NUMERICAL MODELLING OF RC BEAMS WITH BAMBOO REINFORCEMENT USING FINITE ELEMENT ANALYSIS (ANSYS)

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ABSTRAK

Kajian ini bertujuan untuk mengkaji tingkah laku rasuk konkrit bertetulang dengan tetulang buluh separa dan sepenuhnya. Objektif penyelidikan adalah untuk menentukan ciri-ciri geometri elemen, untuk menentukan sifat RC pepejal dan rasuk RC dengan bar buluh yang diletakkan samaada separa dan sepenuhnya di dalam rasuk RC apabila digunakan menggantikan bar besi dari segi corak beban dan corak retak dalam analisis unsur terhingga. Keputusan analisa unsur terhingga telah disahkan dengan hasil eksperimen. Sebanyak tiga rasuk dengan dimensi 120 x 300 mm dengan panjang 1600 mm telah dimodelkan sebagai rasuk disokong mudah dalam analisis tiga dimensi menggunakan ANSYS. Jenis rasuk yang dimodelkan termasuk rasuk pepejal (tanpa tetulang, tetulang separa dan tetulang penuh) menggunakan buluh. Di sini, analisis elemen terhingga tidak linear dilakukan untuk menilai prestasi buluh sebagai tetulang dalam rasuk konkrit. Pemodelan berangka dilakukan pada pancaran kendali, pengganti buluh separa dan diganti sepenuhnya dengan buluh sebagai penguatan. Dalam kajian ini, bar penguat telah dimodelkan dengan menggunakan bar berdiameter 10 mm untuk tetulang atas dan bawah serta 6 mm diameter stirrup dengan jarak 300 mm pusat ke pusat. Dari hasil analisa unsur terhingga, beban utama untuk pancaran kawalan didapati 58.15 kN. Beban untuk BR ialah 48.46 kN yang hanya 78% daripada beban CB manakala BSR sampel memperoleh beban 17.78 kN yang mana 64% lebih rendah daripada BR dan hanya mencapai 31% berbanding CB. Beban muktamad bagi rasuk kawalan menunjukkan bahawa beban kegagalan CB, BR, dan BSR adalah 58.18kN, 48.46kN dan 17.78kN dengan pesongan 38.67 mm, 19.98 mm dan 10.89 mm. Dari hasil analisa elemen terhingga, beban mampatan untuk rasuk kawalan menunjukkan beban kegagalan CB, BR, dan BSR adalah 58.18kN, 48.46kN dan 17.78kN dengan pesongan masing-masing 38.67mm, 19.98mm dan 10.89mm. Di akhir ujian, dapat disimpulkan bahwa buluh dapat digunakan untuk menggantikan penguatan besi dalam rasuk bertulang. Aplikasi ini boleh digunakan dalam struktur struktur bangunan kecil untuk mengurangkan penggunaan keluli.

ABSTRACT

This research aims to investigate the behavior of reinforced concrete beams with partially and fully bamboo reinforcement. The objective of the research was to determine the geometrical properties of the element, to determine the behavior of solid RC beams and RC beams with partially and fully bamboo reinforcement in terms of load-deflection and crack pattern in finite element analysis. The finite element analysis results were validated with the experiment results. A total of three beams with a dimension of 120 x 300 mm with a length of 1600 mm were modeled as simply supported beams in a three dimensional analysis using ANSYS. The types of beam modelled include solid beam (without reinforcement, partial reinforcement and fully reinforcement). Here a nonlinear finite element analysis is carried out in order to evaluate the performance of bamboo as reinforcement in concrete beam. The numerical modelling was conducted on control beam, partial bamboo replacement and fully replaced with bamboo as reinforcement. In this research, the reinforcement bars were modeled as 10 mm diameter bar for top and bottom reinforcement as well as 6 mm diameter stirrups with spacing of 300 mm center to center. From the finite element analysis results, the ultimate load for control beam was found to be 58.15 kN. The load for BR was 48.46 kN which is only 78% of the load of CB whereas the sample BSR obtained the load of 17.78 kN which is about 64% lower than BR and only achieved 31% compared to CB. The ultimate load for control beams was show that the failure loads for CB, BR, and BSR are 58.18kN, 48.46kN and 17.78kN with deflections of 38.67 mm, 19.98 mm and 10.89 mm respectively. In the end of the testing, it can be concluded that bamboo can be used to replace steel reinforcement in reinforced concrete beam. This application can be used in small structures of buildings structures in order to reduce the consumption of steel.

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LIST OF SYMBOLS

m	meter
mm	millimetre
kN	Kilo Newton
MPa	Mega Pascal
GPa	Giga Pascal
E	Modulus of Elasticity
v	Poisson’s ratio

LIST OF ABBREVIATIONS

3D	3 Dimensional
RC	Reinforced Concrete
CB	Concrete Beam
BSR	Bamboo Steel Reinforced
BR	Bamboo Reinforced
FEA	Finite Element Analysis

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Construction industry is considered as an industry which exploits the environment the most. Concrete is the most important building material due to its high compressive strength characteristic. It is incorporated with steel as reinforcement to cater on its weakness in tensile strength. The combination of both materials which formed reinforced concrete is able to sustain dead load as well as live load of building structures. Due to this large production of concrete and steel is needed to cater the demand. Indirectly, this has contributed to environmental deterioration. Besides that, steel is susceptible to corrosion in the presence of oxygen and water. The rate of steel corrosion is dependent on the concrete's electrical resistivity, moisture content and the rate at which oxygen migrates through the concrete and causing steel to corrode. Carbonation and chloride attack will accelerate corrosion due to the reduction of alkalinity in concrete. Therefore, there is a need to begin the search for materials that are eco-efficient which will be the substitute for steel as reinforcement in concrete.

Nowadays, many researchers have been done using available natural resources. Bamboo is an example of natural resources that has the potential to be substitute of steel reinforcement in reinforced concrete. Generally, bamboo is known as a giant grass which grows rapidly in tropical and subtropical regions. Its strength which is greater than timber and its tensile strength is approximately half as compared to steel making it suitable to be substitute to steel reinforcing bar in concrete (Khare, 2005). Furthermore, bamboo is light weight compared to steel. The utilization of bamboo as reinforcement will consequently reduce the cost of construction. This would be beneficial in which high strength of building can be achieved with lower cost. In short, bamboo has the potential to replace steel as reinforcement in reinforced concrete due to its characteristic to be cheap, easily available and most importantly strong in tension and compression.

1.2 PROBLEM STATEMENT

The popularity of concrete as building material in construction industry is well known and it is produced more than 10 billion tons per year (Meyer, 2009). This is due to its relatively high compressive strength properties. Steel is made up from iron which is found abundant in earth crust. However, it will undergo depletion if continuous exploitation is carried out. In short, steel is not a renewable resource. Furthermore, rapid development and production of materials especially steel, iron and cement have given enormous impact to the environment. Steel industry has contributed to pollution which endangered to the humankind. Due to this, many researchers begun to search for materials that are renewable as well as have eco-efficient characteristic to be substitute for steel. Nowadays, many researchers have been done using one of the available natural resources which is the bamboo to be a potential material used as substitute for steel reinforcement. This is due to its characteristic to be cheap, easily available and most importantly strong in tension and compression. Malaysia has abundant bamboo resources which is not widely been utilized. In this study, finite element analysis is used to analyse its effects and load- deflection curve and crack pattern are generated. The reason of using finite element analysis is to validate results with the laboratory testing. Lab tests have some disadvantages such as time consuming, costly materials and tedious procedure to obtain the data. Finite element analysis can be used to predict the outcomes using various conditions without going through the laboratory testing, which save a lot of time and labour cost.

1.3 OBJECTIVES OF STUDY

This study was conducted to achieve the following objectives:

i. To identify the geometrical properties of element that used in this study
ii. To determine the numerical behaviour of solid RC beam, partial, and fully reinforced bamboo in 3D finite element analysis
iii. To validate the result of finite element analysis with previous experimental work using three dimensional (3D) finite element analysis, ANSYS

1.4 SCOPE OF STUDY

In this study, three-dimensional modelling using software, ANSYS been conducted to run the numerical analysis of finite element method to solve the approximate solution in term of stress, strain, and load-deflection and crack pattern. From previous experimental work, for physical properties of bamboo sticks, five tests were conducted such as density, initial moisture content, water absorption, compression and tensile tests. Based on the results obtained, proper adaptations were applied on bamboo reinforcement in reinforced concrete beams. 3D modeling was conducted to investigate the behavior of beam in terms of load-deflection behavior, crack pattern and failure mode. There were a total of three types of beams to be analyzed to verify the results. The first one was the RC beam, which acted as control beam while the other two beams were partially and fully reinforced with bamboo. All the beams were modeled accordingly and tested by applying four-points loading method. The load-deflection curve and crack pattern were identified as well. The stress-strain diagram was then obtained and the results from modeled analysis then compared with laboratory experimental results for validation. The dimension of the RC beams used for this study was 120 mm x 300 mm with length of 1600 mm. The steel reinforcement used for the RC beams were two steel bars with 10 mm diameter for both tension and compression region. Shear link used was 6 mm diameter at 300 mm centre to centre.

1.5 SIGNIFICANCE OF STUDY

In most of the developing countries, there is a need of replacing traditional building construction materials such as steel to another economic and sustainable material which is in line with the current modernization in construction industry as well as the need of constructing more sustainable, modern structures. In this case, bamboo seems to be able to fulfill all the requirements and provide adequate substitute to steel in reinforced concrete structures. Besides that, the populations nowadays are ever increasing. Due to this, constructing multi storied building is a popular trend nowadays to accommodate with those increasing populations. However, those building are facing the risk of rapid deterioration such as corrosion in steel reinforcement. Therefore, there is a need to provide safe and economical place to live to mankind. This study will provide knowledge on the feasibility of bamboo reinforced concrete to be used in construction industry. In this research, conventional steel reinforcement will be replaced by natural, cheap and readily available natural resources material which is the bamboo sticks. Bamboo is already considered to be an excellent construction material due to its properties which are comparable to steel. However, in Malaysia, the utilization of bamboo in construction industry is still very rare. This will in turn save the construction cost and time as well as more economical. Thus, the usage of finite element analysis is favourable to provide an effectively prevent unpredicted structural failure that might occur. Finite element analysis can save the costing of laboratory works that consumes a lot of time and resources to get the results. Therefore, although laboratory works can provide a more precise and accurate data, finite element analysis are sometimes preferred to predict the outcomes to save time.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Concrete is a composite material which made up of cement, aggregates, water and some admixtures, if required. It is widely used in construction industry due to its high compressive strength property besides being readily available and economical. Therefore, reinforced concrete is able to handle load in compression as well as tension. However, the strength of concrete not only depends on the existence of constituent materials. There are many other factors that influenced the strength such as water/cement ratio, mix design, compaction and curing of concrete. Not only affecting the strength but concrete durability also will also be affected. In this study, finite element analysis software will be used to carry out simulation for solving various engineering analysis. Based on the ability to model elements with precise characteristics and assumptions, it makes simulation a much preferred choice to predict the failure of beam members.

2.2 REINFORCED CONCRETE

Reinforced concrete is a composite material, consisting of steel reinforcing bars embedded in concrete. Plain concrete itself is unable to counteract with tensile and ductility as it has low tensile strength and ductility. The steel that embedded in concrete generally designed to resist tensile stresses in particular region of the concrete that might cause unacceptable cracking or structural failure. Reinforcement is designed to carry tensile forces, which are transferred by bond between the interfaces of steel and concrete.

If this bond is not adequate, the reinforcing bars will just slip within the concrete and there will not be a composite action. It is widely used in civil engineering applications such as construction of buildings, retaining wall, bridges, and foundations.

2.2.1 Properties of Reinforced Concrete

As mentioned earlier, reinforced concrete is a composite which combines plain concrete with steels. This is due to plain concrete is unable to counteract tensile strength and ductility by itself. Steel reinforcement is commonly known as rebar which is fixed in the formwork before pouring and settling of concrete. The combination of both of these material, therefore, a strong building material has formed with high relative strength, improves bonding, and high tolerance to tensile strain which is identified as reinforced concrete.

2.3 STEEL IN CONSTRUCTION

There are much dependent of the usage of steels as building materials in construction industry is due to the positive characteristics such as prefabrication, strength and its speed of erection. Steels are used in many parts of the buildings for different purposes such as load-bearing frames, bridges and trusses. In order to prolong its lifespan, it should be protected against corrosion as well as fire- resistance. Steel is embedded in concrete to cater the tensile strength. Generally, bonding between steel and concrete is increased by using steel bars that have deformations on the surface to provide the “gripping” actions.

Steel properties can be described in terms of Young’s Modulus, yield strength, ultimate strength, steel grade designation as well as size or diameter of the bar. Of all these properties, yield stress, f_y of steel is the most useful property when calculating reinforced concrete design. Figure 2.1 shows the typical stress-strain curves for steel.

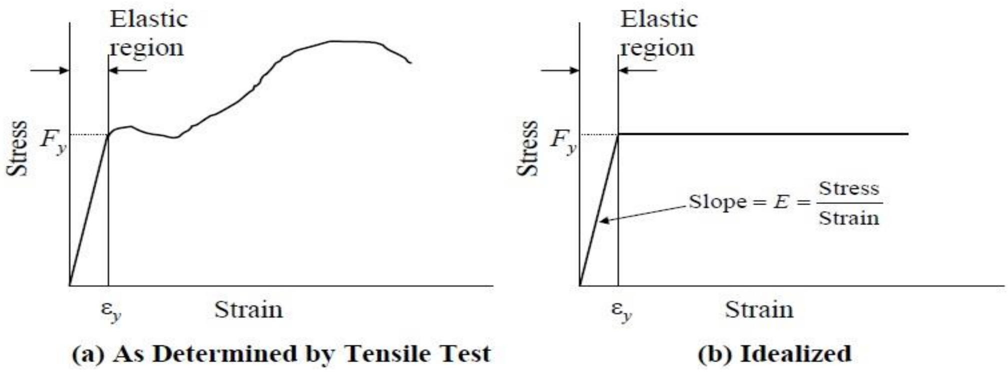


Figure 2.1 Typical stress-strain curves for steel

Source: Steiner (1990)

2.4 BAMBOO IN CONSTRUCTION APPLICATION

Bamboo has a long and well established as a building material throughout the world’s tropical and sub-tropical region. It is widely used for many forms of construction, in particular for housing in rural areas. Bamboo is a renewable and versatile resources, characterized by high strength and low weight, and is easily worked using simple tools. As such, bamboo constructions are easy to build, resilient to wind and even earthquake forces and readily repairable in the event of damage.

