SIMULATION STUDY ON BEHAVIOUR OF REINFORCED CONCRETE BEAM WITH VARIOUS SIZING AND SHAPE OF OPENING IN SHEAR ZONE

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ABSTRAK

Setiap bangunan perlu memasukkan paip dan saluran untuk pemasangan perkhidmatan mekanik dan elektrik. Dengan membuat pembukaan pada rasuk konkrit bertetulang boleh memberikan laluan untuk memasang semua paip dan saluran tersebut. Walau bagaimanapun, kesan pembentukan bukaan pada rasuk konkrit bertetulang perlu dipelajari untuk mengelakkan kegagalan rasuk. Tujuan kajian ini adalah untuk menentukan kesan pelbagai saiz pembukaan pekeliling dan bentuk pembukaan yang berbeza pada zon ricih konkrit bertetulang bertulang dari segi beban muktamad, pesongan dan retak. Ansys 12.0 digunakan dalam kajian ini untuk mensimulasikan ujian pemuatan 4 titik pada sejumlah 6 rasuk. Satu rasuk konkrit bertetulang pepejal yang dinamakan RCB S. Tiga rasuk yang mempunyai diameter pembukaan pusingan diameter yang berbeza iaitu 60mm, 80mm dan 100mm, yang dilabelkan sebagai RCB 1, RCB 2 dan RCB 3 masing-masing. Rasuk 2 yang lain dengan pembukaan segi empat tepat dan pembukaan persegi ditetapkan sebagai RCB 4 dan RCB 5 masing-masing. Saiz pembukaan bentuk pembukaan yang berbeza bersamaan dengan saiz pembukaan pekeliling 100mm. Semua rasuk mempunyai bahagian silang yang sama 120mm X 300mm X 2000mm dan susunan tetulang tidak berubah. Berdasarkan hasilnya, kemasukan pembukaan pekeliling dengan garis pusat yang lebih besar daripada atau sama dengan kedalaman rasuk 0.27 akan mengurangkan kapasiti muatan akhir dengan sekurang-kurangnya 21% sementara pesongan pertengahan rentang menurun sekurang-kurangnya 64%. Di samping itu, dalam kajian ini, bentuk optimum bagi pembukaan adalah pembukaan segi empat tepat kerana ia mempunyai beban muktamad tertinggi. Walau bagaimanapun, bukaan dengan sudut tajam menyebabkan tekanan tertumpu di kawasan yang menyebabkan keretakan awal berlaku. Kesimpulannya, diameter pembukaan pekeliling yang kurang daripada atau sama dengan kedalaman 0.2 rasuk akan tetap menjadi tingkah laku rasuk konkrit bertetulang pepejal.

ABSTRACT

Every building need to include pipes and ducts for the installation of mechanical and electrical services. By creating an opening at the reinforced concrete beam can provide a passage to install all of these pipes and ducts. However, the effects of creating an opening at the reinforced concrete beam have to be studied in order to prevent the failure of the beam. The aim of this study is to determine the effect of various size of circular opening and different shapes of openings on the shear zone of reinforced concrete beam in terms of ultimate load, deflection and cracking. Ansys 12.0 was used in this study to simulate 4 point loading test on a total of 6 beams. A solid reinforced concrete beam named as RCB S. Three beams with different size of circular opening in diameter which is 60mm, 80mm and 100mm, labelled as RCB 1, RCB 2 and RCB 3 respectively. The other 2 beams with rectangular opening and square opening designated as RCB 4 and RCB 5 respectively. The opening size of different shapes of opening was equivalent to the size of a 100mm circular opening. All beams have identical cross section of 120mm X 300mm X 2000mm and the reinforcement arrangement unchanged. Based on the result, inclusion of a circular opening with diameter larger than or equal to 0.27 of the beam depth will reduce the ultimate load capacity by at least 21% while the mid-span deflection decrease by at least 64%. Besides that, in this study the optimum shape for opening is rectangular opening as it has the highest ultimate load. However, openings with sharp corners causes stress to be concentrated at the area which leads to early cracking to occur. In conclusion, the diameter of circular opening less than or equal to 0.2 depth of the beam will remain the behaviour of a solid reinforced concrete beam.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In the structure of a building, reinforced concrete beam plays an important role in transferring the load. It is a horizontal member of a structure which carries transverse loads from floor slab or roof slab which then transfer all the loads including its own self weight to the columns or walls. Beams can have different type of supports such as simply supported beam, fixed beam, cantilever beam and continuous beam. The type of support we will be using for this research is simply supported beam. Nowadays, the construction of modern building requires to include a lot of pipes and ducts for the installation of essential services such as air conditioning, electricity, network cables and water supply system. Creating an opening in reinforced concrete beams can provide a passage to install all of these pipes and ducts. The routes of the pipes and ducts are usually located underneath the beam soffit which will then be covered by a suspended ceiling for aesthetic reason, thus creating a dead space (Mansur, 2006). The dead space will increase the storey-height which will also contribute to the total height of the building. Therefore, installation of pipes and ducts through the opening in reinforced concrete beam can reduce the height of the dead space and leads to a reduction in the total height of the building. Besides that, the weight of concrete beam will also be slightly reduced, thus allowing the designer to produce a more economical design. For a construction of a low-rise building, the cost saving might not be as significant as a construction of a high rise building. This is because that for a high rise building, any reduction in the storey-height are multiplied with the total number of stories of the building which will result in major cost saving.

Most of the time, structural engineers will place the opening at areas that can avoid the beams from losing its original properties. Mansur & Tan (1999) states that in order to avoid the critical region for shear failure, openings should not be placed closer than one-half of the beam’s depth, D to the supports and avoid placing openings closer than 0.5D to any concentrated load. However, there are situations that the opening will be required to create at critical region where shear is the main concern in order to simplify the installation and arrangement of the pipes and ducts. In the shear zone of a beam, the beam experiences greater shear load which tends to have a greater tendency to produce a sliding failure on a material along a plane that is parallel to the direction of the force. The creation of opening in shear zone will cause discontinuity in the normal flow of stresses which will lead to greater reduction of the beam shear capacity and stiffness of beam. As the opening depth or size increases, the greater the reduction in shear capacity of the beam. The reduction of shear capacity will be more significant when the opening is located at the line connecting the load and support points (Jithinbos et al, 2016).

Opening can be classified into pre-planned and post-planned. Post-planned openings are known after the structure have been constructed. It will involve drilling to create an opening at the existing structure. This might be risky because the opening might locate at areas that will affect the reinforcement or affect the behavior of the structure. Pre-planned openings are better than post-planned opening because the shape, size and location are known in advance during the design stage for pre-planned openings. Thus, designer can take the opening into consideration during the designing stage and provide proper reinforcement for the opening to ensure that sufficient strength and serviceability of beams with opening. In addition, opening in beams may come in different types of shapes such as circular, rectangular, triangular, diamond, trapezoidal and even irregular shapes (Prentzas, 1968). Although there are a variety of shapes available for opening, circular and rectangular openings are the most common shape being used in construction. Circular openings are normally for the passage of service pipes such as plumbing, network cables and electric while rectangular openings are required to provide passage for air-conditioning ducts (Mansur & Tan, 1999). However, opening shapes that consist of sharp corners are required to be rounded off to reduce the stress concentration at sharp corners and reduce the possibility of cracking at the sharp corners. In terms of the size of openings, many people use the term small and large to differentiate the size of opening because there are no standards that can be used to define the size of opening. According to Mansur & Tan (1999), classification of small and large opening based on the structural response of the beam. When the opening is small enough to maintain the solid beam behaviour, the opening can be classify as small opening. When the beam fails due to the opening, then the opening can be classify as large opening.

1.2 Problem Statement

Nowadays in the field of construction, reinforced concrete beams are frequently required to create a web opening in it to allow the passage for utility services such as pipes and ducts for the air-conditioning, water supply system, electricity, and telecommunication and computer network cables. Usage of reinforced concrete beams with opening for construction projects has increased significantly due to the convenience and economic considerations, especially for high rise building because opening in beams enable the designer to reduce the total height of the whole building. Circular opening can be classified as small or big opening which is normally differentiate using depth-to-diameter of the opening. Besides that, opening can also come in different type of shapes but the common shape of opening used in construction is the circular and rectangular. Figure 1.1 and Figure 1.2 shows the reinforced concrete beam with opening.

Figure 1.1 Beam with Opening

Figure 1.2 Beam with Opening

However, the presence of web opening in reinforced concrete beams will change the beam's cross section which will cause some changes in the behaviour of the beam into a more complex behaviour. In addition, there are cases where contractors made some modification on site without following the original design. According to Zdanowicz & Wojdak, (2013), there are difference in the static performance between the designed opening and constructed opening. Therefore, modification at site will introduce the risk of unexpected failure of the beam. Besides that, creating an opening in the beam increases the percentage for the beam to fail as the opening represents a source of weakness and the failure plane will always passes through the opening (Mansur, 1998). The ultimate strength, shear strength, crack width and stiffness may also be seriously affected due to the opening created in the beam. Different sizes and shapes of the opening will have different degree of influence to the behaviour of the reinforced concrete beams. In design codes, there are no detailed guideline and specifications in designing a reinforced concrete beam with opening. Finite element analysis can be used to predict the behaviour of the reinforced concrete beams with openings through modelling and meshing. Figure 1.3 shows the failure of a reinforced concrete beam with opening.

Figure 1.3 Failure at Opening of Beam

Source: Zdanowicz & Wojdak (2013)

1.3 Objective

The main objective of this study are:

i. To study the effect of the various size of circular opening on the shear zone of reinforced concrete beam in terms of ultimate load, deflection and cracking.

ii. To study the effect of the different shapes of opening on the shear zone of reinforced concrete beam in terms of ultimate load, deflection and cracking.

1.4 Scope of Study

The scope of this research was to investigate the effect of sizing and shape of the opening in shear zone on the behavior of reinforced concrete beams. ANSYS 12 software are used to simulate 4 point loading test on a total of 6 models. The model of the solid reinforced concrete beam was obtained and amended from a previous study by Chin et al. (2012). A solid reinforced concrete beam model without opening which is the control beam. 3 model of the beam with three different size of circular opening in diameter which is 60mm, 80mm and 100mm. The other 2 model with two different shape of opening which is rectangular and square while keeping the opening size and location unchanged. All beam models have the identical cross section of 120mm X 300mm X 2000mm. The reinforcement arrangement remained the same for every beam which is 2H10 at top and 2H12 at bottom for the main reinforcement while the shear link used H6 with 300 mm center to center. The material properties for concrete and reinforcement steel was adopted from CivilFEM. Grade 35 concrete was used for concrete with compressive strength, Fck = 35 MPa, modulus of elasticity, Ex =$33.282 \times 10^9 Pa$ and Poisson's ratio, $\upsilon_{xy} = 0.2$. As for the main reinforcement, reinforcing steel S400 was used with yield strength, Fyk = $400 \times 10^6 Pa$, modulus of elasticity, Ex =$200 \times 10^9 Pa$ and Poisson's ratio, $\upsilon_{xy} = 0.3$ while the link reinforcement, reinforcing steel Gr250 was used with yield strength, Fyk = $250 \times 10^6 Pa$, modulus of elasticity, Ex =$200 \times 10^9 Pa$ and Poisson's ratio, $\upsilon_{xy} = 0.3$. Figure 1.4 shows the cross section of the reinforced concrete beam and Figure 1.5 shows the section view of the reinforced concrete beam and the location of the opening. Table 1.1 shows the dimensions of the reinforced concrete beam and the dimensions and shapes of the openings. Figure 1.6 shows the setup of 4 point loading test. 4 point loading test in Ansys with 2 point loads at the midspan of the beam. Both of the point load was 500mm apart and 650mm from support. The standard used are ASTM C78-02.

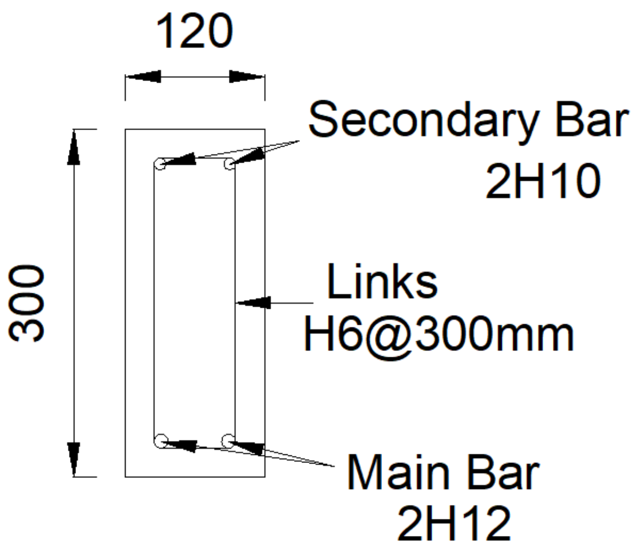

Figure 1.4 Cross Section of Beam

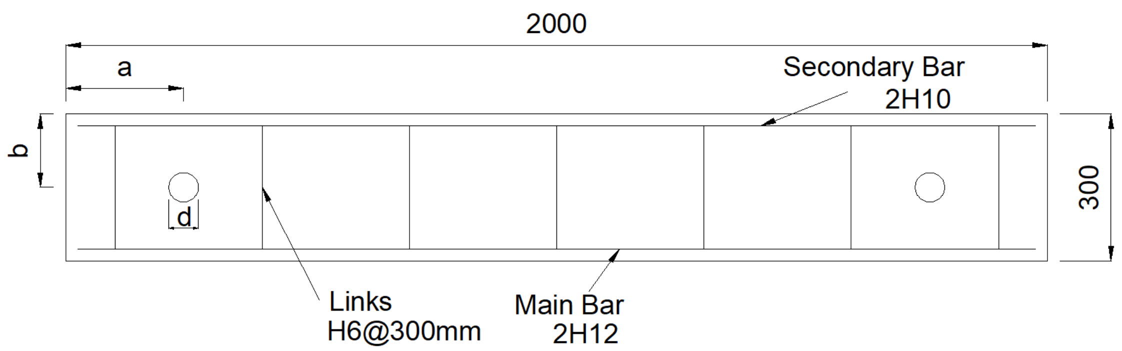

Figure 1.5 Section View of Beam and Location of Opening

Table 1.1 Beam Dimensions

Beam Model	**Size of Beam (B*H*L)**	**a (mm)**	**b (mm)**	**Size of Opening, d (mm)**	**Area of Opening (mm^2)**	**Shape of Opening**
RCB S	120 X 300 X 2000mm	-	-	-	-	-
RCB 1	120 X 300 X 2000mm	240	150	60	2827	Circular
RCB 2	120 X 300 X 2000mm	240	150	80	5027	Circular
RCB 3	120 X 300 X 2000mm	240	150	100	7854	Circular
RCB 4	120 X 300 X 2000mm	240	150	121×65	7865	Rectangular
RCB 5	120 X 300 X 2000mm	240	150	88×88	7744	Square

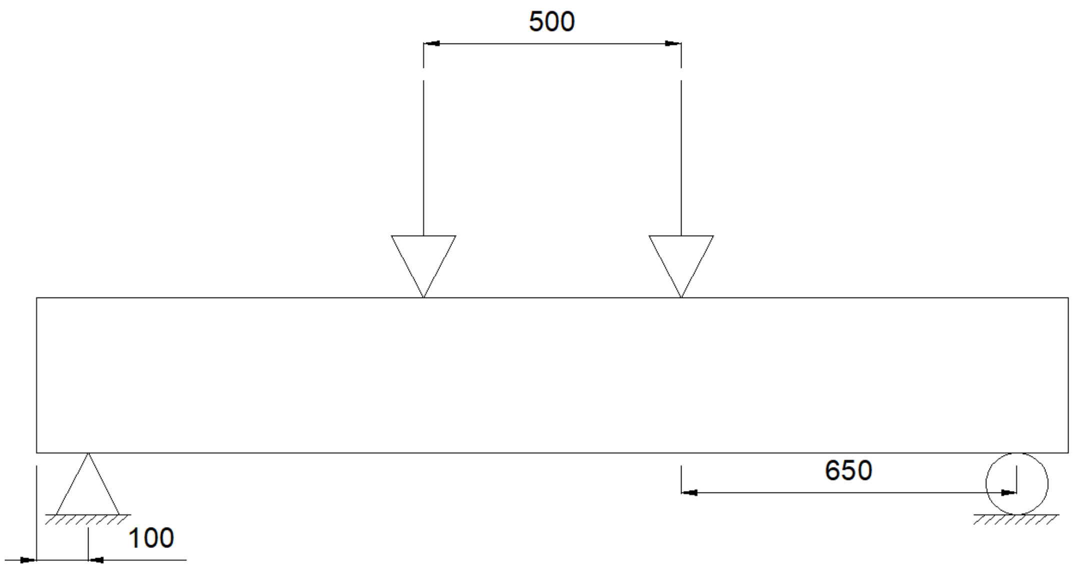

Figure 1.6 4 Point Loading Test

1.5 Significance of Study

This study provided a better understanding on the effect of various sizing and shape of opening on the behaviour of reinforced concrete beam in terms ultimate load, deflection and cracking. As different sizes of circular opening and different shape of openings have different degree of effect towards the behaviour of reinforced concrete beam. ANSYS were used to simulate the behaviour of the reinforced concrete beam. Therefore, design engineers can know in advance the behaviour of the reinforced concrete beam and provide proper reinforcement for the openings when the openings are located at the reinforced concrete beam in order to simplify the installation of pipes and ducts for essential services.

