and beam with two circular opening (Beam S5). Another 3 sample were different from size of opening with 60mm x 40mm, 100mm x 48mm and 100mm x 80mm which is Beam S6, Beam S7 and Beam S8 respectively. The FEM software used to run the analysis is ANSYS 12.0 software. All of the sample were tested under four-point loading. The load apply to all the sample were the same. The effect of opening with different shape and size were studied in term of mid-span deflection and crack pattern. From the test results, it can be concluded that, the circular opening is the best shape of opening as it give least mid-span deflection compare to other geometries of opening. Due to orthogonal corner of rectangular opening, crack concentrate at the corner causing early cracking to occur. When opening was provided, it cause stress concentration around the opening. Crack pattern become more serious and obvious when opening size increase.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 General

Beam is one of the core component inside a building where it transfer and carry the load from the top of building to the foundation and then into the ground. There are many way to construct a beam. In the past, beam were constructed solely by timber and until now a lot of modern engineering concrete mixed beam or steel beam were invented for the construction.

In the past, beam was constructed only for load bearing purposes. However, with the advance of technology and demand, beam not only function as a load bearing member. Instead, it was designed for the architectural purposes as well. In order to save headroom in buildings, and optimize the required storey height in buildings, beams were provided with openings in the web for the passage of service ducts

These openings may be of different shapes and sizes, however, circular openings were required to accommodate service pipes, such as for plumbing, while rectangular openings provide the passage for air conditioning ducts that are generally rectangular in shape. The presence of transverse openings will transform a simple beam behaviour into a more complex behaviour. The making of openings produces disturbances in the normal flow of stresses and therefore cause early cracking around the opening region. Hence, design and calculation was required before opening is make to avoid structural failure.

1.2 Problem Statement

Nowadays, there had been a lot of structure being constructed using the floor joints and bearers with web openings in residential, industrial and commercial building. However, a lot of research had been done regarding the effect of opening on the steel beam, precast beam and reinforced deep beam while very limited data have been reported on the effect of opening on the traditional rectangular reinforced concrete beam. Due to the fact that, normal rectangular RC beam had limited depth, the making of opening in these beams was very significant. Traditionally, transverse opening in reinforced concrete beams was a facility which allows the utility line like water supply piping, electrical, telephone and computer network to pass through the structure (Amiri & Masoudnia 2011). However, the making of opening produce uneven and discontinuously disturbance toward the stress distribution in beam and thus result in stress concentration and early cracking near the opening area (Mansur 2006). Strength of the reinforced concrete beam will be reduced, thus causing deformation and excessive deflection under service load and considerable distribution of forces and internal moments in a continuous beam. Special consideration regard to design of these beams is needed, however, current code of practice for design of concrete building structure do not provide provision for design of beams with opening (Javad & Morteza 2004).

1.3 Objective of Study

The main objectives of this study are as follow:

i. To determine the mid-span deflection of reinforced concrete beam with variation of shape and size of opening.

ii. To investigate the crack pattern of reinforced concrete beam with variation of shape and size of opening.

1.4 Scope of Study

In this study, the model of solid RC beam was adopted and modified from the previous study by (Rezwana Binte Hafiz et al., 2014). The dimension of the RC beam models was 150mm width x 300mm depth x 2000mm length. All the sample has the same reinforcement which is 2T12mm for top rebar and 2T12mm for bottom rebar. There were total of 8 reinforced concrete beams sample in this study, 1 solid beam without any opening as the controlling model, while the other 7 beams model with opening were analysed. The shape of opening include are circular, square, rectangular and double circular opening. The location of opening for all the beam sample was kept constant which a = 1000 mm and b=150mm, and the zone of opening is at the mid-span of the beam. For the variation of opening, the area of the opening are the same which was 14400 mm^2. However, for the variation of opening size, the opening area were 2400mm, 4800mm^2 and 8000mm^2 respectively. The sample of model were shown in Figure 1.1 and location of opening were shown in Figure 1.2. In this study, all the detail of the beams were show in Table 1.0.

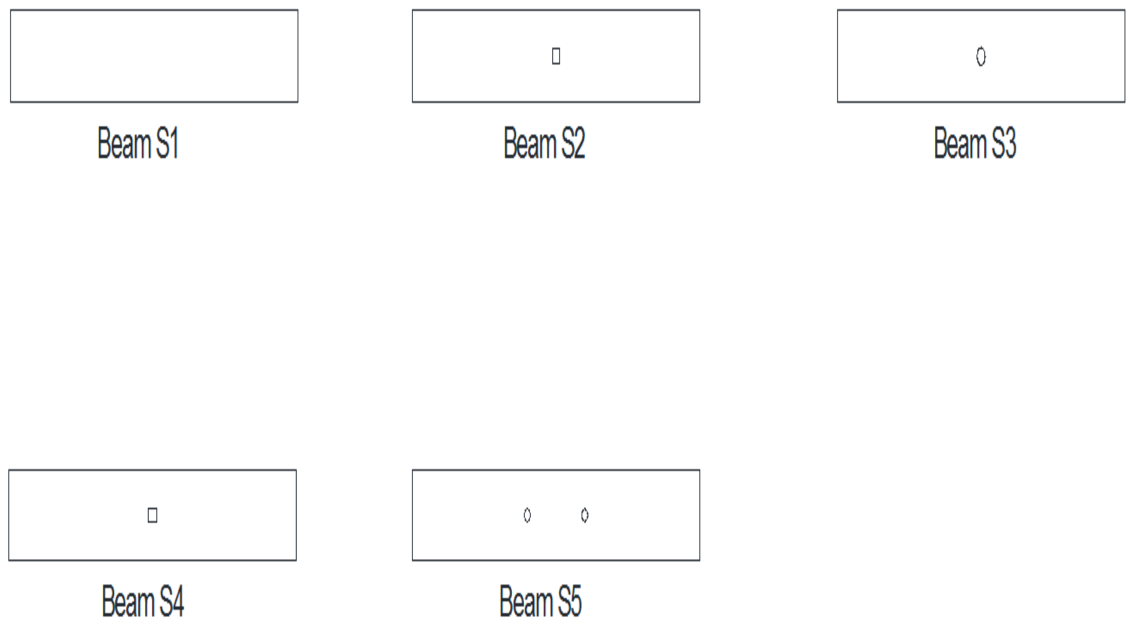

Figure 1.1 Sample of Beams

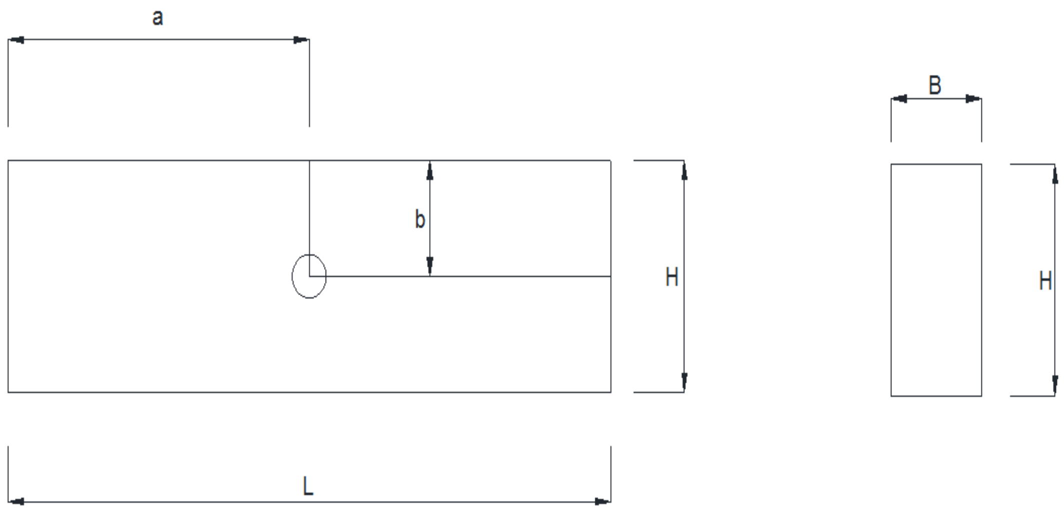

Figure 1.2 Location of the Opening on the Rectangular Beam

Table 1.1 Detail and Dimension of Sample Study

Beam	Type of Opening	Dimension of Beam	Size of opening (mm)	Area of Opening (mm^2)	Location of Opening (mm)	
					a	b
Beam S1	Solid	150x300	-	-	-	-
Beam S2	Square	150x300	120 x 120	14400	1000	150
Beam S3	Circle	150x300	135.4	14400	1000	150
Beam S4	Rectangular	150x300	180 x 80	14400	1000	150
Beam S5	Left Circle	150x300	95.75	7200	775	150
	Right Circle		95.75	7200	1225	
Beam S6	Rectangular	150x300	60 x 40	2400	1000	150
Beam S7	Rectangular	150x300	100 x 48	4800	1000	150
Beam S8	Rectangular	150x300	100 x 80	8000	1000	150

For the reinforcement of the rectangular beam, all sample were using the same reinforcement which is 2H12 for the main bar and secondary bar. Also, all the sample using the same links which is H6-150. The reinforcement bars configuration was shown in Figure 1.3 while Figure 1.4 and Figure 1.5 shown the section view of reinforcement in the sample.

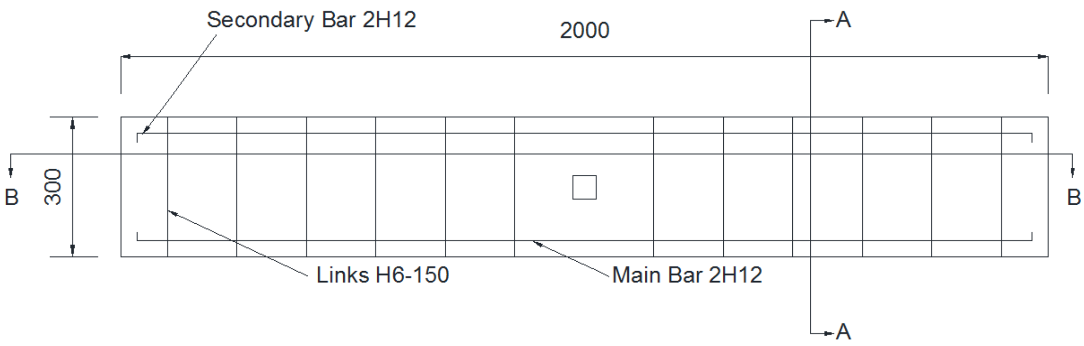

Figure 1.3 Reinforcement Detail of Rectangular Beam

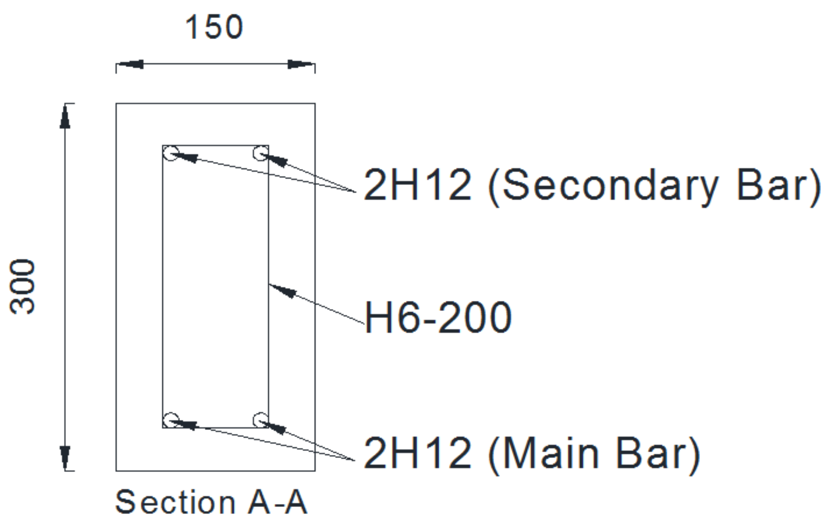

Figure 1.4 Reinforcement Cross Section View A-A

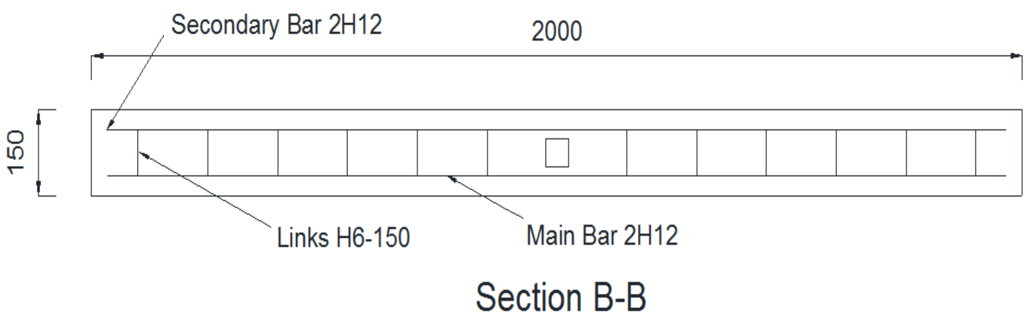

Figure 1.5 Reinforcement Cross Section View B-B

In this study, simulation and analysis of model was conducted by using a software called Civil FEM with ANSYS 12.0. To do the study on the flexure behaviour which is deflection and stress distribution of the reinforced concrete beam with opening, the 4 point bending test was conducted. The loading was put at the mid span of the reinforced concrete beam. There were 2 steel plate placed at the support. For the boundary condition of reinforced beam model, the displacement in the direction which is perpendicular to the plane equal to zero. For this study, both end was pinned supported.

The input data for material properties of the concrete and the reinforcement bars in ANSYS software were shown in the Table 1.2 and 1.3.

Table 1.2 Properties of Concrete Material

Material properties of concrete	
Elastic Modulus, E_c	30,000 MPa
Poisson's ratio, v	0.2
Open shear transfer coefficient	0.2
Closed shear transfer coefficient	0.8
Uniaxial cracking stress	3.5 MPa
Uniaxial crushing stress	40 MPa

Table 1.3 Properties of Reinforcement Bars

Material properties of reinforcement bars	
Elastic modulus, E_c	200,000MPa
Yield stress, f_y	450 MPa
Poisson's ratio, v	0.3

CHAPTER 2

LITERATURE REVIEW

2.1 General

Generally, a beam was a structural member which spans horizontally between supports and carries loads which act at right angles to the length of the beam. A beam was subjected to two sets of external forces and two types of internal forces. The external loads are the loads applied to the beam and reactions to the loads from the supports. The two types of internal force are bending moments and shear forces. Even though several attempts had been made to evaluate the ultimate strength of beams, there were still limitations and uncertainties on the understanding of the behaviour and the failure mechanism of reinforced concrete beam with opening.

2.2 Classification of Opening

According to Mansur, (1998), there were various way of defining the opening into large or small opening. This paper mention a research done by Somes and Corley, (1974), a circular opening may be considered large opening when its diameter exceed quarter of the beam depth. Also there are author classify the opening based on the structural response of beam. When the beam was maintain as beam-type behaviour, the opening is considered small opening. The opening is considered large opening if the beam-type behaviour ceases due to provision of opening.

2.3 Effect of Creating Opening in Existing Beam

Creating opening on beam will create unexpected alterations which cause the opening corners to subject to high stress concentration which will then lead to early cracking. The beam reduced in stiffness and may give rise to excessive deflection. According to Mansur, (2006), creating an opening near the support region may seriously impair the safety and serviceability of structure. Also, it is found that the filling of the opening with non-shrink grout is not adequate to restore the original strength and stiffness of the structure. However, the risk can be minimized by limiting the size of opening or making the opening without cutting or removing any stirrups.

In the study from Nilesh & Patel, (2013), a total of 5 beam with changes of diameter and position of opening were being experiment. One of the aim of study was to evaluate the load carrying capacity and deflections of the beams with variation of the opening. From the result they get, it is observed that when the diameter of the opening increase, it cause the reduction of ultimate strength in the beam.

According to research by Amiri & Masoudnia, (2011), nine simply supported reinforced concrete rectangular section beams was studied using a three dimensional nonlinear finite element method using ANSYS software. The effect of opening size with circular size was investigate. Each of the circular opening was different in term of diameter. The samples were loaded monotonically with 2 incremental concentrated loads. The load-deflection behaviour of the sample was studied and compared with solid beam. The result they get was that the performance of the beams with circular opening with diameter less than 0.48D has no effect on the ultimate load capacity. However, if the diameter more than 0.48D, the load capacity of the RC beam decrease by at least 26%.

2.4 Beam with Small Opening

According to Mansur, (2006), it may be considered as small openings if the depth or diameter of the opening is less than 40% of the overall beam depth regardless the shape is circular, square or nearly square in shape. Beam action may be assumed to prevail in such a case. Hence, the analysis and design of the beam with small openings may follow the similar course of action as that of solid beam.

2.5 Beam with Large Rectangular Opening

Similar to a beam with small openings, incorporation of a large opening in the pure bending zone of a beam will not affect its moment capacity provided that the depth of the compression chord is greater than or equal to the depth of ultimate compressive stress block, and that instability failure of the compression chord is prevented by limiting the length of the opening Mansur and Tan, (1999).

2.6 Effect on Shape of the Opening

According to research done by Al-sheikh, (2014), a total of 27 RC beam specimens were tested to failure under 4 point test. From the result, it is showed that the circular opening only caused an average reduction in ultimate load about (1%), while square opening caused average reduction about (19%) and rectangular opening caused and 23% reduction.

When comparing between circular and square opening of same area, square opening caused 8% more reduction in ultimate strength of reinforce beam than circular opening. The reason behind is that square opening exist orthogonal corners which will cause more stress concentration at these corners. The sudden change in dimension at the cross section cause high stress concentration and lead to undesirable cracks. When comparing square opening and rectangular opening of the same height, it is observed that rectangular opening caused about 3-4% more reduction in ultimate strength of reinforce beam than square opening. This is because the shear stresses developed in the top and bottom chords at rectangular opening, which the beam act more like a frame.

In the study by Amiri & Masoudnia, (2011), few simply supported RC beam was modelled using ANSYS software. The strength of beam with circular opening and square opening were studied and compared. From the result they get, it was concluded that, RC beam with circular opening has more strength than equivalent square opening. In another word, circular opening is better than square opening.

2.7 Effect on Size of the Opening

From the research carried out by Al-sheikh, (2014), the author compare sizing of opening for circular and square opening. It is found that, there is a slight difference between beams with opening and solid beam (without opening). Changes occur when opening size increase more than 0.4H which the ultimate load decrease significantly. Hence, author consider the opening is small when opening size less than 0.4H.Besides, author also compare square opening of sizes 40, 80 and 140 mm. It is found that when increasing the size of opening, the ultimate load bearing of the beam decrease.

2.8 Failure Mode on Beam

According to paper by Mansur, (2006), there are two type of failure mode on beam which mention as below:

2.8.1 Beam-Type Failure

This is a type of failure plane which cross the centre of the opening and it is a failure plane which inclined at 45^{o}. It may be seen that, the stirrups available to resist shear across the failure plane are those by the sides of the opening. Figure show the illusion of Beam type failure.

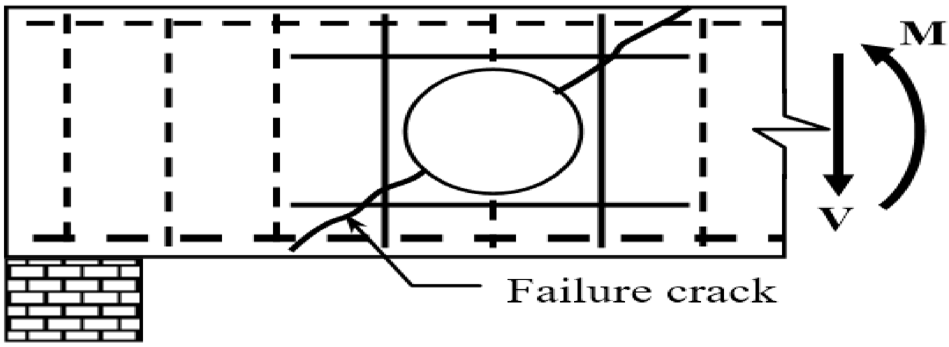

Figure 2.1 Beam-type Failure
Source: Mansur, (2006)

2.8.2 Frame-Type Failure

This type of failure occurs due to the formation of two independent diagonal cracks, one on each of the chord members below and above the opening. It appears that each member behave individually similar to the member in a framed structure. It is illustrate as shown in figure.