Bamboo can be used to make all the components of small building, both structural and non-structural, with the exception of fireplaces and chimneys (Jayanetti & Follet, 2008). Bamboo building construction is characterised by a structural frame approach similar to that applied in timber frame construction. In this case, the floor, wall and roof elements are interconnected and often one depends on the other for overall stability.

2.4.1 Bamboo Reinforced Concrete

The use of bamboo as concrete reinforcement is one of the more broadly used relating to bamboo in construction. It is because bamboo is low in cost compared to steel. Other than that, the good reasons why bamboo considered as reinforcement for concrete is because it is readily available and it strength to weight ratio compares favourably with steel. However, bamboo exhibits certain characteristics which limit its effectiveness as concrete reinforcement.

2.4.2 Bridges

A bridge can be defined as an elevated structure supported at interval for carrying traffic across obstacles. In general terms, therefore, the range of types, spans and capacities is almost infinite. Bamboo bridges, however, are generally of trestle construction and of limited span for carrying only light traffic. Simple trussed constructions have also been built and shown capable of supporting substantial loads. Figure 2.2 shows of the bamboo bridge in Cambodia that has been built every dry season.

Figure 2.2 Bamboo Bridge connecting Kampong Cham to Koh Paen, Cambodia

Sources: www.phnompenhpost.com

2.4.3 Scaffolding

Bamboo scaffolding is widely used throughout South and South East Asia and also South America as a temporary structure for supporting working platforms in building construction and maintenance as shown in Figure 2.3. The main advantages of bamboo scaffolding when compared with steel are its lightness and low cost. It is also readily tailored to suit the shape of a building. However, problems such as lack of durability, and non-standardised jointing currently limit its wider application.

Figure 2.3 Bamboo scaffolfing used to build Hong Kong Skyscrapers

Sources: www.archdaily.com

2.5 FINITE ELEMENT ANALYSIS

The finite element analysis is a simulation of any physical phenomenon using the numerical technique called Finite Element Method (FEM). It is an efficient method widely used in civil engineering field to predict how a structural member reacts to real work. In addition, due to the cost effective and time efficiency, the use of FEA has been preferred method to investigate the behaviour of concrete beam. Usually, the behaviour of concrete beam was defined by full-scale experiment investigation where the results obtained were validated with theoretical calculations to calculate the deflection, ultimate load and stress-strain distribution within the beams.

Theoretical calculation might encounter problems when dealing with the analysis of non-linear complex behaviour of model and time consuming if conducted manually. Hence, the application of FEA software were getting more popular due to the huge advancement of computer knowledge, as it can be used to conduct non-linear analysis of complex model numerically and to provide a valuable validation supplement of the laboratory investigation. Several studies related to non-linear finite element analysis of RC beam using various commercial software such ANSYS, and ABAQUS were documented by few searchers.

2.5.1 ANSYS CivilFEM

ANSYS is one of engineering software available, used to stimulate engineering problems and disciplines including finite element analysis, structural analysis, computational fluid dynamics, and heat transfer. This software adapts Newton-Raphson method, which is capable to conduct non-linear analysis of RC beam, where in reality, RC beam behaved non-liner in term of geometry or material. So, non-linear analysis for RC beam is essential to study the behaviour of the beam, ultimate load capacity, tensile and shear strength.

ANSYS software is the most advanced package for single and multiphasic simulation, offering enhanced tools and capabilities that enable engineers to complete their jobs in an efficient manner. ANSYS includes significant capabilities, expanding functionality, and integration with almost all CAD drawing software, such as Pro/ENGINEER, AutoCAD, and Solid Edge. In addition, ANSYS has the best-in-class solver technologies, an integrated coupled physics for complex simulation, integrated meshing technologies customizable for physics, and computational fluid dynamics.

There were only a few researchers who attempted the simulation to study the behaviour of reinforced concrete strengthened with natural fibers.

Sen & Reddy (2011) had done a numerical study of strengthening a RCC Beam using bamboo fibers. Sen & Reddy (2011) adopted the commercially available software ANSYS to analyse the behaviour of strengthened RCC beams and un-strengthened RC beams using finite element method. The materials were considered to behave non linearly and thus nonlinear finite element analysis was used to determine the stress distribution. In determining the geometrical model of concrete, Sen & Reddy (2011) suggested that SOLID65 was to be used to model the 3D concrete with and without the existence of reinforcing bars. However, Pipe 16 was used as the element to model uniaxial form of reinforcing bars that was capable of tension-compression and bending capabilities. As for the bamboo fiber itself, Sen & Reddy (2011) proposed SHELL63 to be the suitable element capable of bending and bonding. Figure 2.4 and figure 2.5 shows finite element modelled of reinforcement and meshed finite element model.

As for the material properties, the study followed the Indian code of practice IS 456:1958 for design. 20 MPa was chosen as the compressive strength of the concrete with Young's modulus of 22361 N/mm^2 and Poisson's ratio of 0.15. As for the reinforcing bars, the Young's modulus is 200000 N/mm^2 with Poisson's ratio of 0.3.

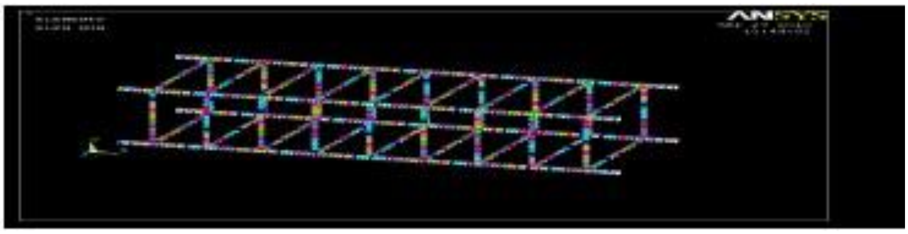


Figure 2.4 Finite element modelled of reinforcements.

Source: Sen & Reddy (2011)

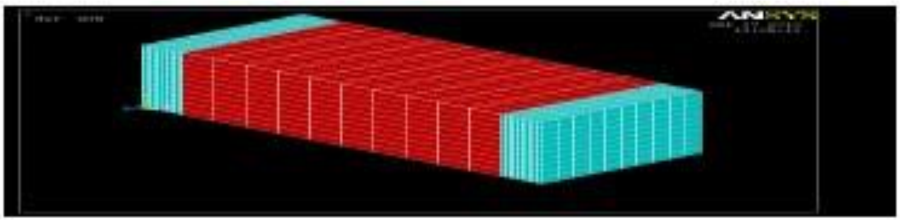


Figure 2.5 Meshed finite element model wrapped with bamboo fiber.

Source: Sen & Reddy (2011)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In general, this chapter covers the topic regarding the planning, preparation and execution in terms of modelling and analysis method. The main focus of the research is to study the behaviour of RC beams with partially and fully bamboo reinforcement using finite element analysis software, ANSYS CivilFEM 12.0. ANSYS CivilFEM 12.0 is engineering software combined of two programs which are ANSYS and CivilFEM. The combinations provide wide accessibility of project in construction and civil engineering fields with the possibility of applying high-end technology. In additional, finite element analysis can be performed and analysed by CivilFEM postprocessor as well as its capabilities of providing a unique and extensive materials and section library for steel and concrete structures (Moreno et al, 2001). Ansys CivilFEM 12.0 is relatable engineering simulation software for the finite element modelling and analysis.

ANSYS is a software capable of modelling and analysis. Using this software, various mechanical components can be assembled and visualized the intended finite element analysis result. ANSYS is popular among academia and research institutions for its wide selection on material modelling options, as well as extensive range of material models such as plasticity, elasticity that focuses on both non- linear and linear physical behaviour. The simulation results will then be used to verify with the experimental works on the same conditions.

3.2 RESEARCH FLOW CHART

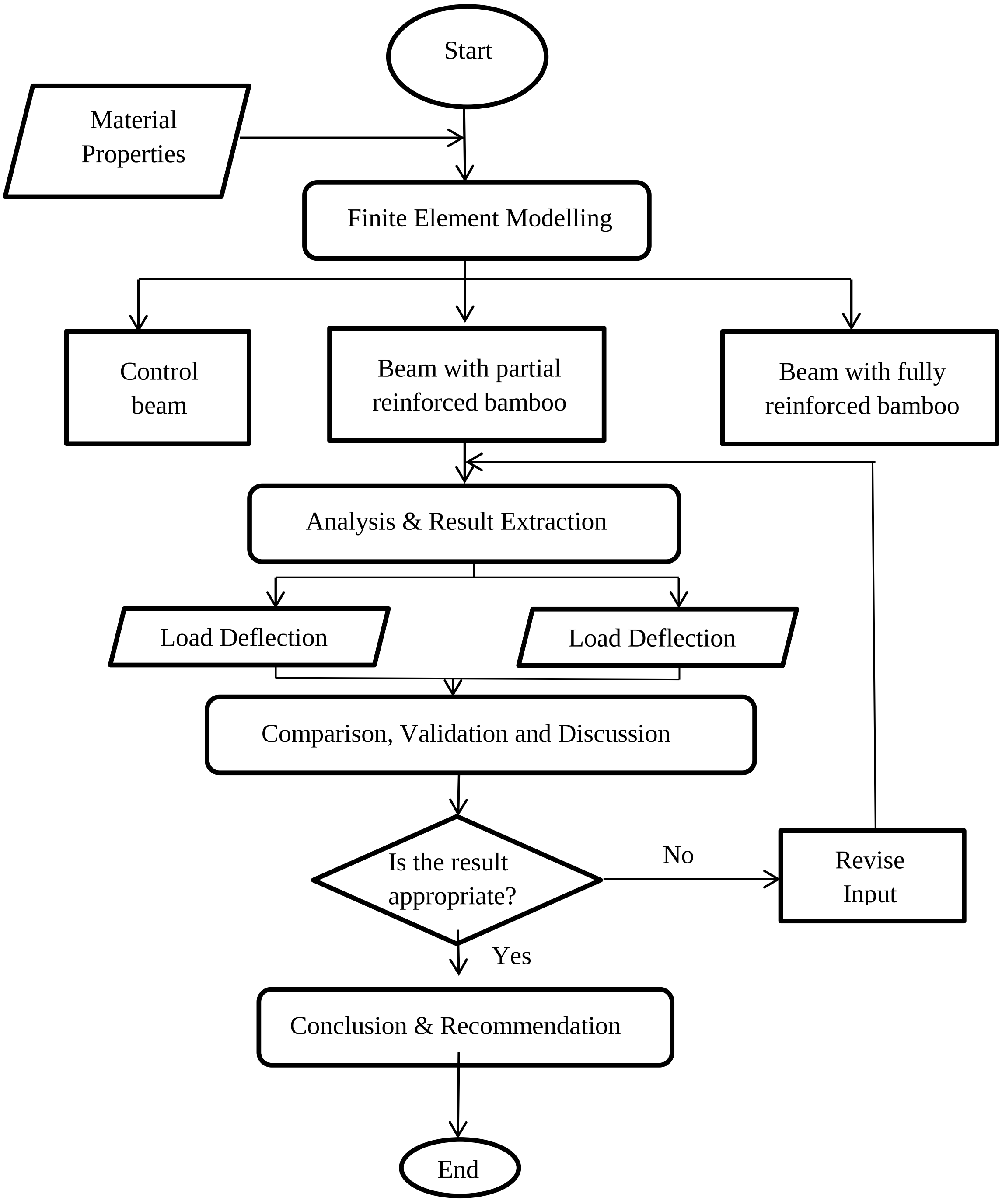


Figure 3.1 Flowchart of Research

3.3 FINITE ELEMENT ANALYSIS (ANSYS)

In the research, three (3) solid beams were modelled as simply supported beams in three dimensions (3D) with the finite element analysis concept by using ANSYS. One (1) of the beam act as a control beam, one (1) is partially reinforced with bamboo reinforcement and one (1) is fully reinforced with bamboo. All three (3) beams had been subjected to four point loading up to beam failure in order to obtain crack patterns, load-deflection curve, and stress and strain contour

Figure 3.2 shows the schematic diagram of the control beams and the reinforcement arrangement that being used in this study. The cross section of RC beam was 120mm x 300mm with a length of 1600mm as shown in figure.

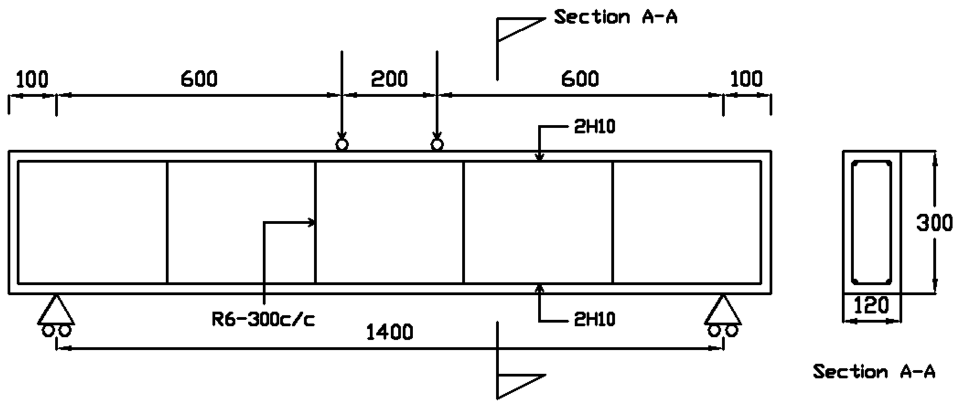


Figure 3.2 Schematic Diagram of RC Beam

All beams have steel reinforcement bars of 10 mm in diameter for both tension and compression region, while the shear link used was 6 mm diameter at 300 mm centre to centre. The first beam acted as control beam (CB) where the steel reinforcement is used for both main reinforcement and stirrups. The partial bamboo reinforced beam consists of bamboo as main reinforcement while steel are used for stirrups are namely as BR. For fully bamboo reinforced beam was labeled as bamboo steel reinforcement (BSR) used bamboo as main reinforcement and stirrups. All the modelled beams are listed in Table 3.1 that summarizes the different category of beams.