CHAPTER 2

LITERATURE REVIEW

2.1 General

This chapter was done to understand better on the behaviour of reinforced concrete beam with opening based on previous researches. The main function of a reinforced concrete beam is used to transfer the load from slab to column. However, there are times where opening are required to be located at the shear zone of reinforced concrete beam which will cause the reinforced concrete beam to have a complex behaviour. Opening with different size, shape and location will have different impact towards the reinforced concrete beam. There are a number of previous research has been carried out on reinforced concrete beam with openings which was reviewed in this chapter.

2.2 Failure Mode of Beam

In the service life of a concrete structures, it may be subjected to various loading and excessive loading may cause the concrete structure to fail. Failure of a reinforced concrete beam with opening can be classified into 2 different types of failure modes which is beam-type failure and frame-type failure.

2.2.1 Beam-type Failure

Beam-type failure is a phenomena that can be observed normally in a solid beam. According to Mansur (1998), a 45 degree inclined failure plane may be assumed. It is the same for a beam with opening but the failure plane passes through the center of the opening. Figure 2.1 shows the beam-type failure.

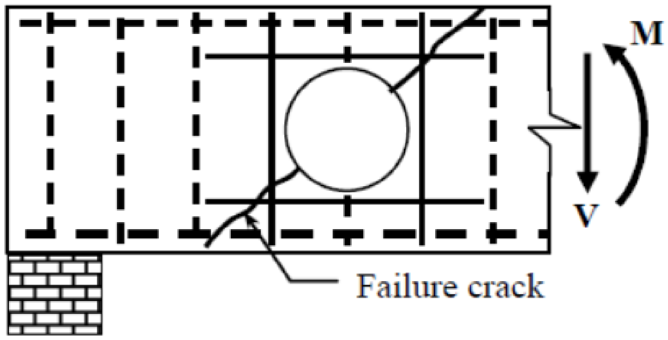

Figure 2.1 Beam-type Failure
Source: Mansur (1998)

2.2.2 Frame-type Failure

Frame-type failure happens because of the formation of the 2 independent diagonal cracks which located above and below of the opening. From this type of failure, it shows that each member behaves as an independent entity similar to a member in a framed structure (Mansur 1998). Figure 2.2 shows the frame-type failure.

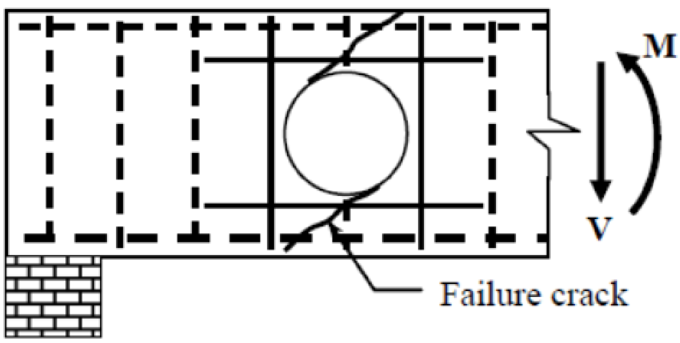

Figure 2.2 Frame-type Failure
Source: Mansur (1998)

2.3 Size of Opening

In terms of the size of openings, many people use the term small and large to differentiate the size of opening because there are no standards that can be used to define the size of opening. Mansur & Hasnat (1979) states that openings that are circular, square, or nearly square in shape are consider as small openings. According to Mansur & Tan (1999), classification of small and large opening based on the structural response of the beam. When the opening is small enough to maintain the solid beam behaviour, the opening can be classify as small opening. When the beam fails due to the opening, then the opening can be classify as large opening. Whereas, according to Somes and Corley (1974), a circular opening can be classify as large opening when its diameter exceeds 0.25 times the depth of the web. The mode of failure of a small opening in the web of a beam, unreinforced in shear, remains the same as the failure mode of a solid beam. Besides that, depth of openings should be limited to 50% of the overall beam depth. For situation where larger opening are required, it is preferable to create multiple openings to replace the single opening. Saksena et al. (2013) states that by fixing the location of opening at distance L/4, introducing opening with diameter of 45% of depth will decrease the strength by at least 21% while introducing circular opening with diameter of 55% of depth will decrease the strength by at least 52% compared to solid beam. Based on El-kareim and El-sayed (2017), reinforced concrete beams with circular openings have diameters equal to 0.25d and 0.5d, the shear force were equal to 65% and 37% from the shear force of the control beam respectively. According to Suresh and Angeline (2014), the ultimate load capacity reduces as the size of the opening increases.

2.4 Location of Opening

The location of opening in reinforced concrete beam is also one of the factors that will affect the behavior of the reinforced concrete beam. According to Mansur & Tan (1999), the optimal location for openings in rectangular beams are at mid-depth of the section. The location of openings should avoid shear regions which is closer than one-half of the beam's depth D to the supports. This is to avoid the critical region for shear failure and reinforcement congestion. Similarly, areas that are closer than 0.5D to any concentrated load should be avoided while selecting the location of opening. According to Saksena et al. (2013), the best location to create an opening in the beam is the flexure zone of the beam which is the center part of the beam. The effects on the load carrying capacity is very small when the opening is located at L/2 distance of the beam. By using the same size of opening, locating the opening at distance L/4 of the beam will decrease the strength of the beam by at least 52% compared to solid beam while locating the opening at distance L/8 of the beam will decrease the strength of the beam by at least 62% compared to solid beam. Based on Ahmed (2014), the location of the opening has a large effect on the behavior of the beam. The largest effect on beam will occur when the opening is located at the shear zone and the least effect on beam will occur when the opening is located at the flexure zone. Therefore, flexure zone which is the middle of a beam is the best location to create an opening. Morsy and Barima (2018), states that when the opening is in the shear zone, the load capacity of the reinforced concrete beam will greatly reduce compared to opening in the flexural zone.

2.5 Shear Zone

There are 2 different zones in reinforced concrete beam which is flexural zone and shear zone. Shear zone is consider as critical region in the beam. Introducing an opening in the shear zone of a beam will greatly affect the behavior of the beam. The ultimate shear strength decreases as the location of the web opening move towards the support which is also known as shear zone (Aziz, 2016). According to Maaddawy and Ariss (2012), inclusion of web opening in the shear zone will drastically reduce the beam shear capacity and stiffness. The shear capacity will further reduce when the size of the opening increases. Based on Abdalla et al. (2003), experimental investigation on the behaviour and strength of reinforced concrete beams with shear openings. The ultimate load carrying capacity of a reinforced concrete beam significantly decreases when an un-strengthened opening is located in the shear zone of the reinforced concrete beam. The beam capacity may reduce by 75% when an un-strengthened opening with height of 0.6 the beam depth is introduced in the shear zone of a reinforced concrete beam. Openings located at the shear zone of a beam has the largest effect on the behavior of the beam. Excessive shear cracks were found around the opening when a large opening is located at the shear zone of a reinforced concrete beam. The failure mode of the beam was in shear (Ahmed, 2014). Chin, Shafiq and Nuruddin, (2012), a significant decrease in the beam capacity approximately 74% and 69% when introducing large square openings in a shear zone of reinforced concrete beam at a distance of 0.5d and d respectively, away from the support. Campione and Minafo (2012), a reduction in load-carrying capacity occurs in the range of 18 to 30% when the opening is placed within the shear zone of a beam. According to Ibrahim and Erfan (2017), locating an opening at the shear span of the reinforced concrete beams will reduces its ultimate strength. Suresh and Angeline (2014), states that the load capacity of the reinforced concrete beam are reduced by 45% to 70% when there is opening located in the shear zone of the reinforced concrete beam.

2.6 Shape of Opening

There are various type of shape of opening. Amiri and Masoudnia (2011), investigates the effects of unreinforced opening on the behavior of concrete beams using fem method. From the study, they states that circular and square opening have difference in terms of ultimate load capacity. The ultimate load capacity of circular opening is 9% higher than square opening. According to Latha and Naveen (2017), also states that the circular opening is 9.58% stronger than the square opening in terms of ultimate load capacity. Based on El-kareim and El-sayed (2017), reinforced concrete beams with circular, square and rectangular opening, the shear forces were equal to 37%, 27% and 23% from the shear force of the control beam respectively. The best shape of an opening is the circular shape because circular opening shows the least reduction in ultimate load Ahmed (2014). According to Alsaeq (2013), the optimum shape for opening is the narrow rectangular with the long sides extended in the horizontal direction. Besides that, according to Aykac et al. (2014), reinforced concrete beam with the same reinforcement, reinforced concrete beam with circular openings have higher ultimate load and ductility compared to reinforced concrete beam with rectangular openings. Morsy and Barima (2018), states that circular opening showed the least reduction in terms of ultimate load, therefore circular opening is the optimum shape for opening.

2.7 Deflection

Deflection is the degree of a structural element is displaced under load. Reinforced concrete beam may not fail due to excessive deflection. However, it is necessary to check the deflection to prevent it from deflecting excessively which will cause damage to architecture finishes. Deflection of a beam can be calculated by using formulas which will depend on the type of beam and type of loading. The maximum deflection of a beam with opening usually happens at the high moment end of the opening. In general, as the load increases, the slope of the load deflection curve of the beam decreases until it becomes horizontal at ultimate load. At any particular load, the deflection increases as the length of the opening gets longer or the opening depth increases (Mansur & Tan, 1999). Figure 2.3 shows the model for the estimation of deflection at opening. Mansur (2006) states that the deflection of a reinforced concrete beam with opening can be calculated using:

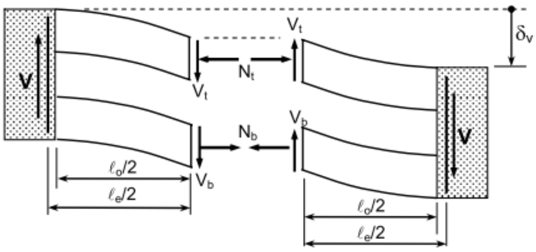

Figure 2.3 Model for the Estimation of Deflection at Opening

Source: Mansur (2006)

$$\delta_v = \frac{V l_e^3}{12 E_c (I_t + I_b)} \quad 2.1$$

Where:

l_e = distance between the full-depth stirrups on each side of the opening.

I_t = moment of inertia for top struts

I_b = moment of inertia for bottom struts

E_c = modulus elasticity of concrete

The maximum deflection of the beam can be calculated as

$$\delta = \delta_w + \delta_v \quad 2.2$$

Where δ_w is the maximum deflection of the beam without opening.

A research shown that a beam with 2 circular openings, one in each shear zone is found that the presence of opening cause approximately 30% of reduction in shear strength and the deflection was increased by approximately 24% when compared to control beam without openings. Introducing opening in reinforced concrete beams will cause the stiffness value to decrease and increase in the deflection values (Osman et al, 2017). According to Daniel and Revathy, (2014), investigates on flexural strength of reinforced concrete beam with rectangular opening. It was found that larger deflection will occur when the length of the opening of the beam increases. Ahmed (2014), the beam deflection increased by 11% more than the control beam when the large opening is located at the flexure zone of a reinforced concrete beam. Whereas, the beam deflection decreased by 57% more than the control beam when the large opening is located at the shear zone of a reinforced concrete beam. According to Kumar et al (2013), the maximum deflection decreases when the circular opening is introduced in the reinforced concrete beam. Suresh and Angeline (2014), states that the deflection of the reinforced concrete beam reduces from 20% to 55% when openings are located in the shear zone of the reinforced concrete beam. The deflection of the reinforced concrete beam with opening reduces when compared to solid beam because of the immediate cracks propagated at the area of the openings and flexural cracks at mid-span.

2.8 Ultimate Load

Ultimate load will be affected when an opening is introduced in a reinforced concrete beam. According to Mansur & Tan (1999), the strength of reinforced concrete beam decreases whenever the opening is located further than the center or the size of the opening increases. There have been numerous studies states that when the diameter of an unreinforced circular opening in a beam is less than or equal to 44% of the depth of the beam, the beam will behave similarly to a solid beam. While, when the diameter of an unreinforced circular opening in a beam is more than 44% of the depth of the beam, the opening will reduce the ultimate load capacity of the reinforced concrete beam by at least 34.29% (Latha and Naveen, 2017; Rezwana et al., 2014). According to Ahmed (2014), introducing a small opening at the shear zone of a reinforced concrete beam will cause the ultimate load to reduce by a maximum of 2.5%. While introducing a large opening at the shear zone of a reinforced concrete beam will lead to a reduction of maximum 64% in terms of ultimate load. Introducing large circular opening in reinforced concrete beam which is the diameter more than 48% of the depth of the beam reduces the ultimate load capacity by at least 26% (Amiri and Masoudnia, 2011). According to Abdulla (2015), the load capacity decreased by 37.57% when the circular opening is introduced in the beam.

2.9 Type of Cracking

One of the failure mode is the crack pattern of the beam. There are different type of cracking pattern. Mansur and Tan (1999), states that as the size of opening increase, the maximum crack width at all load levels increases. Besides that, increase in the distance of the opening from the center will lead to larger crack widths. Aykac et al, (2014), states that rectangular openings with sharp corners causes stress concentrations which result in cracking and leads to the reductions in the flexural rigidities without exhibiting full ductility. According to Ibrahim and Erfan (2017), there are more cracks concentrated at the area of the opening compared to the other areas of the reinforced concrete beam. Suresh and Angeline, (2014), states that there will be more formation of cracks when the size of the opening increases. According to Kum, (2011), cracking of a beam can be classified into 6 types which are flexure tension cracks, flexure shear cracks, diagonal tension shear cracks, shear compression cracks, flexural compression cracks and dowel cracks. Shear compression and flexural compression cracks are the symptom of ultimate physical failure while the other 4 types appear at loads well beyond service. Figure 2.4 shows the types of cracking.

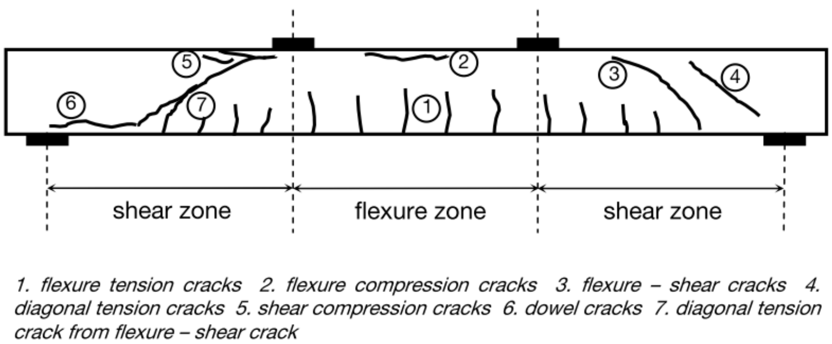

Figure 2.4 Types of Cracking

Source: Kum, (2011)

CHAPTER 3

METHODOLOGY

3.1 General

In this study, ANSYS CivilFEM 12.0 was used to simulate the reinforced concrete beam with openings in order to determine the effect of openings on the reinforced concrete beam. ANSYS CivilFEM 12.0 is a finite element software which can be used to simulate interactions of all disciplines. The general process of ANSYS in this study can be divided into 3 part which is preprocessing, solution and postprocessor. The details of the process were elaborated in the following sections. Figure 3.1 shows the flow chart of the process.