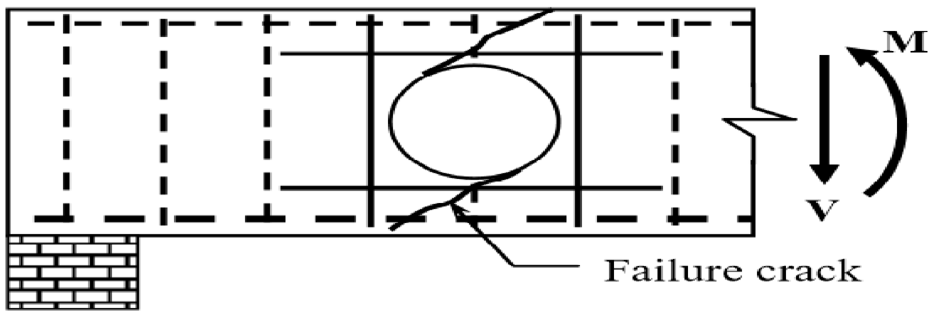

Figure 2.2 Frame-type Failure
Source: Mansur, (2006)

One of the experiment conducted by Nilesh & Patel, (2013) concluded that the increase of the diameter of opening in beams with opening cause the change in type of failure from flexural failure to frame type or beam type shear failure.

2.9 Crack Behaviour

In the research done by Mansur et al., (1983), it was found that , the cracking torque decreased with an increase in opening length. The cracks appear at top cross member at first and these crack were inclined at an angle of about 45^{o} to the beam axis. As the torque was increased, the cracks at the corners of the opening propagated upward in a diagonal direction into solid section of beam. The crack on the inside horizontal faces of the cross-member occurred at a later stage of loading. This was due to the fact that the shear stresses due to torsion and transverse shear acted in opposite direction on these faces.

In the study of Nilesh & Patel, (2013), 5 beam with variation of size and location of opening were experiment. One of the aim of the study was to observe the crack pattern of the beam. From the result they get, the crack pattern of the solid beam tell that the failure of the beam is due to flexure cracks and not by the shear. However, when the crack pattern for the beam with openings were studied , it is known that , the failure of the beams were due to the shear crack passing through opening region and the shear crack was developed at the low load level. It is concluded that, beam with opening are failed due to shear cracks passing through opening. From their study it was also concluded that the increase of the diameter of opening in beams with opening can cause the change in the pattern of cracks.

According to research from Allam, (2005), nine reinforced concrete beam were experimental study in order to investigate the efficiency of external strengthening of beam with opening within their shear zones. From his research, it can be concluded that the inclusion of opening in a reinforced concrete beam within shear zone will tremendously decrease its ultimate strength performance and stiffness. Other than that, due to stress concentration, various cracks are formed around the opening corners and diagonal cracks are formed along its upper and lower chords due to the lack of shear resistance.

In the study from Anesta, (2010), she modelled a double reinforced concrete beam with circular opening in the mid span by using ANSYS software. One of the objectives of her study was to analyse cracked reinforced beam with ANSYS. The conclusion that made from the result was that , in the early stages of loading, before the beam cracks, the presence of the opening cause a stress concentration at the top and bottom of the hole. The cracks form at the bottom of the opening was due to the stress concentration.

From the research of Yang et al., (2006), 32 reinforced concrete deep beam with or without opening were tested under two-point loading. The aim of the study is to investigate the influence of web opening in reinforced concrete deep beams. It was found that, after the first appearance of diagonal cracks, the deflection at mid-span increased. It was also observed that the reduction of the rigidity of reinforced concrete beam is closely related to the occurrence of inclined crack. The first diagonal cracks occurred near the bottom and top corners of openings. It was found that crack pattern was depend on opening size and these crack gradually developed toward the load points and supports. The strength at initial diagonal crack decreased because the tensile stress is highly concentrated at corner of the opening when the width and depth of the opening increase Yang et al., (2006).

According to Amiri et al., (2011), the behaviour of both reinforced concrete beams with rectangular and circular openings was investigated. He mentioned that, the introduction of an opening in the web of a beam causes early diagonal cracking and the load at first crack reduced with an increase of either length or depth of the opening. Unless additional reinforcement was provided to restrict the growth of cracks, the corners of the opening have tendency to show wide cracking.

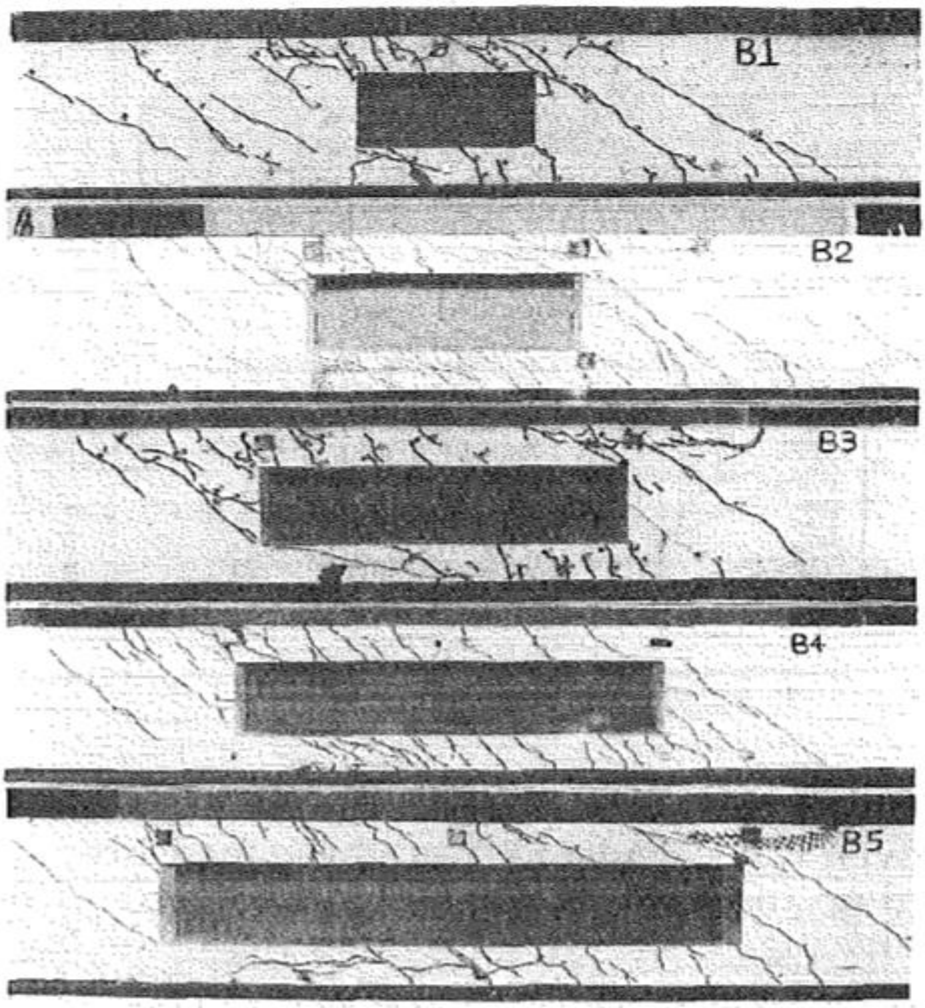

Figure 2.3 Experiment Sample after Failure
Source: Mansur et al., (1983)

2.10 Load-Deflection Behaviour

According to the finding from Torunbalci, (2002), the load-deflection behaviour of the beam is closely related to the location of the web openings. The openings close to the section under a single load will get larger deflection. Maximum deflection occur in the middle of the beam for all opening condition. The effect of opening eccentricity on deflections is less important than the effect of opening length. To add on, the deflection of beams containing large openings having the same area are smaller than those of beams containing a few small openings.

In the study of Suresh & Prabhavathy, (2014), 14 sample of RC beam was experimental studied and the load-deflection of the beam was discussed. From their study it was found that the beam with opening in the shear zone show reduces in load carrying capacity as well as deflection. The deflection is less for beam with opening compared to solid beam which is due to immediate formation of wide cracks around the opening in addition to flexural cracks that propagated that the beam mid span.

From the study of Yang et al., (2006), 32 reinforced concrete deep beam were experimentally and analytically study in order to estimate the influence of web openings in reinforced concrete deep beam. Such conclusion has been drawn, the mid span deflection at initial loading stages is not affected by the width and depth of opening, but it tremendously affect the deflection after the occurrence of diagonal crack.

2.11 Finite Element Analysis

Finite Element Analysis (FEA) is a computerized method of predicting how a component reacts to real world forces. It is a numerical method for solving problem of engineering and mathematical physics. It is very powerful even a very complicated stress problem can be solved by numerical solutions through FEA. Lately, the number of people using FEA to solved 2-D problem have been significantly increase. More and more researcher been using the FEA method in doing their research. The using of FEA somehow become a trend as it bring a lot of advantages. FEA can save a lot of times as it can solved very complicated problem in very short time. In doing research, it also help to save a lot of money in term of material cost. There are a lot of FEA software which available on the market for example ANSYS, LUSAS, ABAQUS, ADINA, SAP and ATENA. In this study, ANSYS was chosen to do the analysis. According to Hawileh , (2012), it is proved that the FEA are valid and capable of capturing the response of the RCC beams and could be used as a tool to predict the influence of several parameters that were not experimentally tested.

2.12 ANSYS Software Simulation and Modelling

ANSYS is one of the advanced software which can be used to do simulation and modelling in civil engineering. It is not only applicable in structural modelling, it can also use to simulate bridge for bridge engineering design. With the availability of code checking, it actually make engineers easier to check for the defect in design. In this study, ANSYS version 12.0 is used to do analysis on the reinforced concrete beam with opening.

2.12.1 Material Modelling of ANSYS

In ANSYS software, it is very crucial to make sure the correction selection of element types for the analysis as this will directly contributes to the accuracy and effectiveness of the result obtained. In this analysis, there are 3 element being used which is ‘’SOLID 65’’, ‘’LINK 180’’, and ’’ SOLID 185’’.

2.12.2 Reinforce Concrete in ANSYS

The solid element (Solid 65) in ANSYS has eight nodes with 3 degrees of freedom at each node and translations in the nodal x, y and z directions. It is used for the 3-D modelling of solids with or without reinforcing bars (rebar). The element has the capabilities of cracking in three orthogonal directions, deformation and crushing (Alsaeq 2013). The figure 3.x show the geometry and node location for Solid 65. This element is suitable for modelling the nonlinear behaviour of the concrete and the filling materials due to its capability in cracking in tension (in three orthogonal directions) and crushing in compression. It is not easy to accurately establish the material property of concrete in ANSYS especially it is required to input the data for stress-strain relationship for concrete. Concrete has the crack and crush possibilities and it will behave differently when it is in tension and compression condition. Other parameter that required to input when performing finite element analysis is the shear transfer coefficient. These coefficients are range from 0 to 1.0. 0 coefficient mean that it is a smooth crack (complete loss of shear transfer) and 1.0 representing a rough crack (no loss of shear transfer) (Alsaeq 2013). In this study, the parameter of modelling concrete is adopted from Izzet & Dakel, (2016).

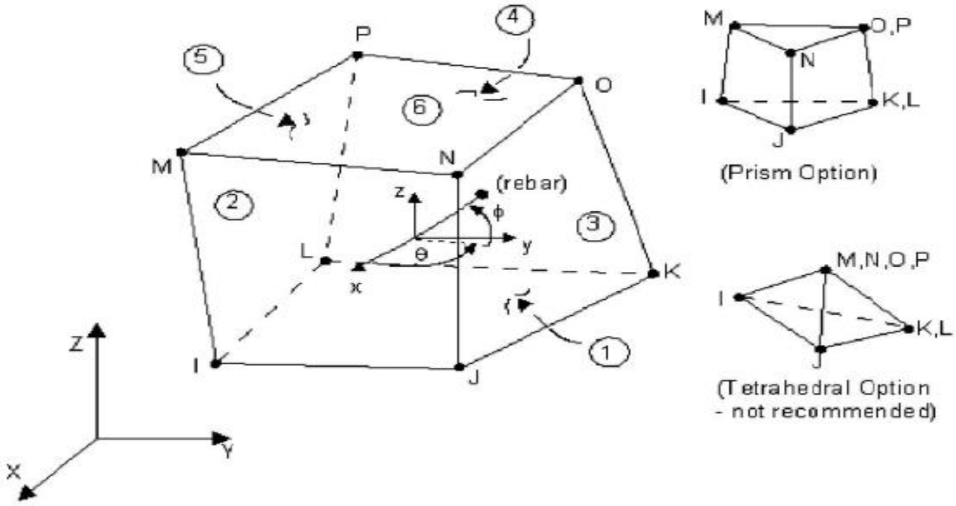

Figure 2.4 Geometry of Solid 65
Source: Eldeeb et al., (2016)

2.13 Steel Plate in ANSYS

In order to model the steel plate in ANSYS, Solid 185 is being used. The Solid 185 is defined by element with eight nodes having 3 degrees of freedom at each node, which the translation in the nodal x, y and z direction. The steel plate will be added at the support locations in order to avoid concentration of stress and to prevent localized crushing of concrete elements near the supporting points and load application locations. Besides, steel plate is added to distribute the stress more evenly over the support area. The figure below show the geometry of Solid 185.

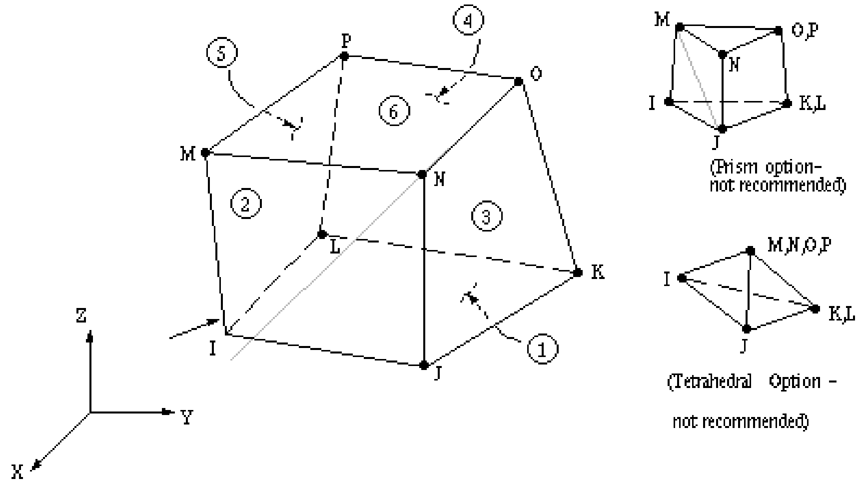

Figure 2.5 Geometry of Solid 185

Source: Eldeeb et al., (2016)

2.12.4 Reinforcement Bar in ANSYS

LINK 180 is a 3-D spar that is very useful in engineering application. This element can be used to model a lot of thing for example: trusses, sagging cables, links, springs and so on. The element is a uniaxial tension-compression element with three degrees freedom at each node which translate in x, y, and z directions. Plasticity, creep, swelling, stress stiffening, and large deflection capabilities are included. In this study, LINK 180 is used to model the reinforcement bar in concrete. When the node of rebar aligned with node of concrete, the rebar will bonded perfectly with the concrete. Figure show the geometry of LINK 180.

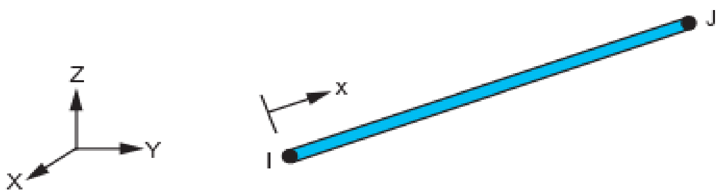

Figure 2.6 Geometry of Link 180

Source: Eldeeb et al., (2016)

2.12.5 Non-Linear Analysis

In non-linear analysis, the total load applied to a finite element model is separated into a series of load increments called load step. Upon the completion of each incremental solution, the stiffness matrix of the model is adjusted to reflect nonlinear changes in structural stiffness before proceeding to the next load increment. Newton-Raphson equilibrium iterations is being adopted in the ANSYS programme for updating the model stiffness. Newton-Raphson equilibrium gives convergence at the end of each load increment within tolerance limits. In this study, for the reinforced concrete solid elements, convergence criteria were based on force and displacement, and the convergence tolerance limits were initially selected by the ANSYS program.

CHAPTER 3

METHODOLOGY

3.1 General

In this study, ANSYS software was used. ANSYS software was widely used in the industrial for design work nowadays. There are 3 main process for the analysis, which were preprocessor, solution and general postprocessor. These process including modelling, analysis and generate result data.

Preprocessor was the process of modelling. In this stage, the element and materials properties were set. Every element had their own element and material properties. For this study, the element being used were ‘’SOLID 65’’, ‘’LINK 180’’ and ‘’SOLID 185’’. These element were used for modelling of concrete, reinforcement bar and steel plate.

Solution stage is a stage where analysis was being conducted. Before the analysis start, there were few parameter that needed to be set. First, the boundary condition for the RC beam needed to be set. Next, the loading was another parameter needed to be added before analysis start. In this study, the loading was being keep constant throughout different model. The manipulating factor for this study will be the shape and size of the opening.

The next stage was general postprocessor after the analysis stage was being conducted. At this stage, all the data was collected for discussion. In this study, there were two results being considered which were the deflection and the crack pattern of the model. ANSYS is a very powerful software where the deflection can be obtained from list of data, while crack pattern can be obtained from the ‘’concrete plot’’.

3.2 Flow Chart of the Methodology

The Figure 3.1 show the flow chart of methodology of this research.

