ANALYTICAL SIMULATION OF REINFORCED CONCRETE BEAM WITH FOUR OPENINGS USING ANSYS SOFTWARE

NGIAM TEE HUNG

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ABSTRACT

Construction of structural using beam with opening becomes an alternative way to solve the limited spaces available for installation of pipes or ducts. The additional services pipes underneath the beam will cause reduction in dead space. In term of cost saving, opening in beam for small buildings doesn't really affect much but it will give a huge impact for the high buildings. However the opening in beams can make huge significant changes on the simple beam behavior to complex one. Beam with openings will not only affect the overall behavior of the beam, it will also eventually affect the serviceability and ultimate limit state of a building. There have been numerous of engineering software available on the market for analysis such as STAAD.Pro, LUSAS, and MATLAB but most of them are expensive and it is hard to obtain its license for small companies. ANSYS with finite element modeling have been widely used to analyse for structural problem hence the study will be based ANSYS using Finite Element Method. Numerical solutions to even complicated stress problems can be obtained by using ANSYS and CivilFEM. This study is going to be basic guidelines for civil engineer to analyse the beam openings by using ANSYS software. This study is conducted to analyse beam with four opening by using simulation of various loadings using ANSYS software. The objective of this study is analysing the result based on its strength behavior, deflection, and stress and strain using simulation with various loading.

ABSTRAK

Pembinaan struktur yang menggunakan rasuk dengan pembukaan menjadi cara alternatif untuk menyelesaikan ruang yang terhad untuk pemasangan paip atau duktus. Perkhidmatan paip tambahan di bawah rasuk akan menyebabkan pengurangan ruang. Dari segi penjimatan kos , membuka dalam rasuk untuk bangunan kecil tidak benar-benar memberi kesan kepada banyak, tetapi ia akan memberi kesan yang besar untuk bangunan yang tinggi. Walau bagaimanapun pembukaan di rasuk boleh memyebabkan perubahan ketara yang besar ke atas tingkah laku rasuk mudah untuk satu kompleks. Rasuk dengan bukaan bukan sahaja akan memberi kesan kepada tingkah laku keseluruhan rasuk, ia akan juga akhirnya menjejaskan kebolehkhidmatan dan keadaan had muktamad bangunan. Terdapat banyak perisian kejuruteraan yang terdapat di pasaran untuk analisis seperti STAAD.Pro , LUSAS, dan MATLAB tetapi kebanyakan mereka adalah mahal dan sukar untuk mendapatkan lesen untuk syarikat-syarikat kecil . ANSYS dengan model unsur terhingga telah digunakan secara meluas untuk menganalisis untuk masalah struktur dengan itu kajian ini akan berdasarkan ANSYS menggunakan Kaedah Unsur Terhingga. Penyelesaian berangka untuk masalah tekanan walaupun rumit boleh diperolehi dengan menggunakan ANSYS dan CivilFEM . Kajian ini akan menjadi garis panduan asas untuk jurutera awam untuk menganalisis bukaan rasuk dengan menggunakan perisian ANSYS . Kajian ini dijalankan untuk menganalisis rasuk dengan empat pembukaan dengan menggunakan rangsangan pelbagai bebanan menggunakan perisian ANSYS . Objektif kajian ini adalah menganalisis keputusan berdasarkan tingkah laku kekuatan, pesongan, dan tekanan dan terikan dengan menggunakan rangsangan dengan pelbagai muatan.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

In structural buildings, an opening in beam is necessary for Mechanical and Electrical (M&E) services to install pipes and duct for the essential services such as electrical supply, water supply, sewage, air conditioning and etc. For the traditional buildings, these services pipes are usually located underneath the beam and it is covered with false ceiling due to aesthetic reasons. The additional services pipes underneath the beam will cause reduction in dead space. In term of cost saving, opening in beam for small buildings doesn't really affect much but it will give a huge impact for the high rise buildings.

The openings in beams can make huge significant changes on the simple beam behaviour to a complex one. It is due to the changes in sectional configuration which will decrease the flexural strength, shear strengths, flexural stiffness and increase in the deflection of the beam. Reinforcement at the opening is needed to ensure the strength of the beam. There are numerous experimental have been conducted to investigate the strength of the reinforced concrete with openings. ACI design provisions specify that the openings in the web of a member can reduce the shear strength, and the effect of any openings on the shear strength shall be considered. (Building code requirements for structural concrete, 2005)

As a conclusion, the opening in the beam will eventually affect the strength of the beam compared with the normal beam without any opening.