Table 3.1 Categories of Beams

Beam	Reinforcement
CB	Main reinforcement : Steel
	Shear Link : Steel
BR	Main reinforcement : Bamboo
	Shear Link : Steel
BSR	Main reinforcement : Bamboo
	Shear Link : Bamboo

3.3.1 Material Properties

The use of material properties in ANSYS had to be similar to the physical properties of the materials that being used in experimental work. The materials properties of each part were summarized in the following section

3.3.1.1 Concrete

There were three types of properties needed to be input for material properties of concrete. The parameters for elastic behaviour such as density, Young's modulus and Poisson's ratio were assumed from Eurocode 2 as listed in Table 3.2

Table 3.2 Material Properties of Concrete

Properties	Value
Density	2.4E-09 tonne/mm^3
Elastic Behaviour	
Young's Modulus	33GPa (33000MPa)
Poisson's Ratio	0.2

3.3.1.2 Steel

Steel is an alloy of iron and carbon and other elements. Because of its high tensile strength and low cost, it is a major component used in building and infrastructure. There are various types of steel, and the use of this alloy is widespread across industries and infrastructure owing to its many useful properties and characteristics. The parameters required by steel were referred to Eurocode 3. The properties were summarize in Table 3.3

Table 3.3 Material Properties of Steel

Properties	**Value**
Density	7.85E-09 tonne/mm^3
Elastic Behaviour	
Young's Modulus	210GPa (210000MPa)
Poisson's Ratio	0.3
Plastic Behaviour	
Yield Stress (MPa)	Plastic Strain
550	0
640	0.09

Sources: Eurocode 3, EN1993-1-1-2005

3.3.1.3 Bamboo

Most countries have no standard building codes for bamboo which makes it difficult for those who wish to use the material in construction. There is a kind of legal uncertainty surrounding the determination of certain bamboo properties such as fire resistance, strength properties, and durability which implies that there is an urgent need for regulations and standards. The properties of bamboo fibre are presented as Table 3.4

Table 3.4 Material Properties of Bamboo

Properties	**Value**
Density	1158g/cm^3
Elastic Behaviour	
Young's Modulus	10-40GPa
Poisson's Ratio	0.3
Tensile Strength	73-505MPa

Sources: Savastano et al. (2000)

3.4 ANALYSIS OF RC BEAM

Steps involved through the process of modelling of beam and the details of every step are presented discussed in each sub-topic.

3.4.1 Pre Processing

Pre-processing is the first step in solving problem in ANSYS. The used of the tools in this stage is considered as defining the element type, materials properties, modelling, meshing, load input and method to analysed the modelling. There were prior step for the modelling because it defined all properties and input data that be included in building a model. Input data for the geometrical elements, mesh generation, reinforcement, supports, loads were inserted by following purposed.

3.4.2 Material Parameters

Material parameter was setting up once starting the new modelling. The unit was set as international system and the codes that been selected should be the one that we are referred as shown in Figure 3.3. Next, the element type was selected as shown in Figure 3.4. Parameters modelling should be matched with the experimental parameters to achieve acceptable result.

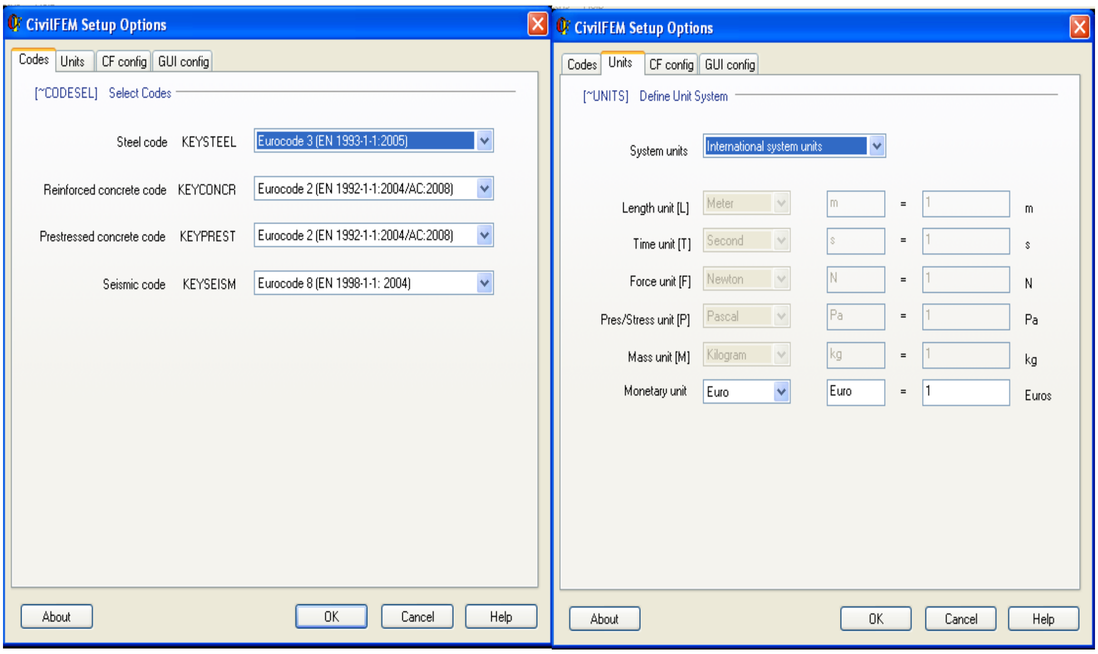


Figure 3.3 Parameter Setup Options

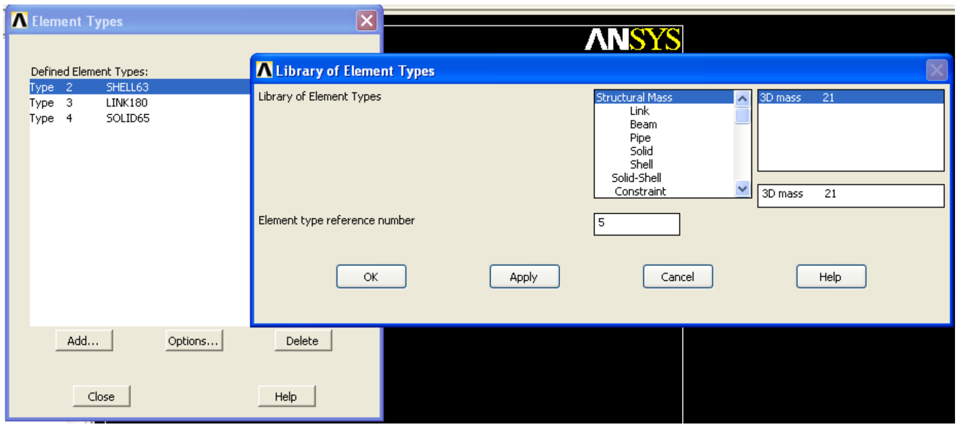


Figure 3.4 Defining the Element Type

The element type could be choosen in the pre-processing panel. The selection of elemengt is important because every element type has different purposed and later, it will be effected the result. The material choosen should be matched with the experimental as we will validated the result of finite element model with the experimental result. Table 3.5 shows the type of element used in the analysis.

Table 3.5 Element Type used in Analysis

Materials	**Element Type**
Concrete	SOLID65
Steel Reinforcement	LINK180
Bamboo	SHELL63

3.4.2.1 Concrete

For concrete, SOLID65 is usually used for the three-dimensional (3D) modelling of solids either with or without reinforcement bars. It is capable to resist the cracking in tension and crushing in compression. In concrete applications, the capability of the solid element may be used to model the concrete while the capability of rebar is available for modelling the behaviour of the reinforcement. In additional, the treatment of nonlinear material properties is the most important aspect of this element. Figure 3.5 shows the coordinate system of SOLID65- 3D reinforced concrete solid.

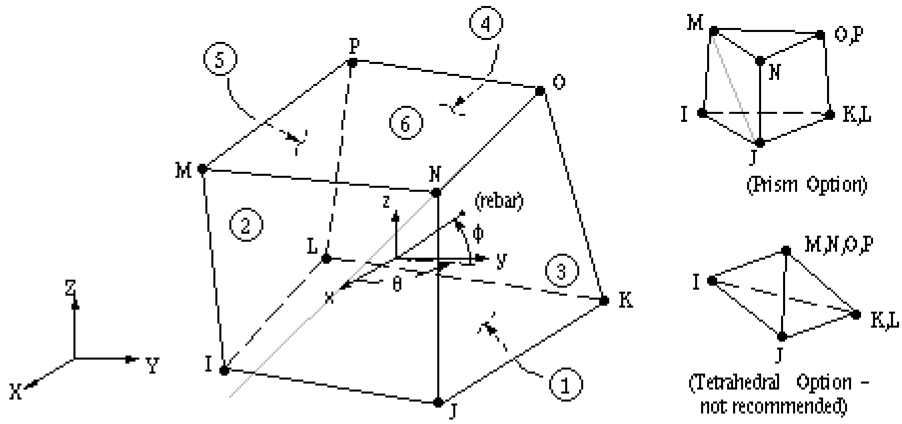


Figure 3.5 Coordinate System of SOLID65

3.4.2.2 Steel Reinforcement

In this study, the element used for steel is LINK180. It is useful in a variety engineering applications. LINK180 includes stress-stiffness terms in any analysis that includes large-deflection effects. Elasticity, isotropic hardening plasticity, kinematic hardening plasticity, and creep are supported. To simulate the tension and compression options, a nonlinear iterative solution approach is necessary. This element also can be used to model trusses, links and springs.

3.4.2.3 Bamboo

SHELL 63 has both bending and membrane capability. Both in plane and normal loads are permitted. The element has six degree of freedom at each node which is translations in the nodal x, y, and z directions and rotations about the nodal x, y, and z axes. Stress stiffening and large deflection capabilities are included. A consistent tangent stiffness matrix option is available for use in large deflection analysis. The ANSYS theory references have more details about this element. There are few elements that have the same properties as SHELL 63. They are SHELL 43 and SHELL 181 which for plastic capability and SHELL 93 for the mid side node capability. Figure 3.6 shows the coordinate system of SHELL 63.

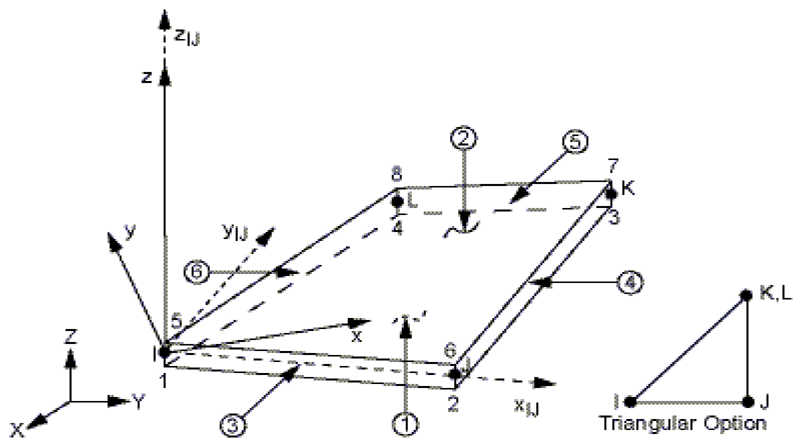


Figure 3.6 Coordinate System of SHELL63

After classified the element type, material properties should been assigned to the element so that the analysis can be done according to the behaviour of the materials. The different properties of element were inserted according to the data from experimental work. It will show a convincing result at the end of the analysis if the correct materials are chosen for all elements. Figure 3.7 shows the material properties of model analysis and Figure 3.8 shows the overall material used in analysis.

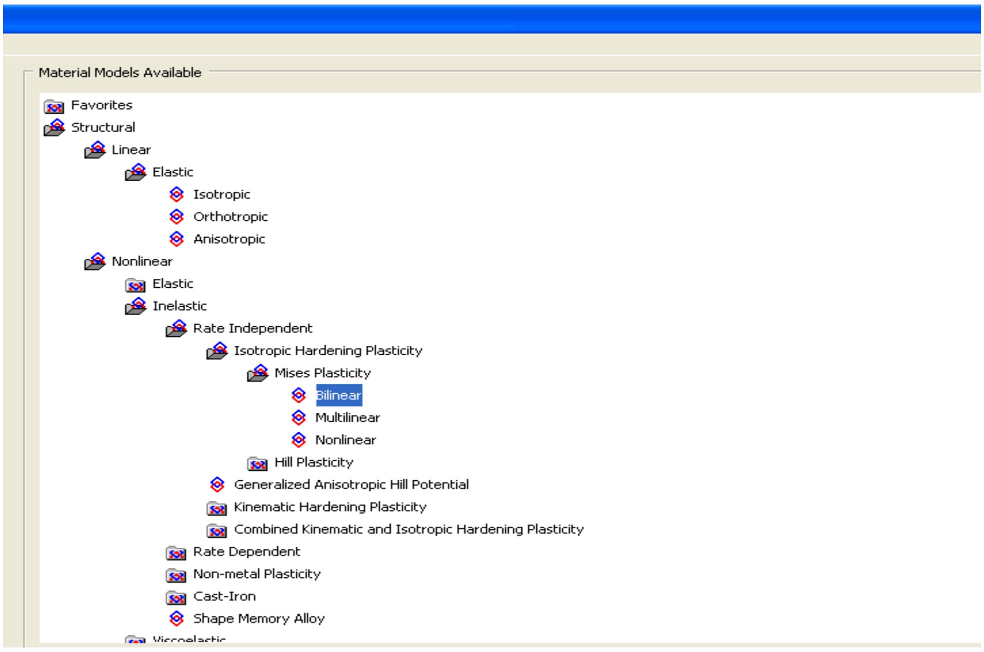


Figure 3.7 Material Properties of Model Analysis

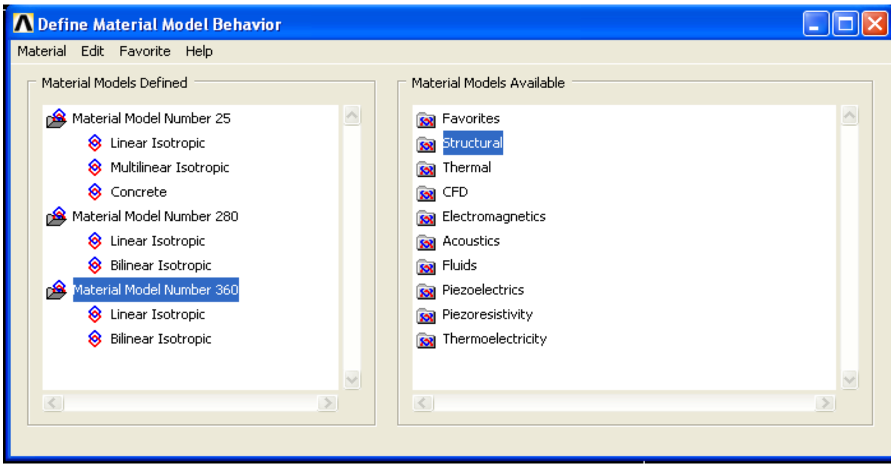


Figure 3.8 Summary of Material Assigned to the Element in Analysis

For steel reinforcement, the diameter used for both tension and compression were 10mm and the stirrups are 6mm. Since the element type for reinforcement bars are the same, the area of the cross section of the reinforcement bar was defined for it real constant. Table 3.6 shows the real constant of cross sectional area of reinforcement and Figure 3.9 shows the input data on how to defined the real constant of the cross sectional area of reinforcement bar.