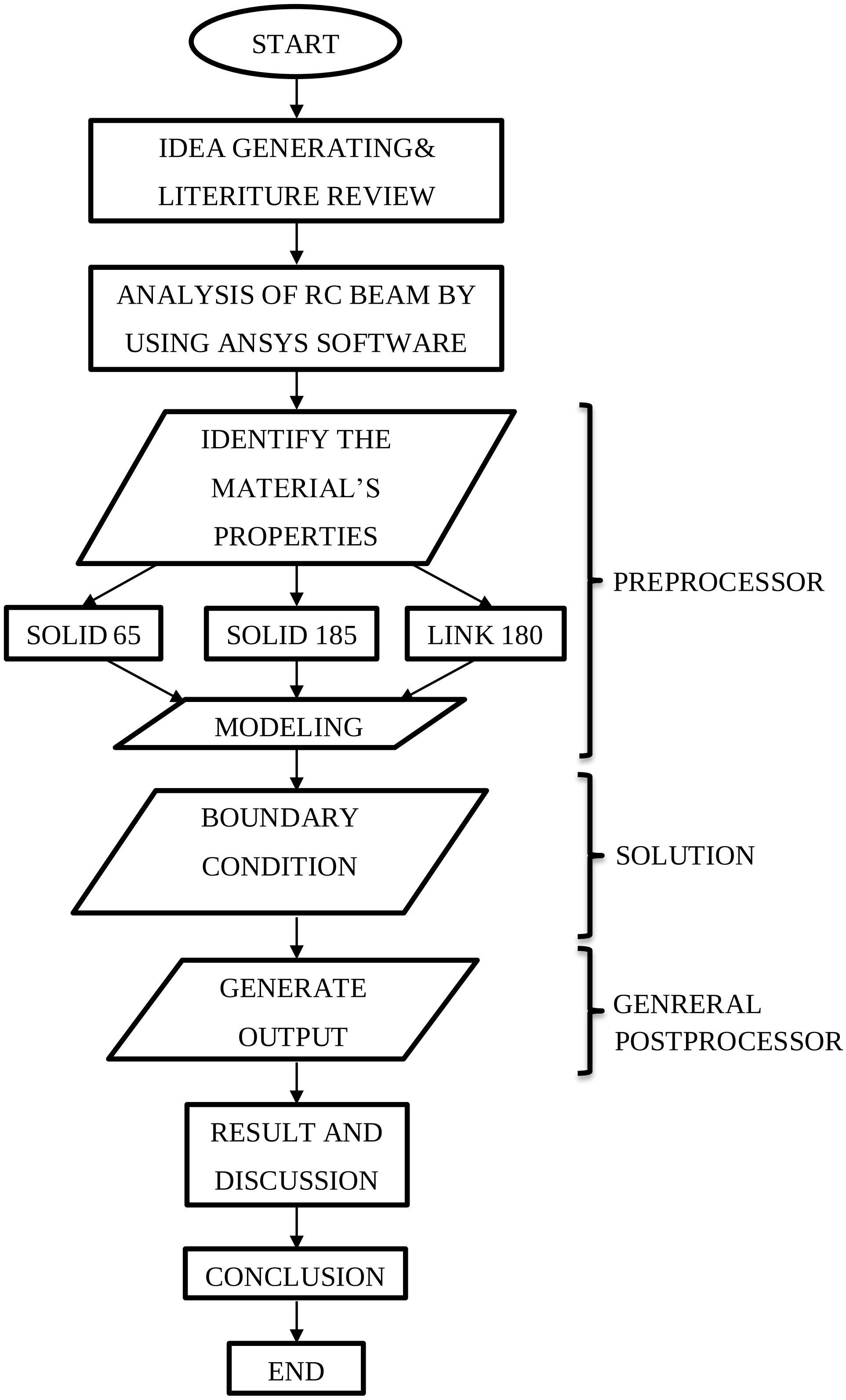

Figure 3.1 Flow Chart of Methodology of this Research

3.3 Pre-processor

Pre-processor stage is a stage where the model was being created. The first thing to do in creating the model was defined the elements and materials properties. Figure 3.2 showed the table for defining the element types.

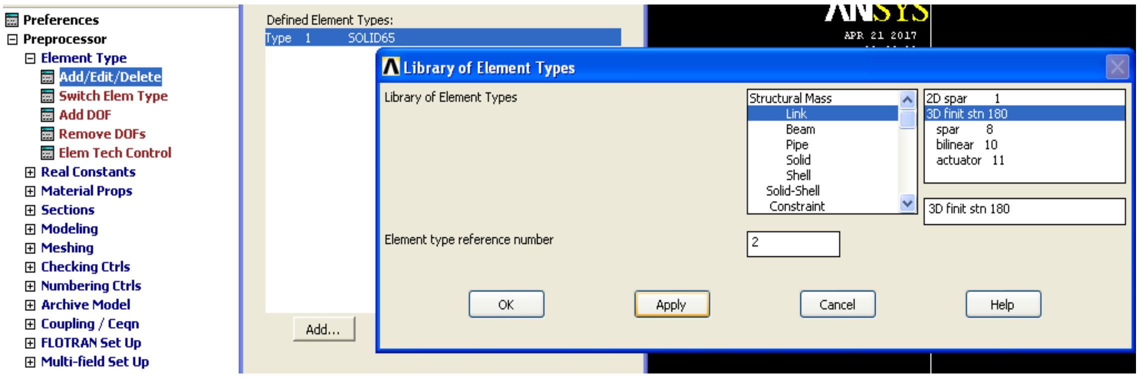

Figure 3.2 Table of Define Element Types

The Element Type in the Main Menu of ANSYS software was used to define the element type to be used for the element of the model. In ANSYS, there are more than 100 types of elements in the library. In this study, the elements used were, ''SOLID 65'', ''LINK 180'' and ''SOLID 185''. The ''SOLID 65'' was used to define the concrete element, ''LINK 180'' was used to define the reinforced steel bar and ''SOLID 185'' was used to define the steel plate which attached at the top and bottom of reinforced concrete.

The real constant tool in ANSYS was used to define the property of the element. In the real constant setting, for example, the area of reinforcement steel bars were set. Figure 3.3-3.5 showed how the cross sectional area of '' Link 180'' was set. In this analysis, the steel reinforcement bar sizes used were 12mm which was used for main bar and secondary bar while size 6mm was used for link of the reinforcement beam.

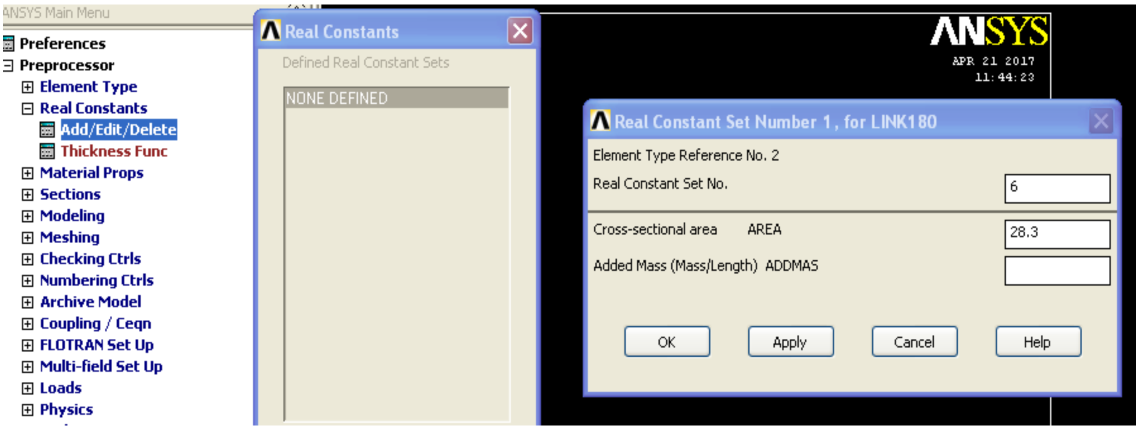

Figure 3.3 Real Constant For Reinforcement Steel Bar 6mm

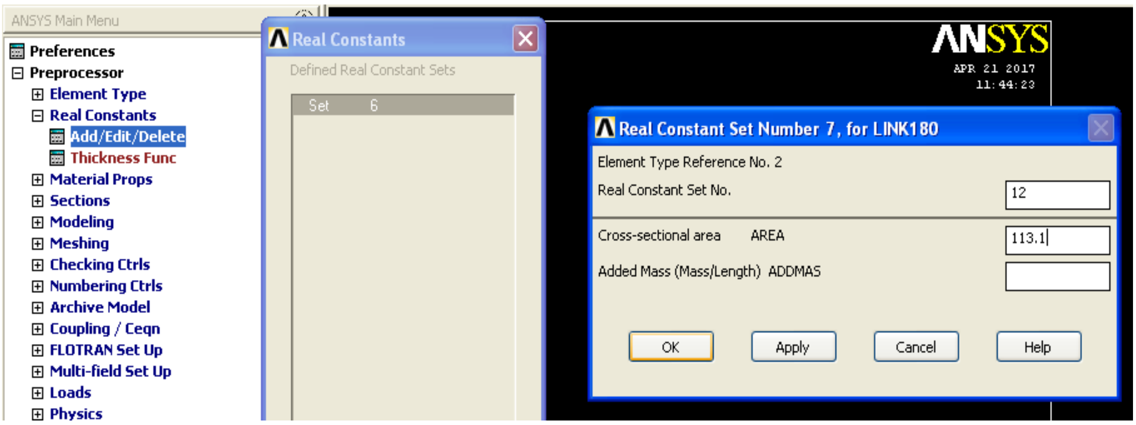

Figure 3.4 Real Constant For Reinforcement Steel Bar 12mm

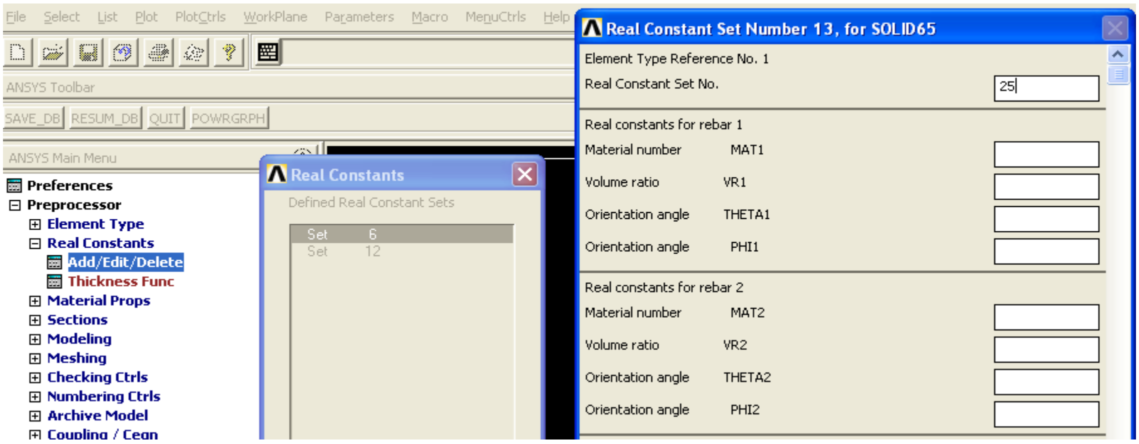

Figure 3.5 Real Constant For Concrete

For setting the material property, it was showed in the Figured 3.6. All the material properties were set first before the model were created. Different element have different property, in this analysis, we contain 3 element which is concrete, reinforcement steel bar and steel plate. All the properties were set in such a way they can run for non-linear analysis.

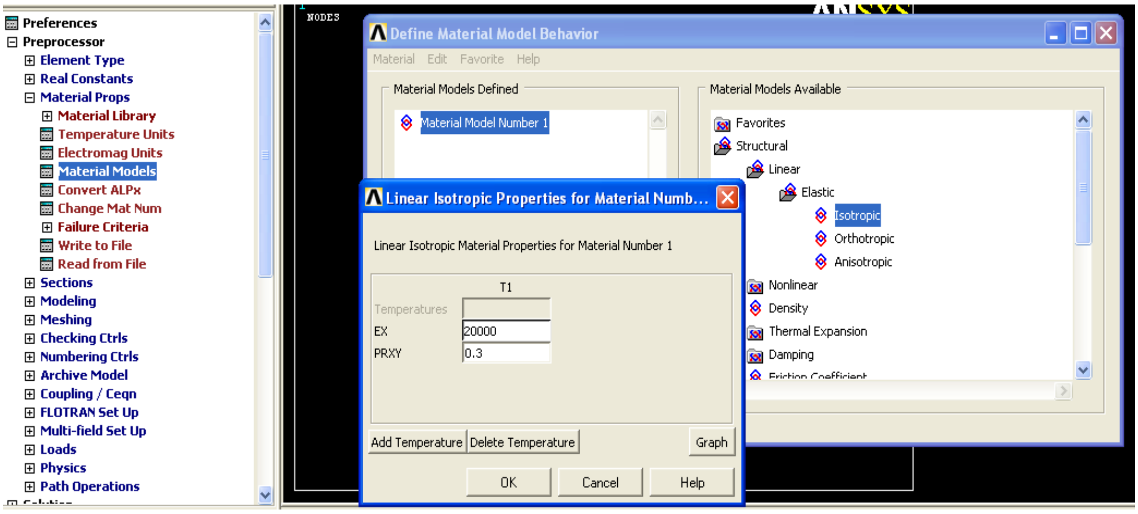

Figure 3.6 Table where Material Properties were Set

In Figure 3.7 and Figure 3.8, the way on how to create the block and cylinder solid were showed. The block created in this analysis was 2000mm x 300mm x 150mm. The dimension of two steel plates at top were 100mmx20mmx150mm while the dimension of steel plates at bottom were 100mmx25mmx150mm. A cylinder solid was created in the middle of the block in order for creating a circular opening.

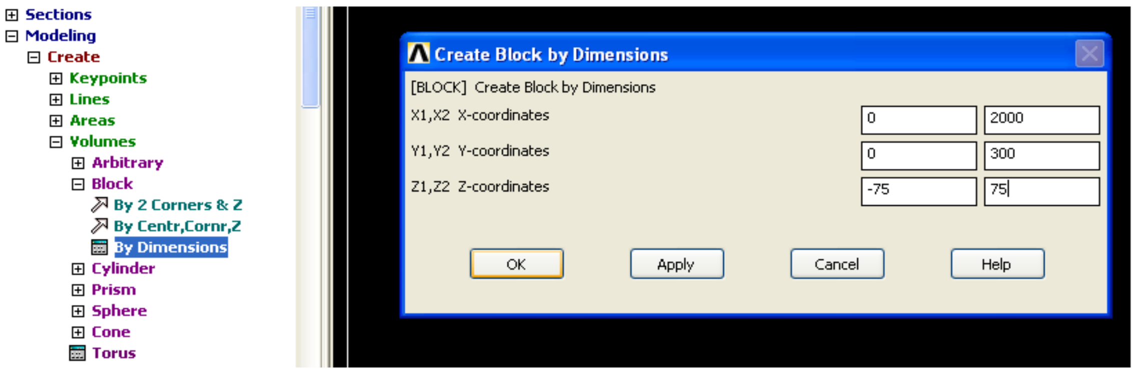

Figure 3.7 Table of Create Block By Dimension

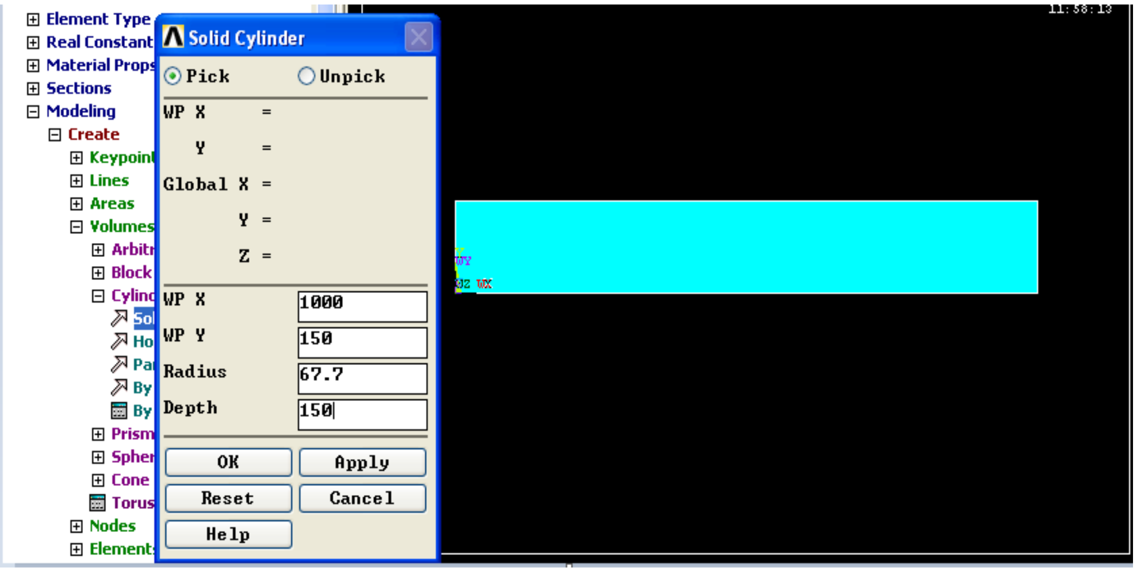

Figure 3.8 Table of Cylinder Solid Created by Dimension

Figure 3.9 showed the step of creating circular opening on the block. By using the ''Subtract'' option in ''Booleans'', the opening was created. In order to create the opening, the whole block was selected first followed by selecting the solid cylinder.

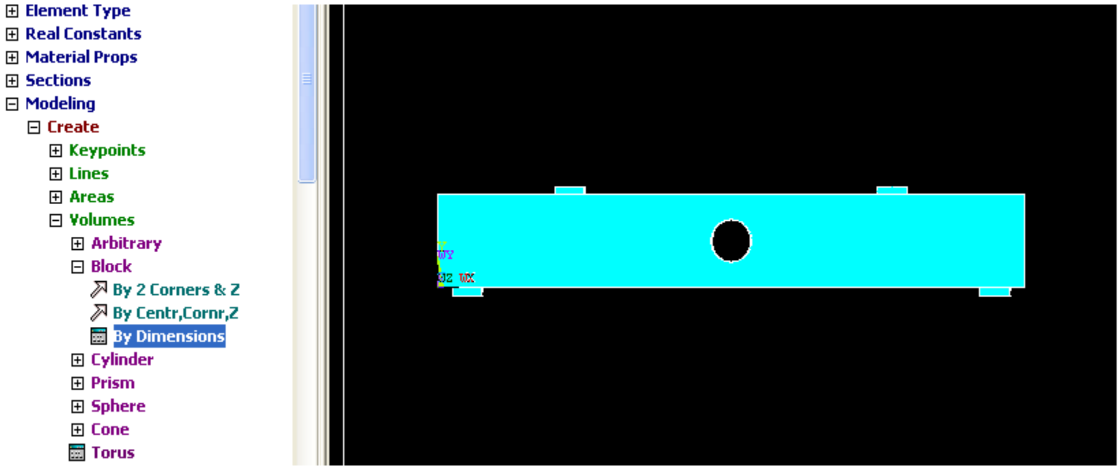

Figure 3.9 A Circular Opening was Created in the Middle of the Block

There are many way of locating the reinforced steel bar and define them in component manager. In this analysis, the ‘’define lines as elements’’ method was used. Figured 3.10 showed how Copy Area was done. In order to use this method, the lines were all created by copy areas. The offset of the copied areas were according to the location of the reinforced steel bar of the model.

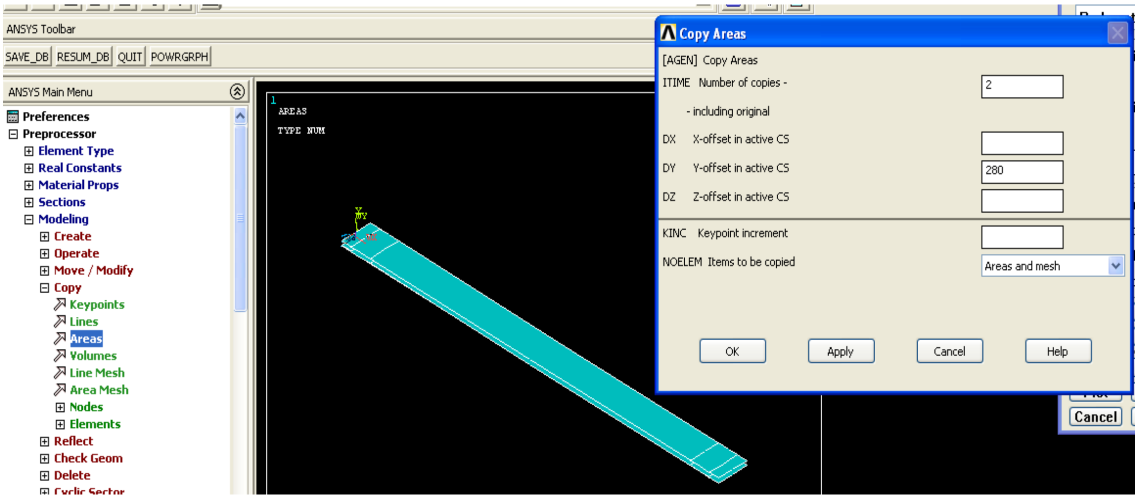

Figure 3.10 Table of Creating Line by Copy Areas

When all the location of link and steel bars were located, the whole model was undergo a process called ‘’ Divide Volume by area’’. The purpose of doing this process is to create coincide node when all the element was merged. Figure 3.11 and Figure 3.12 show a model which was undergo volume divide by areas.