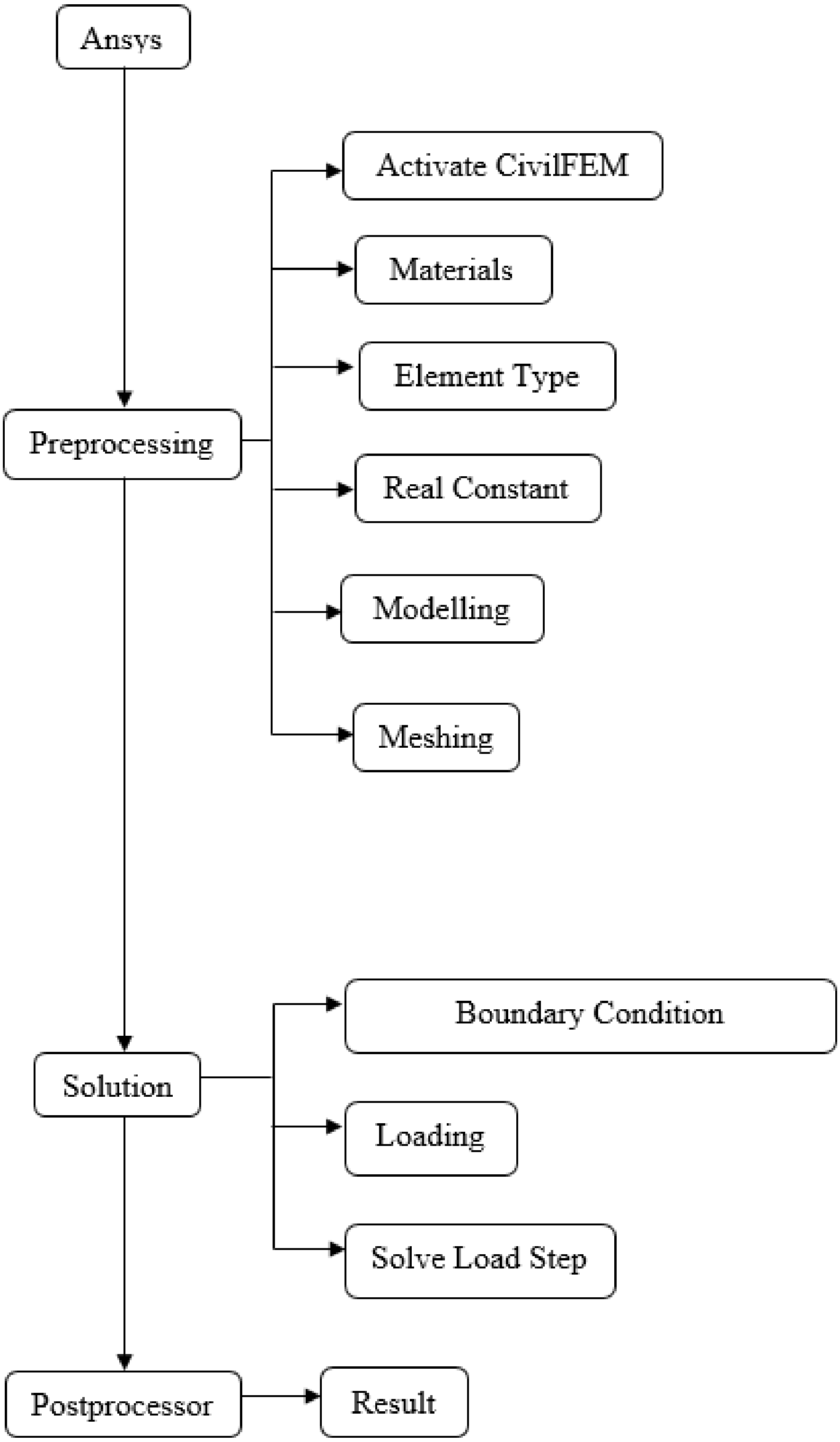

Figure 3.1 Flow Chart for ANSYS

3.2 Preprocessing

Preprocessing is the stage where the model is set up. This is the stage where the geometry of the beam and materials used are defined.

3.2.1 Activate CivilFEM

The first step in the preprocessing stage is to activate CivilFEM. After CivilFEM is activated, the codes and units are set. The codes used for this study is Eurocodes 2 (EN 1992-1-1:2004/AC:2008) which is for reinforced concrete analysis and design. In order to model accurately, the system unit used is international system unit. Figure 3.2 shows the activation of CivilFEM. Figure 3.3 shows code set-up. Figure 3.4 shows the selection of the unit system.

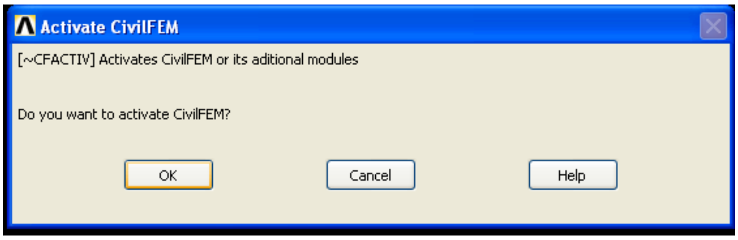

Figure 3.2 Activate CivilFEM

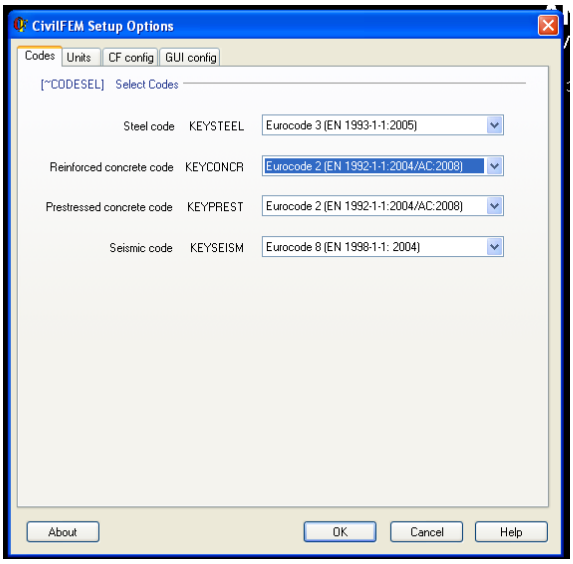

Figure 3.3 Select the Code Used

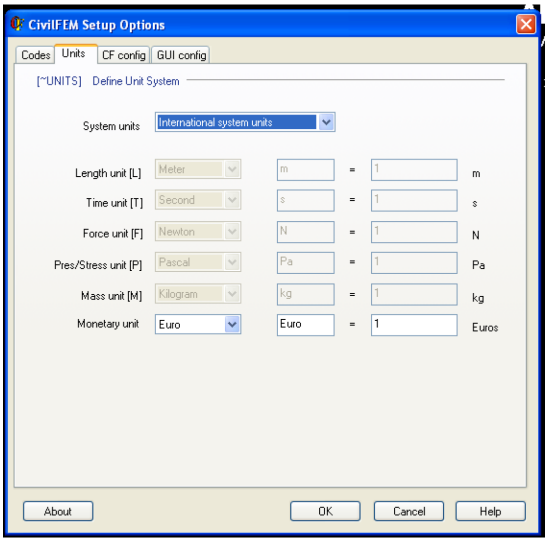

Figure 3.4 Select System of Units Used

3.2.2 Materials

A material is defined by its material constants. Every element has to be assigned a particular material. The material used to model is selected from the material library of CivilFEM which is concrete grade C35/45, main reinforcement S400 and shear link is Gr250. The material properties of the materials used in this study are defined by the material library of CivilFEM which is based on Eurocode 2. Figure 3.5 shows the material used.

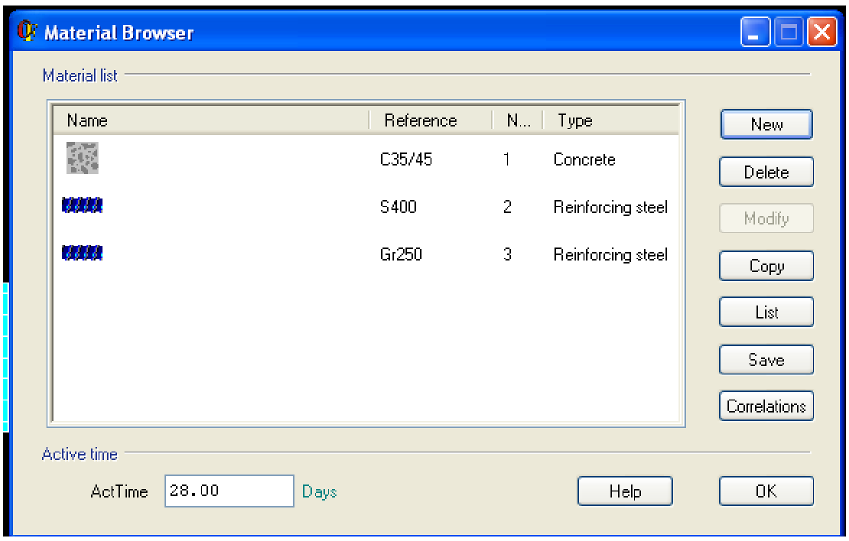

Figure 3.5 Material Used

3.2.3 Element Type

There are a lot of different element type available to choose in ANSYS. Each element type has a unique number and a prefix that identifies the element category. However, the element type used for this model is SOLID 65 and LINK 8. SOLID 65 which is suitable for three-dimensional modelling of solids is used to define concrete in this analysis. LINK 8 which is three-dimensional spar element is a uniaxial tension-compression element with three degrees of freedom at each node is used to define steel reinforcements in this analysis. Figure 3.6 shows the element type used.

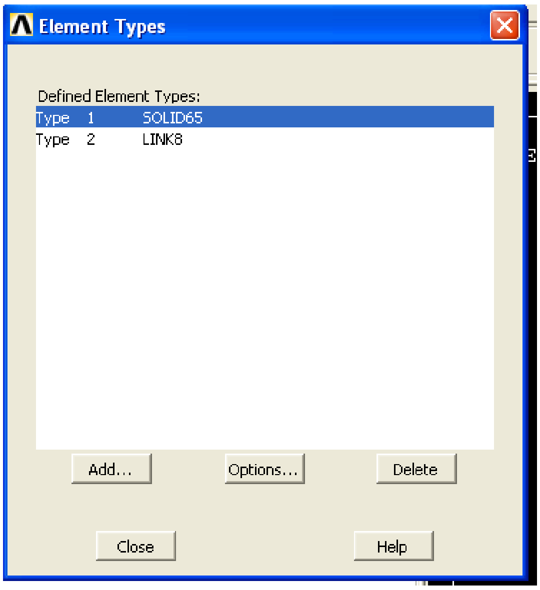

Figure 3.6 Element Type Used

3.2.4 Real Constant

Real constant are properties used to define the element, such as cross-sectional properties. In this analysis, the cross-sectional area of LINK 8 are set for steel reinforcement bar of size 6mm, 10mm and 12mm respectively. The cross sectional area of 6mm steel reinforcement bar is $2.827 \times 10^{-5} m^2$. The cross sectional area of 10mm steel reinforcement bar is $7.854 \times 10^{-5} m^2$ while cross sectional area of 12mm steel reinforcement bar is $11.31 \times 10^{-5} m^2$. Figure 3.7 – 3.9 shows the real constant for 6mm, 10mm, 12mm reinforcement respectively.

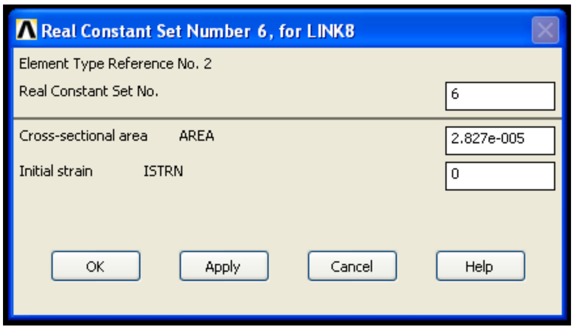

Figure 3.7 Real Constant for 6mm Steel Reinforcement Bar

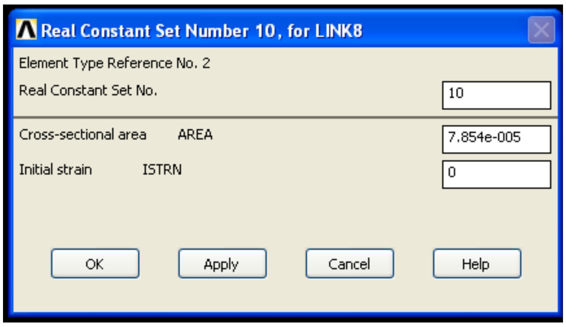

Figure 3.8 Real Constant for 10mm Steel Reinforcement Bar

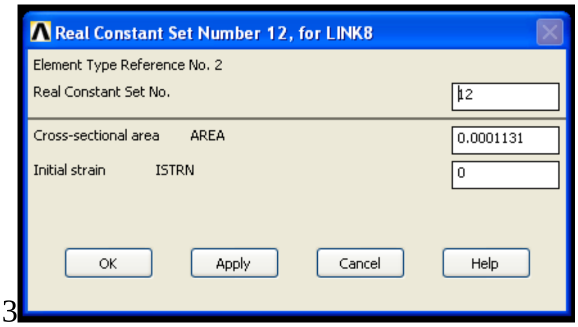

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Figure 3.9 Real Constant for 12mm Steel Reinforcement Bar

3.2.5 Modelling

This is the step where the dimension of the reinforced concrete beam are modelled. In ANSYS, model can be made up of nodes, lines, areas or volumes depending on whether the model is one, two or three dimensional. In this analysis, volumes are used to define the concrete beam and lines are used to define the steel reinforcement bar. These volumes and lines are created base on the coordinate system. Opening of the beam are created by using Boolean operations. Figure 3.10 shows the model of the reinforced concrete beam with 100mm circular opening. Figure 3.11 shows the model of the reinforcement.

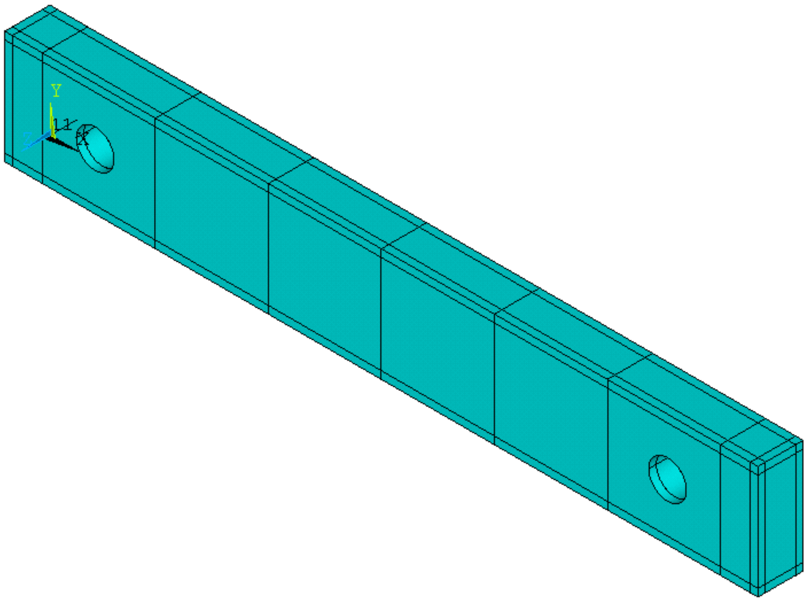

Figure 3.10 Model of Reinforced concrete beam with 100mm circular opening

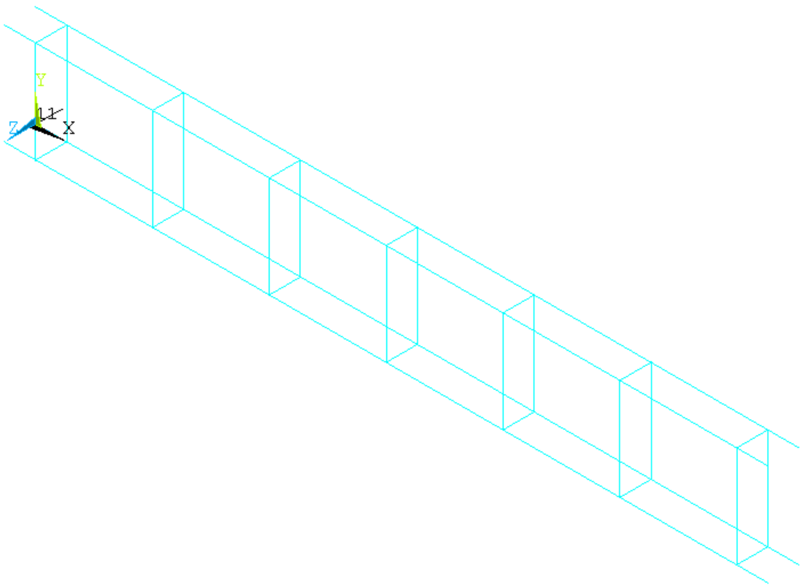

Figure 3.11 Reinforcement of reinforced concrete beam

3.2.6 Meshing

Meshing is a step where it will affects the accuracy and the duration of the whole analysis. If a smaller mesh size is used, the accuracy of the analysis will be more accurate but more computational time is needed in order to solve the analysis. In ANSYS, the mesh size can be done automatically or given a specified number of elements or specified size of element. The mesh size used in this analysis is 0.05m. Figure 3.12 and 3.13 shows the meshed model of the reinforced concrete beam and reinforcement respectively.