Table 3.6 Real Constant of Cross Sectional Area of Reinforcement

Reinforcement Bar Diameter	**Cross Sectional Area**
6 mm	28.27 mm^2
10 mm	78.54 mm^2

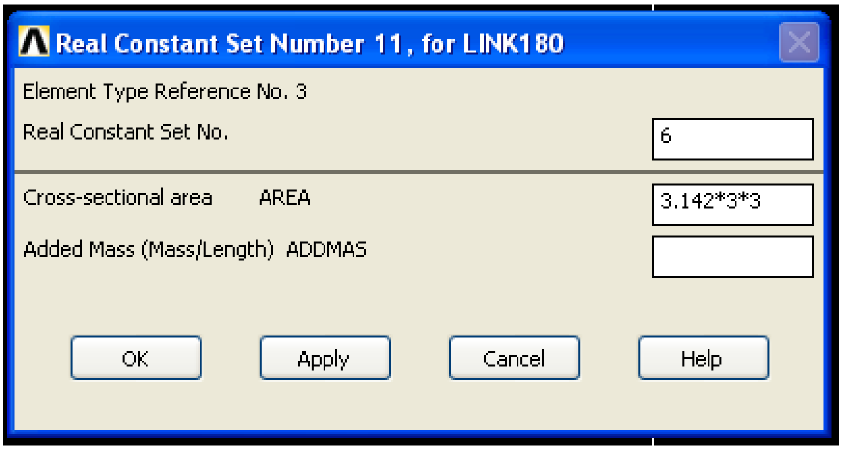


Figure 3.9 Input Data to Defined Real Constant of Cross Sectional Area of reinforcement

3.4.3 Creating Parts

3.4.3.1 Beam Model

In this stage, the structure was designed according to its requirement based on experimental work such as the size and shape. The model was created using the volume options and the block option was chosen. The volume of the model was defined by dimension of concrete beam. The dimension work as nodes in the Cartesian plane and the block was build according to shape and dimension as experimental work. This would give the first view of the beam shape before further step taken. It is the simplest method to model a beam structure. Figure 3.10 shows the coordinate for each x, y, and z direction in order to model a concrete beam model and Figure 3.11 shows the modelled beam has been modelled on the Cartesian plane along x, y, and z direction.

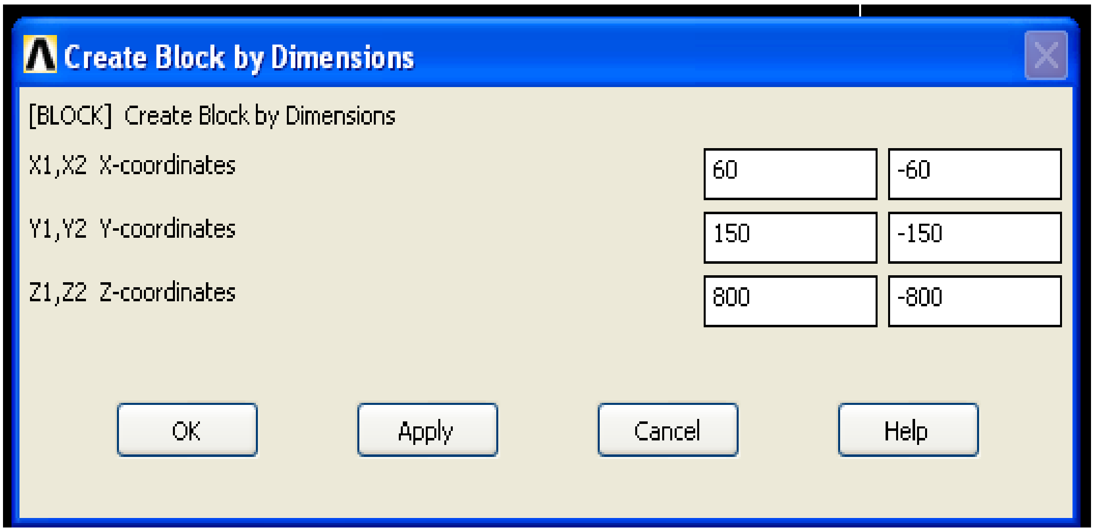


Figure 3.10 Coordinate for Creating Block by Dimension

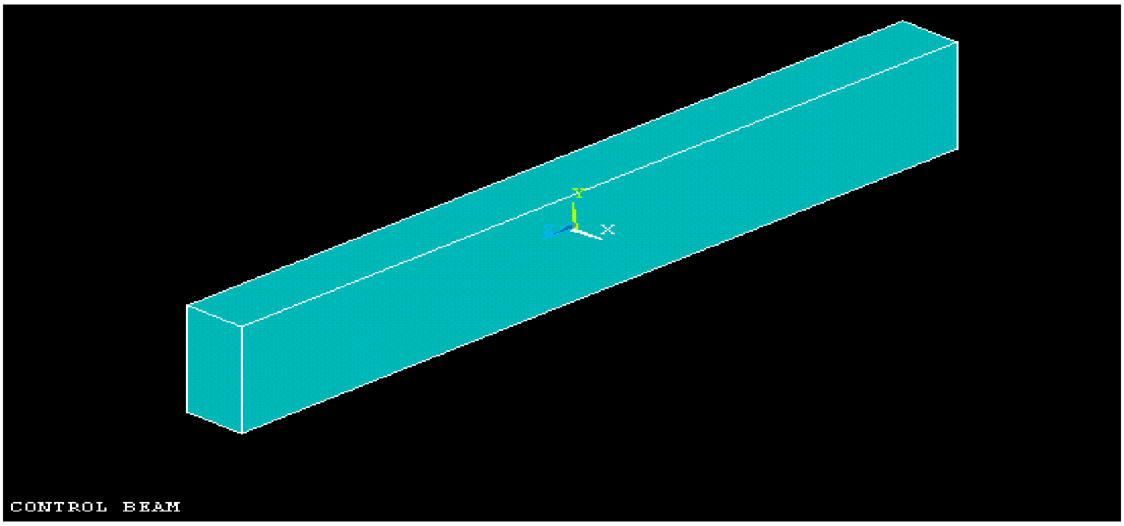


Figure 3.11 Modelled Beams Created

Method copy the area with combination of dividing volume by work plane was used to get the section for the definition of reinforcement bar later. The cross sectional area of 120mm x 300mm was selected and copied according to its distance to create the section of link with accurate distance. It can be seen from the side or oblique view. Method of dividing the volume by work plane was used to offsetting the link by 20mm as shown in Figure 3.12 from outer of the concrete beam. This method was applied by inserting the coordinate on the Cartesian plane. The distance between the links is 300mm center to center. Figure 3.13 and Figure 3.14 shows the section after the method of copy and divided area done in side view and oblique view.

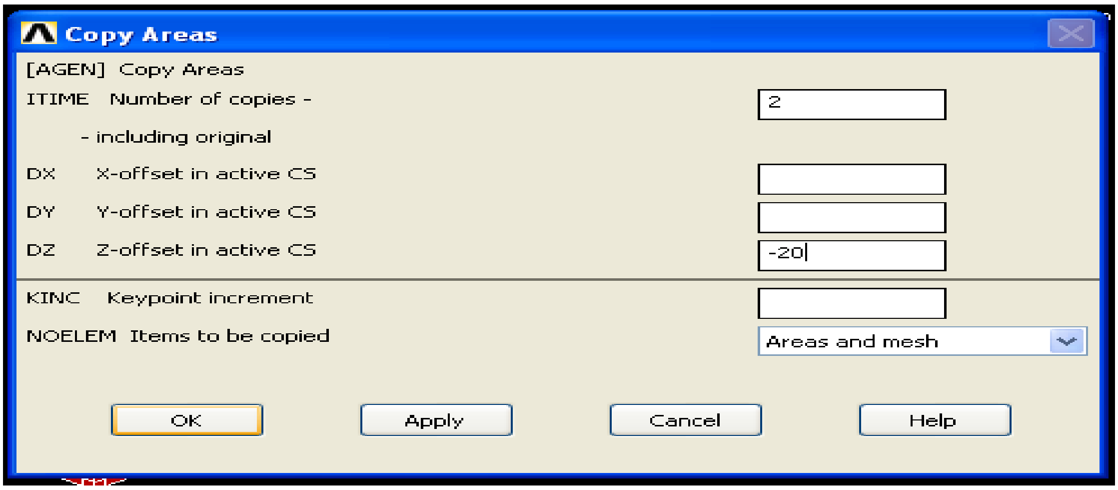


Figure 3.12 Method of Copy of Cross Sectional Area Using Copy Area Option

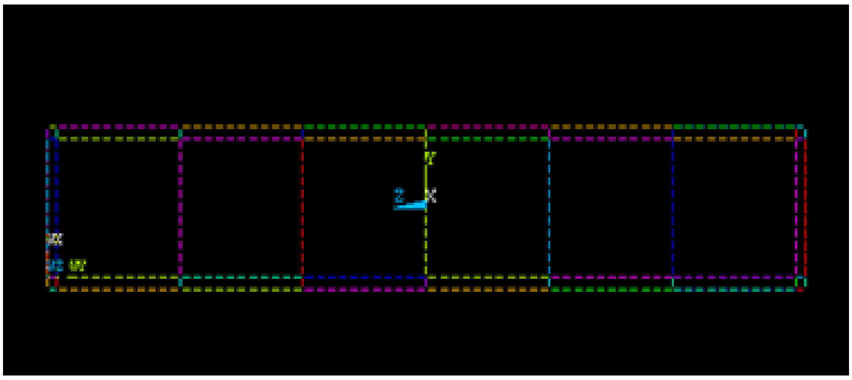


Figure 3.13 Bar Reinforcement Draft from Side View

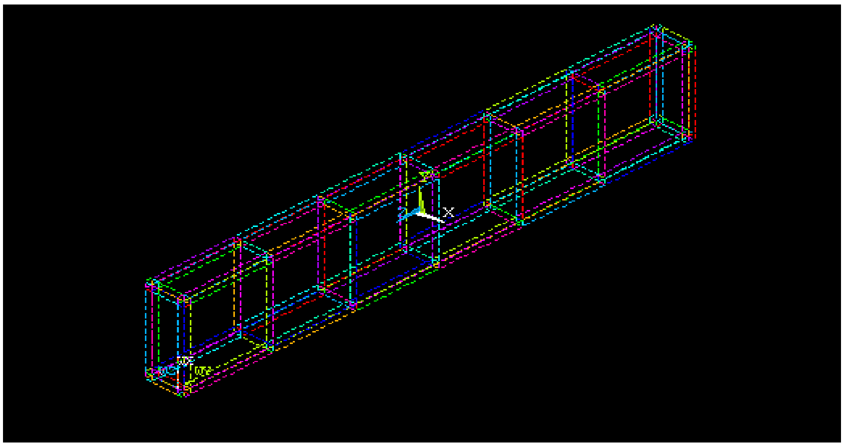


Figure 3.14 Bar Reinforcement Draft from Oblique View

3.4.3.2 Steel Reinforcement Bar

Defining steel reinforcement bar was taken place after dividing and cutting plane. The lines involved for link were chosen using selected entities as shown in Figure 3.15 from the select option. Figure 3.16 and Figure 3.17 shows the line selected that would be used as link and reinforcement bar. The reinforcement at top and bottom has the same cross section were aligned in the concrete beam.

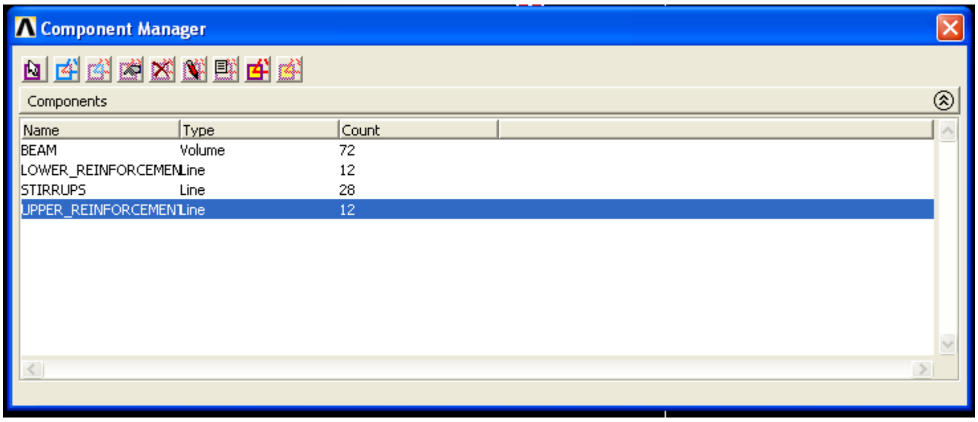


Figure 3.15 Component Manager of Selected entities

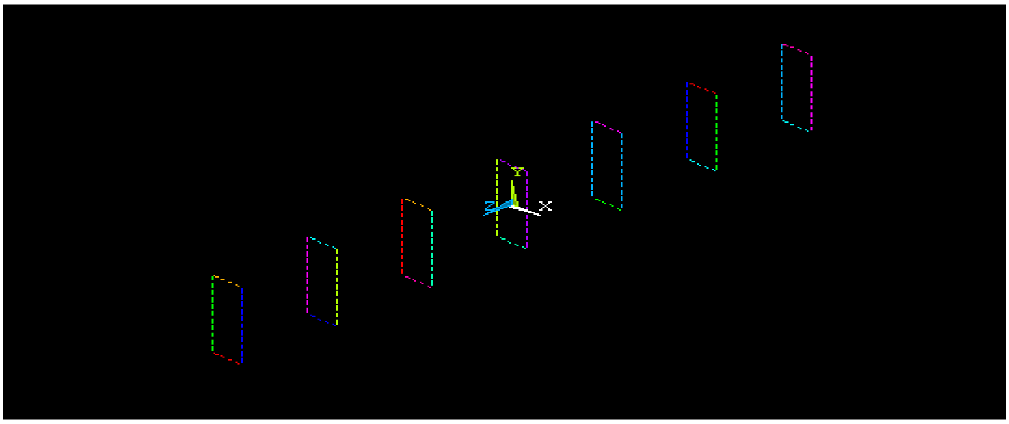


Figure 3.16 Selected Lines for Shear reinforcement

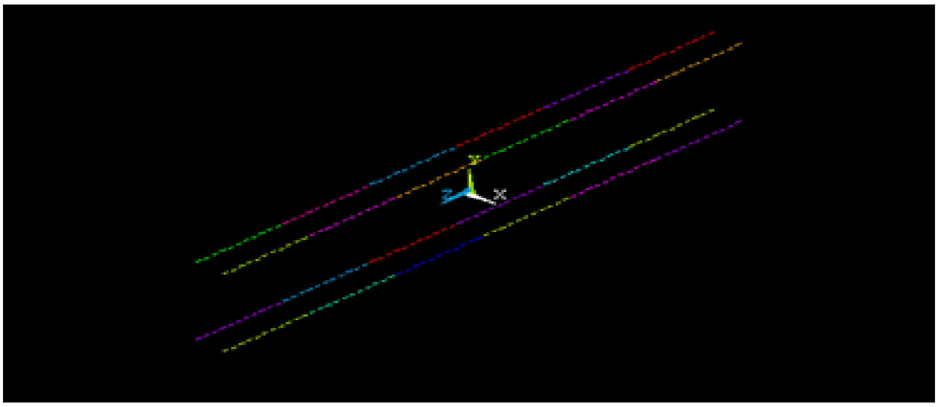


Figure 3.17 Selected Lines for Top and Bottom Reinforcement

3.4.3.3 Mesh Generation

Mesh generations used for defining all components to form a concrete model including the reinforcement bar and concrete. The meshing was done after all the components were saved in Component Manager Option as shown in Figure 3.15. The process should be done step by step. The first step was deciding the element size on picked line to divide the line into section as shown in Figure 3.18. The lines were cut into a section in every 25mm.