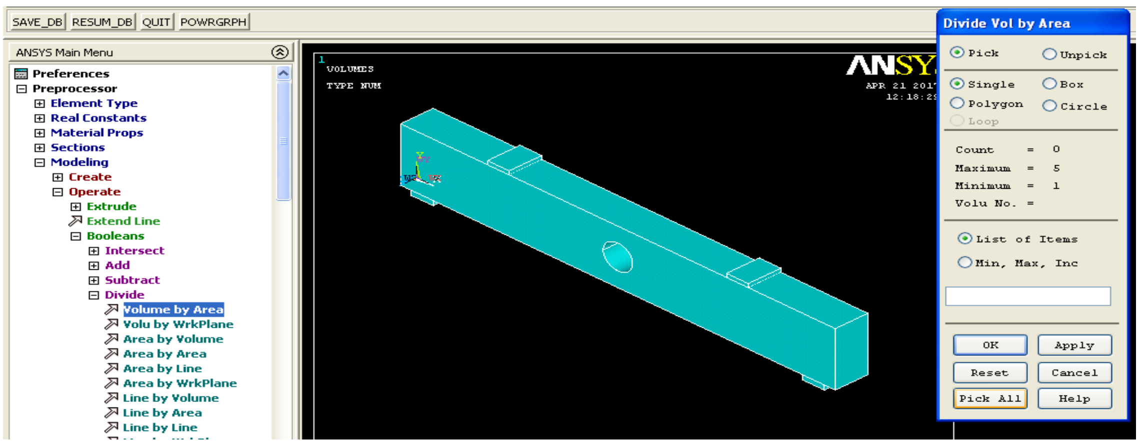

Figure 3.11 Table of Divide Volume by Area

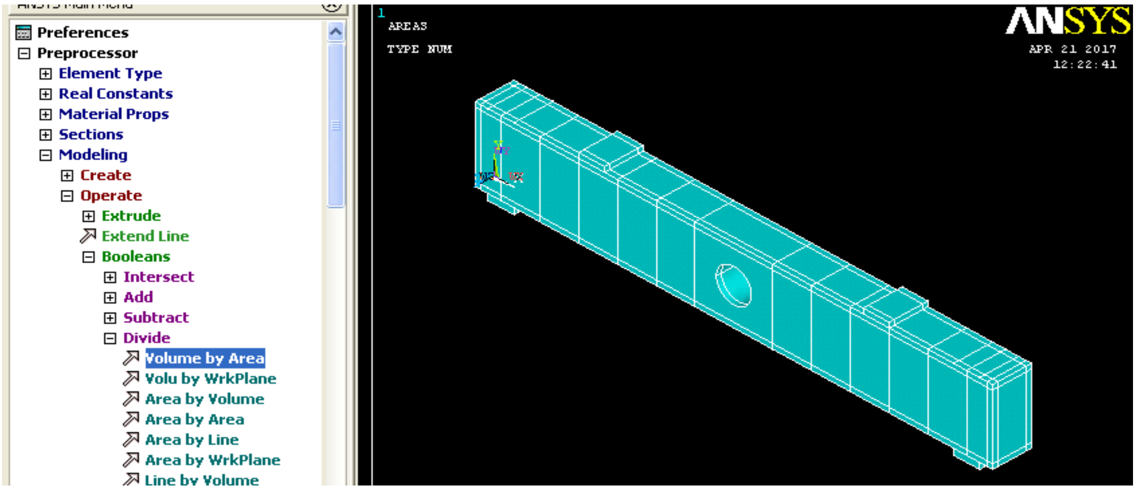

Figure 3.12 Model after Divide Volume by Areas

After the copy area and divide volume by area step, all the numbering of the elements, nodes, lines, volumes and other entities that were created are coincident. Hence, all of these entities had to be merged. Figure 3.13 showed the step where all the coincident were merged. At the preprocessor menu, ‘’merge item’’ was selected, and all the separated entities at the same location were merged together into one single entity where all the nodes with higher numbering were removed.

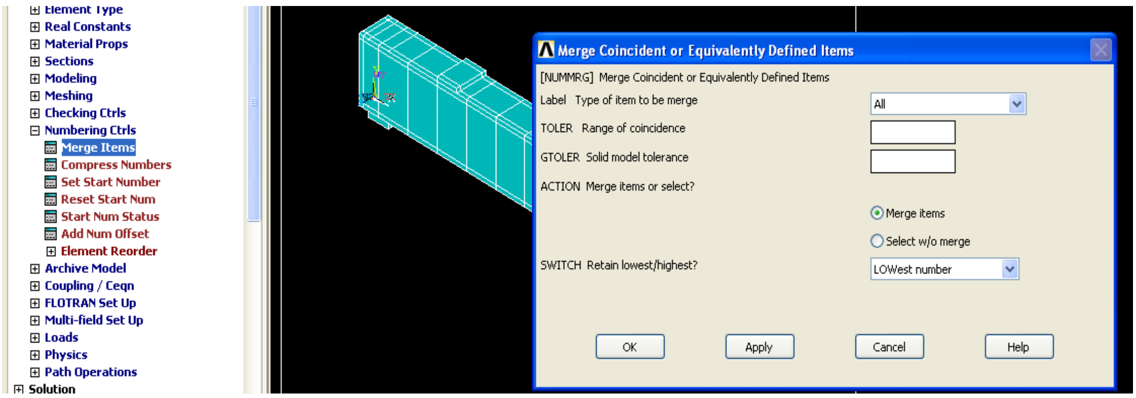

Figure 3.13 Table of Merging the Elements

Before meshing the whole model, the lines at the desired location needed to be categorized and group. The lines were selected and categorized them into specific group for example link, main bar and secondary bar. The purpose of this step was important so that it allow us to mesh the element more easily. Figure 3.14 showed lines being selected and group into main bar before going to meshing step. Other than that, links and secondary bar were also created.

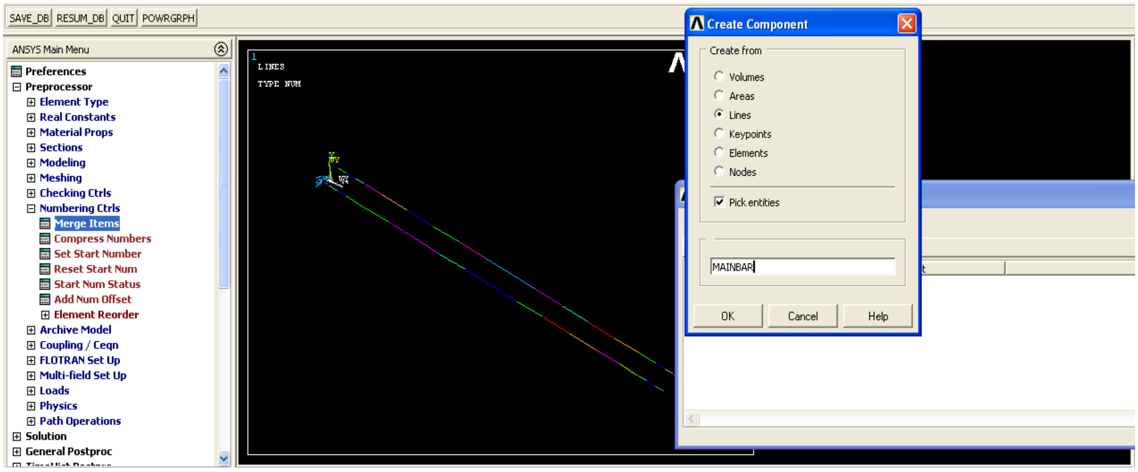

Figure 3.14 Lines were Selected and Group into ''MAINBAR''

After all the elements were defined and group, the meshing is the next step. Figure 3.15 showed the table of setting for meshing. As shown in the Figure 3.15, the [TYPE] was the element type were in this analysis were SOLID 65, SOLID 185 and LINK 180. The [MAT] and [REAL] were the material model and real constant respectively. Reinforced concrete beam was defined by ''SOLID 65'', steel plate was ''SOLID 185'' and all the link and steel bars were ''LINK 180''. For the reinforced steel bars, there were two different sizes, which the main bar and secondary bar were 12mm and the links were 6mm.

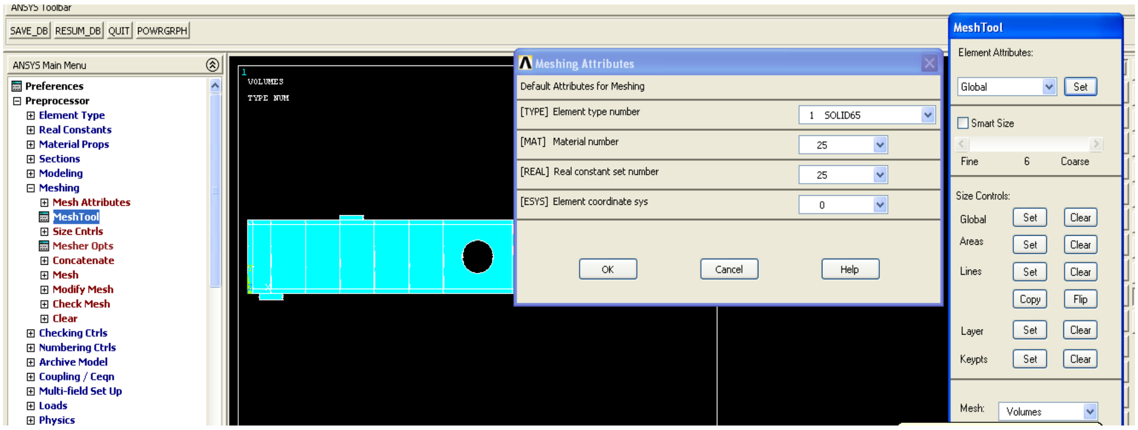

Figure 3.15 Table of Meshing Tool

Figure 3.16 showed the model after being meshed. The model was divided into small tiny elements after meshing. The smaller the mesh size, which mean higher number of element, the more precise is the analysis result. However, it cost u longer time if the number of element created is too many. After the model was meshed, the modelling process was considered complete.

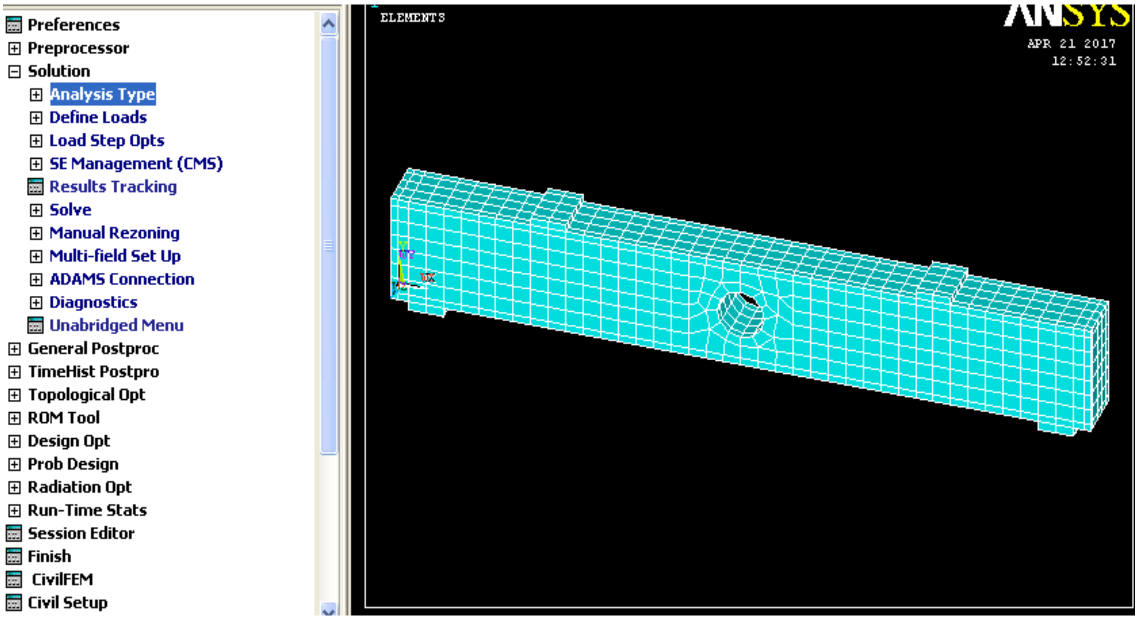

Figure 3.16 Model after Meshed

3.4 Boundary Condition and Loading

Boundary condition and loading is necessary for an analysis. The boundary condition was set after the model was completely meshed. Figure 3.17 showed the tool bar for setting the boundary condition for the model. In order to set the boundary condition, the nodes at the steel plate which act as the support was selected and constrained in displacement (DOF to be constrained.)

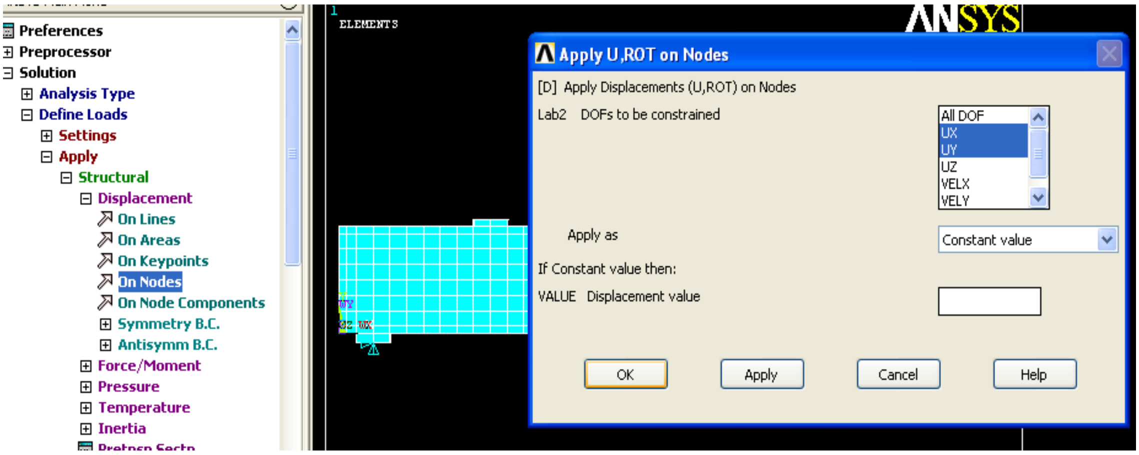

Figure 3.17 Tool Bar to Set Boundary Condition

In this analysis, the boundary condition in both support were set to be pinned. In another word, the displacement of UX and UY were set to be constrained. Figure 3.18 showed the boundary condition at the support of the model which both of it was pinned.

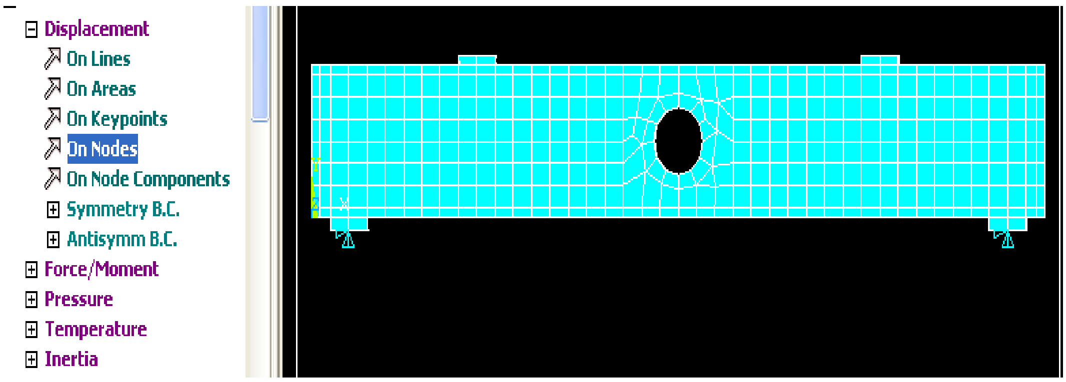

Figure 3.18 Boundary Condition at Both Support was Pinned

In this analysis, the load was applied at both steel plate which located at top of the model. At the Apply Structural Force/Moment, ‘’On Nodes’’ were selected. 25kN of forces was apply at both steel plate on each node. There were a total of 12 nodes on the plate, so the total force apply on the beam was 300kN. Figure 3.19 showed tool bar of applying and set the force. Force FY was selected which mean the force is acting in Y direction and negative 25 kN was set to apply on each node, the negative sign indicate the force was acting downward.

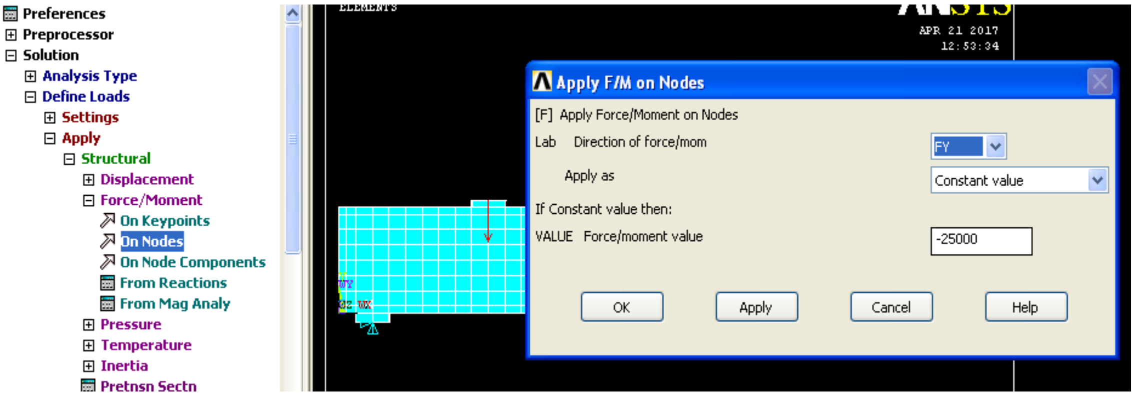

Figure 3.19 Tool Bar of Applying Force.

Before analysis is run, some feature needed to be set. In the ‘’Solution Control’’, there was ‘’Basic’’, ‘’Sol’ n Option’’, ‘’Nonlinear’’, and ‘’Advanced NL’’. Figure 3.20-Figure 3.23 showed the tool bar in the Solution Control. There were several setting that needed to be set before analysis was being conducted. It completely depend on how the analysis will be conducted. The number of set of data was also depending on the setting in this section.