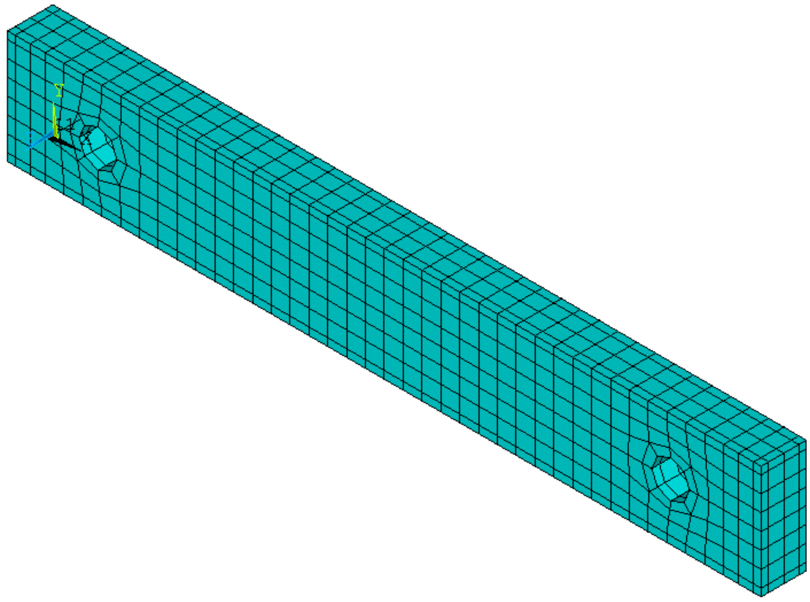

Figure 3.12 Meshed model

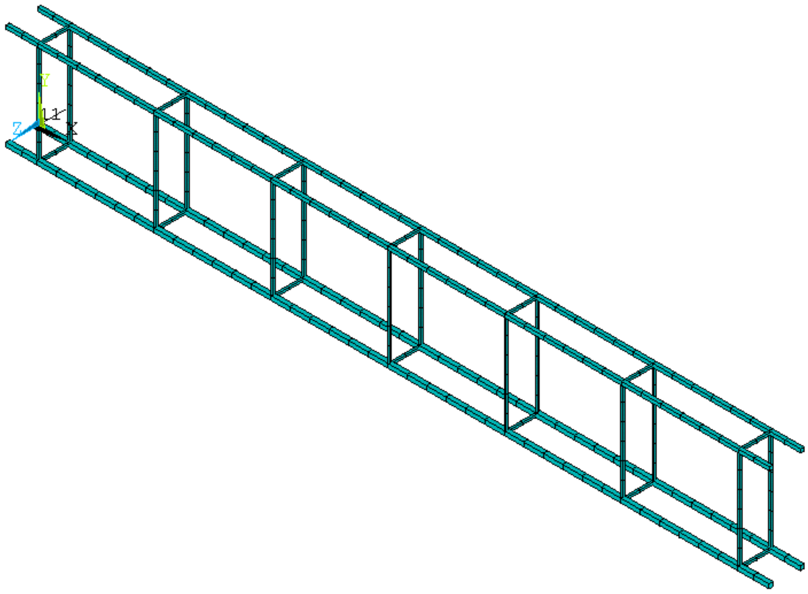

Figure 3.13 Meshed reinforcement

3.3 Solution

Solution is the stage to define the type of analysis, loading, boundary conditions and solve the analysis. Everything have to be assigned properly otherwise it will affect the result of the whole analysis because there are different type of loading and boundary condition.

3.3.1 Boundary Condition

Boundary conditions are usually applied on nodes or elements and it is used to define whether the support of the model is fixed, pinned or roller. In this analysis, the beam is simply supported where one end is pinned and the other end is roller. The support are 100mm away from both ends and 1800mm apart from each other. Figure 3.14 shows the boundary condition of the model.

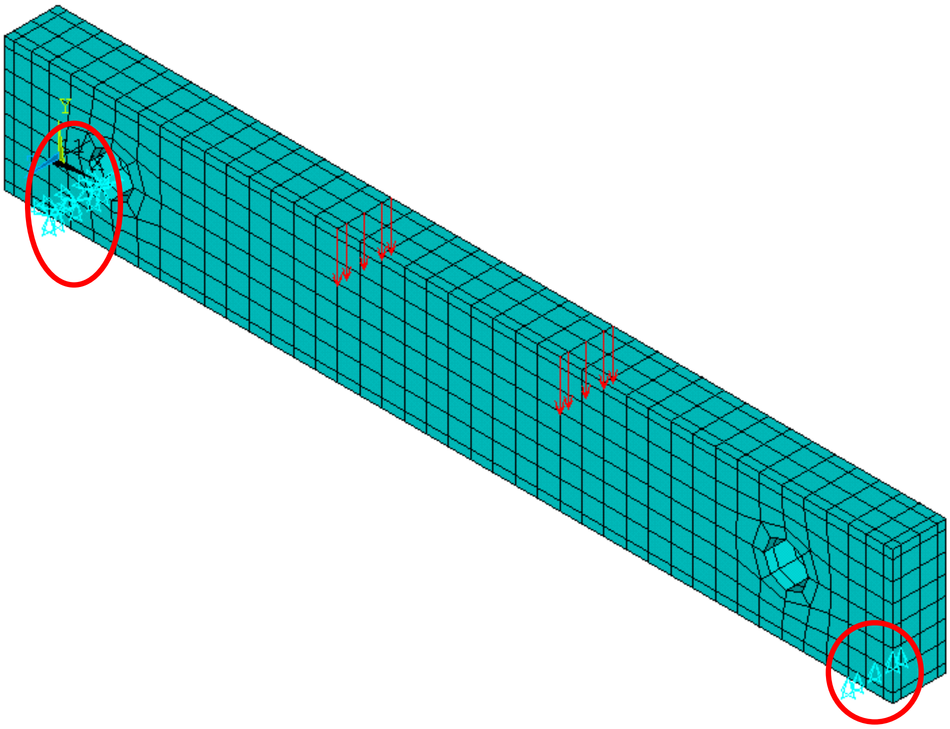

Figure 3.14 Boundary conditions of the model

3.3.2 Loading

In this analysis, four point bending test are used. There will be two concentrated point load at the midspan of the beam which is 750mm from the end and 500mm apart of each other. The increment of the load is 10N for every sub-step until the failure of the reinforced concrete beam. Figure 3.15 shows the loading on the model.

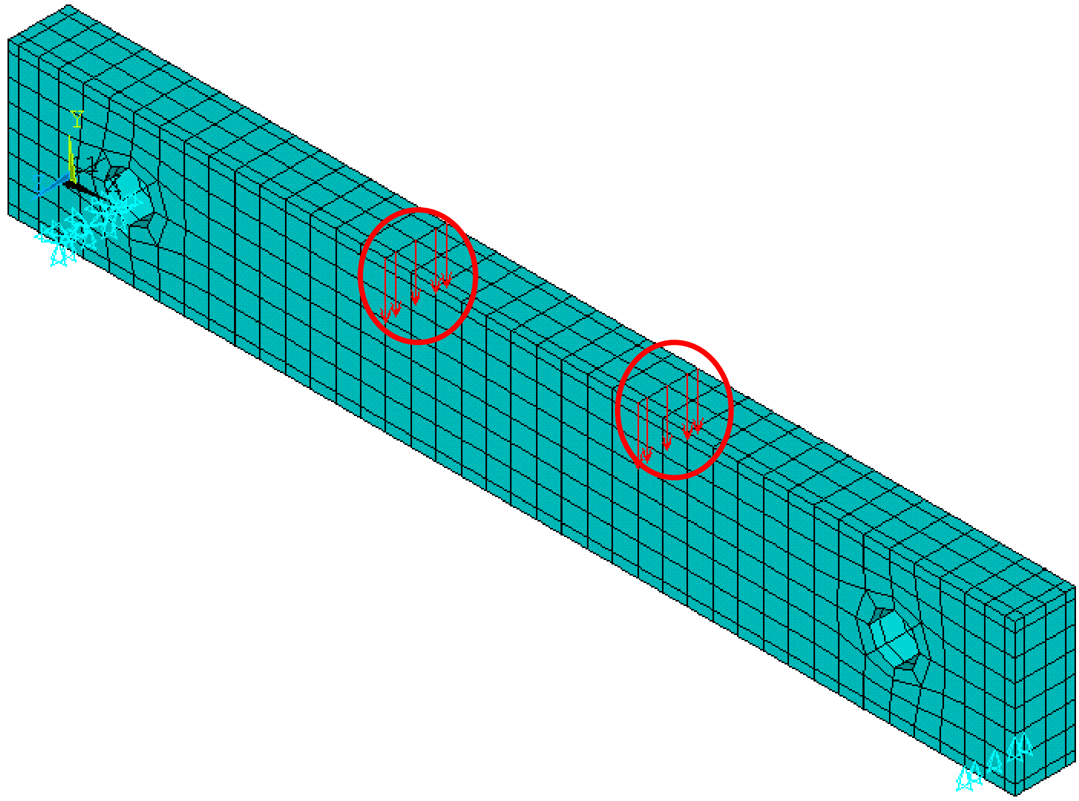

Figure 3.15 Loads applied on model

3.3.3 Solve Load Step

After the boundary condition and loading are assigned, the analysis is solved using ANSYS. In this analysis, non-linear finite element analysis is used. Figure 3.16 – 3.20 shows the set-up for the simulation.

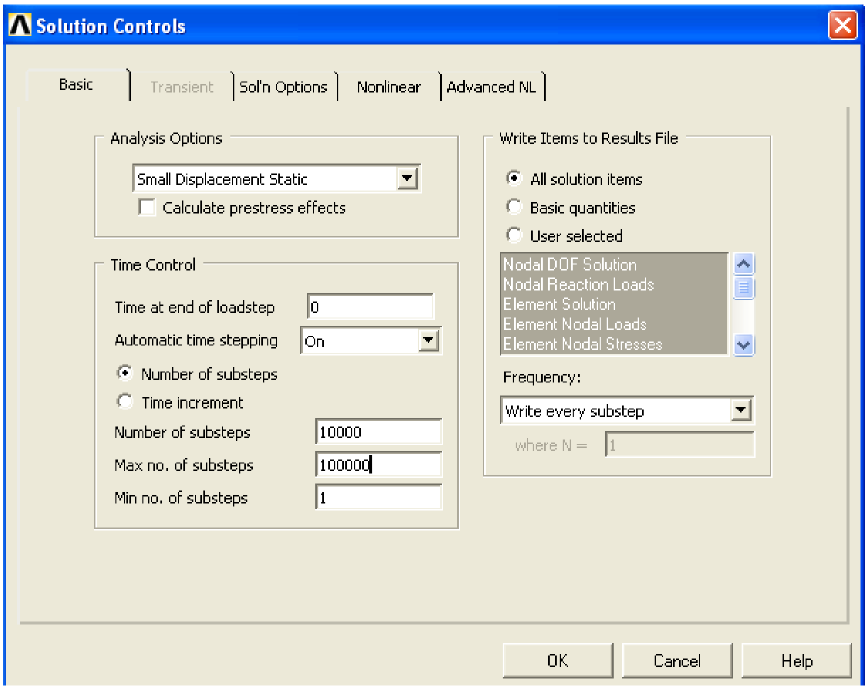

Figure 3.16 Tab of 'Basic'

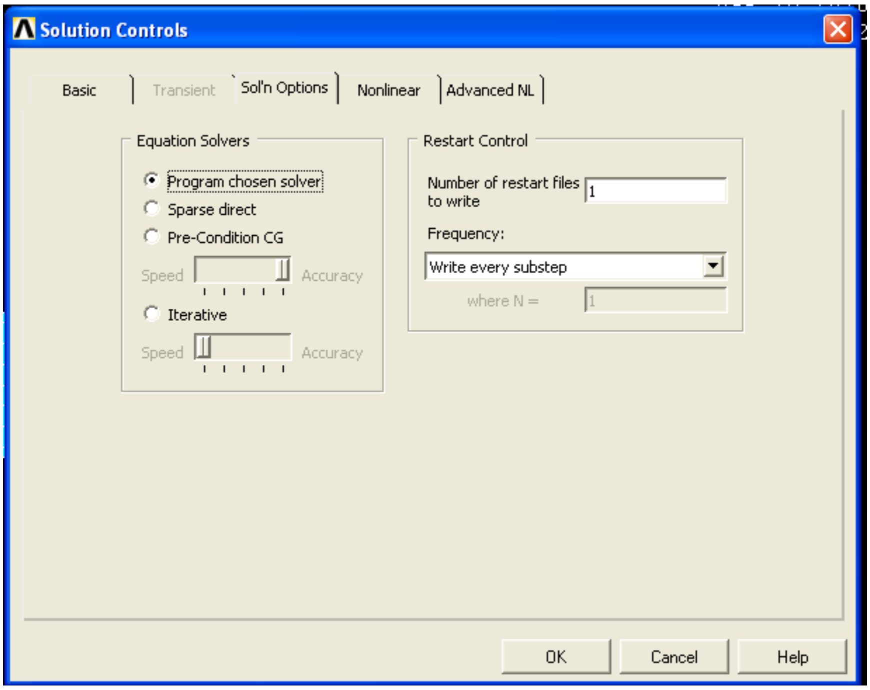

Figure 3.17 Tab of 'Sol'n options'

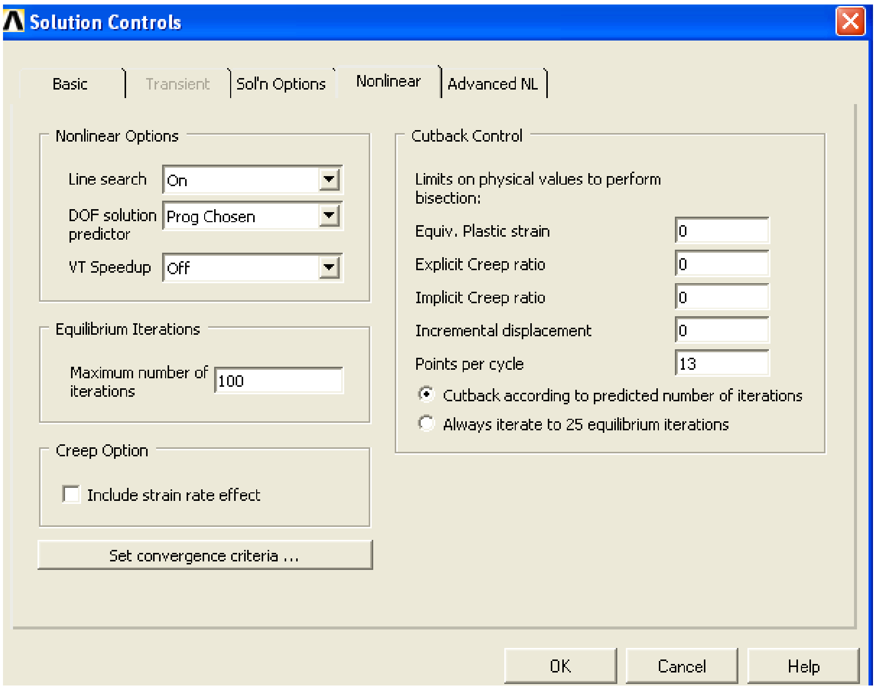

Figure 3.18 Tab of 'Nonlinear'