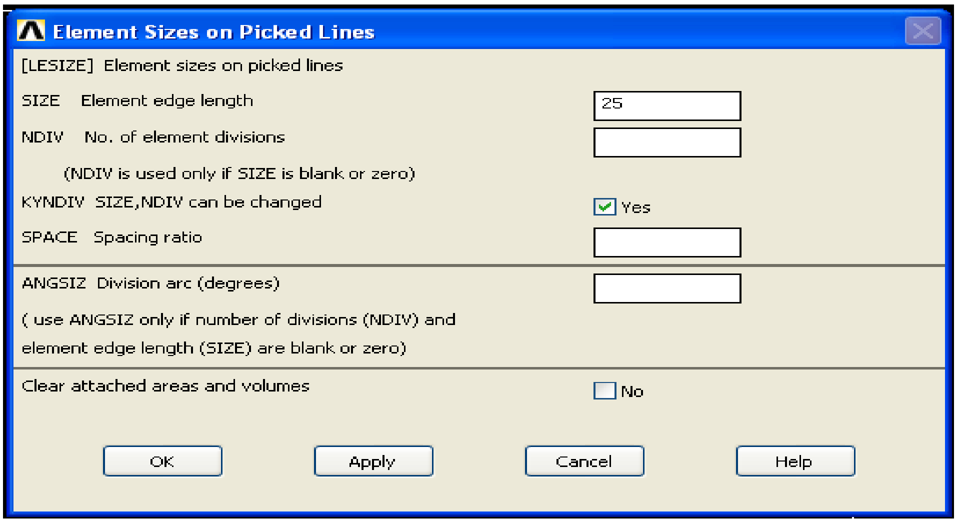


Figure 3.18 Element Size on Picked Lines for Meshing Element Attributes

The next step is defined the meshing to all elements according to its properties that had been decided in the early stage. Figure 3.19 shows the options for the meshing according to the selected element type, materials and real constant and Figure 3.20 shows the lines that had been meshed.

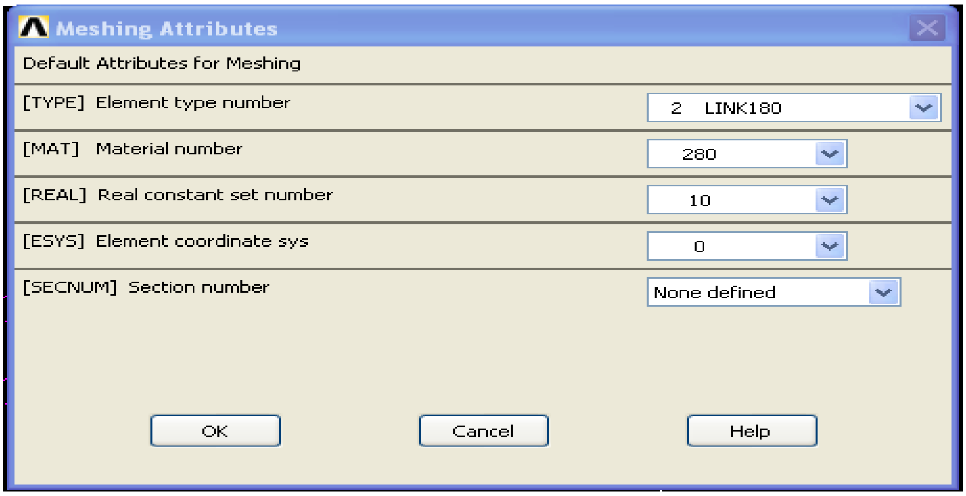


Figure 3.19 Meshing Attributes According Element Type, Material and Real Constant

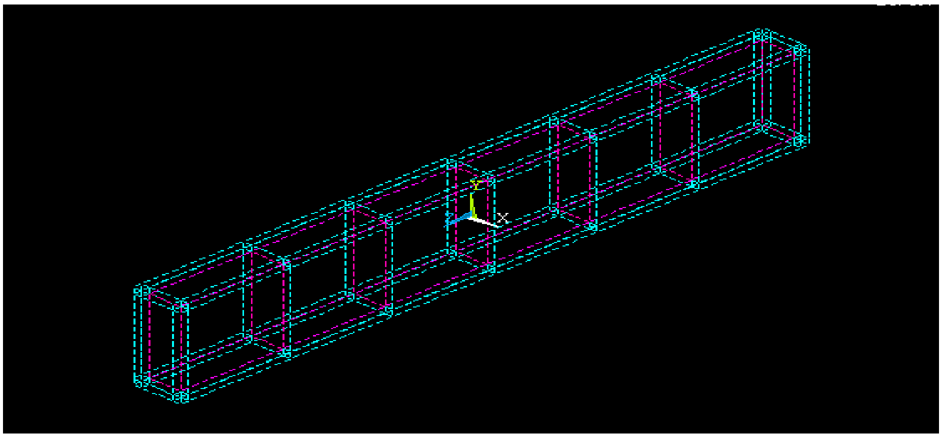


Figure 3.20 The Lines that had been Meshed

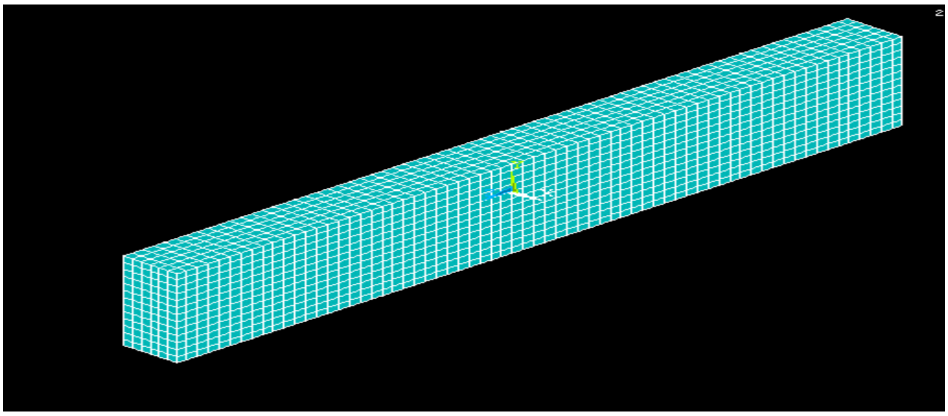


Figure 3.21 The Meshed Concrete Beam

3.4.4 Four Point Bending Test

The four-point bending test was conducted to the modeled beam. Generally, it is consists of two support nodes and two loading nodes as shown in Figure 3.21. For this study, the loading points are 200 mm apart in which the points were equally distant to the center line. Loading was delivered to the beam specimens by using a spreader beam. The loads were applied in a direction vertically downward until the beam specimens failed. The displacement point and load point was determine according to Figure 3.22 and 3.23 respectively.

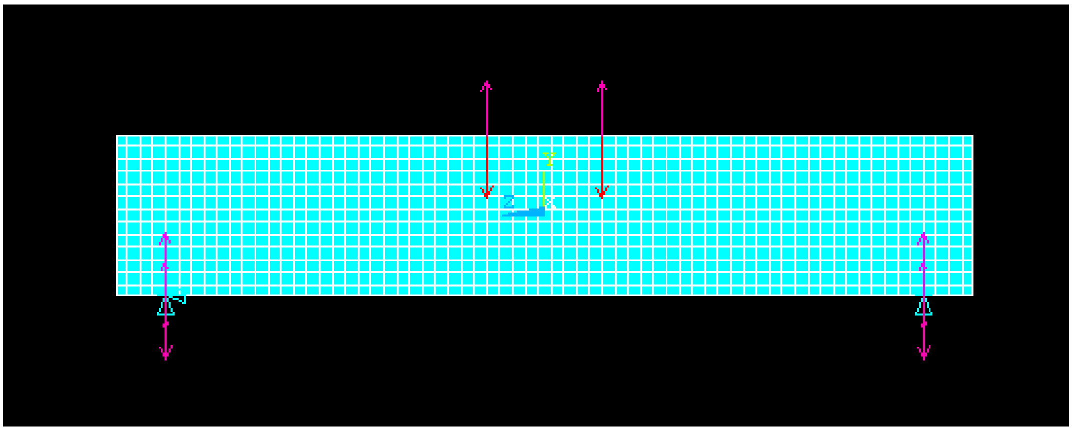


Figure 3.22 Four Point Bending Test

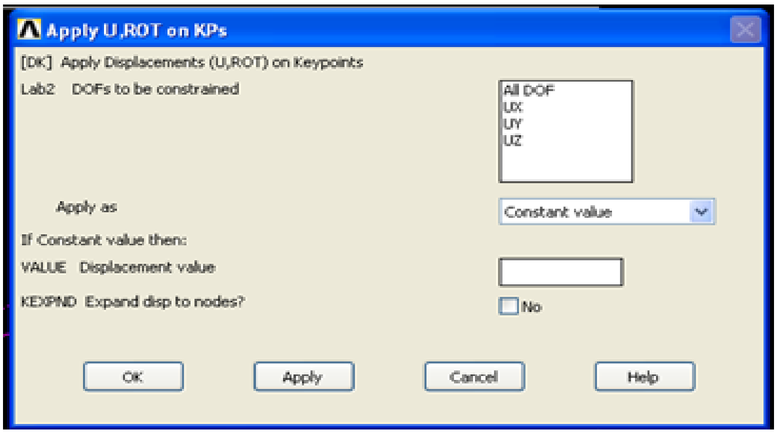


Figure 3.23 The Displacement Point on Keypoints

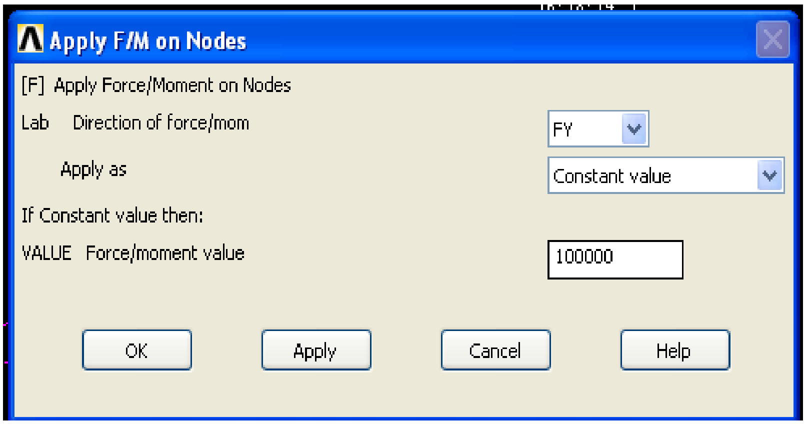


Figure 3.24 The Load Applied on the Nodes

3.4.5 Analysis

Before the analysis can be run, step should be created in Solution control. In the research, the analysis was done for Non-Linear Geometry. Stabilisation should be on to allow smoother analysis and the increment was set as shown in Figure 3.25 to allow larger period to analyse non-linear failure and solve the current load steps to get the result as shown in Figure 3.26.