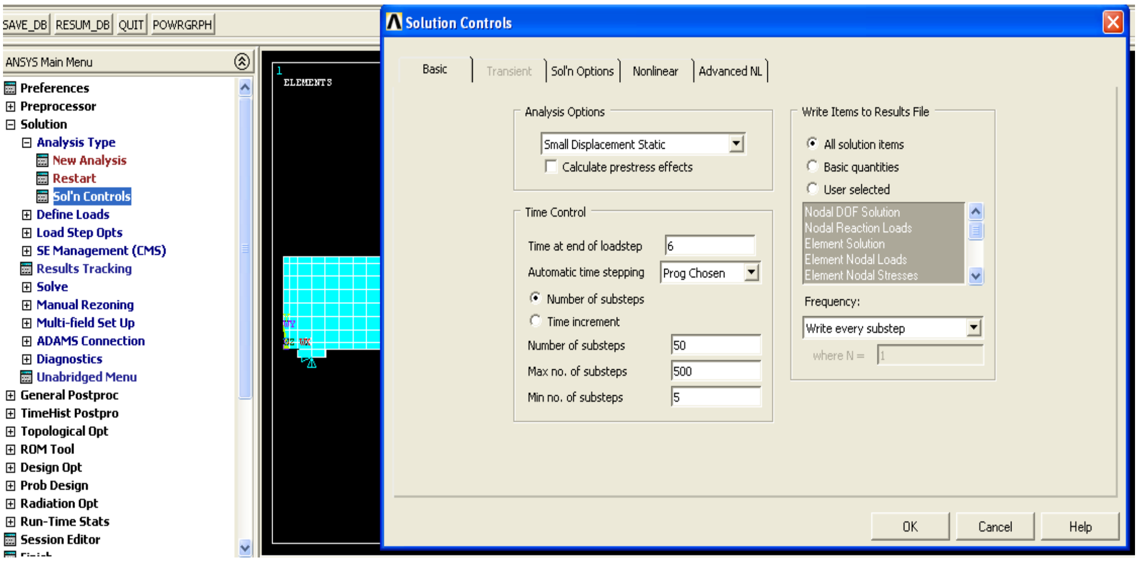

Figure 3.20 Basic Tool Bar in Solution Controls

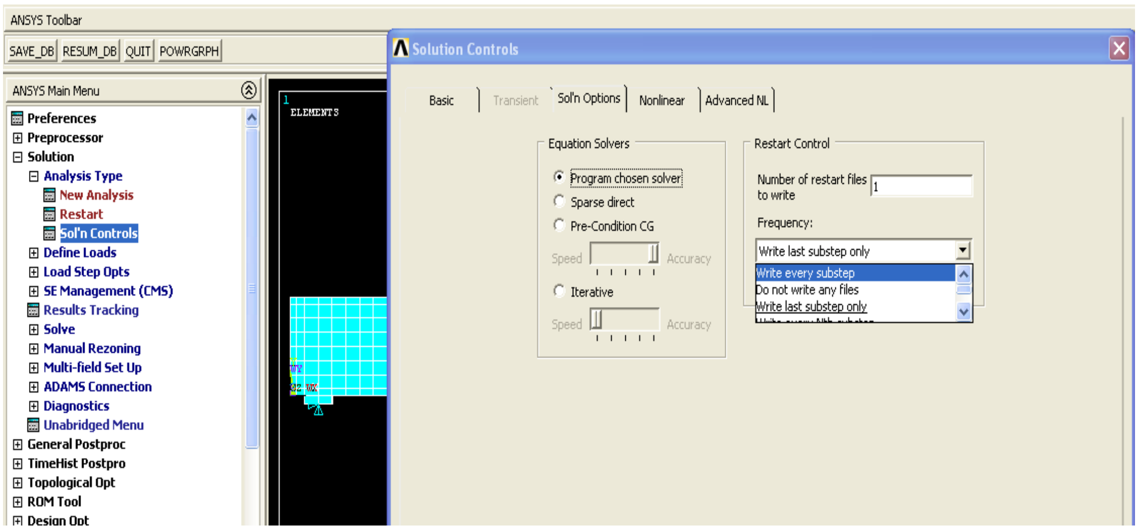

Figure 3.21 Sol’ n Options Tool Bar in Solution Controls

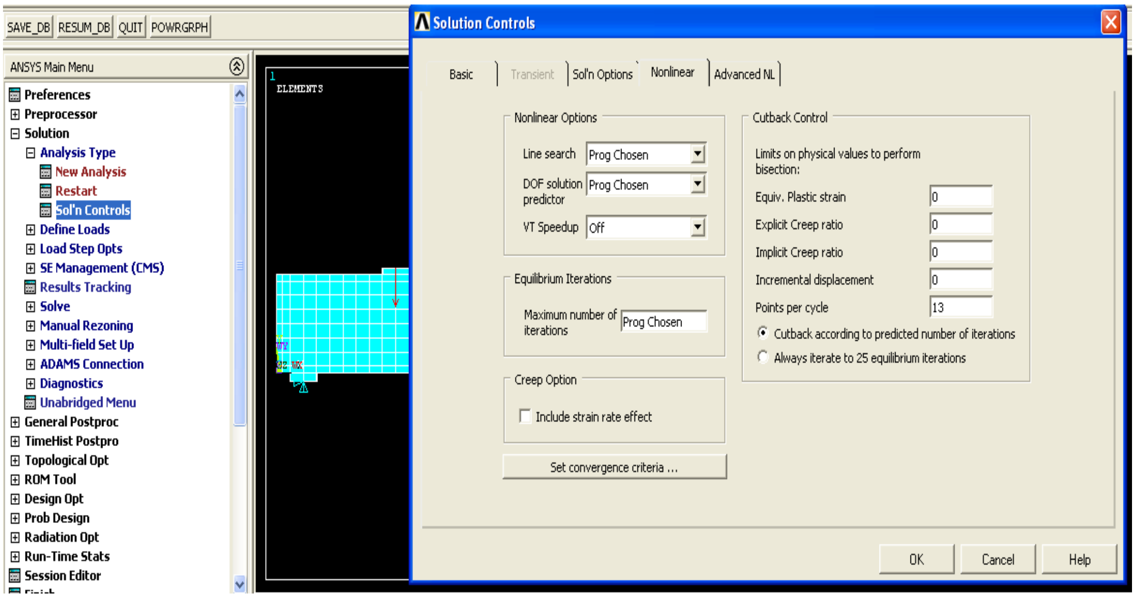

Figure 3.22 Nonlinear Tool Bar in Solution Controls

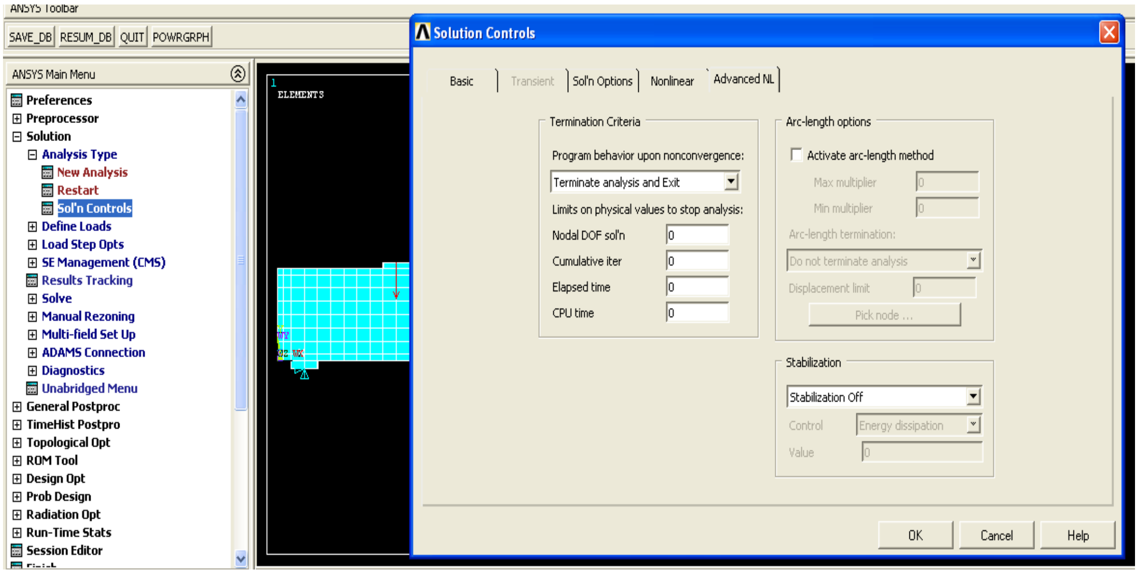

Figure 3.23 Advanced NL Tool Bar in Solution Controls

3.5 General Postprocessor

This was the last section for the analysis process. After analysis was being done, general postprocessor is done in order to get the result. In this section, result was read from the desire sub-step number. Figure 3.24 showed tool bar of reading the result.

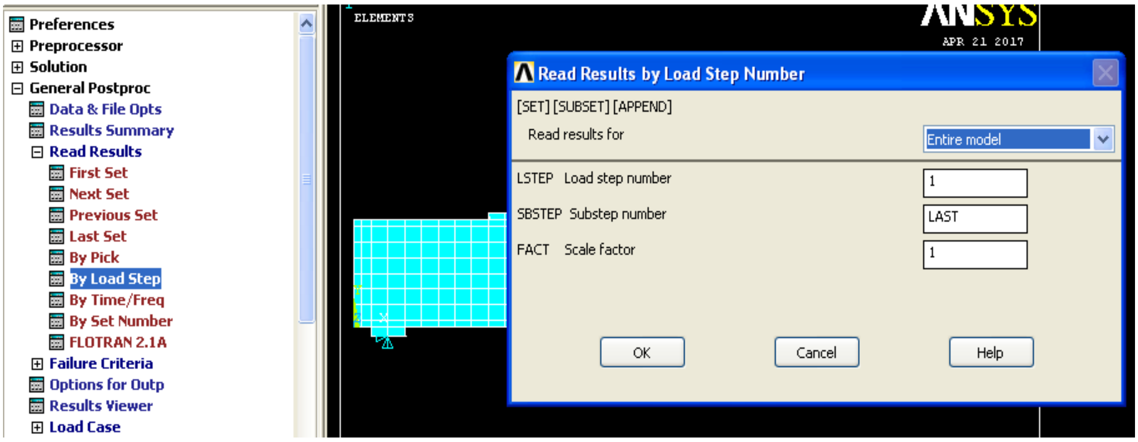

Figure 3.24 Tool Bar of Result Read by Load-step

In this study, one of the objective was to study the deflection of the beam from 1/3 of span and mid span. To obtain the data of deflection, the node number was first identify. From the desired node number, the result was read from list of ''Nodal Solution''. Figure 3.25-Figure 3.26 showed how the result was obtained.

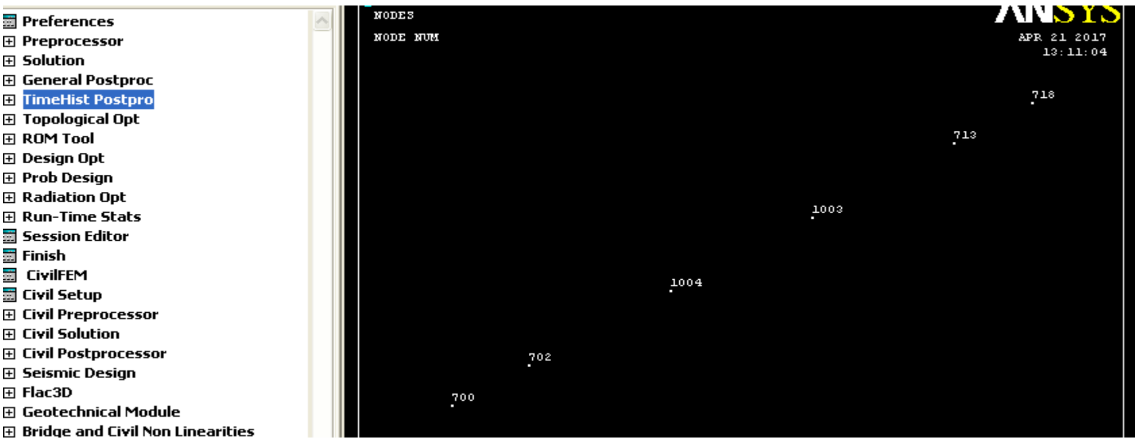

Figure 3.25 Desired Node Number was Identify

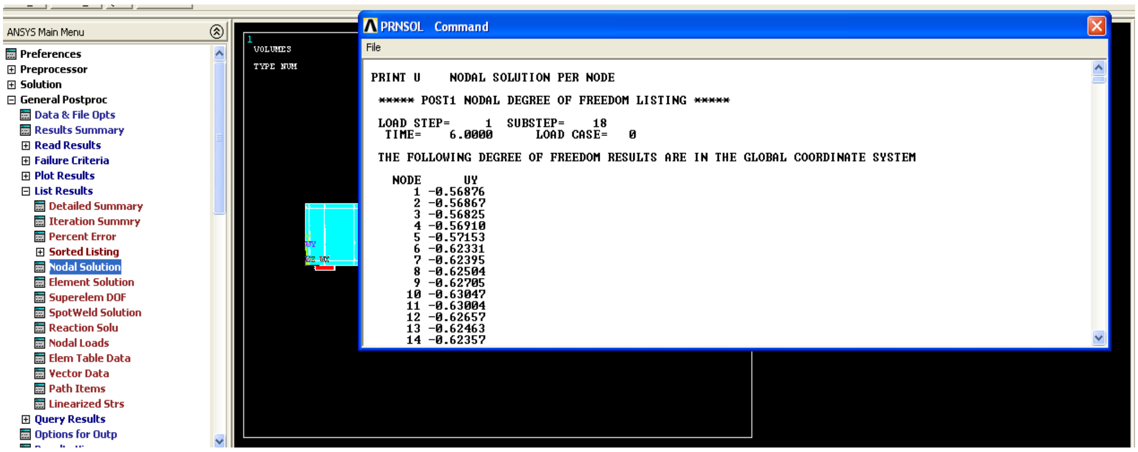

Figure 3.26 Result of Deflection based on Node Number

In this study, another objective was to study the crack pattern of the reinforced concrete beam. The crack pattern can be viewed from ''crack/crush'' in the ''plot results''. Figured 3.27 showed tool bar of showing crack pattern.

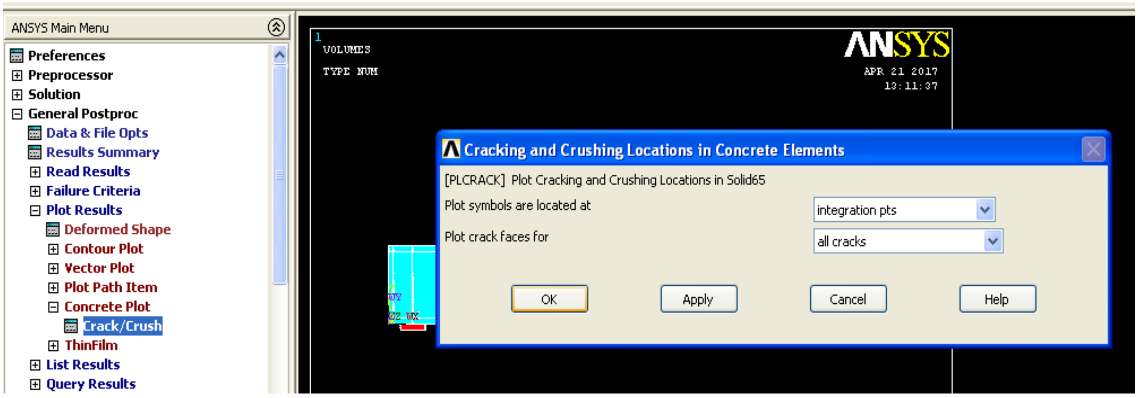

Figure 3.27 Tool Bar of Showing Crack Pattern

From the tool bar, crack pattern can be view in different stage which was first crack, second crack and third crack. The first crack was showed in red color, second crack was showed in blue color while third crack was showed in green color. Figure 3.28 showed an example of crack pattern obtain from ANSYS software.

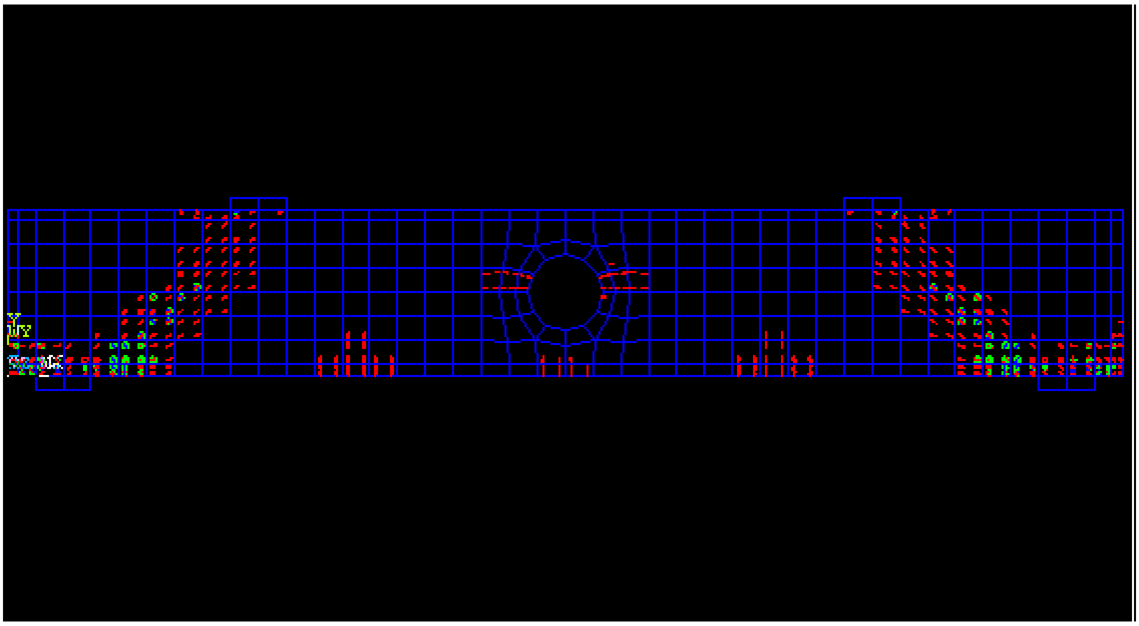

Figure 3.28 Illustration of Crack Pattern

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General

The analysis was conducted by using the ANSYS software 12.0. There were two objectives for this analysis. The first objective was to study the load deflection of beam based on different type of opening shape and size of the opening. These opening shape including square, circular, rectangular and double circular. Each of these shape had the same area of opening which was 14400 mm^2. From the analysis of different shape of opening, the shape of opening with the largest mid-span deflection was used for analysis base on different size of opening. With different size of opening, the mid-span deflection was then study. All the load for the study was the same which was 300kN. The second objective of the study was to investigate the crack pattern of the concrete. The diagram of crack pattern of the first analysis was obtained from the result of analysis. From the diagram, there was 3 type of crack which is ‘’first crack’’, ‘’second crack’’ and ‘’ third crack’’. The first crack was in red colour, second crack was green colour and the third crack was in blue colour. However, in this study, only combined crack of first, secondary and third was taken.

4.2 Deflection

In order to determine the effect of different shape of opening on RC beam in term of mid-span deflection, the value of the nodal solution was obtained from the analysis by using ANSYS. Before taking the nodal solution value, the node number at mid-span was first identified. After knowing the node number, in the nodal solution option, the DOF in y-direction was chosen. There will be showing the deflection value of all node. In this study, the deflection at 1/3 of the span and mid-span along the span was taken. However, mid-span deflection will be emphasised in this study. There were two parameter that will be manipulated in studying the deflection of RC beam with web opening. The first one was different shape of opening and the other one was different size of opening. The location of opening for this study was kept constant.

From the results obtained, it was known that, among the different geometries of opening, rectangular opening gave the largest mid-span opening, followed by square, circular and double circular opening. The trend was obtained when the load applied to the RC beam which was 300kN.

Beam S1 which was the solid beam act as control sample. When 300 kN of forces was applied to the beam, the mid-span showed a deflection of -0.8622mm. When square opening with area 14400mm^2 was introduced in the beam (Beam S2), the deflection of the beam was increase. The mid-span deflection of the beam with square opening was -0.8955mm, which showed an increase of deflection about 3.90%. When the beam was introduced with same area of circular opening (Beam S3), it showed an increase of deflection which is -0.8937 mm which was about 3.60%. For Beam S4 which was the RC beam with rectangular opening, the deflection was -0.9148mm and it was an increase of 6.10% when compared to solid beam. When the opening was changed to double circular of same area (Beam S5), the deflection value was -0.8652mm and an increase of 0.30%. From the result obtained, it was known that, the best geometry for opening was circular shape as it gave the least deflection increment among all the shape. It showed an increase of 3.60% compared to solid beam. If the circular shape was divide into two similar circular it gave a better result which was only 0.30%. Hence, rectangular opening was the worst shape to make for opening as it gave the highest increment of deflection which was 6.10% compared to solid beam. The result was tabulated in the Figure 4.1-4.6 and Table 4.1.

Another parameter to study was the opening size with rectangular shape of opening. From the result of different shape of opening, it was known that rectangular opening is the most critical shape of opening and was taken to study for opening with different size. The beam S6 was the beam with rectangular opening of size 60mm x 40mm. It showed the deflection of -0.8646mm and an increase of 0.28%. For beam S7 the size of opening was increase to 100mm x 48mm and it showed an increase deflection of -0.8662mm which was an increase of 0.46%. However, when the size of opening increase to -0.8699mm it showed an increase of 0.89%. From the result obtained, there was a trend showing that when the size of opening increase, the deflection of the beam also increase. The result was tabulated in the Figure 4.7-4.9 and Table 4.2.