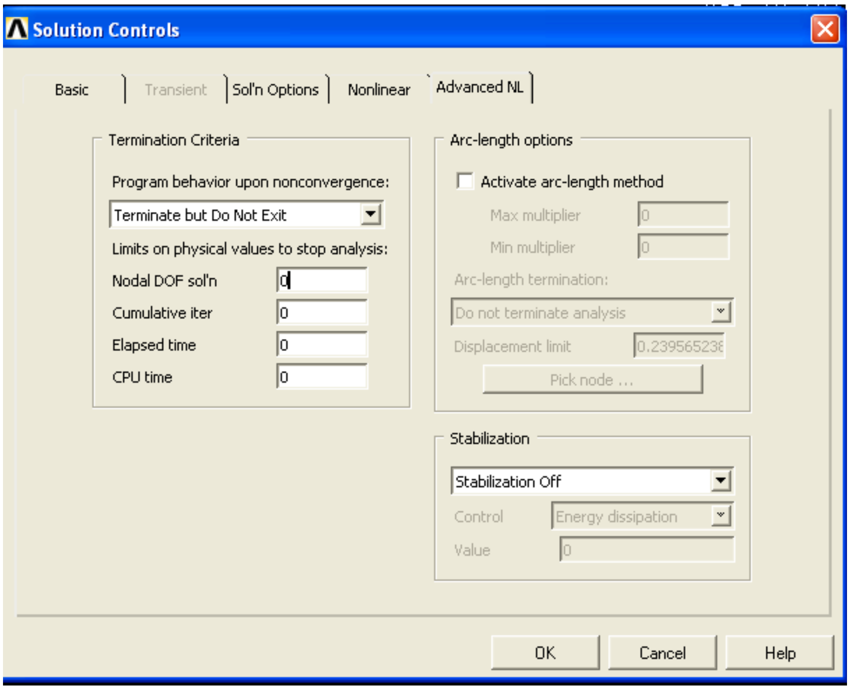

Figure 3.19 Tab of 'Advanced NL'

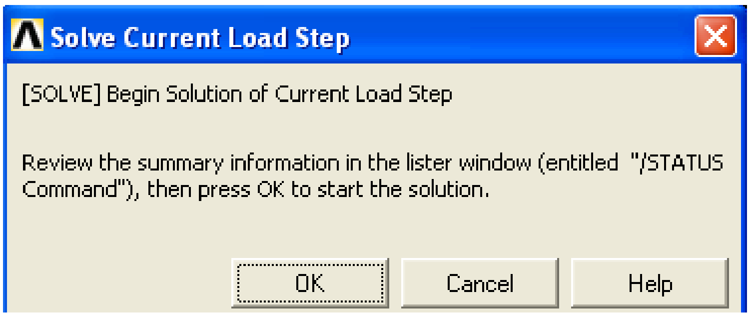

Figure 3.20 Solve load step

3.4 Postprocessor

Postprocessor is the stage where the results of the analysis are obtained. In ANSYS, different type of results can be obtained. However, the result that are needed is the ultimate load, deflection and cracking of the reinforced concrete beam. 'TimeHist Postpro' were used to obtain the load and deflection at a specified node which were then used to plot the load-deflection curve and deflection along the span of the reinforced concrete beam. The crack pattern of the reinforced concrete beam are generated from ANSYS. The crack pattern can be viewed in 4 different cracks which is first crack, second crack, third crack and the combination of all cracks. First crack are red in colour, second crack are green in colour and third crack are blue in colour. However in this study, only the combination of all cracks are studied.

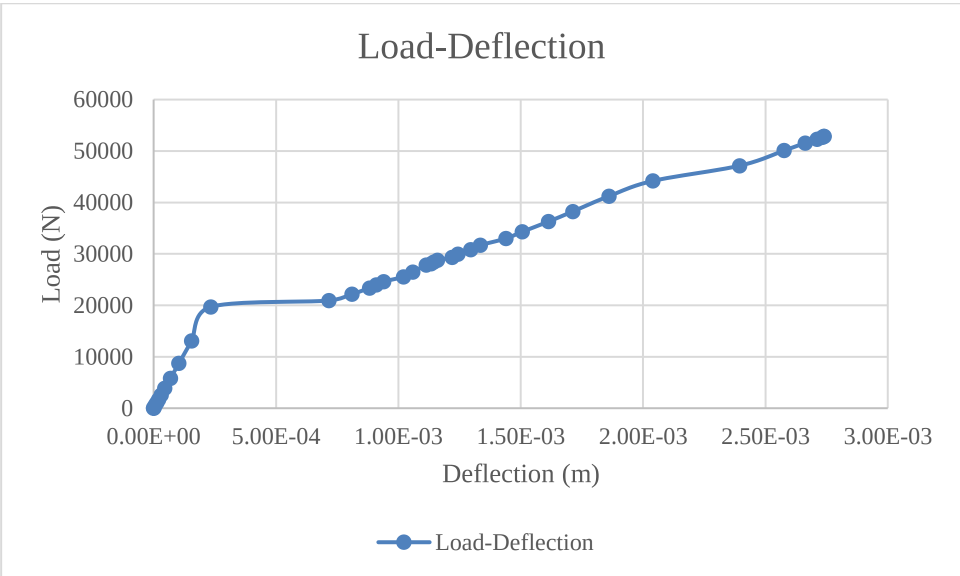

Figure 3.21 Load-deflection of reinforced concrete beam with 100mm circular opening

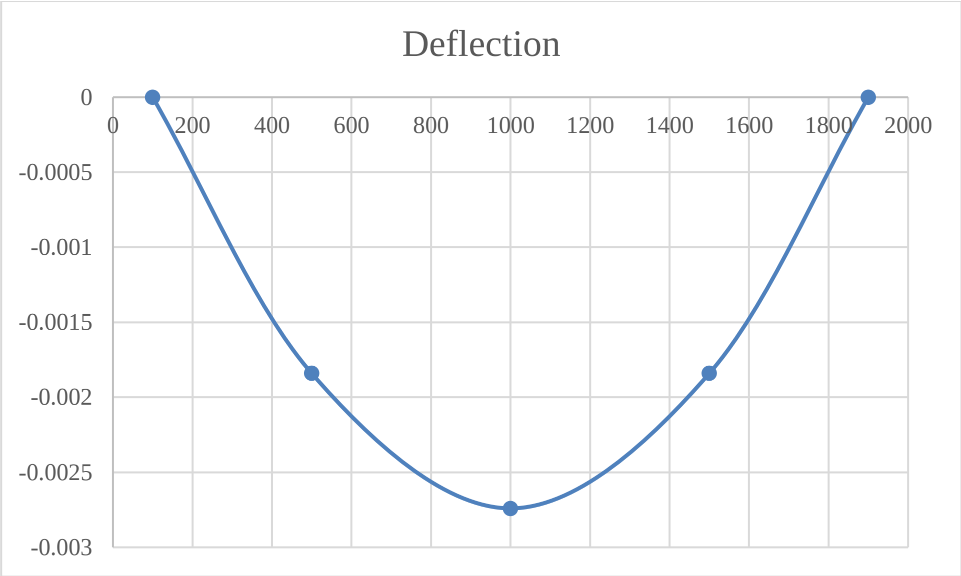

Figure 3.22 Deflection along the span of reinforced concrete beam with 100mm circular opening

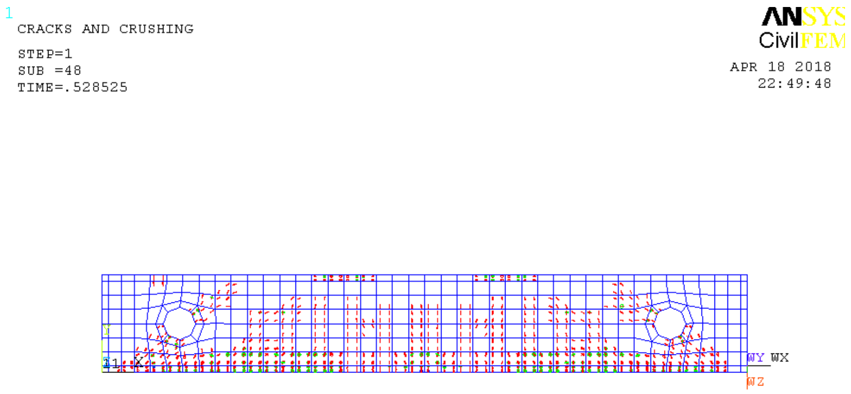

Figure 3.23 Cracking of reinforced concrete beam with 100mm circular opening

CHAPTER 4

RESULTS AND DISCUSSION

4.1 General

ANSYS 12.0 was used to model 6 reinforced concrete beam which includes a solid reinforced concrete beam, three different size of circular opening in diameter and three different shape of opening. A solid reinforced concrete beam named as RCB S are used to compare the effect of the various size of circular opening and shape of opening on the shear zone of reinforced concrete beam in terms of ultimate load, deflection and cracking. Three reinforced concrete beam with size of circular opening in diameter of 60mm, 80mm and 100mm are named as RCB 1, RCB 2 and RCB 3 respectively. Three reinforced concrete beam with circular opening, rectangular opening and square opening are named as RCB 3, RCB 4 and RCB 5 respectively.

4.2 Ultimate Load

Ultimate load for each model is obtained from ANSYS 12.0. From Figure 4.1, the ultimate load of RCB S, RCB 1, RCB 2 and RCB 3 were 75.774kN, 76.298kN, 59.757kN and 52.852kN respectively. Whilst from Figure 4.2, the ultimate load of RCB 4 and RCB 5 were 58.274kN and 53.854kN respectively.

The ultimate load of solid reinforced concrete beam, RCB S is smaller than the ultimate load of experimental data of 79.40 kN by only 4.57%. There is a 0.7% difference in terms of ultimate load between RCB S and RCB 1. By introducing 80mm circular opening, the ultimate load of RCB 2 reduced by 21% when compared to the ultimate load of RCB S. When the ultimate load of RCB 3 were compared to RCB S, there is a reduction of 30% in terms of ultimate load while the ultimate load reduced by 11% when compared to RCB 2. The ultimate load of RCB 4 is 10.26% higher than RCB 3. The ultimate load of RCB 5 is 1.9% higher than RCB 3 and 7.6% lower than RCB 4.

One of the parameter is the effect of size of opening on the behaviour of reinforced concrete beam. RCB S, RCB 1, RCB 2 and RCB 3 was used to investigate the effects. RCB S behaves similarly to the experiment solid reinforced concrete beam. RCB 1 with a 60mm circular opening does not affect the behaviour of the reinforced concrete beam. As the circular opening of RCB 1 is 60mm in diameter which is 0.2 depth of the beam smaller than 0.25 depth of the beam so it does not have effect on the reinforced concrete beam. Inclusion of a circular opening with diameter larger than 0.27 of the beam depth will reduce the ultimate load capacity by at least 21%. From the results obtained, there is a trend of when the size of circular opening increases in the shear zone of the reinforced concrete beam, the ultimate load capacity of the reinforced concrete beam will be reduced.

The other parameter is the effect of shape of opening on the behaviour of reinforced concrete beam. RCB 3, RCB 4 and RCB 5 was used to study the effects. RCB 4 having the highest ultimate load when compared to RCB 3 and RCB 5. The difference between the ultimate load of RCB 3 and RCB 5 are within 2%. However, RCB 3 having the lowest ultimate load among the 3 model. From the results, it shows that RCB 4 with rectangular opening having the highest ultimate load while RCB 3 with circular opening with the lowest ultimate load. However based on previous research, circular opening is the optimum shape for opening because it shows the least reduction in ultimate load.

From the study, a 60mm circular opening can be classify as a small opening whereas a circular opening having a diameter larger than 80mm can be classify as large opening. This is because a 60mm circular opening does not changes the behaviour of the reinforced concrete beam while a circular opening larger than 80mm reduced the load capacity of the reinforced concrete beam. There was a research done by Mansur & Tan (1999), where classification of small and large opening based on the structural response of the reinforced concrete beam. The opening is classify as small opening when the presence of opening does not changes the behaviour of the reinforced concrete beam. When the opening causes the reinforced concrete beam to fail then the opening is classify as large opening.

In the research done by Somes and Corley (1974), when the diameter of the circular opening is smaller than 0.25 depth of the beam, the mode of failure of the beam with circular opening remains the same as the failure mode of solid beam. In this study, a 60mm circular opening which is equivalent to 0.2 depth of the beam is used in RCB 1 and it does not changes the behaviour of the reinforced concrete beam. The failure mode of RCB 1 remain the same like a solid reinforced concrete beam. Besides that, according to Ahmed (2014), where introducing a small opening at the shear zone of a reinforced concrete beam will cause the ultimate load to reduce by a maximum of 2.5%. This supported the study where there is only a 0.7% of difference in terms of ultimate load between the 60mm circular opening which is consider as a small opening and a solid reinforced concrete beam.

In this study, there is a trend of when the size of opening increases, the ultimate load capacity of the reinforced concrete beam is further reduced. This trend is supported by the research done by Maaddawy and Ariss (2012), which stated the presence of opening in the shear zone will reduce the beam ultimate load capacity and stiffness drastically. As the size of the opening increases, the ultimate load capacity will further reduce. Furthermore, in the research of Mansur & Tan (1999), they also stated that the strength of reinforced concrete beam decreases whenever the size of the opening increases.

When the opening is located within the shear zone of the reinforced concrete beam, the ultimate load capacity is reduced by at least 21%. This finding was supported by Osman, et al (2017), when a beam with 2 circular openings, one in each shear zone is found that the presence of opening cause approximately 30% of reduction in shear strength. Besides that, there was also another research done by Campione and Minafo, (2012), which can also support the finding. They stated that inclusive of opening within the shear zone of a reinforced concrete beam will lead to a reduction in load-carrying capacity in the range of 18 – 30%.

According to El-kareim and El-sayed, (2017), reinforced concrete beams with circular openings have diameters equal to 0.25d and 0.5d, the shear force were equal to 65% and 37% from the shear force of the control beam respectively. This supported the study where a 100mm circular opening which is equivalent to 0.33 depth of the beam, is located at the shear zone of the reinforced concrete beam, there is a reduction of 30% in terms of ultimate load.

From the study of (Latha and Naveen, 2017; Amiri and Masoudnia, 2011), they states that circular and square opening have difference in terms of ultimate load capacity. The ultimate load capacity of reinforced concrete beam with circular opening is approximately 9% higher than reinforced concrete beam with square opening. Besides that, based on the research by El-kareim and El-sayed, (2017), reinforced concrete beam with circular, square and rectangular opening, the shear forced were equal to 37%, 27% and 23% respectively from the shear force of the control beam. There is also a study by Ahmed (2014), which stated that the most suitable shape for opening is circular opening which showed the least reduction in ultimate load. In this study, the result showed that reinforced concrete beam with rectangular opening, RCB 4, have the highest ultimate load. This was due to the size of mesh used are too large to define the shape of opening which cause some inaccuracy.