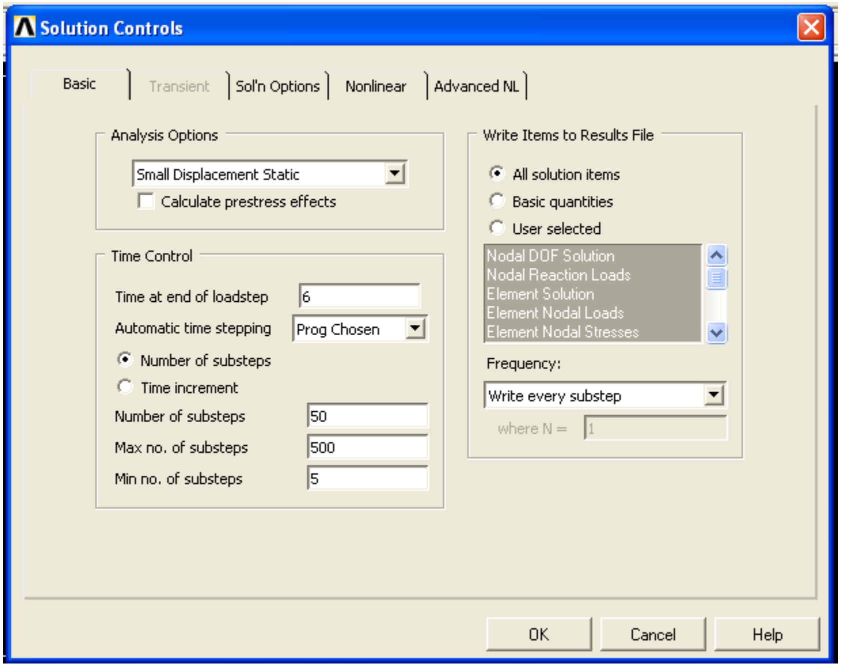


Figure 3.25 Solution Control for Incremental Sub steps

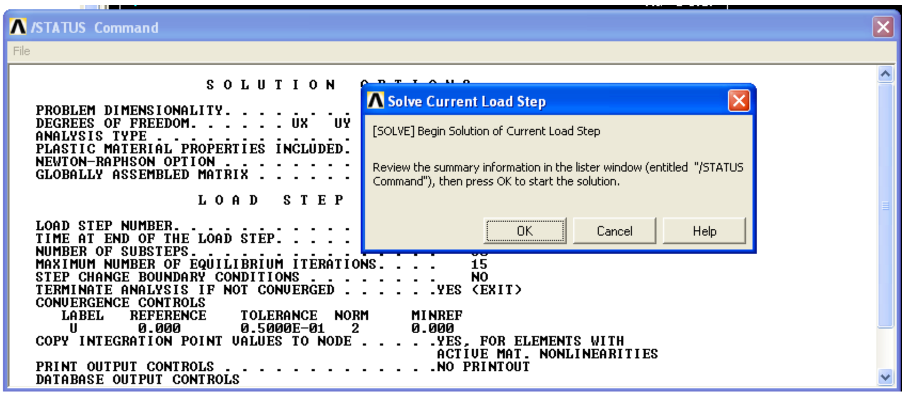


Figure 3.26 Solution of Current Load Steps

3.4.6 Post Processing

The post processing was done in Visualisation Module. To see the contour, contour plot for nodal element was selected. The respective stress contours, strain contours or crack patterns can be determined through this method as shown in Figure 3.27 and Figure 3.28. To plot the load-deflection graph, each load steps was selected which represented the reaction force and displacement on negative y-direction. Then, the nodes were selected at the locations of applied loading and the graph was plotted.

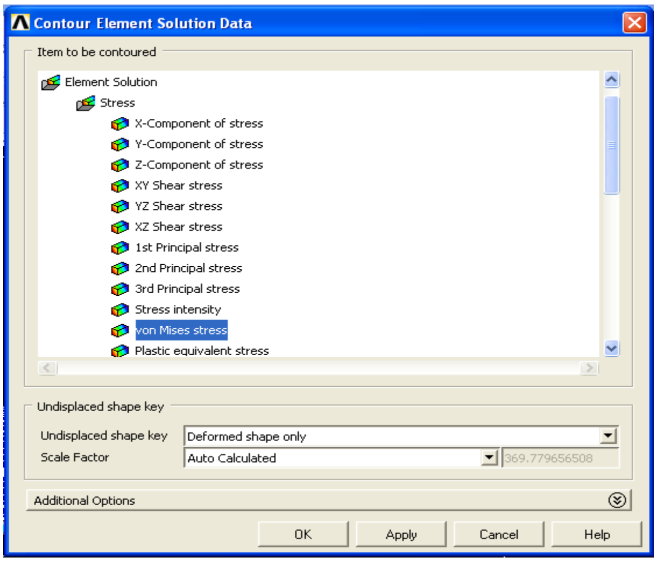


Figure 3.27 Control Plot for Nodal Element

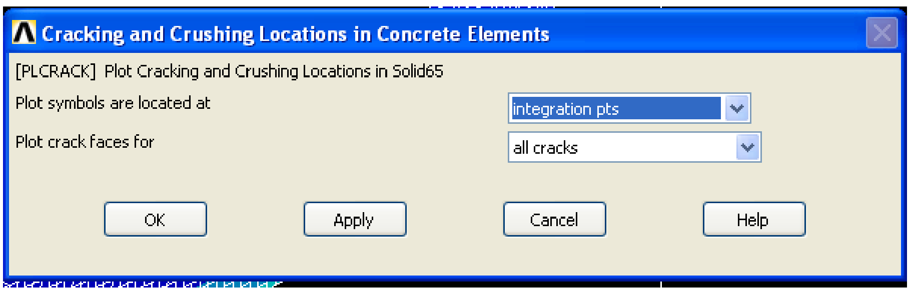


Figure 3.28 Cracking and Crushing Location in Concrete

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

Results that were extracted from FEA include load-deflection behaviour, crack pattern and strain contours. At the end of this section, validation between FEA results and experimental results of the same beams are discussed. Bonding between the concrete and bamboo reinforcement was assumed to be perfect bonding. Different types of failing behaviour of the beams are discussed and compared in the summary of results.

4.2 FLEXURAL BEHAVIOUR

4.2.1 Load Deflection Behaviour

In this research, non-linear finite element analysis was used to analyze all RC beams modeled including control beam, partially bamboo reinforced and fully bamboo reinforced using ANSYS. Based on the extracted load-deflection curve, the ultimate load that can be sustained before the beam failed and the total displacement due to failure can be determined. The following section discussed the load-deflection behaviour for all the modelled RC beams.

4.2.1.1 Control Beam (CB)

Control beam was modelled as beam with full configuration of rebar and shear links. Control beam as a reference beam for the other modelled beam to determine the behaviour of RC beam such as the reduction of load capacity and the regain of load capacity after the use of bamboo as reinforcement.

Control beam showed the highest load capacity among the other beams. The ultimate load of the control beam using finite element analysis was 58.15 kN with 38.67 mm deflection as shown in Figure 4.1. With deflection, the load increased gradually until a constant load was achieved before failure. The beam experienced plastic deformation indicating control beam has ductile behavior. Due to the full configurations of rebars and shear links used are adequate, the control beam had a very stiff behaviour. The beam was able to withstand high load capacity among the other modelled.

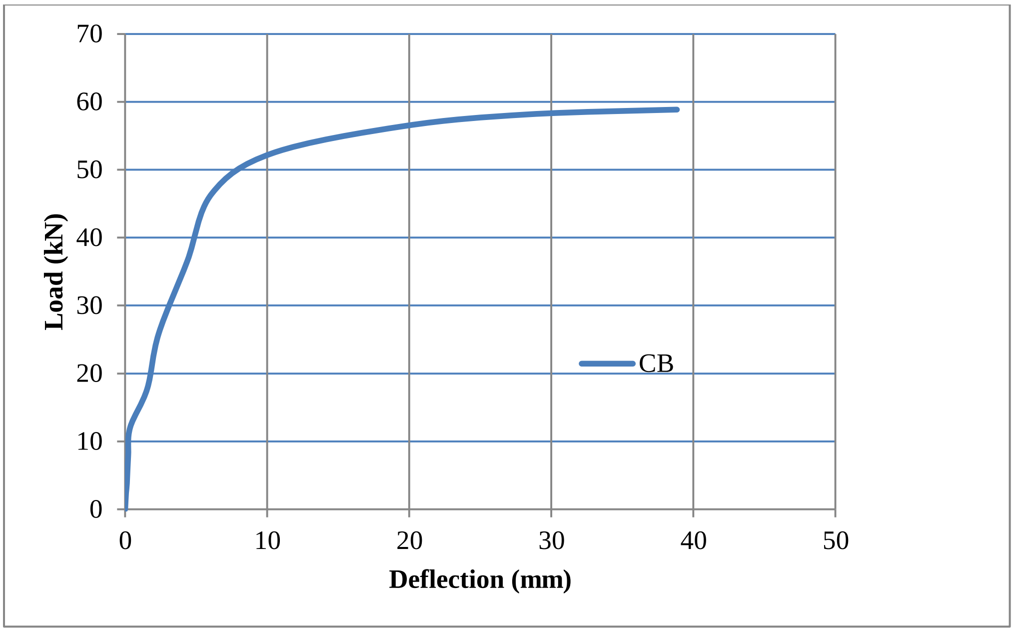


Figure 4.1 Load-deflection curve for control beam (CB)

4.2.1.2 Bamboo Reinforcement (BR)

Partial bamboo reinforcement was modelled as RC beam with the bamboo as main reinforcement. Figure 4.2 shows the comparison of behaviour of load deflection between control beam (CB) and bamboo reinforcement (BR). According to Figure 4.2, BR experienced a large deflection with lower ultimate loading which was 48.46 kN with 19.98 mm deflection. It was 78% reduction of load compared to CB. This explained that bamboo reinforcement was weak to resist tensile forces, thus, most of the loading was resisted by the concrete in compression strength.

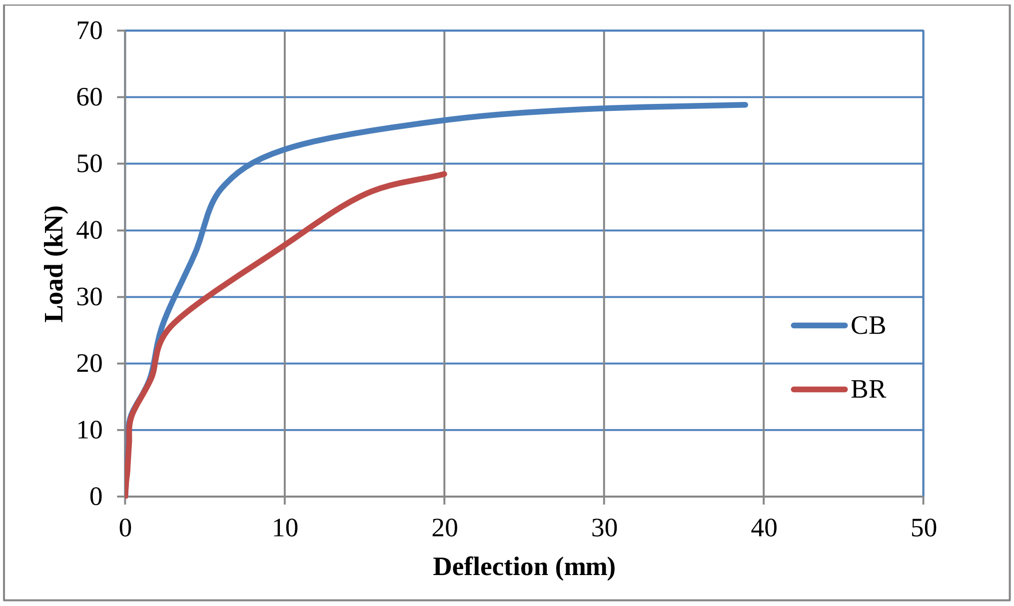


Figure 4.2 Load-deflection curve for Bamboo Reinforcement (BR).

4.2.1.3 Bamboo Steel Reinforced (BSR)

The load deflection curve for beam BSR which is fully bamboo reinforced exhibited a sudden decrease in load after the first cracking load at 17.78 kN and failed at the same load as shown in figure 4.3. Similar failure mode of beam BR was found in beam BSR. The beam experienced strain hardening before a brittle failure. In this case, there is no significant difference in load was traced when steel shear link was incorporated to replace bamboo shear link in beam BSR.

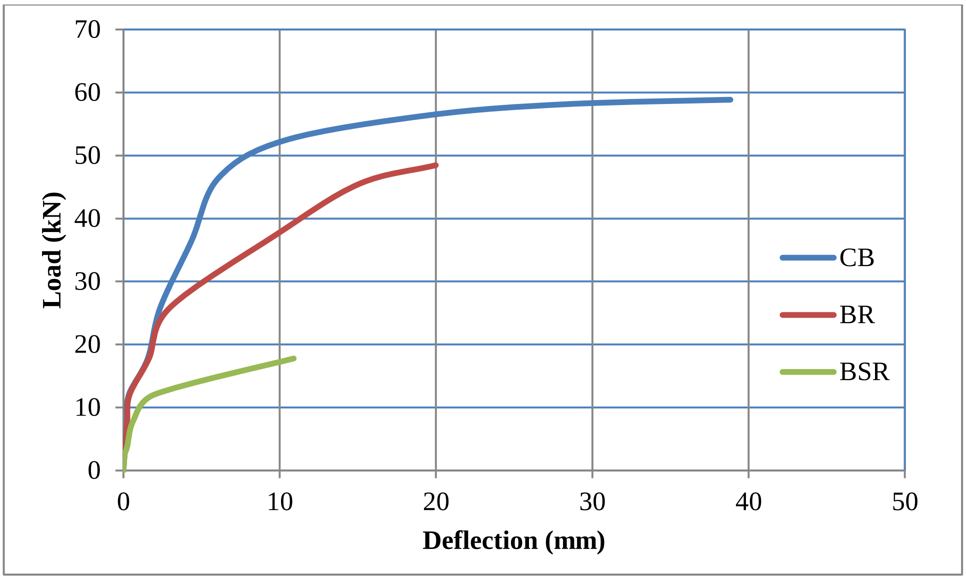


Figure 4.3 Load-deflection curve for Bamboo Steel Reinforcement (BSR)

4.2.2 Crack Pattern

Crack pattern was analysed to study the behaviour of RC beams in flexural. The cracking patterns were obtained after the analysis of the RC beams were completed. The cracking pattern generated was then presented and discussed in this section. The crack patterns of the beams in this section indicates that the beam experienced failure in flexural. The crack patterns showed in ANSYS indicating a flexural crack in the mid-span of the beams. The crack patterns were visualized in FEA using ANSYS and the crack width can be determined.

4.2.2.1 Control Beam (CB)

Figure 4.4 shows the crack pattern of the control beam at the end of analysis. The crack located at the mid-span of the beam, indicating a flexural crack. Hairlines of crack were observed at the mid-span of the beams.

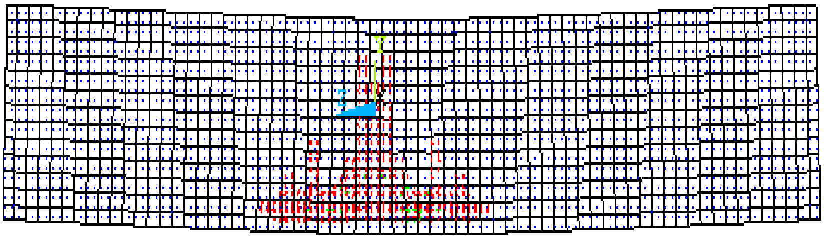


Figure 4.4 Crack Pattern for Control Beam (CB)

4.2.2.2 Bamboo Reinforcement (BR)

The crack pattern for beams BR and BSR are illustrated in Figure 4.5 and Figure 4.6. The crack pattern for beams BR and BSR were found to be dissimilar as compared to CB. Only a vertical crack was found in the mid-span of the beam. Before failure, the vertical crack penetrated to the neutral axis besides enlargement of crack was observed. The cracking behavior indicates that longitudinal bamboo reinforcement placed along the tension zone was unable to resist the tensile stresses and thus, a vertical crack appeared in the middle of the tension zone of the beam. There are no significant differences in terms of crack pattern recorded.