From general point of view, it was shown that the deflection of beam increase with the inclusion of web opening. This was supported by the thesis prepared from Venugopal, (2014). In his thesis, he mentioned that providing web opening in beams will cause reduction in torsion moment capacity and increase in deflections dude to reduction in beam stiffness. In the analysis of the effect of the opening with different shape, it showed that the circular opening is the best opening among all the shape. This finding was agreed by the study done by Aykac et al., (2014), the result from his research found that when the circular opening was provided, it have much greater energy capacities when it was compared with the beams with rectangular openings. The less favourable behaviour of RC beam with rectangular opening was probably due to the stress concentrations in the corners result in cracking which leads to the reductions in the flexural rigidities which in another word larger deflection.

There was also research done by Rezwana Binte Hafiz et al., (2014), the result from the study show that the RC beam with square opening exhibit lower ultimate load as it compare to equivalent circular opening. The ultimate load will directly affected the rigidity and deflection of the beam. Hence, it was supported the finding of this analysis which square opening exhibit higher mid-span deflection than circular opening. This was explained due to the stress concentration occurs at the existing orthogonal corners in square opening.

In the research done by Al-sheikh, (2014), it was found that when comparing the circular opening with square opening, the circular opening exhibit higher ultimate load which mean lower deflection of the beam. This was due to the sudden change in the dimension of cross section which leaded to high stress concentration at the corners of the square opening. The square opening however, show better ultimate capacity compare to rectangular opening because the shear stresses distribute in the top and bottom chords at rectangular opening causing the beam to act like a frame. This support the trend in this study whereby the circular is the best shape to be opening follow by square and rectangular.

When comparing double circular and single circular opening, it was found that double circular had lesser mid-span deflection. This finding was supported by Torunbalci, (2002), where when small opening were arrange consecutively, it produced a positive attitude to the beam. This allow the load transfer to the support through part between the openings, which reduced the negative effect of opening.

In studying the effect of different size of opening to the mid-span deflection of the beam, the trend show when the size of opening increase, the mid-span deflection of the beam also increase. This trend was supported by the study done by Nilesh & Patel, (2013), where by the result showed that increasing of opening size also increase the deflection of the beam. The result showed that there was an increment about 30% in the deflection as the sizing of the opening increase from 0.45D to 0.55D.

In this study, all the effect of deflection was not more than 1mm. The difference among different shape of opening also show small different among each other. There was a research done by Amiri & Masoudnia, (2011) which indicate that, if the size of opening is not more than 48% of the depth of the beam, there has no effect on the ultimate load capacity of the RC rectangular beams which mean these beams behave similar to the beams without opening. In this study, all the opening size was no more than 48% of the beam depth hence, the effect of the opening toward the deflection of the beam was not obvious.

Table 4.1 Deflection of RC Beam with Different Shape of Opening

Span (mm)	Deflection (mm)				
	Solid	Square	Rectangle	Circle	Double Circle
0	0	0	0	0	0
650	-0.7437	-0.7643	-0.7842	-0.7575	-0.754
1000	-0.8622	-0.8955	-0.9148	-0.8932	-0.8652
1350	-0.7437	-0.7643	-0.7842	-0.7575	-0.754
2000	0	0	0	0	0

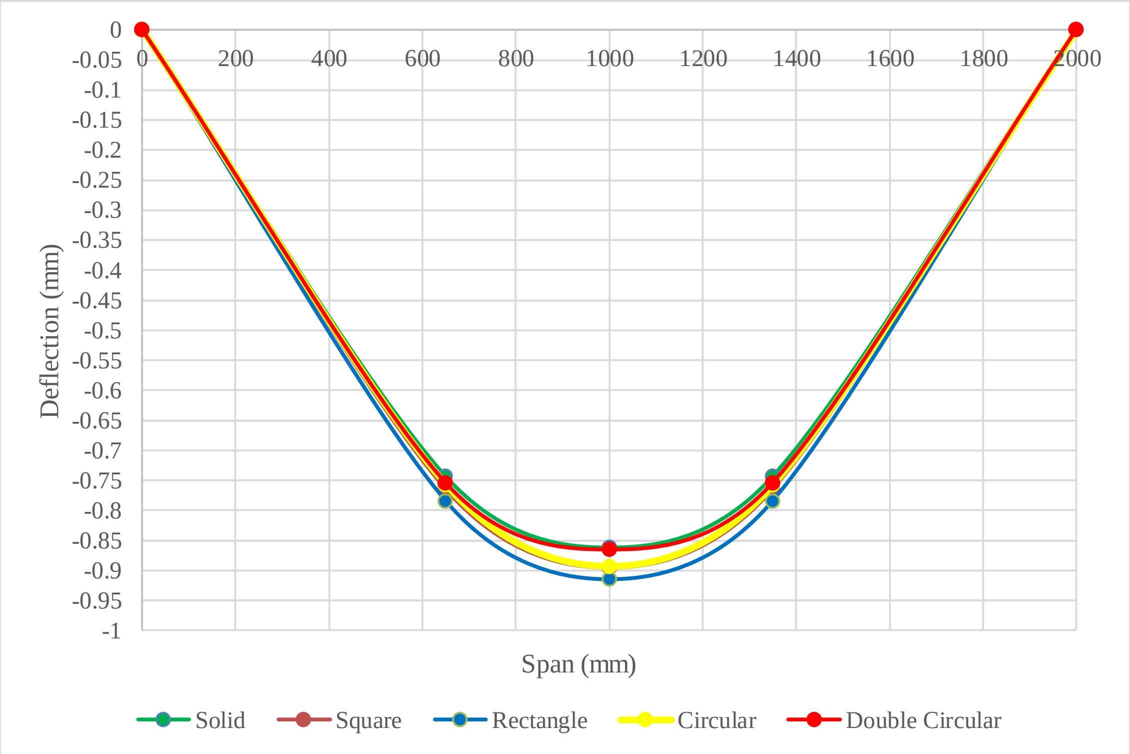

Figure 4.1 Deflection Profile of the Beams with Various Shape of Opening

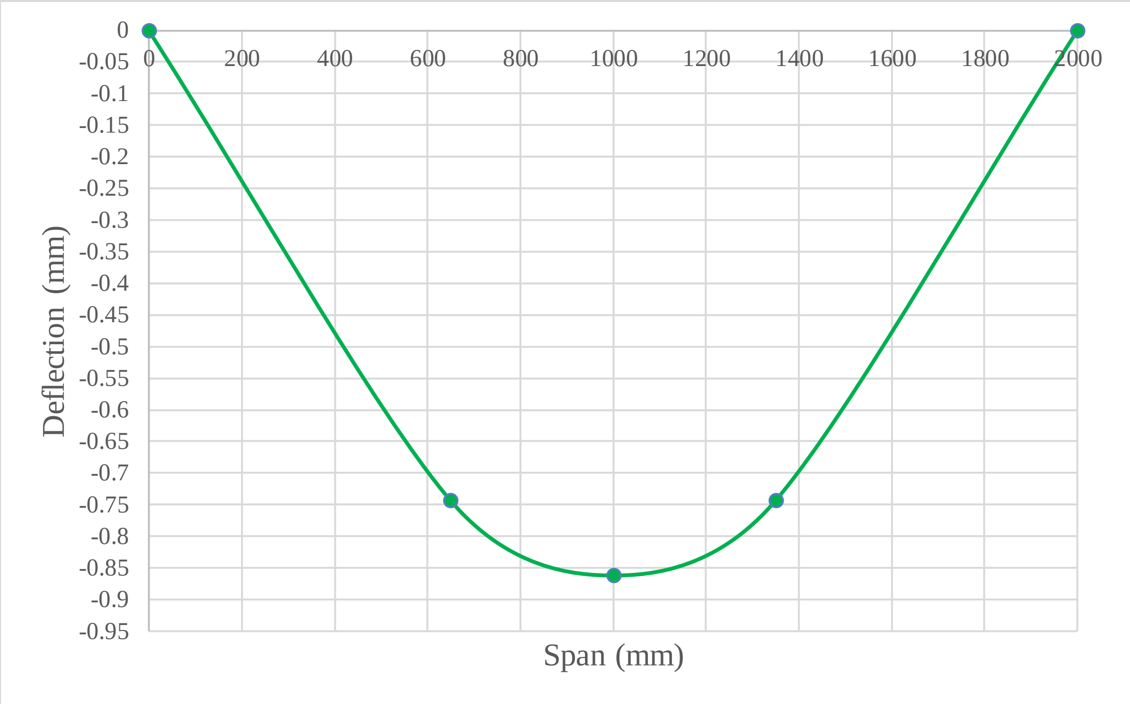

Figure 4.2 Deflection Profile of Beam S1

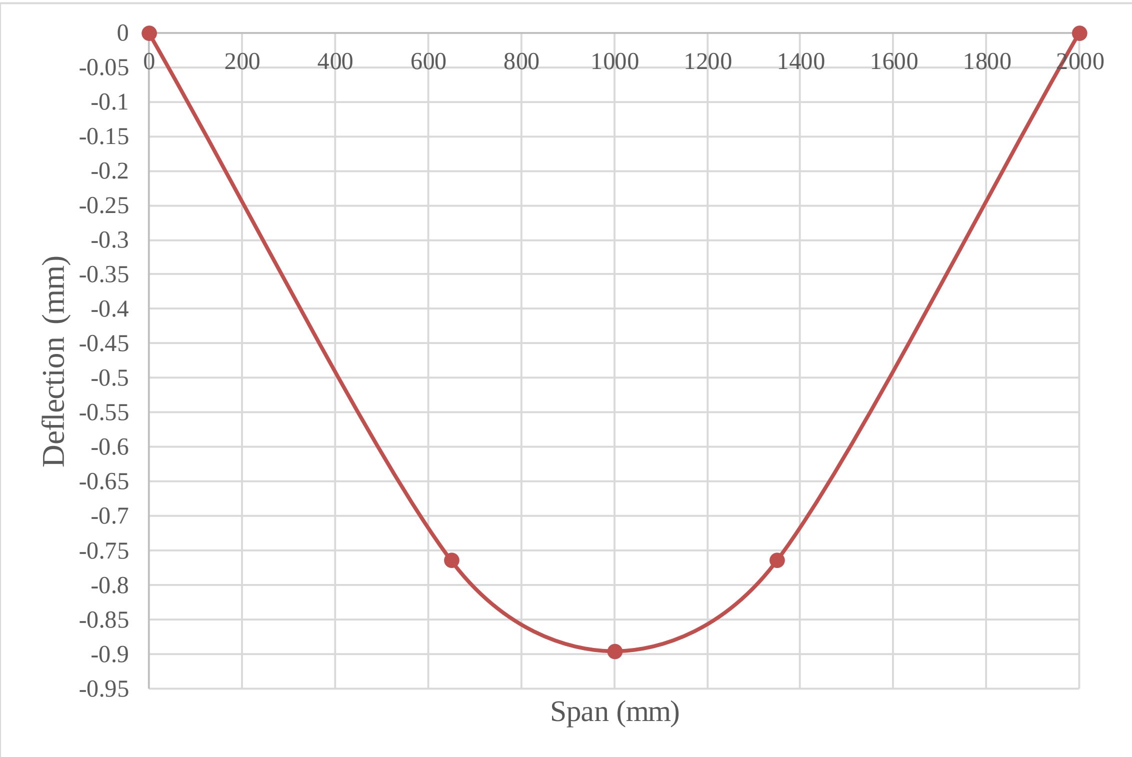

Figure 4.3 Deflection profile of Beam S2

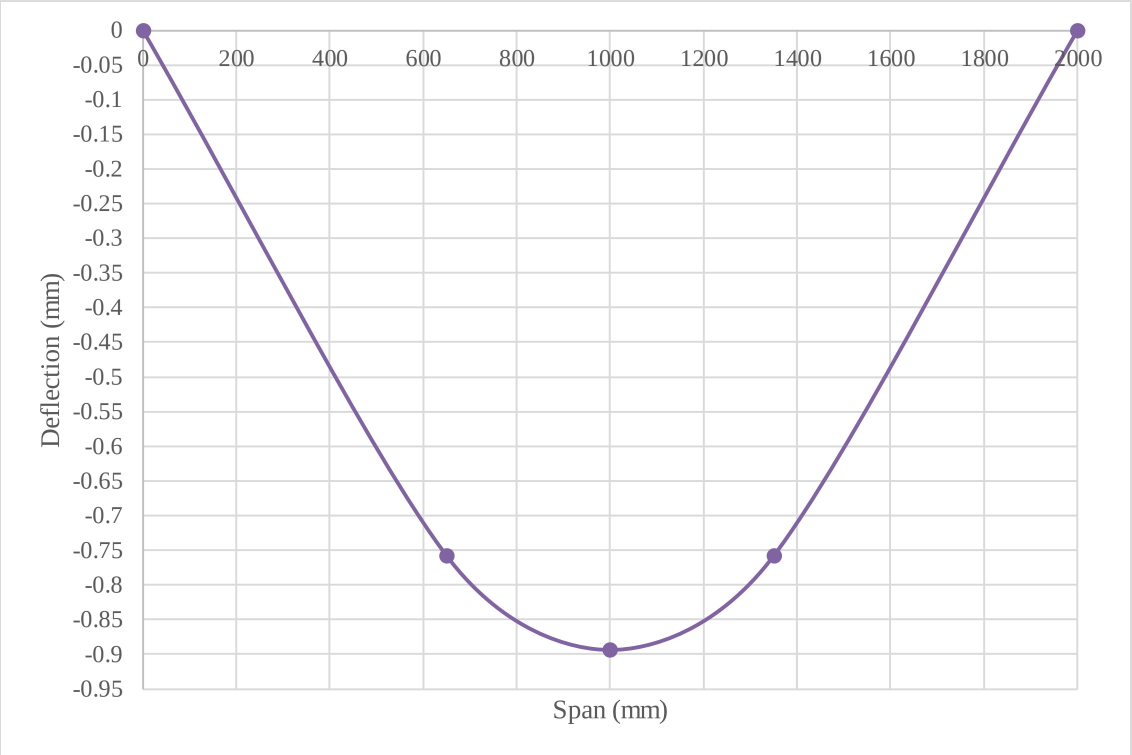

Figure 4.4 Deflection Profile of Beam S3

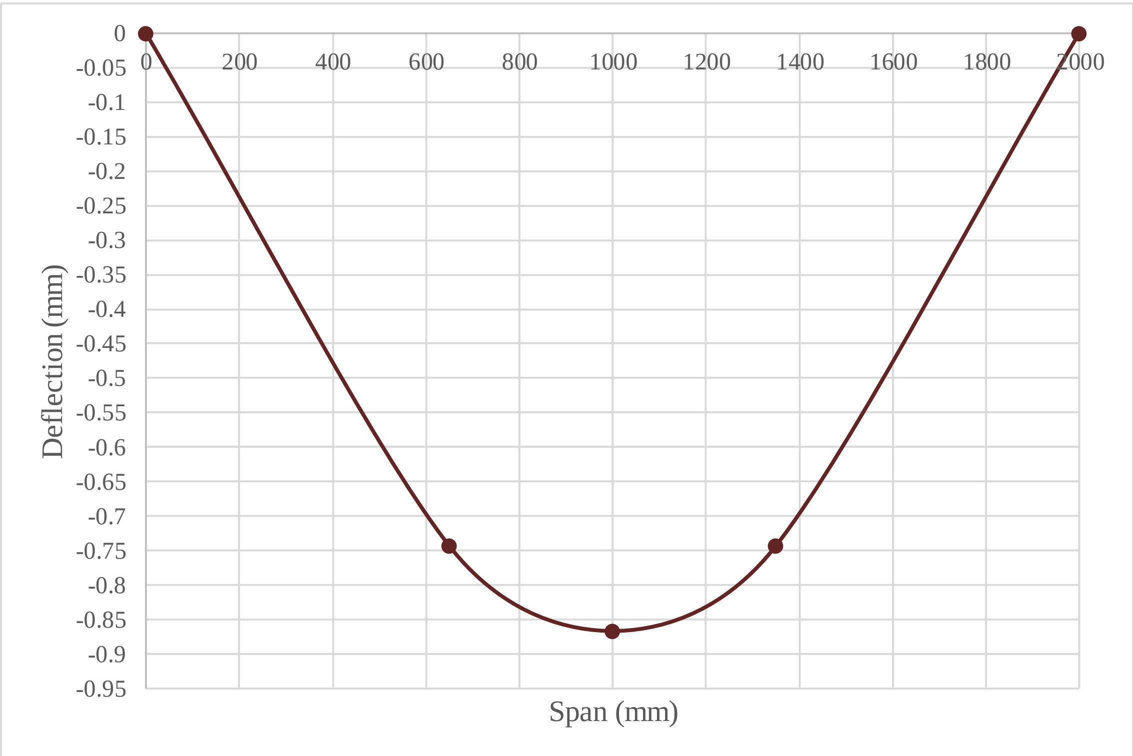

Figure 4.5 Deflection Profile of Beam S4

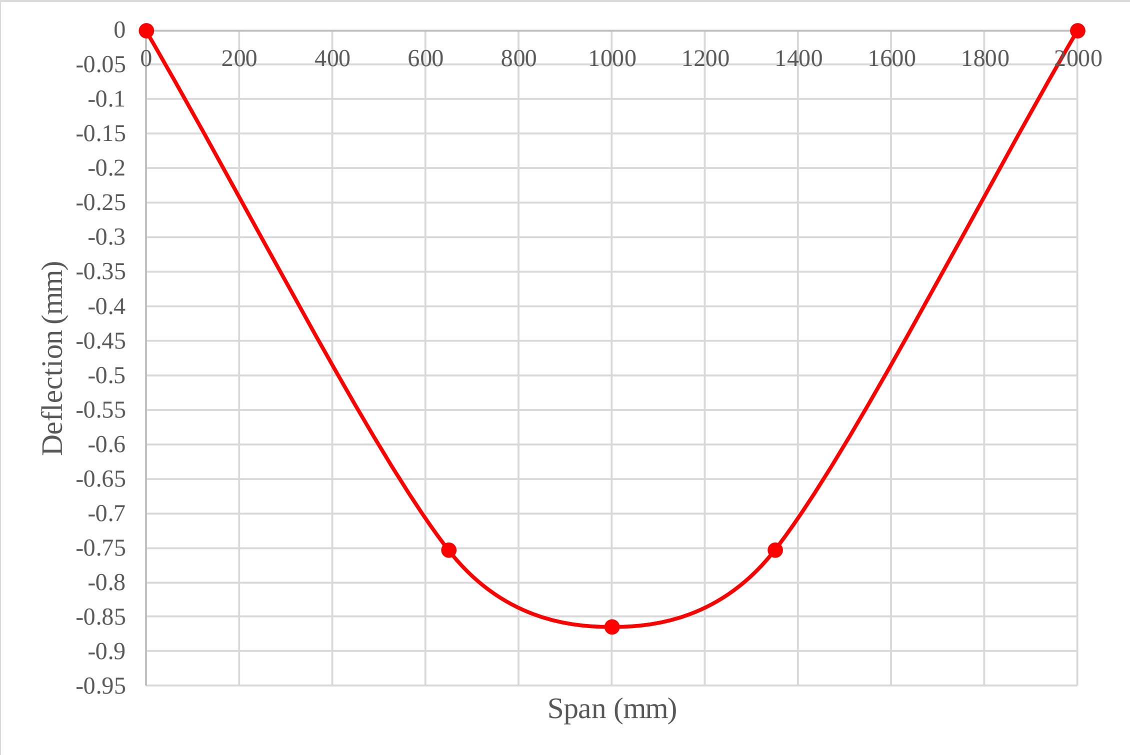

Figure 4.6 Deflection Profile of Beam S5

Table 4.2 Deflection of RC Beam with Different Size of Rectangular Opening

Span (mm)	Deflection (mm)			
	Solid	Size 1	Size 2	Size 3
0	0	0	0	0
650	-0.7437	-0.7415	-0.7428	-0.7522
1000	-0.8622	-0.8646	-0.8662	-0.8699
1350	-0.7437	-0.7415	-0.7428	-0.7522
2000	0	0	0	0