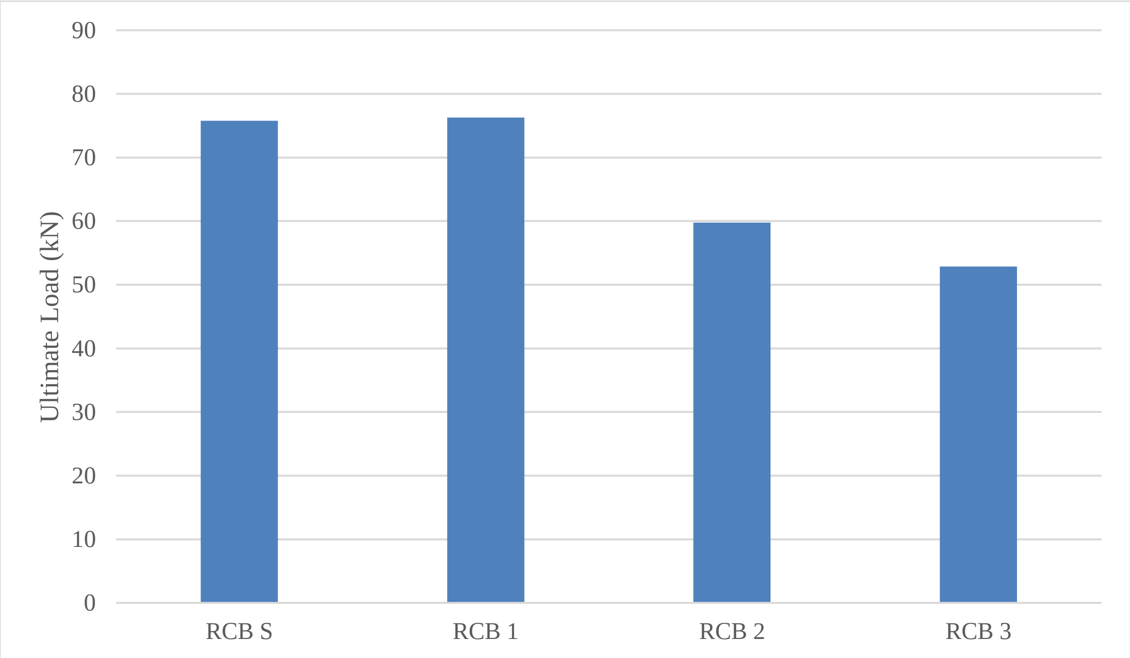

Figure 4.1 Ultimate Load of RCB S, RCB 1, RCB 2 and RCB 3

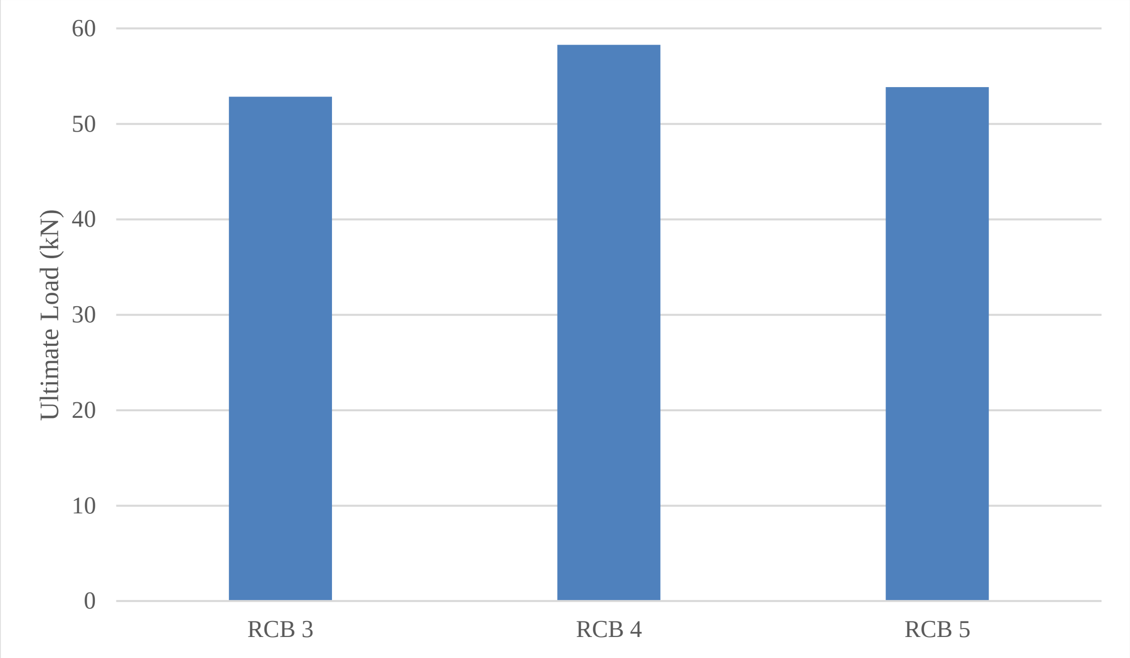

Figure 4.2 Ultimate Load of RCB 3, RCB 4 and RCB 5

4.3 Deflection

In this study, load-deflection curve and the deflection at the quarter of the span and mid-span are obtained from ANSYS. The load-deflection curve are plotted using the load and mid-span deflection. However, the mid-span deflection are emphasised on this study. Figure 4.3 – Figure 4.8 shows the load-deflection curve of the beam while Figure 4.9 – Figure 4.14 shows the deflection at the quarter of the span and mid-span. From Figure 4.3 and Figure 4.9, the mid-span deflection of RCB S is 8.84mm. From Figure 4.4 and Figure 4.10, the mid-span deflection of RCB 1 is 10.6mm. From Figure 4.5 and Figure 4.11, the mid-span deflection of RCB 2 is 3.17mm. From Figure 4.6 and Figure 4.12, the mid-span deflection of RCB 3 is 2.74mm. From Figure 4.7 and Figure 4.13, the mid-span deflection of RCB 4 is 3.18mm. From Figure 4.8 and Figure 4.14, the mid-span deflection of RCB 5 is 2.80mm.

Figure 4.3 shows that the load deflection curve of RCB S from ANSYS 12.0 agrees well with the experimental data. The mid-span deflection of 8.84mm from RCB S is smaller than the mid-span deflection of 9.50mm from the experimental data by only 6.95%. Figure 4.4 shows the load-deflection curve of reinforced concrete beam with circular opening of 60mm diameter, RCB 1. The load-deflection curve of RCB 1 is almost the same as the load-deflection curve of RCB S. Figure 4.5 shows the load-deflection curve of reinforced concrete beam with circular opening of 80mm diameter, RCB 2. The mid-span deflection of RCB 2 decreased by 64% when compared to the mid-span deflection of RCB S. Figure 4.6 shows the load-deflection curve of reinforced concrete beam with circular opening of 100mm diameter, RCB 3. When compared to RCB S, the mid-span deflection of RCB 3 decreased by 69%. When compared to RCB 2, there is a reduction of 13.5% in terms of mid-span deflection. Figure 4.7 shows the load-deflection curve of reinforced concrete beam with rectangular opening, RCB 4. The mid-span deflection of RCB 4 is 16% higher than RCB 3. Figure 4.8 shows the load-deflection curve of reinforced concrete beam with square opening, RCB 5. The mid-span deflection for RCB 5 and RCB 3 is almost the same while the mid-span deflection for RCB 4 is 16% higher.

In order to study the effect of size of circular opening on the reinforced concrete beam in terms of deflection, RCB S, RCB 1, RCB 2 and RCB 3 was used. The load-deflection curve of RCB S are almost similar to the experiment solid reinforced concrete beam. RCB 1 with a 60mm circular opening also have the similar load-deflection curve as RCB S. As the circular opening of RCB 1 is 60mm in diameter is consider as small opening so it does not have effect on the reinforced concrete beam. The mid-span deflection of RCB 2 with 80mm circular opening is decreased by 64%. RCB 3 with 100mm circular opening reduced the mid-span deflection by 69%. This shows that inclusion of a circular opening with diameter larger than 0.27 of the beam depth will decrease the mid-span deflection by at least 64%. From the results obtained, there is a trend of when the size of circular opening increases in the shear zone of the reinforced concrete beam, the deflection of the reinforced concrete beam will be reduced.

RCB 3, RCB 4 and RCB 5 was used to determine the effect of shape of opening on the reinforced concrete beam. From the load-deflection curve obtained from ANSYS, RCB 4 having the highest mid-span deflection when compared to RCB 3 and RCB 5. The difference between mid-span deflection of RCB 3 and RCB 5 are within 2%. Both RCB 3 and RCB 5 having load-deflection curve that are almost similar. However, RCB 3 having the lowest mid-span deflection among the 3 model. From the results, it shows that RCB 3 with circular opening with the lowest mid-span deflection. This agrees well with previous research where circular opening is the optimum shape for opening because it shows the lowest mid-span deflection.

In this study, there is also a trend of when the circular opening with diameter equal to or larger than 0.27 depth of the reinforced concrete beam, the ultimate load capacity are reduced by at least 21% and the mid-span deflection are decreased by at least 64%. This trend is supported by the research done by Ahmed (2014), where he stated that the beam deflection decreased by 57% more than the control beam when the large opening is located at the shear zone of a reinforced concrete beam. Besides that, introducing a large opening at the shear zone of a reinforced concrete beam will lead to a reduction of maximum 64% in terms of ultimate load.

According to Rezwana et al., (2014), the result shows that circular opening has more strength than equivalent square opening. This supports the finding where the mid-span deflection of circular opening, RCB 3, is lower than the other 2 shape of opening. This is because that there are more stress concentrated at the corners of square and rectangular opening. Besides that, this study is also support by Aykac et al., (2014), where circular opening have much greater energy capacities when it is compare to rectangular openings.