1.2 Problem Statement

Opening in beam has widely used in construction, due to the space available to install for pipes and duct. Mechanical and Electrical (M&E) contractors have to rely on the available space for utility access. In this case, the contractor will normally drill holes through the concrete beams in order to allow for passage for the pipes and ducts. These will affect the overall behaviour of the beam and will eventually affect the serviceability and ultimate limit state of the building.

There are large number of studies that have been conducted to study about the effect of opening on T-beam, precast beam and deep beam but only a few of research that have been conducted to perform on rectangular beam with web opening. Due to the limited research done on the rectangular reinforced concrete beams, introducing the opening in these beams are very important. The alternations of the opening of beams and the type of stirrup used for the opening may lead to cracking which is unacceptable due to aesthetic and durability viewpoint. The reduced stiffness of the beam may also give rise to excessive deflection under service load and result in considerable redistribution of internal forces and moments in a continuous beam (Mansur M. , 2006).

The amount of stirrup will give an impact on the behaviour of reinforced concrete members especially with opening because the structures will possible to fail if the shear stress rides over the shear carry capacity. The number of stirrup can be reduced by using a higher strength of stirrup without affecting the shear strength of flexural members (Munikrishna, Hony, Rizkalla, & Zia, 2011). Thus, the location of the opening and amount of stirrup used can give a huge impact on the opening of the beam.

1.3   Objective of Study

The objectives of this study are:

i.   To determine the deformation, stress and strain of beam with opening

ii.   To determine the ultimate strength of the beam

1.4   Scope of study

The dimension of beam is 200x400x3000mm with four openings. The concrete grade that will be using to analyse the beam is grade 30. The reinforcement for the beam is S500 while the steel grade is 500 N/mm^2. Analysis of the beam is required by using ANSYS to obtain the results. The reinforcement bar, link and stirrup that will be using in ANSYS are link 8. Link 8 is a three-dimensional spar element with plasticity, employing to model the internal reinforcement in the beams. On the other hand, Solid 65 will be used to create three dimensional concrete beams with opening with three degree of freedom at each node. The scope of this research is to do simulation of loading on reinforced concrete rectangular beam with circular opening via ANSYS to obtain the load deflection, bending and moment of the beam.

1.5   Expected Outcome

It is expected that with ANSYS and finite element method, the objective of the research can be achieved. The objective of this study is to determine the deflection and ultimate strength of reinforced concrete beam due to simulation of various loadings.

1.6   Significant of Study

It is very significant to have knowledge about the behaviour of the beam opening because opening at beam will have effect on its ultimate strength and behaviour. Randomly drilling of opening at the beam will eventually affect the beam behavior and it might eventually fail at its serviceability or ultimate limit state. The strength of concrete is important to avoid structure from collapsing so it is very important for designer to take serious consideration before designing for beam opening. The main

purpose of this research is to stimulate the behaviour of beam opening using Finite Element Method.

This study can be a reference for further studies and further improvement for related research in the future. The behaviour and strength of concrete beam will be obtained by using Finite Element Method and accurate result can be obtained by using finite element formulation.

1.7   Summary of Chapter

Beam opening enable ducts and pipes to pass through the entire building in order to solve death space due to aesthetic reasons. However, when designer considering about opening at beam, designer must take note about the strength and behaviour of the beam opening. This study is conducted to determine whether the beam opening will sustain its behavior as normal beam. Simulation of various types of loadings will be applied to the beam openings using ANSYS software for this study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In design, opening in reinforced concrete beams is facility which allows services duct to pass through the structure. This type of concept enable designer to solve the problem of dead space due to services ducts that underneath the beam and also for aesthetic reasons which leads to an economical design. The cross section of beam dimension due to opening will subjected to stress concentration and it might able to induce transverse cracks in the beam. The openings in beams will alter the simple beam behaviour into a complex behaviour. Other than that it will also reduce the stiffness of the beam which will lead to deformation and deflection under serviceability limit state. The size and dimension of the opening of beam can be various. According to (Prentzas, 1968) consider openings of circular, rectangular, diamond, triangular, trapezoidal and even irregular shapes. However the size of opening that is widely used are basically circular and rectangular. In term of the size of opening, there is no clear definition or clear cut regarding to the size. According to (Mansur & K.H., 1999) the classification of size of opening depends on structural response of the beam. If the small opening is able for the beam to maintain its own behaviour then it is considered as small opening and vice versa.