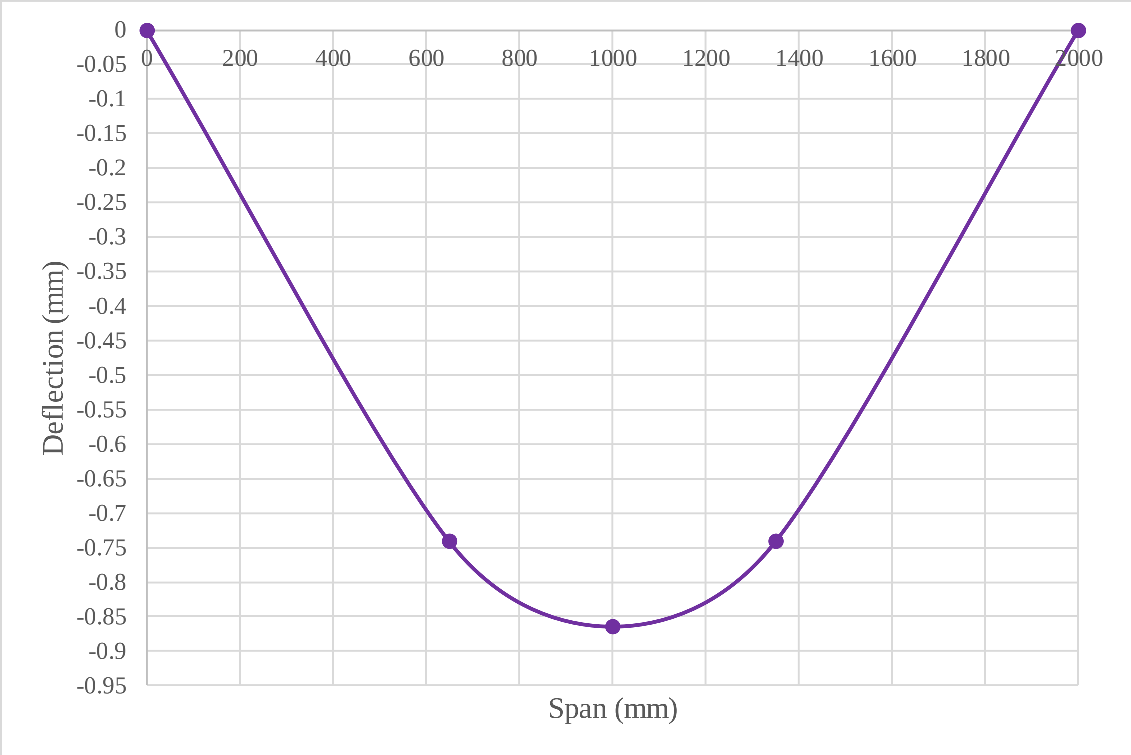

Figure 4.7 Deflection Profile of Opening Size 60mm x 40mm

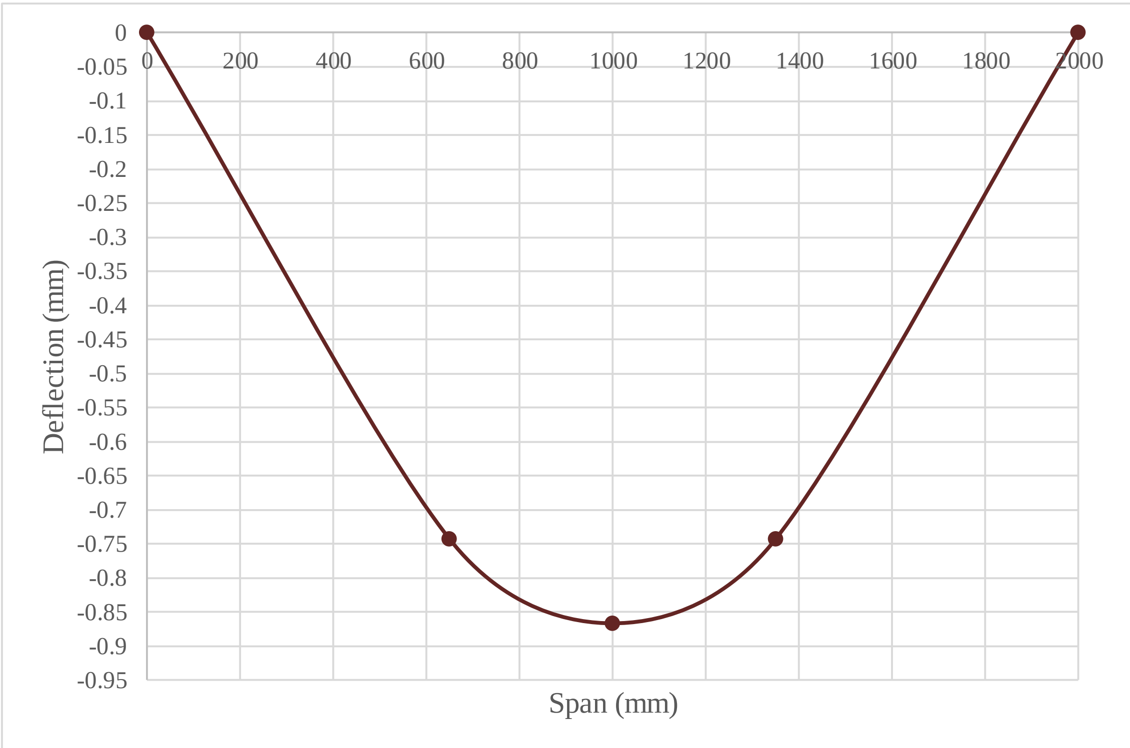

Figure 4.8 Deflection Profile of Opening Size 100mm x 48mm

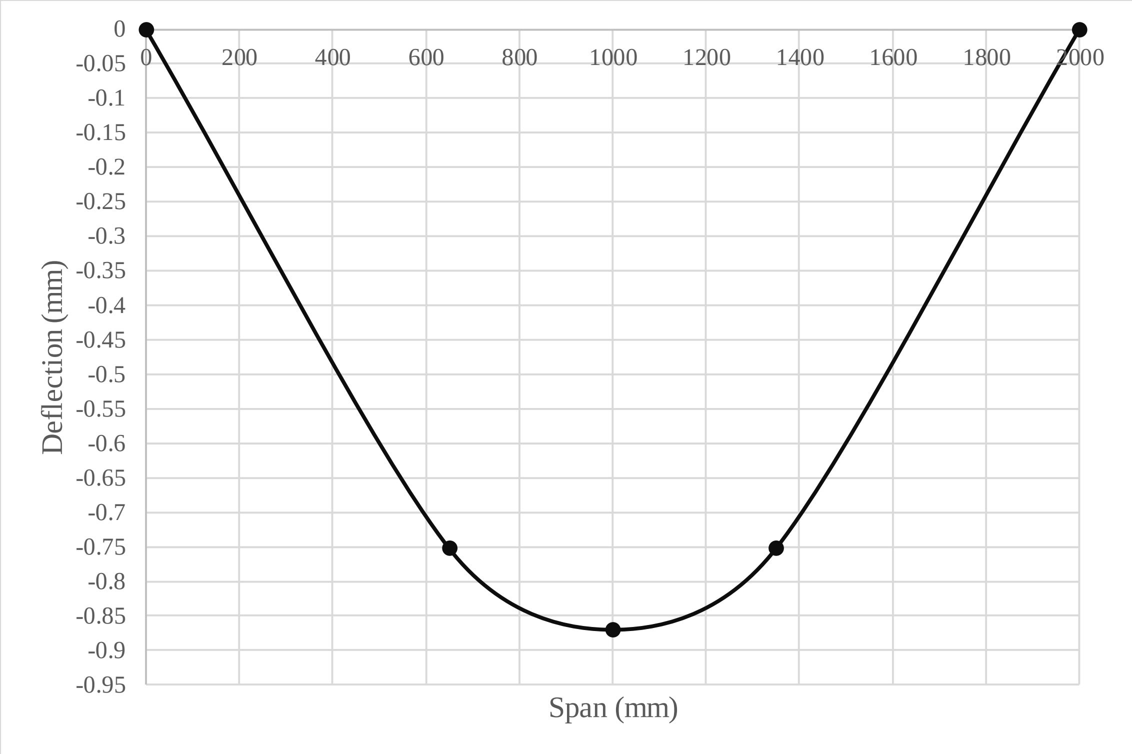

Figure 4.9 Deflection Profile of Opening Size 100mm x 80mm

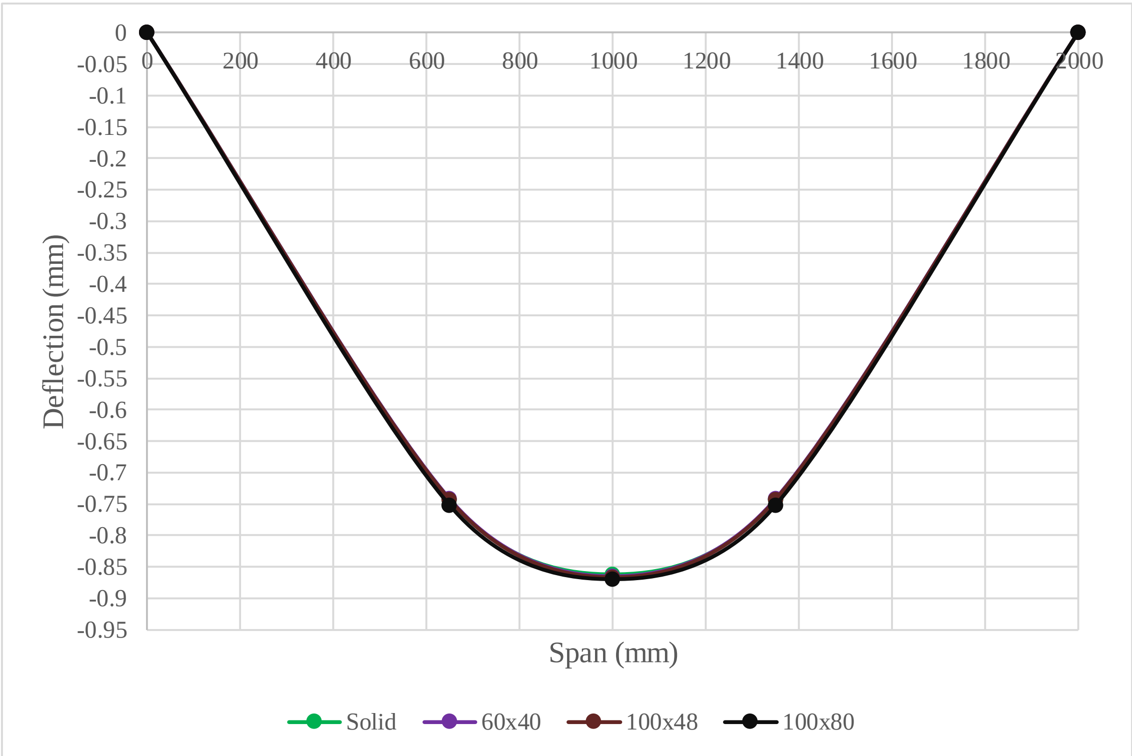

Figure 4.10 Deflection Profile of Beam with Variation Opening Size

4.3 Crack Pattern

In this study, all the crack pattern was taken at the same load which is 300kN. From the results obtained, a trend was get which is the first crack will occur at the bottom of the beams. This type of crack was known as flexural crack where the crack was occur at the zone where flexural is high. Another obvious trend that can be observed was that the crack will be propagated from the support toward the loading point. When the crack reach the loading point, it started to propagate to the side of the loading point. The crack will be coverage when it come closer to the loading point. This type of crack was known as shear crack. The figure 4.10 showed the cracking pattern of Beam S1 which was solid beam with load applied which was 300kN.

When the web opening was produced in the RC beam, there was some effects to the crack pattern of the beam. The introducing of web opening to the RC beam not only reduced the ductility of the beam, it also reduced the strength capacity of the beam. When opening was introduced, it caused the stress to be concentrated at the opening which will potentially cause early cracking to the beam. From the result obtained, it clearly showed that there was crack happen at the corner of square opening. For circular opening, it can be observed that there was crack occur around the opening region of the circular opening. The analysis was conducted on each RC beam with different shape of opening under the same load which was 300kN. The results of the crack pattern was shown in the Figure 4.10-4.14.

Another parameter to study was the crack pattern of the RC beam with different sizing of opening. The model Beam S6, Beam S7 and Beam S8 was used in this study. The sizing of the model was different where Beam S6 with opening size of 40mm x 60mm, Beam S7 with opening size of 100mm x 48mm and Beam S8 was opening size of 100mm x 80mm. All the sample was study under the same loading which is 300kN. From the result obtained, the crack pattern has only little different when it was compared with the crack pattern of solid beam. This might be due to the fact that the inclusion of opening size was too small that there was no obvious effect toward the cracking of beam. From the result, it was observed that there was crack occur at shear zone and flexural zone. When the opening size increase, the region of crack occur at the flexural zone and shear zone also increase. However, the increment was not obvious due to small opening size. It was also observed that there was no cracking occur at the opening. This might be also due to the opening size was too small and cause no effect toward the crack pattern of the RC beam. The result of the opening was shown in Figure 4.15-4.17.

According to the study of Mansur, (2006), there are two main type of failure mode in beam. The one is the beam-failure and another one is frame-failure. The beam failure is the failure where failure occur at 45^{o} inclined to the opening. This can be seem from the failure occur at square opening where the cracking is occur at 45^{o} of the corner of the opening. Meanwhile, the other failure was frame failure where the failure occur due to two independent diagonal cracks, each happen at top and below the opening. This can be seen from the cracking pattern from circular opening.

According to the study from Venugopal, (2014), he concluded that beam with circular opening exhibited a frame type failure, this was because the stress concentrated across the opening is uniform at edges of openings. Beam type of failure will be exhibited at the beam when the beam is provision with rectangular opening. This is due to the fact that rectangular opening contain orthogonal corner which cause maximum stress concentrate at the corners of the openings. This finding supported the result for this study where circular opening exhibit frame type of failure and square opening exhibit beam type of failure.

Allam, (2005), mentioned that, due to the stress concentration, various cracks were formed around the opening corners and at the upper chords, diagonal cracks are formed due to lack of shear resistance. This can be seen in this study shown in Figure 4.11 where diagonal crack was found. Apart from that, research done by Aykac et al., (2014) also found that, the less favourable behaviour of RC beams with square openings was mainly due to the stress concentrations in the corner of the opening. Besides, study from Chin et al., (2012), mentioned that in the early stage of un-strengthened beams, diagonal crack were formed at the four corners of square openings and eventually leads to yielding of steel reinforcement and crushing of concrete cover.

According to Yang et al., (2006), it was found that provision of opening reduced the beam rigidity and increase mid-span deflection. Due to the opening, the crack pattern gradually developed toward the load points and supports depending on opening size. This trend can been seen from the result obtained from this study where the crack pattern was found propagated from support to the loading point.

Apart from that, when comparing the flexural crack of the beam with opening and solid beam, it was found that, the solid beam had a more evenly distribute flexural crack. When opening was provided to the beam, the flexural crack of the beam was sharper and more concentrated. This finding was supported by the research done by Anesta, (2010), where she concluded that, when there is presence of openings, it causes stress concentration at the top and bottom of the RC beams. The consequences was causing the increase of tensile stress which will then lead to forming of flexural cracks at the bottom of the hole.

In this research, the crack pattern for beam with different sizing, there were not much different when compared to solid beam. This was due to the fact that, the size of opening was too small to effect the beam behaviour. According to Amiri & Masoudnia , (2011), when the diameter of the opening size was less than 48% of the beam depth, the ultimate load of the beam will not be affected, meaning these beam will act like a solid beam. Research from Ramadan et al., (2015) concluded that , when the central opening was provided to the beam, the crack pattern of the beam with opening will be same as the beams without opening.