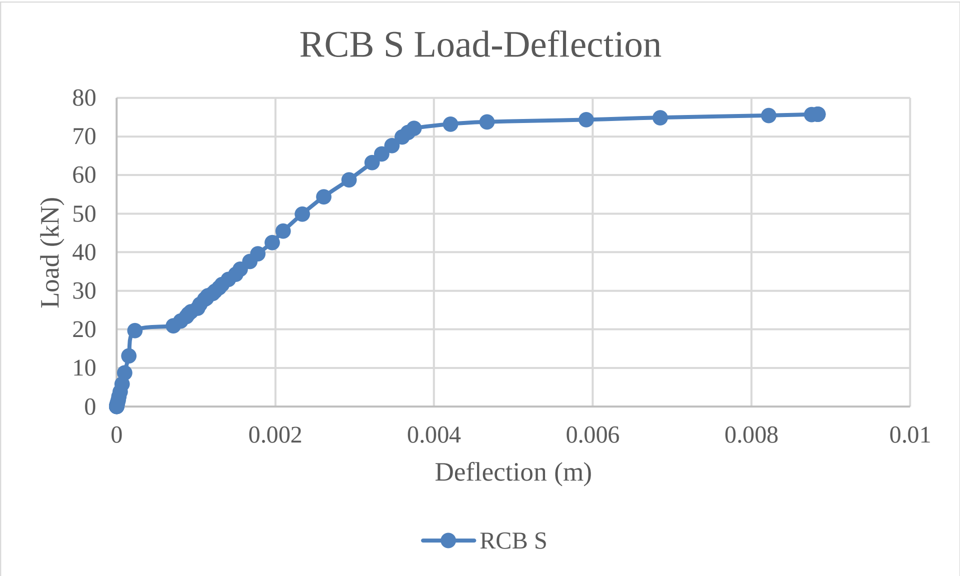

Figure 4.3 RCB S Load-Deflection curve

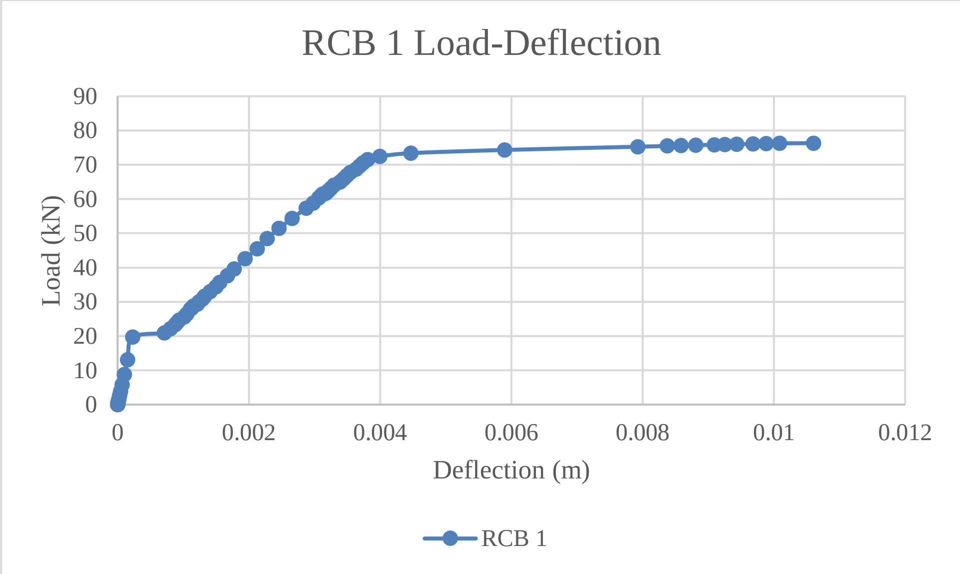

Figure 4.4 RCB 1 Load-Deflection curve

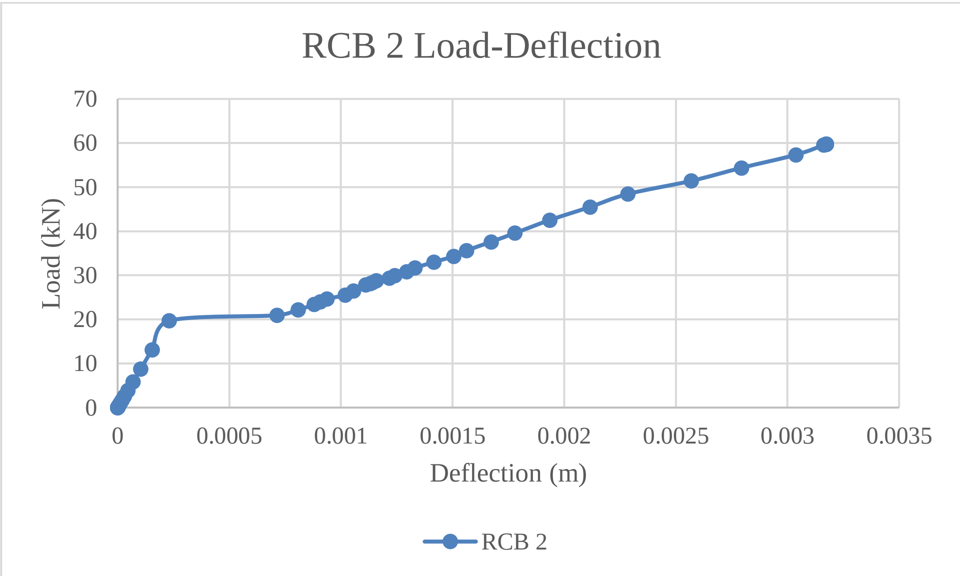

Figure 4.5 RCB 2 Load-Deflection curve

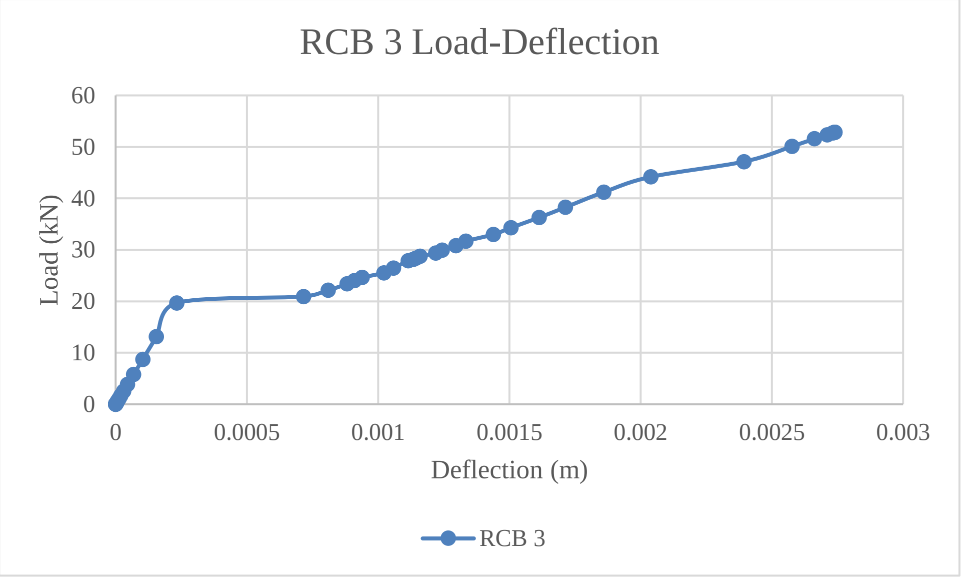

Figure 4.6 RCB 3 Load-Deflection curve

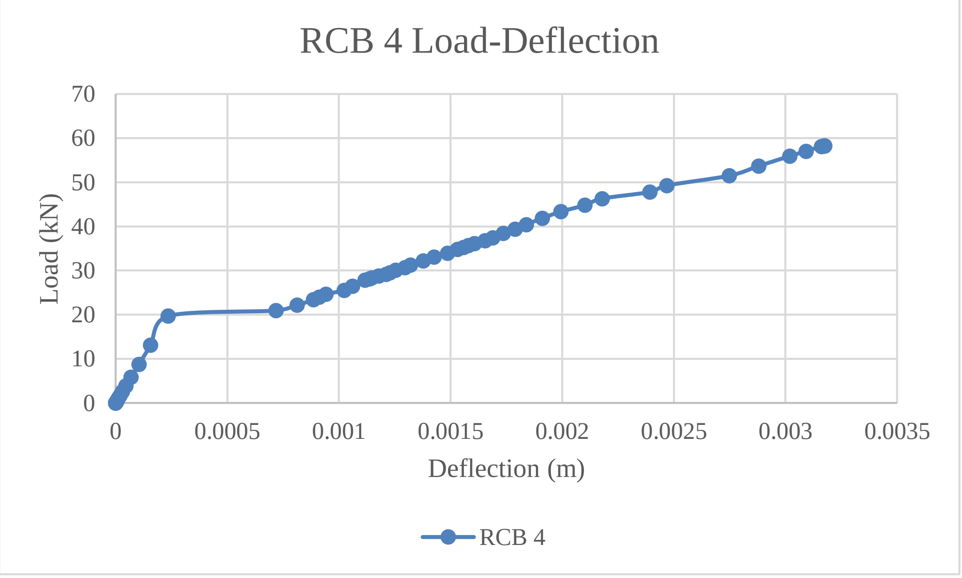

Figure 4.7 RCB 4 Load-Deflection curve

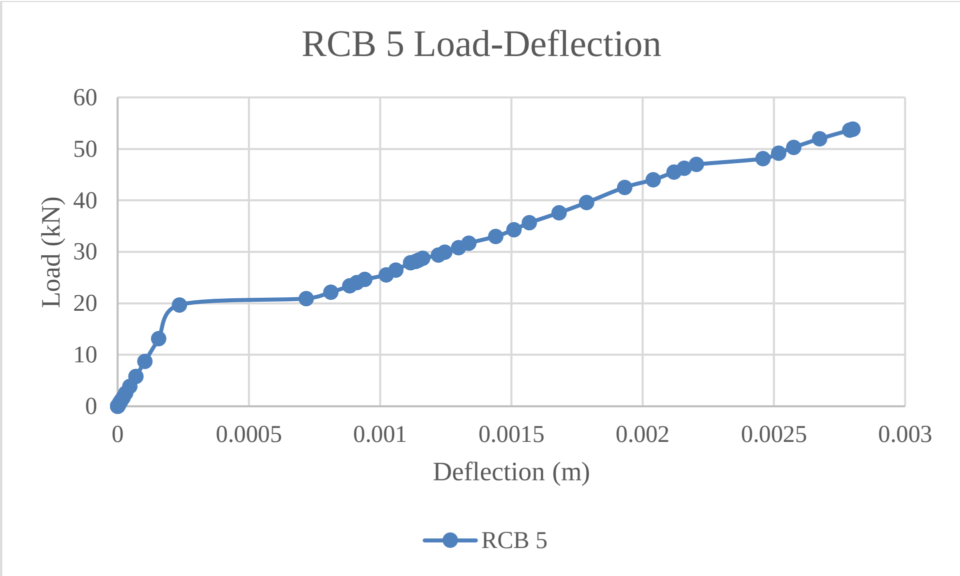

Figure 4.8 RCB 5 Load-Deflection curve

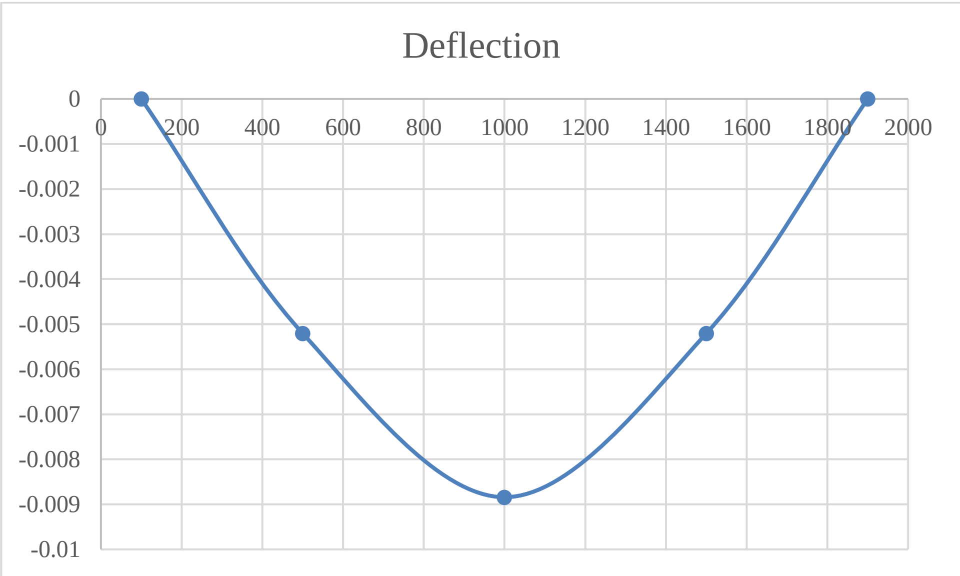

Figure 4.9 RCB S deflection along the span

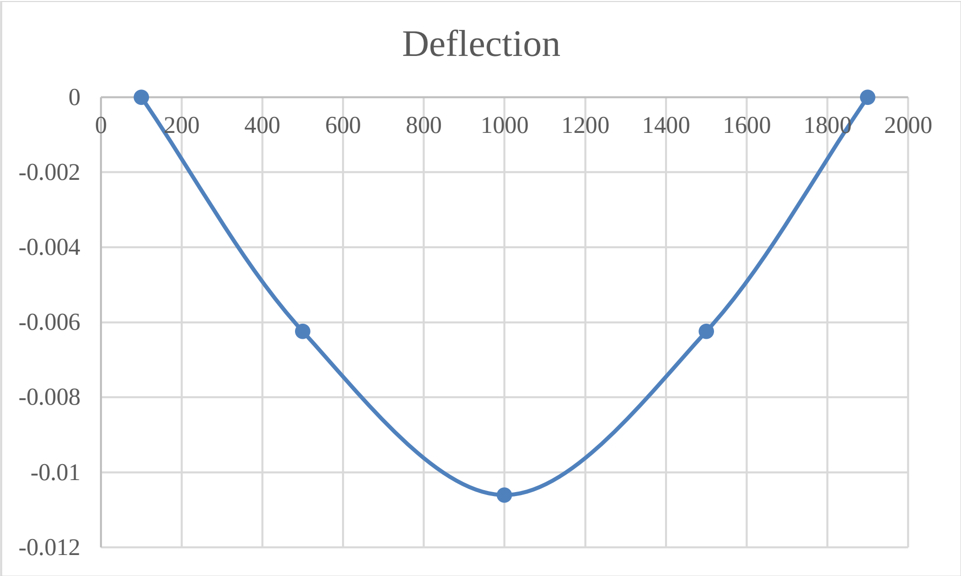

Figure 4.10 RCB 1 deflection along the span

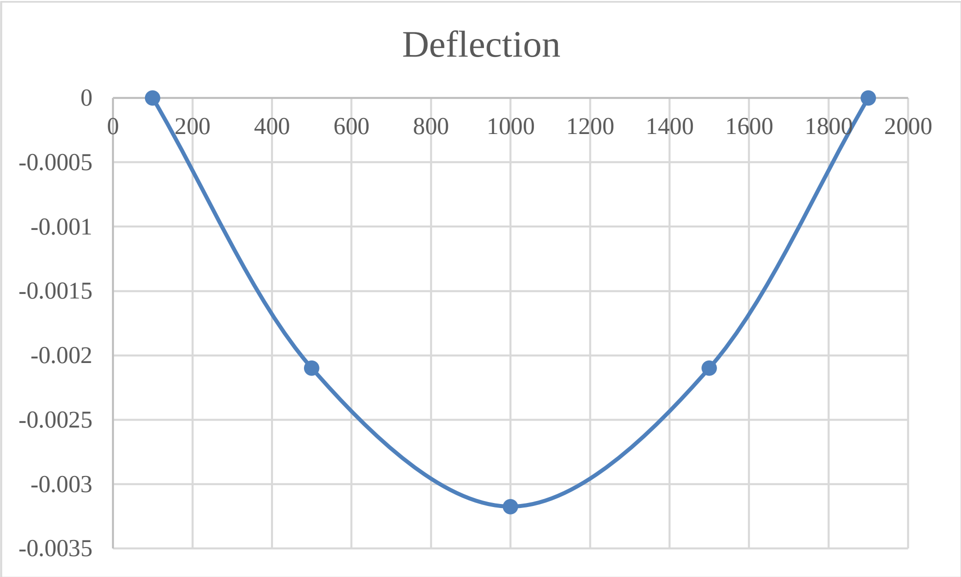

Figure 4.11 RCB 2 deflection along the span

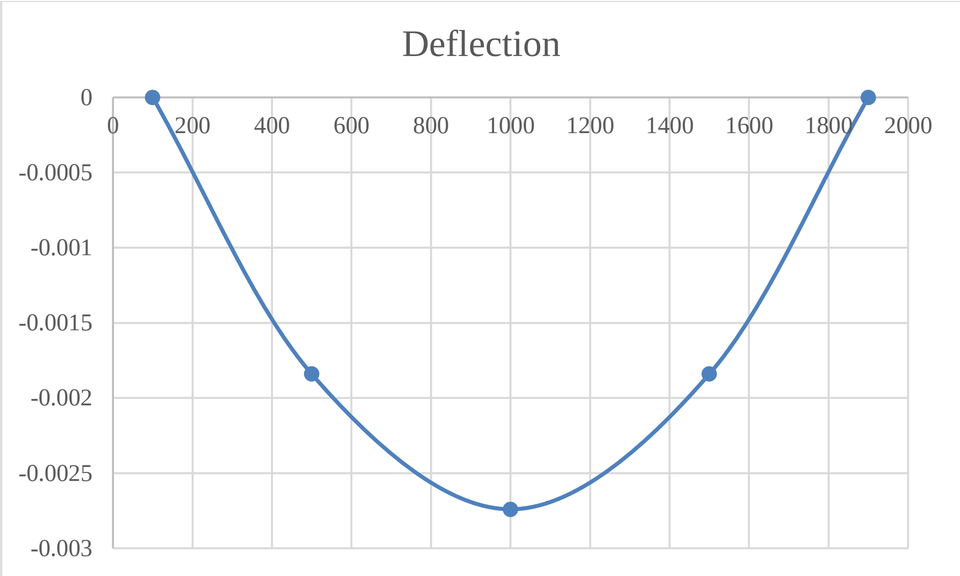

Figure 4.12 RCB 3 deflection along the span

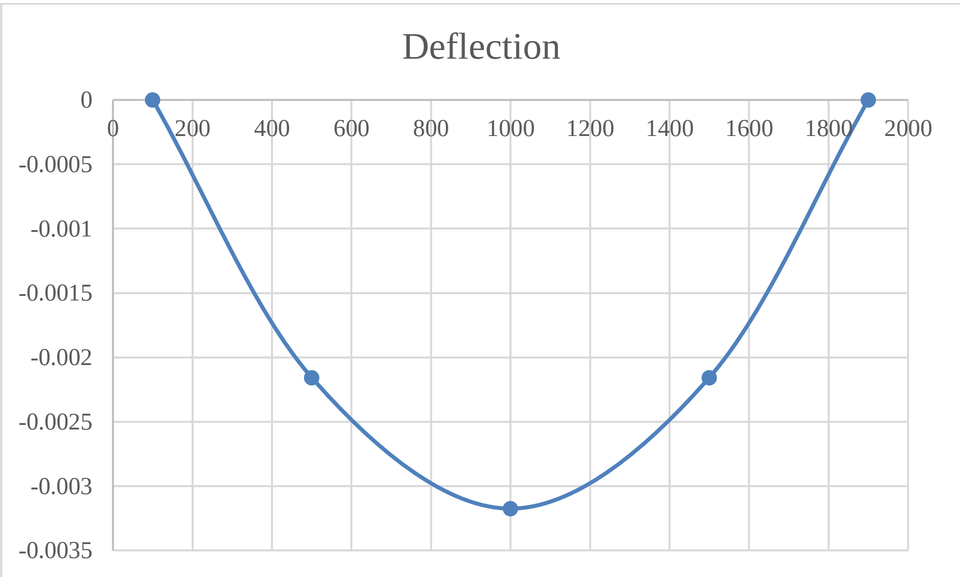

Figure 4.13 RCB 4 deflection along the span

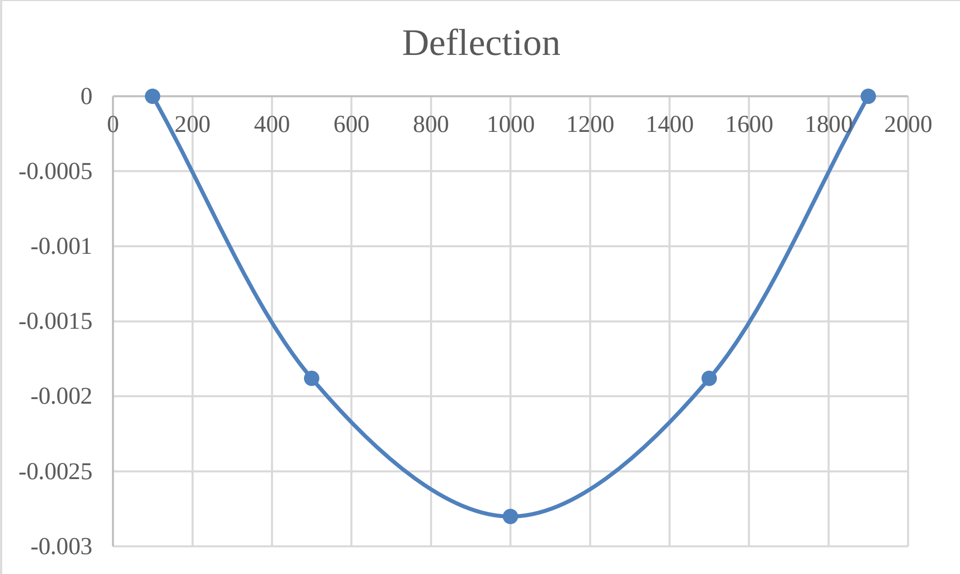

Figure 4.14 RCB 5 deflection along the span

4.4 Cracking

The cracks are obtained at the ultimate load of each of the model. There are 3 type of cracks in ANSYS which is first crack, second crack and third crack. The first crack is red in colour, second crack is green in colour while the third crack is blue in colour. However in this study, only the combination of first crack, second crack and third crack was taken to study.

Figure 4.15 shows the crack pattern of RCB S. The crack pattern of RCB S mainly occur at the zone where flexural is high where it is known as flexural crack. Flexural crack will occur at the bottom of mid-span of the beam where flexural is high. Shear crack is also observed in the crack pattern of RCB S. The shear crack propagated from the support toward the loading point which is also known as shear zone where shear is critical. Figure 4.16 shows the crack pattern of RCB 1. For RCB 1, both flexural and shear cracks are observed but mostly is the flexural cracks at the mid-span where flexural is higher and the failure is caused by flexural cracks at the ultimate load which is behaving quite similar to RCB S. This shows that the behaviour of the reinforced concrete beam with opening behaves similarly to solid reinforced concrete beam when the circular opening with diameter less than 20% of the depth of the beam. Figure 4.17 shows the crack pattern of RCB 2. For RCB 2, the crack pattern at ultimate load shows both flexural at mid-span and shear crack at shear zone. The shear crack develop through the opening with an angle of 45 degrees from support towards loading point because opening is a source of weakness. From the crack pattern, it can be seen that the failure mode of RCB 2 is shear at opening region. When opening is located at the shear zone of the reinforced concrete beam, it will reduce the ductility and strength capacity of the reinforced concrete beam. Besides, stress are concentrated at the location of the opening and potentially cause the reinforced concrete beam to experience cracks earlier. Figure 4.18 shows the crack pattern of RCB 3. In the crack pattern of RCB 3, both flexural at mid-span and shear cracks through opening are observed. The crack pattern of RCB 3 is almost similar to the crack pattern of RCB 2. The difference between the crack pattern of RCB 2 and RCB 3 is not obvious due to the difference of the size of the circular opening is not significant and the mesh size used for both model is too large to show the difference of cracking pattern between RCB 2 and RCB 3. Both failure mode of RCB 2 and RCB 3 are due to shear at opening region. Figure 4.19 shows the crack pattern of RCB 4. The crack pattern of RCB 4 at ultimate load is obtained. From the crack pattern, we can clearly see that there is both flexural and shear cracks. However when comparing RCB 3 and RCB 4, at the corners of the rectangular opening in RCB 4, there are more cracks observed. This is because the sharp corner of the rectangular opening are subjected to higher stress concentration. Figure 4.20 shows the crack propagated at the ultimate load of RCB 5. Both flexural and shear cracks are observed in RCB 5. The crack pattern of RCB 5 is almost similar to the crack pattern of RCB 4 where at the corner of the square opening, more cracks are observed. This is because the square opening also have sharp corners similar to the rectangular opening.