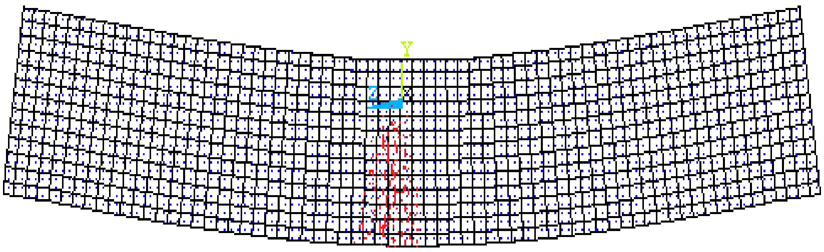


Figure 4.5 Crack Pattern for Bamboo reinforcement (BR)

4.2.2.3 Bamboo Steel Reinforcement (BSR)

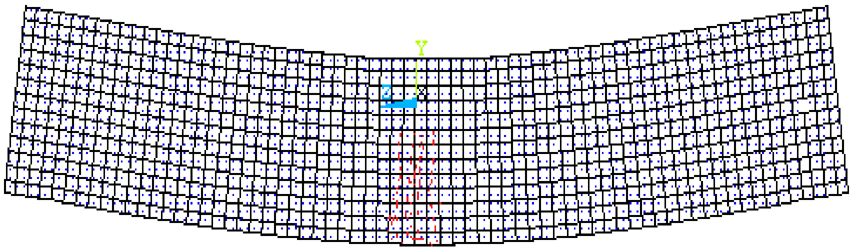


Figure 4.6 Crack Pattern for Bamboo steel reinforcement (BSR)

4.2.3 Strain Contour

Strain contour is the colour scheme that represents the intensity of deflection experienced by the beams under loading until it reaches ultimate load and cracks. Strain contour can be used to predict the values of crack as well as the pathway of cracking for the beam models.

4.2.3.1 Control Beam (CB)

The strain contour of control beam (CB) is shown in Figure 4.7. From the Figure, the strain contour shows the most deformable path at the mid-span of the beam. This implied that the deformation was the most critical and concentrated at the mid-span.

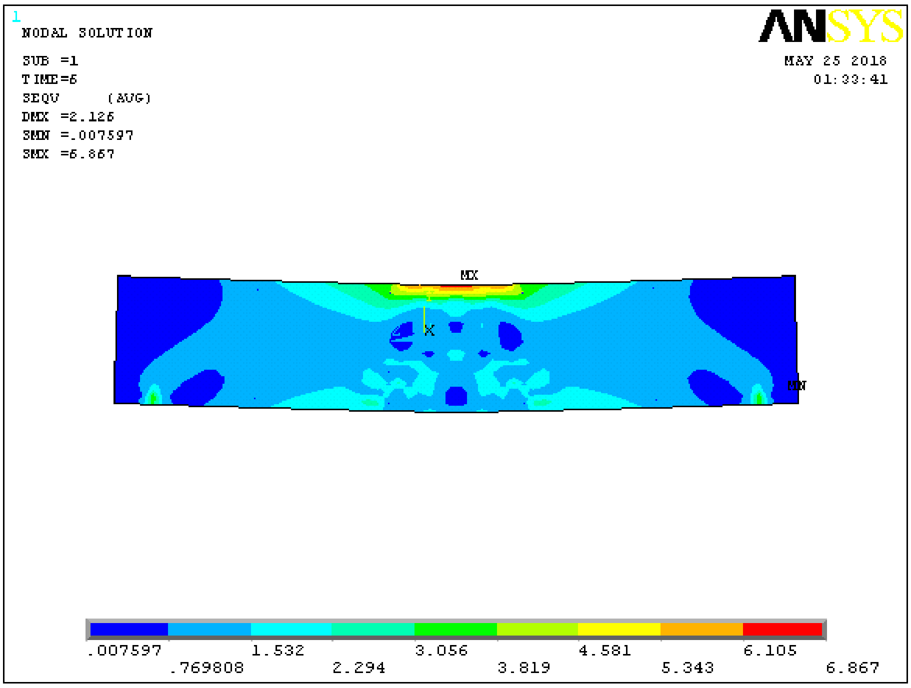


Figure 4.7 Strain Contour for Control Beam

4.2.3.2 Bamboo Reinforcement (BR)

The most critical strain was located at the bottom mid-span of the beam. The deformation of beam concentrated on the mid-span indicating a typical flexural failure behaviour. The red colour region showed the most area with higher strain value while blue colour showed the lowest strain value. Figure 4.8 shows the strain contour for BR which shows the same strain contour as BSR in Figure 4.9. However, there was a difference in strain value between them due to different strength.

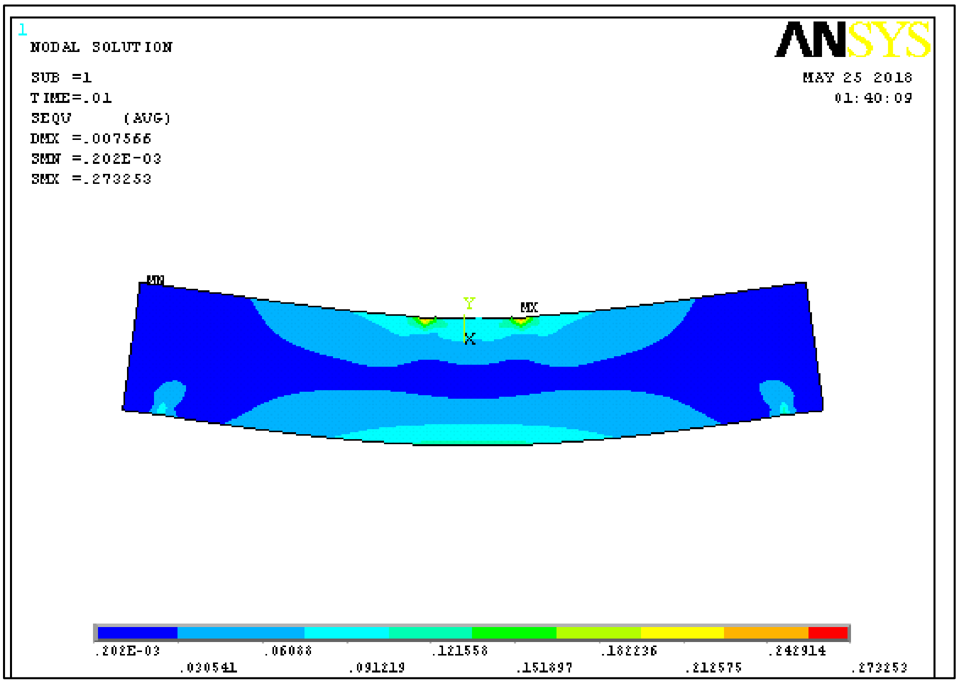


Figure 4.8 Strain Contour for Bamboo Reinforcement (BR)

4.2.3.3 Bamboo Steel Reinforcement (BSR)

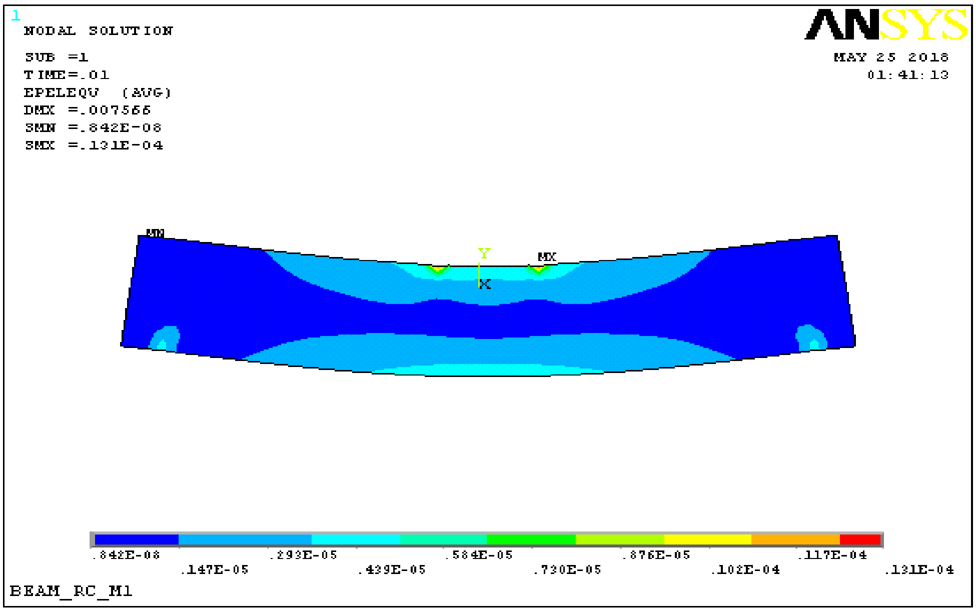


Figure 4.9 Strain Contour for Bamboo Steel Reinforcement (BSR)

4.3 VALIDATION OF FINITE ELEMENT ANALYSIS RESULT WITH EXPERIMENTAL RESULT

Finite element analysis was adopted in this study to analyse various behaviours of RC beams. Therefore, the beams modelled in this study were compared with experimental results in terms of load-deflection curve as well as crack pattern for validation purposes.

4.3.1 Load Deflection Behaviour

Based on the result, all samples of beams shows a remarkable result. From the result, the control beam (CB) with steel reinforcement can support the maximum load without failure compare to BR and BSR. The ultimate load for BR is 48.46 kN which is 78% of the CB's ultimate load which is 58.15 kN whereas the sample of BSR obtained the load of 17.78 kN which is about 64% lower than BR. The experimental results showed the ultimate load of 63.31 kN while FEA showed a lower ultimate load of 58.15 kN. The difference between them the two results was 8%. Figure 4.10 and shows the comparison between experimental and FEA results of control beam. In Figure 4.11, the experimental results for ultimate load for BR were 34.06 kN while FEA show 48.46 kN. The differences between the ultimate loads of both results were 42%. The different load deflections for BSR were 50% where the ultimate load for experimental was 11.83 kN and FEA was 17.78 kN as shown in Figure 4.12. Therefore, in FEA, the concrete possessed a very high ultimate load before starting to yield, resulted in large difference of ultimate load as compared to experimental results.

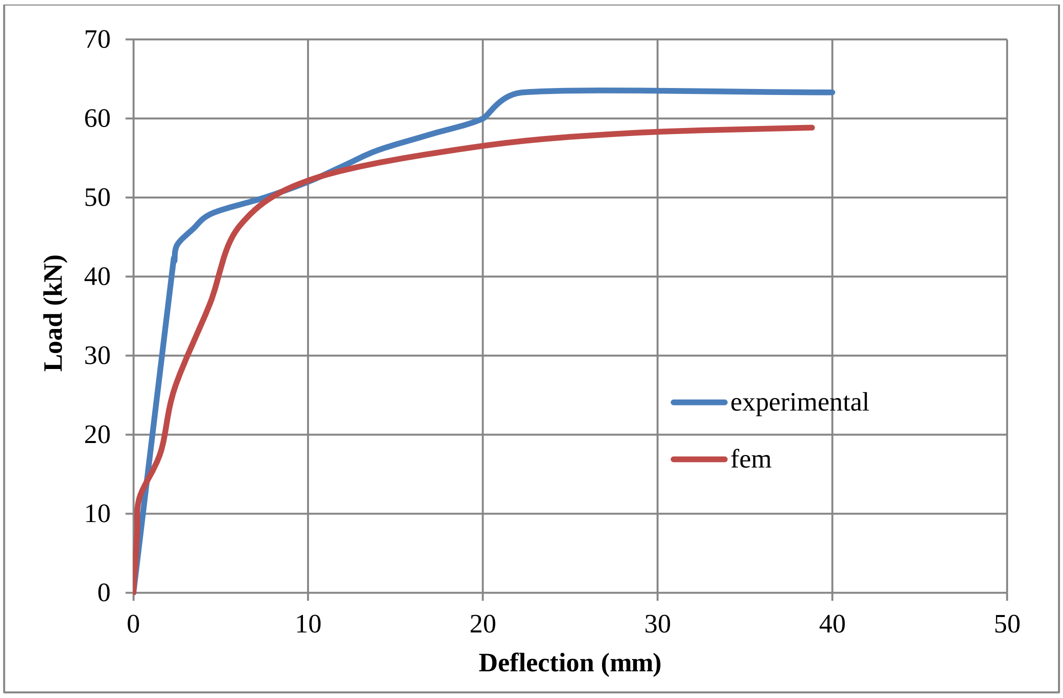


Figure 4.10 Comparison of Load deflection curves of control beam (CB)

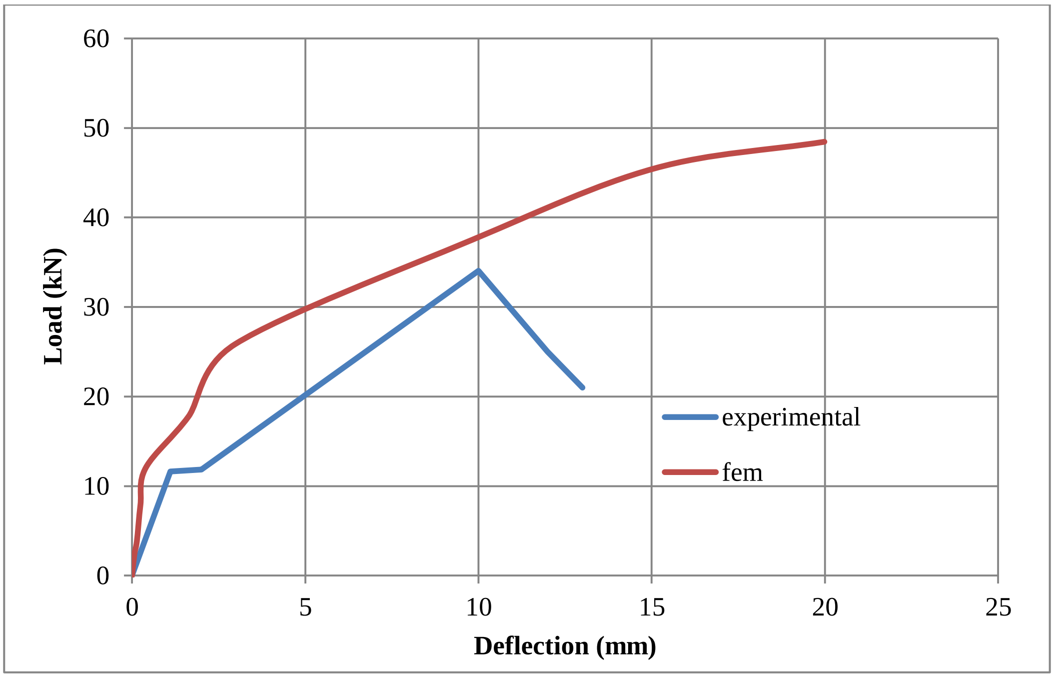


Figure 4.11 Comparison of Load deflection curves of partial replacement, bamboo reinforcement (BR)