2.2 ANSYS and Finite Element Analysis

ANSYS is complete finite element analysis software used based on civil or structural engineering worldwide. ANSYS is a product which includes all the capabilities to calculate and analyse all engineering disciplines. The component products of ANSYS will highly focus on nonlinear structural problems for beam opening research. The structural analysis using ANSYS will determine the deformations, strains, stresses with different simulation forces.

Finite element analysis consists of computer modelling of a material that is stressed and analysed for specific results. Finite element analysis was first developed by R.Courant in 1943 who utilized the Ritz method of numerical analysis and minimization of variation calculus to obtain the solution. Finite element analysis was applied to nonlinear problems and large deformation in late 1960s and early 1970s (Tirupathi and Ashok, 2002). In finite element analysis using ANSYS, we are able to determine the fatigue analysis which helps designers to predict the life of structure by showing the effects of simulation loading on structural. The analysis can show where the cracks or fatigue area which is most likely to occur. Finite element analysis has become solution for designer to predict the failure of structural due to unknown stress by showing problems in material which enable designers to see the theoretical stresses within.

2.3 Beam with Openings

The opening on the beam can be various in shapes such as circular, square or even rectangular in shape. According to Amiri.S & Masoudnia.R (2011), the circular opening has more strength than equivalent square opening with difference of 9% in ultimate load capacity. Circular opening may considered as large if the diameter exceeds 0.25 times the depth of web because the opening will reduces the strength of beam (Somes & Corley, 1974). The behaviour of beam with small and large opening is different. The cracks pattern of beams will depends on the increase of the diameter of beams opening.

The first crack on the beam will show more stiffness and less diagonal strain with normal strength concrete if the diameter of opening is less than 1/3 of the depth of beam. However if the opening is more than 1/3 of the depth of beam, the increase of strength of beam before and after the creation and development of cracks reduces the strains and change in length of diagonal direction (Hosseinalibygie.M & Amiri.J.V, 2004). Other than that, in their research they found out that the installation of diagonal bars and small stirrup around the opening will eventually increase the ultimate strength of the beams opening. The result of research done by Hosseinalibygie.M & Amiri.J.V (2004) shows that increase in opening diameter will reduce ultimate strength in beams. Hence it is proven that the size of the opening will eventually affect the behaviour of beams.

2.4   Opening Classification

The opening sizes on the beam are classified based on the diameter of the openings. However the definition of big or small size of openings can be various based on the researcher. Regarding to the size of openings, many researcher use the term small or large without clearly define it. According to Mansur,M.A (1984) and Prentzas E.G (1968), the small openings are defined as circular or square in shape. However according to Somes and Corley (1974), circular opening may be considered as large when its diameter exceeds 0.25 times the depth of the web.

In general, the size of the beam opening is consider small when it is still maintain as beam-type behaviour and consider as large opening when the beam does not apply to usual beam theory. Mansur. M.A (1984) recommended some criteria in determine the size of the opening whether it is small or large opening. It is assumed that hinges form in the chord members at a distance of h/2 from the vertical faces of opening. According to Mansur. M.A (1984), it is consider as small opening if $L_o \leq h_{max}$ and it is consider as large opening if $L_o \geq h_{max}$. In this definition, it is assumed that the members above and below the opening have adequate depth for reinforcement.

2.5   Effect of Circular Openings on Behaviour of Concrete Beam

According to Amiri.J.V & Hosseinalibygie,M. (2004), the opening in beam will cause reduction in term of ultimate strength and the strength will be affected with the diameter of the opening. As the diameter of the opening is bigger, the ultimate strength of the beam will be smaller compared to smaller diameter of opening of beam. Among the research done by Nasser et.al (1967) on the behaviour of beams with openings, they found that the top and bottom chord of opening behaved like Vierendeel panel and contra flexure points occurred at midpoint. They found that the ultimate strength increased with a decrease in moment to shear ratio at the centre of the opening and the amount of external shear.