RCB S, RCB 1, RCB 2 and RCB 3 was used to study the effect of size of circular opening on the reinforced concrete beam. The cracking patterns of RCB S and RCB 1 are almost similar. This shows that a 60mm circular opening does not affect the behaviour of the reinforced concrete beam. The failure mode of RCB S and RCB 1 are mainly due to the flexural failure. However, when a circular opening larger than 80mm is located at the shear zone of the reinforced concrete beam, there are more shear cracks observed around the opening. The shear crack propagated through the opening at 45 degree angle from the support to the loading point which is also known as shear failure. The crack pattern of RCB 2 and RCB 3 are almost the same where the cracking propagated through the opening. There are not much difference between RCB 2 and RCB 3 mainly due to the increment size of opening is not significant and the mesh size used are not fine enough to indicate the difference between the cracking pattern of RCB 2 and RCB 3. Both RCB 2 and RCB 3 having the same failure mode which is shear at opening region. From the results obtained, there is a trend of when the size of the opening increases, the crack tend to propagate from support to loading point which is also known as shear cracks and the mode of failure are shear at opening region.

In order to study the effect of shape of opening on the reinforced concrete beam, RCB 3, RCB 4 and RCB 5 was used. Both flexural cracks and shear cracks can be observed in the cracking pattern of RCB 3, RCB 4 and RCB 5. The failure mode of RCB 3, RCB 4 and RCB 5 are due to shear in opening region. All 3 models have excessive shear cracks passing through the opening region at a 45 degree from support to the loading point. However, there are more shear cracks concentrated at the opening corners of RCB 4 and RCB 5 because of their opening shape having sharp corners.

In this study, the size of circular opening used in RCB 1 is a 60mm circular opening which is equivalent to 0.2 depth of the beam. The cracking pattern of RCB S and RCB 1 are almost the same and the failure mode of RCB 1 remains the same like a solid reinforced concrete beam. This result is supported by the research of Somes and Corley (1974), which they stated that the mode of failure of the reinforced concrete beam with circular opening remains the same as the failure mode of solid beam when the diameter of the circular opening is smaller than 0.25 depth of the beam.

This result is supported by the research done by Mansur (1998). He states that for a beam with opening when the failure plane passes through the center of the opening at 45 degree, it is called as beam-type failure. This is the same as the failure mode of RCB 2 and RCB 3 where the failure plane also passes through the center of the opening.

When the circular opening at the shear zone of the reinforced concrete beam is larger than 80mm, there are shear cracks propagated around the opening. The failure mode of the reinforced concrete beam is known as shear at opening region. This is supported by a research done by Ahmed (2014), where excessive shear cracks were found around the opening at the shear zone of reinforced concrete beams. The failure mode is known as shear failure.

From the research of Aziz, (2016), the presence of opening in the shear zone will cause rapid progressive of cracks to occur due to the opening are located within the path of diagonal cracks. This phenomena can be seen in the result of this study where there are diagonal cracks passing through the opening of RCB 2 and RCB 3.

From the cracking pattern of RCB 4 and RCB 5, there are more cracking propagated at the sharp corners of rectangular and square openings respectively. This is supported from previous research by Allam, (2005), which stated openings with corners will lead to stress concentration, causing various cracks to formed around the opening corners and at the upper chords, diagonal cracks are formed due to lack of shear resistance. Besides that, Aziz, (2016), also stated that opening with sharp corners are subjected to high stress concentration that may lead to reduction in stiffness of reinforced concrete beam and causing cracking and deflection.

Furthermore, Chin et al., (2012), mentioned that in early stage of un-strengthened beams, diagonal crack propagated at the four corners of square openings and eventually leads to yielding of steel reinforcement and crushing of concrete cover. This can be seen from the cracking pattern of RCB 4 and RCB 5, where shear cracks mainly formed at the corners of the opening causing the reinforced concrete beam to experience shear failure. This is also supported by the research by Aykac et al., (2014), using reinforced concrete beam with similar reinforcement, introducing circular opening will have higher ductility and load capacities compared to rectangular openings. Rectangular openings have sharp corners that cause stress to be concentrated at the corners result in cracking, which leads to earlier failure of the reinforced concrete beam.

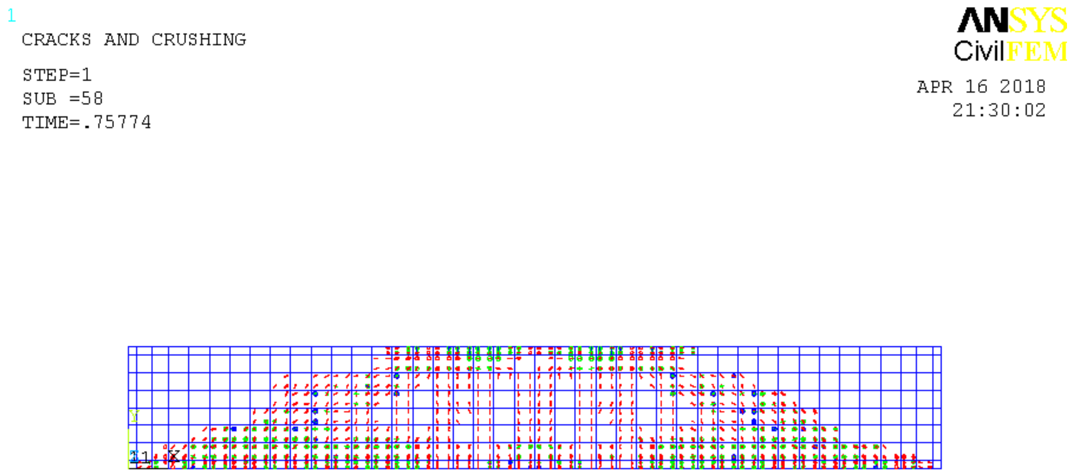

Figure 4.15 RCB S crack pattern

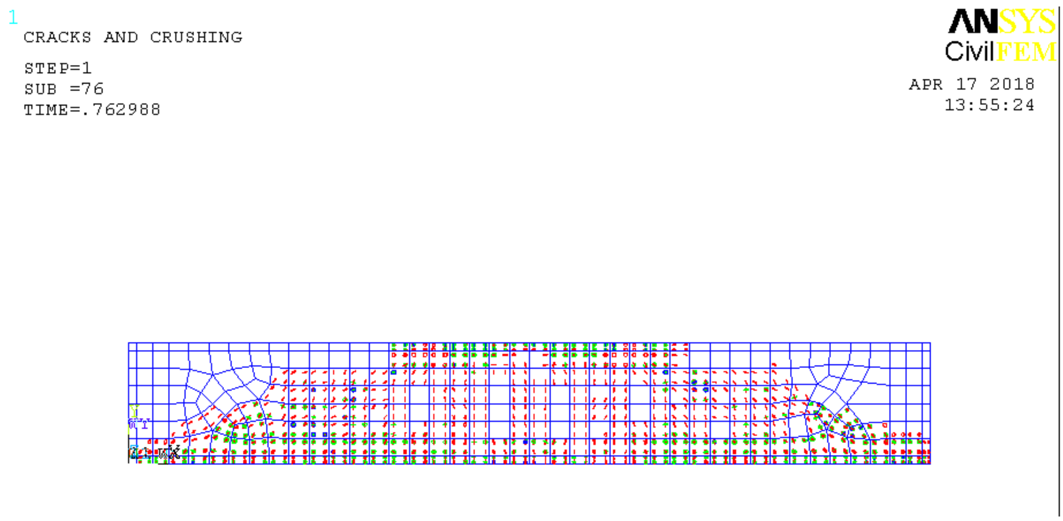

Figure 4.16 RCB 1 crack pattern

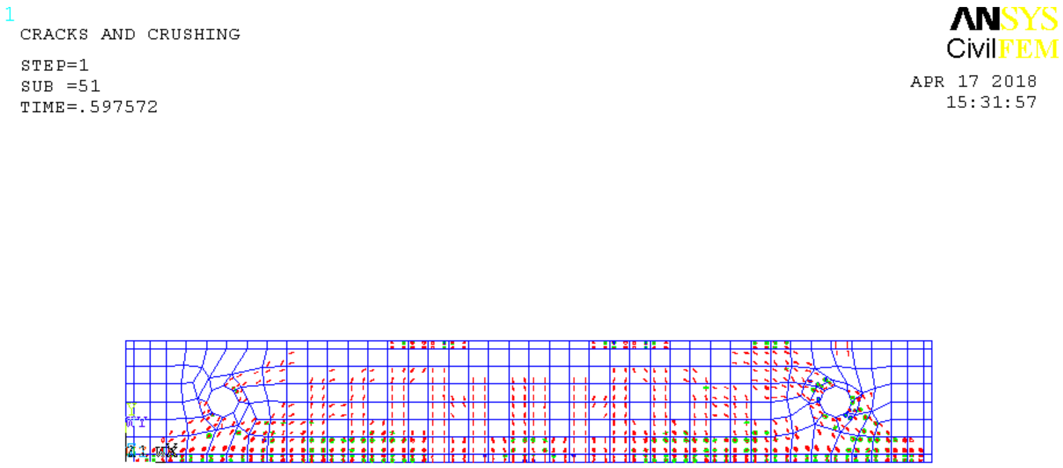

Figure 4.17 RCB 2 crack pattern

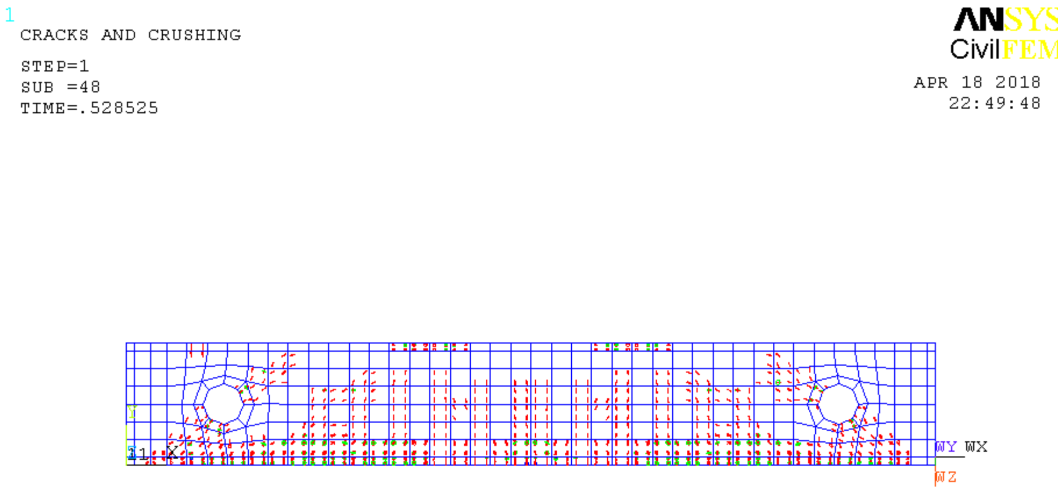

Figure 4.18 RCB 3 crack pattern

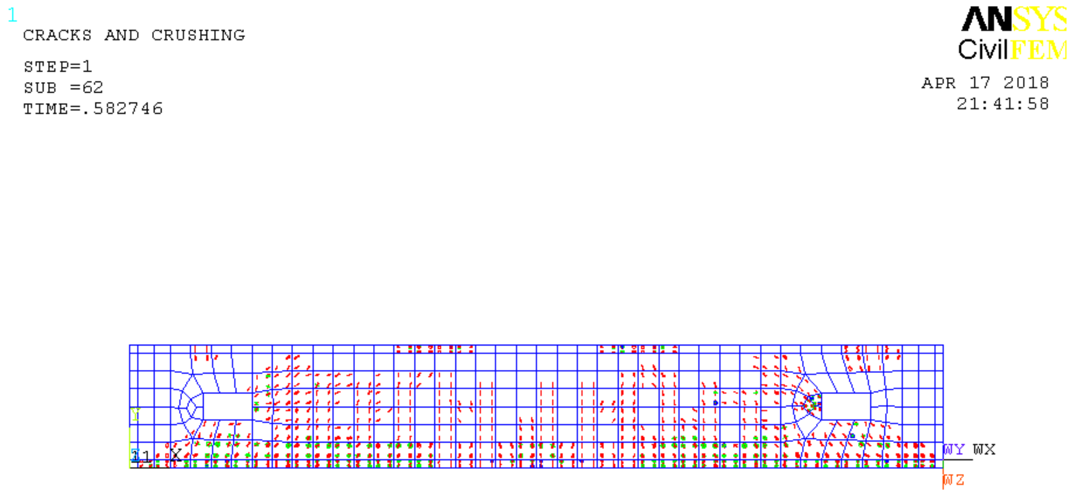

Figure 4.19 RCB 4 crack pattern

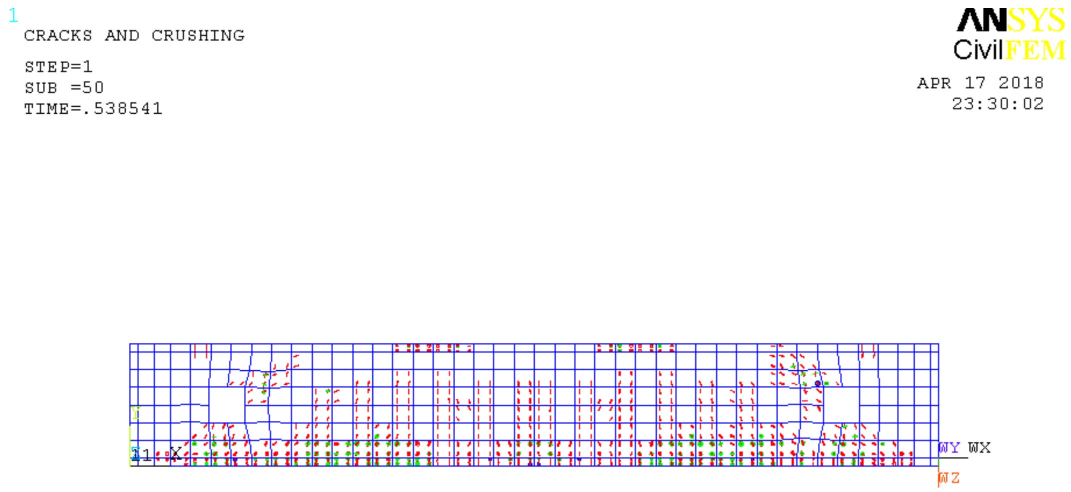

Figure 4.20 RCB 5 crack pattern

CHAPTER 5

CONCLUSION

5.1 General

ANSYS 12.0 is an advance finite element software for engineer product. It is a very powerful and accurate software which can generate a variety of result like load-deflection, crack patter, stress-strain curve and others. Therefore, the behaviour of the reinforced concrete beam with opening is able to determine clearly and the results are reliable. In this study, all the objectives were achieved. The conclusions and suggested recommendations for future studies are presented.

5.2 Conclusion

The following conclusions can be drawn with respect to the results obtained from the analysis of the solid reinforced concrete beam, reinforced concrete beam with circular opening with 60mm, 80mm and 100mm in diameter and reinforced concrete beam with equivalent square and rectangular opening with size of 88 X 88mm and 121 X 65mm respectively. :

i. Reinforced concrete beam with circular opening of diameter less than or equal to 0.2 depth of the beam will behave similar to a solid reinforced concrete beam.

ii. Reinforced concrete beam with circular opening of diameter larger than or equal to 0.27 of the beam depth will reduce the ultimate load capacity by at least 21% while the mid-span deflection decrease by at least 64%.

iii. Reinforced concrete beam with rectangular opening shown the highest ultimate load among circular and square opening while the reinforced concrete beam with circular opening shown the least deflection.

iv. Based on the crack propagation, there are more shear cracks propagated around the opening when the diameter of circular opening is larger than or equal to 0.27 depth of the beam.

v. In terms of shape, there are more cracks concentrated at the areas of opening with sharp corners like square and rectangular.

5.3 Recommendations

The following recommendations are suggested for future researches which are not covered in the present study:

i. Study the behaviour of reinforced concrete beam with larger size of opening.

ii. Smaller mesh size can be used in order to obtain more accurate result.

iii. Study the effect of location and number of opening on reinforced concrete beam.

iv. Studying strengthening opening by reinforcement.

v. The same study can be conducted for lab testing in order to compare the result with simulation finding.

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