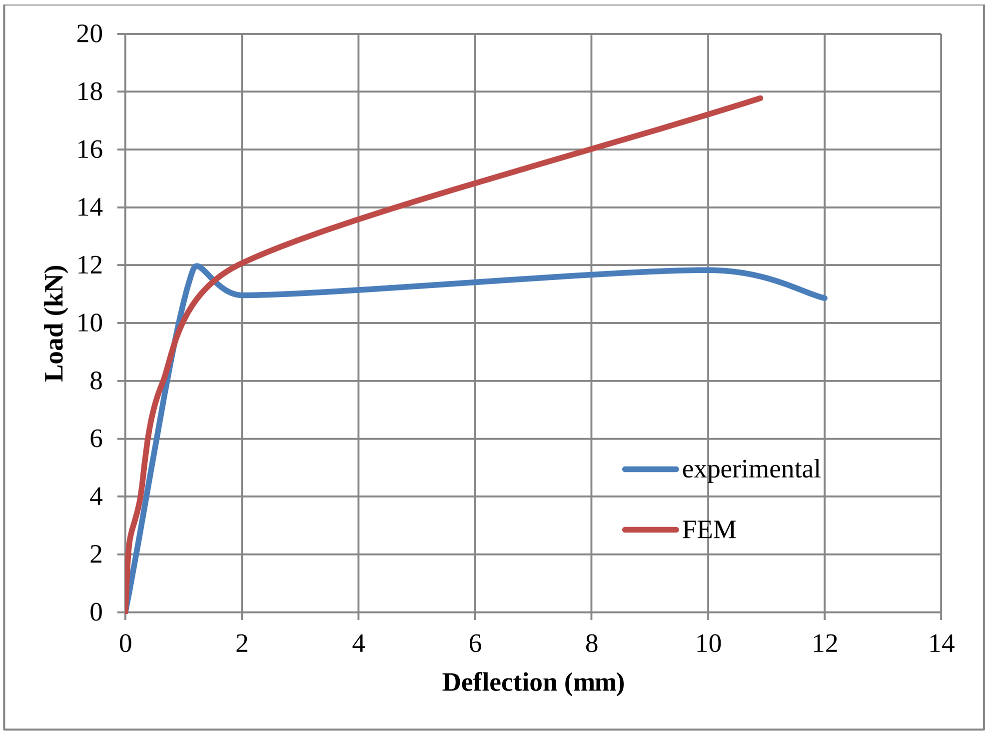
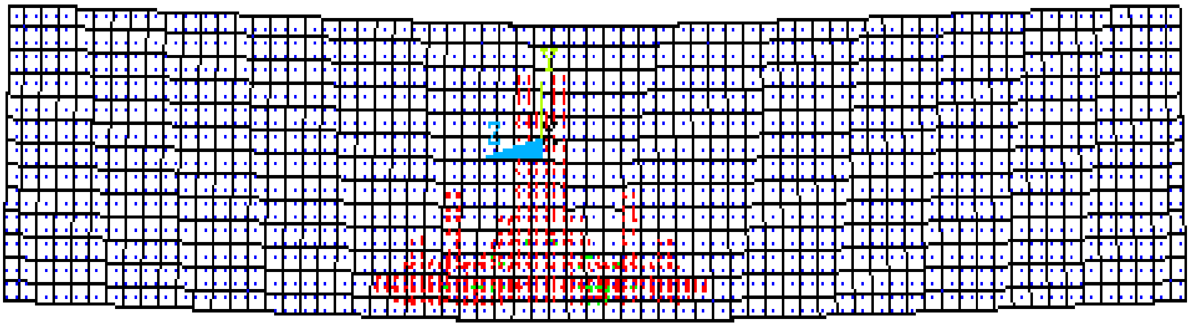


Figure 4.12 Comparison of Load deflection curves of fully replacement, Bamboo steel reinforcement (BSR)

4.3.2 Crack Pattern

The comparison of crack pattern for CB between FEA and experimental results were shown as Figure 4.13. Both the experimental and FEA results are presented that the flexural crack was occurred at the mid-span of the beam from the bottom propagated upwards to the neutral axias. However, the crack lines for experimental results were longer than FEA. This is due to perfect bonding assumption between reinforcement and concrete in FEA analysis.



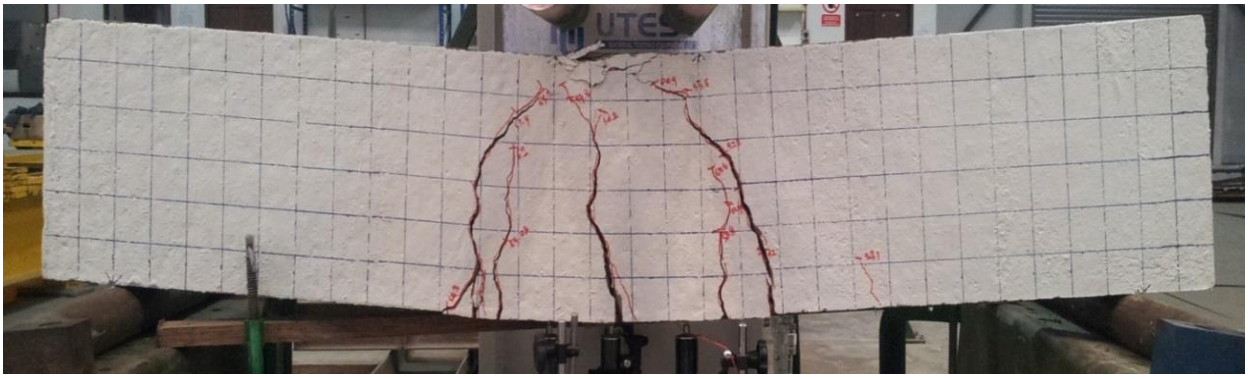


Figure 4.13 Crack Pattern of Experimental vs FEA for control Beam

Figure 4.14 and Figure 4.15 show the comparison between FEA and experimental results of BR and BSR. Both of the crack patterns showed the formation of flexural crack at the mid-span of the beam.

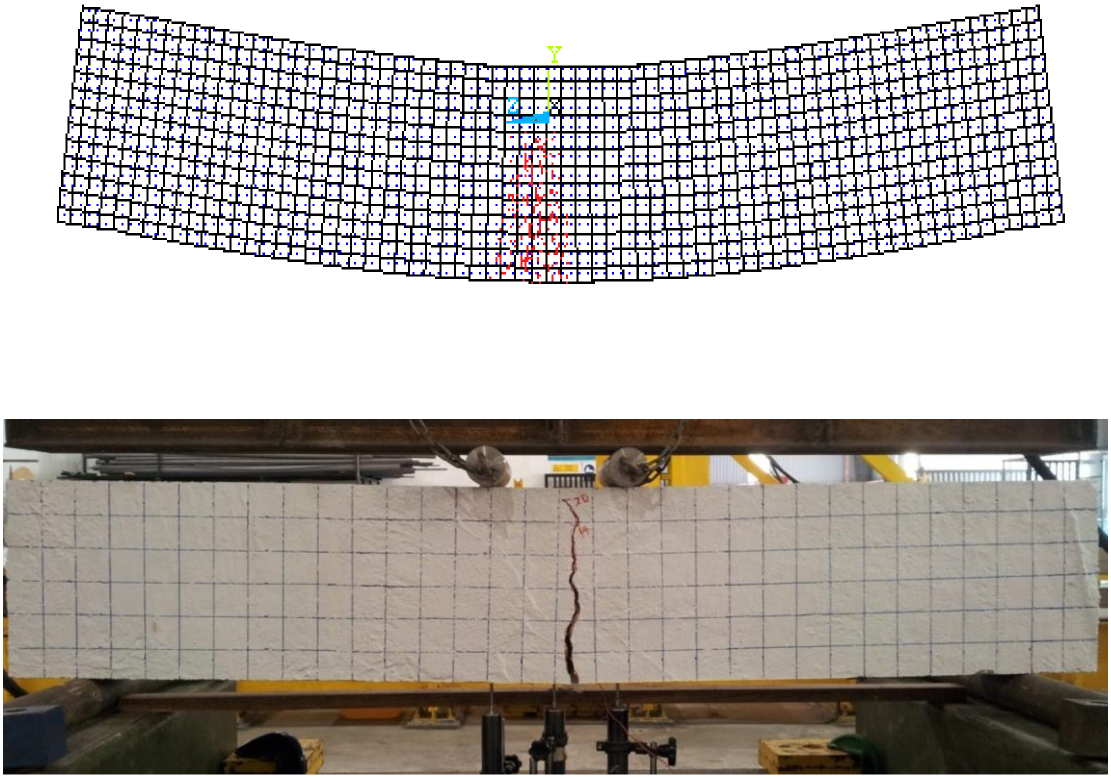


Figure 4.14 Crack Pattern of Experimental vs FEA for BR

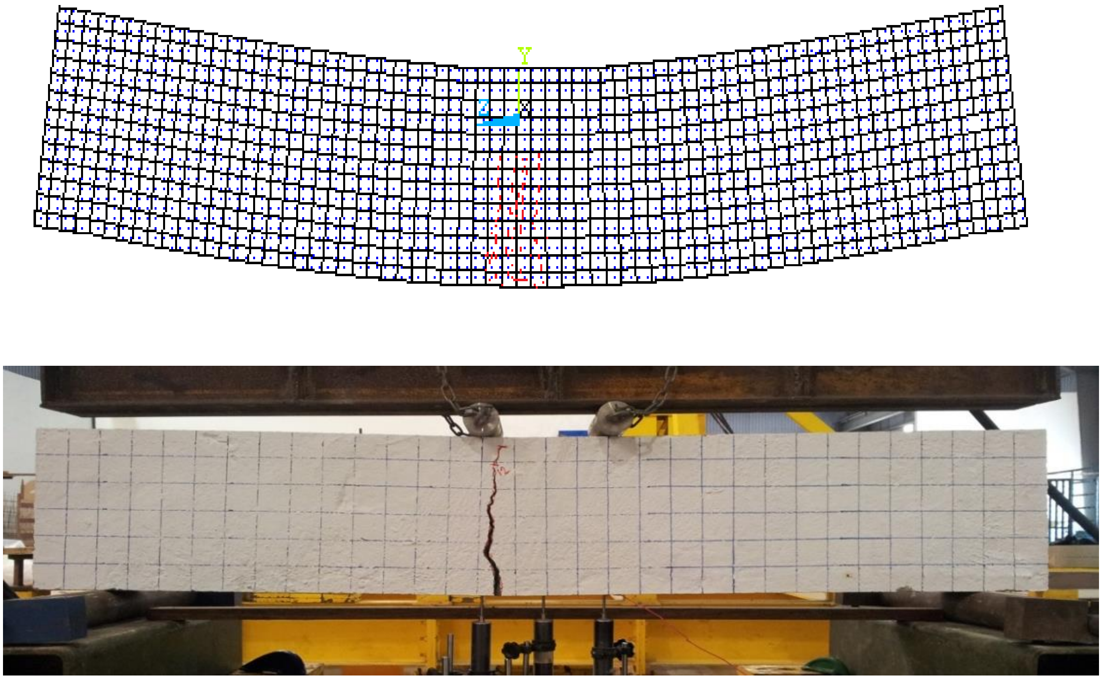


Figure 4.15 Crack Pattern of Experimental vs FEA for BSR

4.4 SUMMARY OF RESULT

From the result, it was found that neither bamboo reinforced (BR) nor bamboo steel reinforced (BSR) were found comparable to the strength of steel. For both beam, which reinforced with bamboo, brittle failure in bending was observed whereas the vertical crack in the mid-span were found propagated to the neutral axis of the beam. On the other hand, beam BSR which is partially reinforced with bamboo did not show any significant effect in term of the beam strength.

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

The main objective of this research is to determine the behaviour of solid RC beams and RC beams with bamboo reinforcement in terms of load-deflection and crack pattern. The results of finite element analysis were validated with experimental results. Therefore, this chapter presents the conclusion and recommendations for future works.

5.2 CONCLUSION

Based on the finite element analysis results obtained, several conclusions can be drawn. The following conclusions are made based on the objectives stated in Chapter 1:

i) Based on the geometrical properties of the element that had been used in this study, it was found that bamboo as reinforcement in concrete beam is capable to resist the cracking in tension and crushing in compression. The capability of the solid element may be used to model the concrete while the capability of rebar is available for modelling the behaviour of the reinforcement.

ii) The load-deflection curves were obtained for solid RC beam and beams with bamboo as reinforcement. The ultimate load for control beam was found to be

58.15 kN. The load for BR was 48.46 kN which is only 78% of the load of CB whereas the sample BSR obtained the load of 17.78 kN which is about 64% lower than BR and only achieved 31% compared to CB. For the crack patterns of the beams, this section experienced failure in flexural. The crack patterns showed in ANSYS indicating a flexural crack in the mid-span of the beams. The crack patterns were visualized in FEA using ANSYS and the crack width was determined.

iii) From the result of ultimate load, it shows neither BR or BSR is stronger than steel. This can be concluded that there is no sign of improvement when bamboo reinforced is being used. The load-deflection curve for behaviour in shear such as CB, BR and BSR showed an agreeable validation to each other with difference of 7.9%, 50 % and 8.2 % respectively. The crack pattern for both experimental and simulation results also showed a good agreement with each other. For solid RC beams, the crack patterns showed the cracking started at the mid-span of the beam, forming flexural crack. For RC beams with openings, the crack patterns showed to be started at the diagonal edges of the openings, which formed the diagonal crack.

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