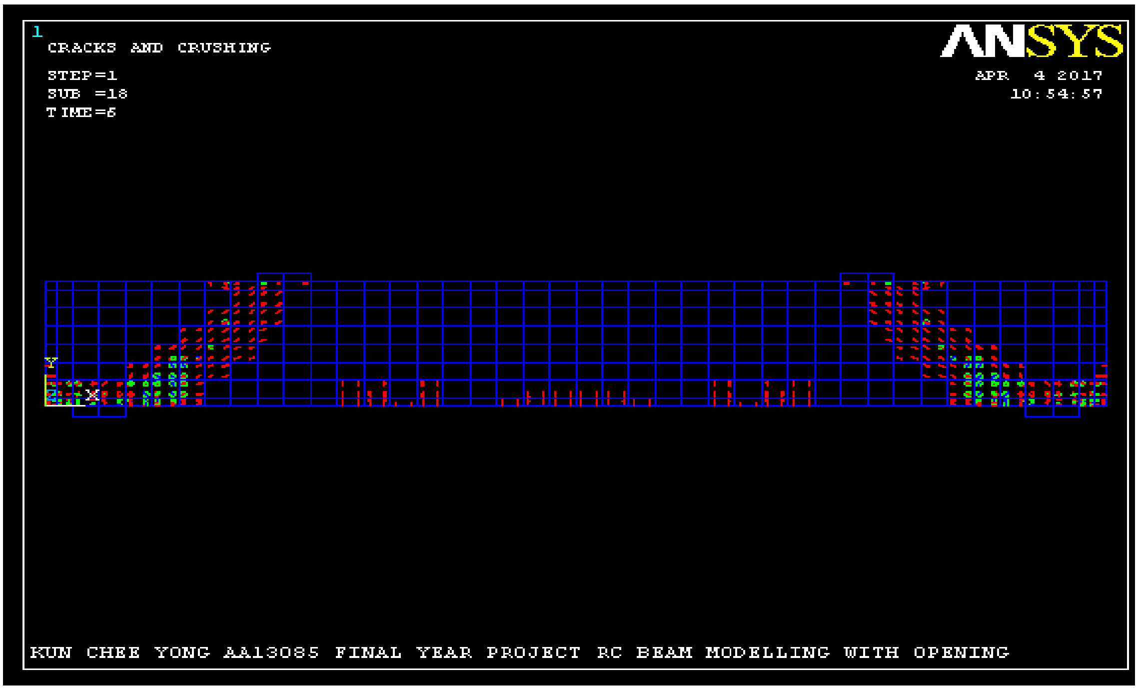

Figure 4.11 Cracking Pattern of Beam S1

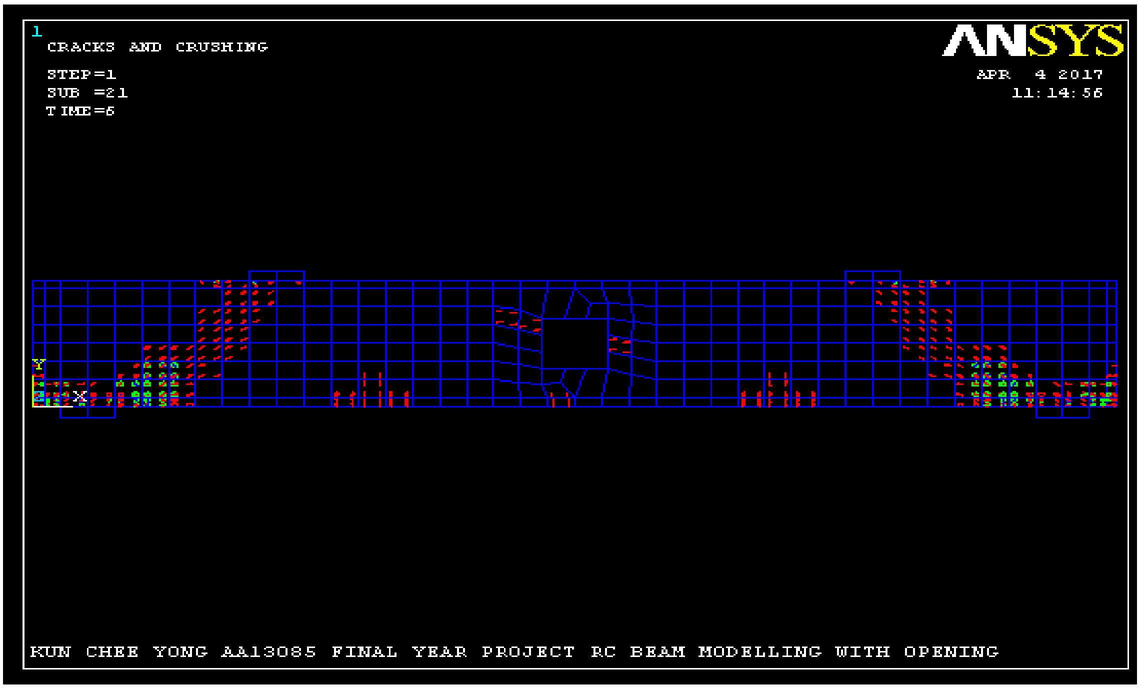

Figure 4.12 Cracking Pattern of Beam S2

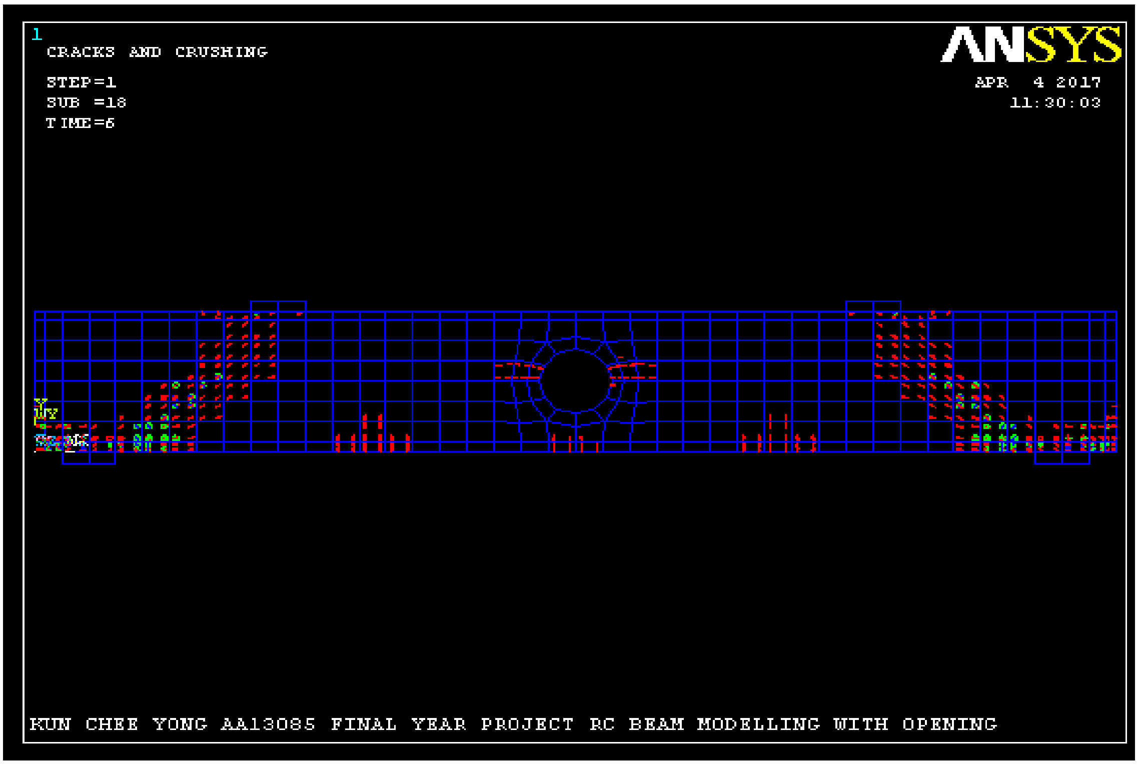

Figure 4.13 Cracking Pattern of Beam S3

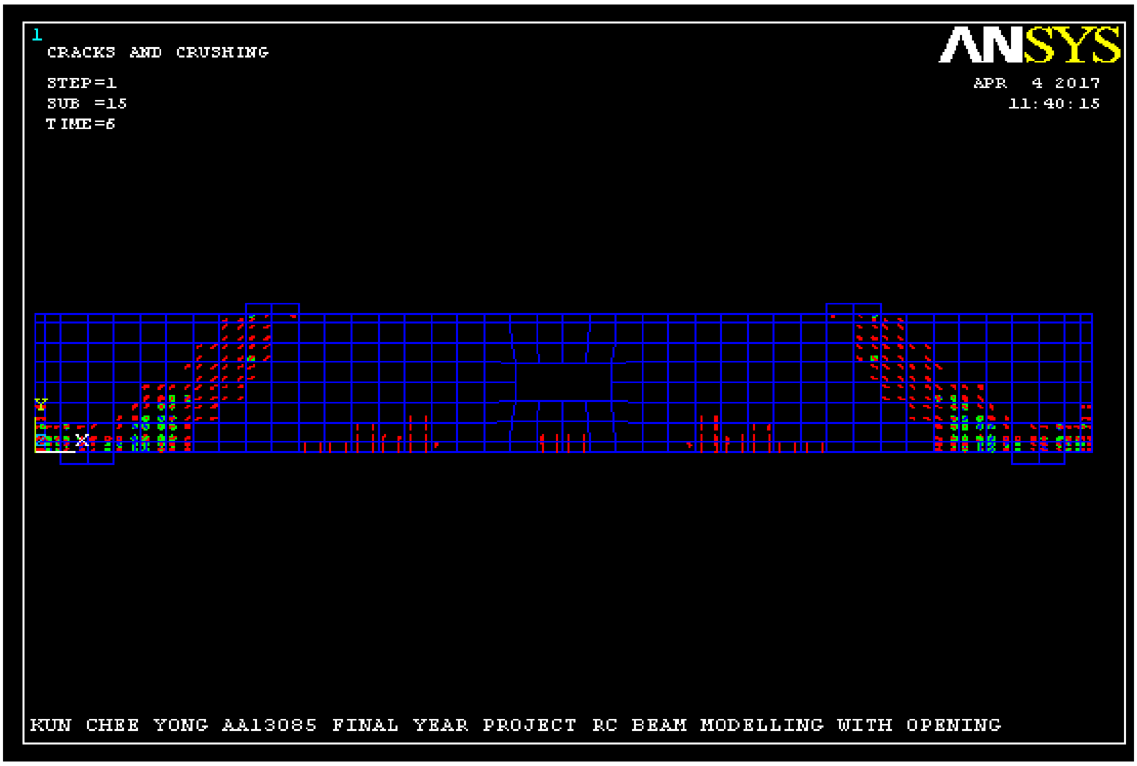

Figure 4.14 Cracking Pattern of Beam S4

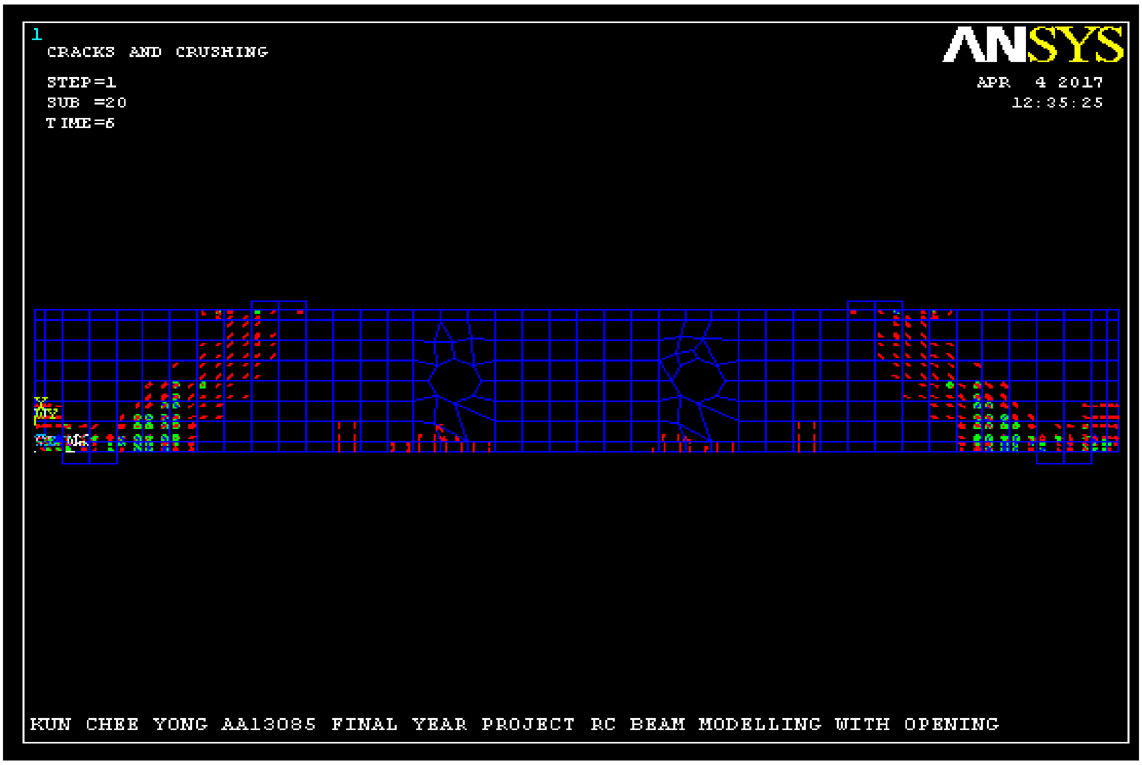

Figure 4.15 Cracking Pattern of Beam S5

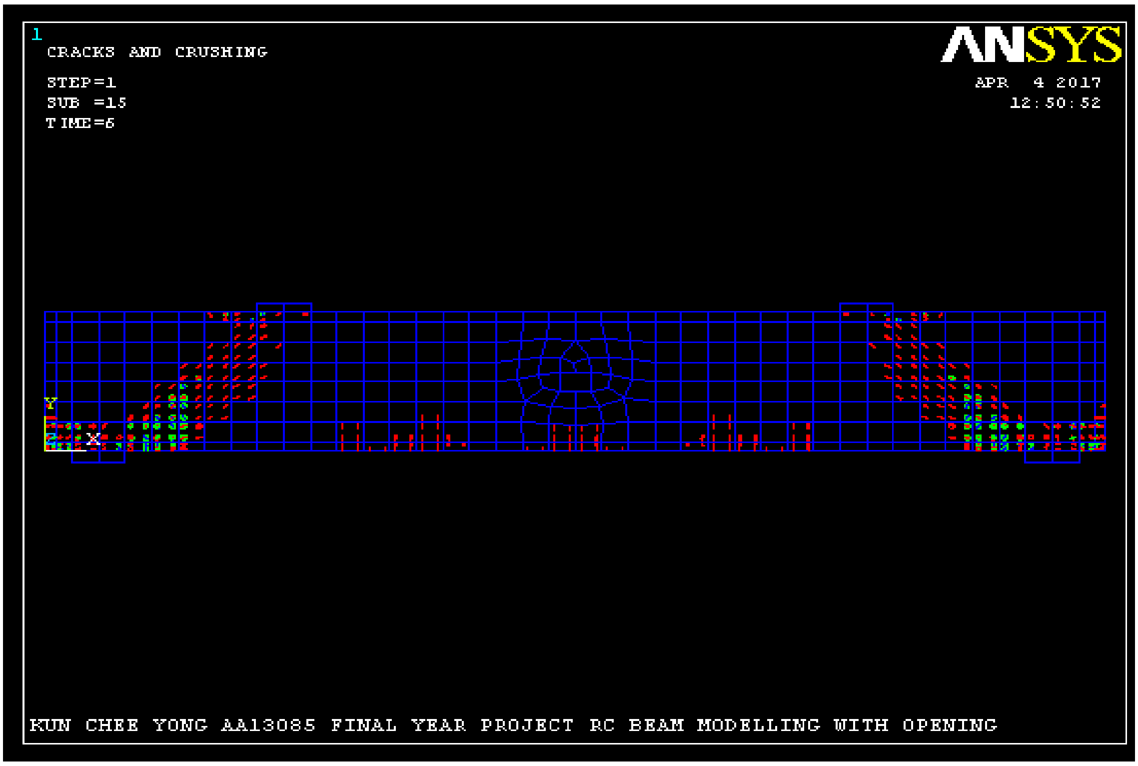

Figure 4.16 Cracking Pattern of Beam S6

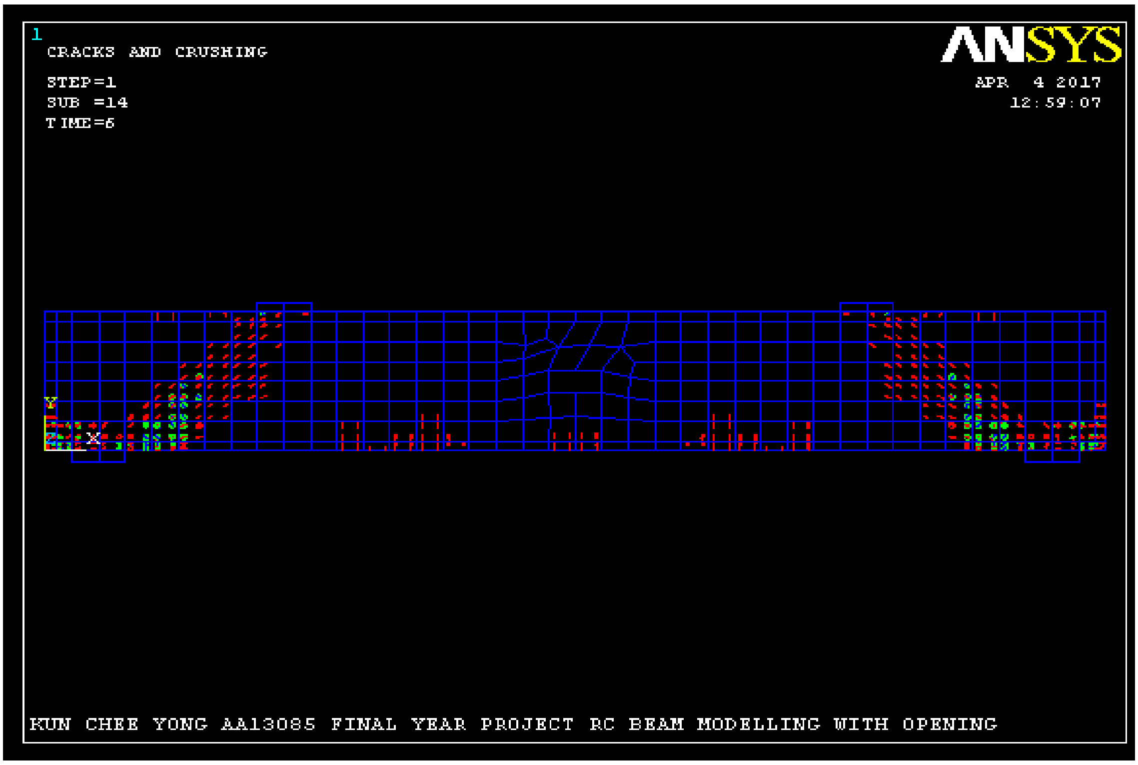

Figure 4.17 Cracking Pattern of Beam S7

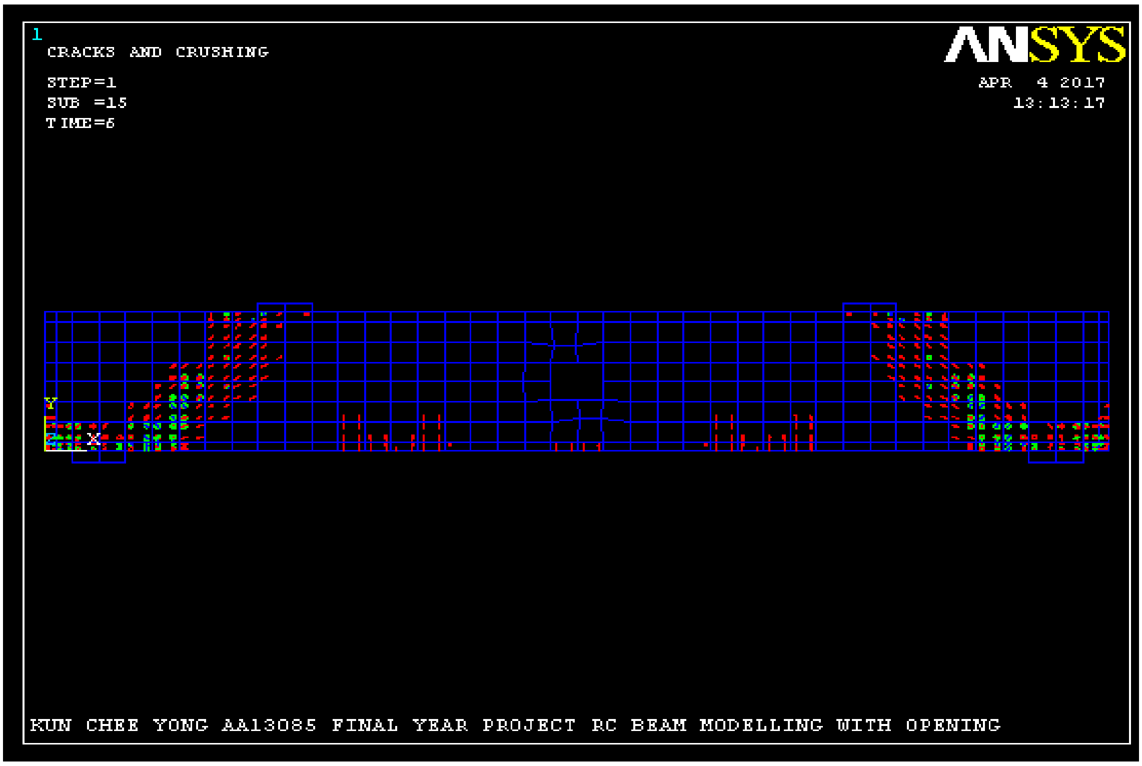

Figure 4.18 Cracking Pattern of Beam S8

CHAPTER 5

CONCLUSIONS & RECOMMENDATIONS

5.1 General

In general, the ANSYS software is a powerful engineering software which can used to run the FEA. The result obtained from the software is very reliable. In this study, all the objectives had been achieved. From this study, it was known that the making of opening in the mid-span of the beam not only affect the beam performance, it also causing disturbance to the load transfer and consequently lead to potential early cracking. Therefore, it is very important that we understand the behaviour of the beam with opening before the provision of opening in the web of RC beam.

5.2 Conclusions

In this study, the focus was on the effect of web opening to the RC beam. The opening was of different shape and different size. The result of mid-span deflection and crack pattern were obtained in order to study the effect of the opening to RC beam.

Based on the finding of the study, the following conclusion has been made:

i. When the provision of opening was not more than 0.48D of the beam width, the effect of opening to the RC beam was very small.

ii. The rectangular opening gave the largest mid-span deflection compared to other shape of opening which was 0.9148mm and an increment about 6.1% compare to solid beam.

iii. The circular opening gave the least mid-span deflection compared to other shape of opening which was 0.8932mm and an increment of 3.6%.

iv. The circular opening was the best geometry to be chosen for opening provision comparing to square and rectangular opening.

v. When the size of opening increase by 0.8646mm, 0.8662mm and 0.8699mm respectively, the mid-span deflection of the opening will also increase from 0.28% to 0.46% and 0.89%.

vi. When size of opening less than 0.48D, all the crack pattern will be same as the solid beam.

5.3 Recommendations

The following recommendation are offered in order to further study the effect of opening to the rectangular RC beam:

i. Larger size of opening can be study on similar RC beam
ii. Effect of different shape and size of opening toward the failure load of the beam can be studied.
iii. Effect of number of opening toward the RC beam performance can be studied.
iv. Same opening with different type of reinforcement arrangement can be considered for future study
v. Same study can be used for laboratory testing to compare the result with simulation finding.

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