However research done by Mansur,M,A (1985) shows that increase in the opening size or moment-shear ratio at the centre of the opening will increase both crack width and maximum deflection. A three-dimensional nonlinear finite element model suitable for the analysis of reinforced concrete beams with openings under flexure (Al-Shaarbaf, Bayati, & Kaisy, 2007). In his studies, the result reveals the behavior of beam depends on the diameter of opening and type of concrete used. The increase of diameter of opening in beams made of normal concrete will cause changes in cracks pattern and also the type of failure. The increase of concrete does not have influence on the ultimate strength; however it will increase the stiffness and improve serviceability of beam. In his study, he stated that the critical position of opening in order to reach ultimate strength in beams is near to the support.

2.6   Bending and Shear for Beam Opening

Shear is associated with bending moment in beam and bending and shear will be affected if the beam opening is implemented. Research done by various researcher such as Hanson (1969), Somes and Corley (1974), Weng (1998) shows that beam will fail in two modes. These two modes of failure are label respectively by Mansur (1998) as beam-type failure and frame-type failure. Figure 2.1 a) shows the Beam-type failure while Figure 2.1 b) shows the Frame-type failure

(a) Beam-type failure   (b) Frame-type failure
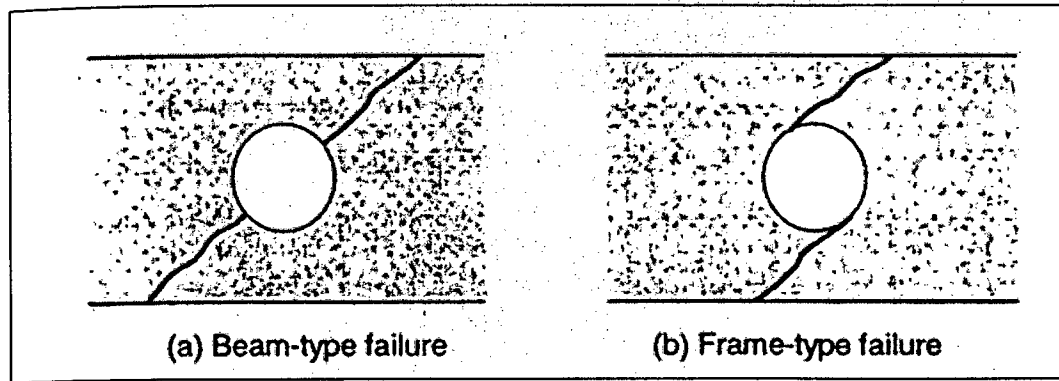
Figure 2.1: Two modes of shear failure at opening

When a small beam is introduced in beam, there will be mode of failure. Research done by Hanson (1969), Somes and Corley (1974), Weng (1998) shows that mode of failure remains essentially the same as solid beam. When opening is introduced, it will normally cause weakness to the beam and failure plane will always occur at centre of opening unless the opening is close to the support. From the research done by Salam (1977), he found out that when sufficient reinforcement is provided to prevent a failure along a diagonal crack at the centre of opening, the failure is precipitated at minimum section.

2.7 Conclusion

For decades of in-depth research of beam opening have given researcher a lot of data to make comparison and to increase the strength of beam openings. Basically the area of the opening will have weaker strength compared to other place hence reinforcement or stirrup must be added surrounding the opening in order to sustain the serviceability and ultimate limit state. Based on studies done, the position of the opening on the beam will affect the ultimate strength and also the shear and bending of the beam. Therefore, it is wise for designer to have opening of beam near to the support so that it would not fail.

CHAPTER 3

METHODOLOGY

3.1 Introduction

In this research, finite element analysis will be applied. Finite element analysis method is used in order to prove the suitability to complement the full scale test on structural. Finite element analysis is done by making computer modelling of a material that is stressed and analysed for specific result. A basic model in ANSYS is used to determine the suitability attributes for the beam model and also to do for the simulation of numerical forces.

Verification study must be done by using previous experimental result in order to serve as a platform to superimpose with current study which can be applied with various variable and conditions. After verification is done, there are three phase to undergo the research that is pre-processing steps, solution process and post processing process.
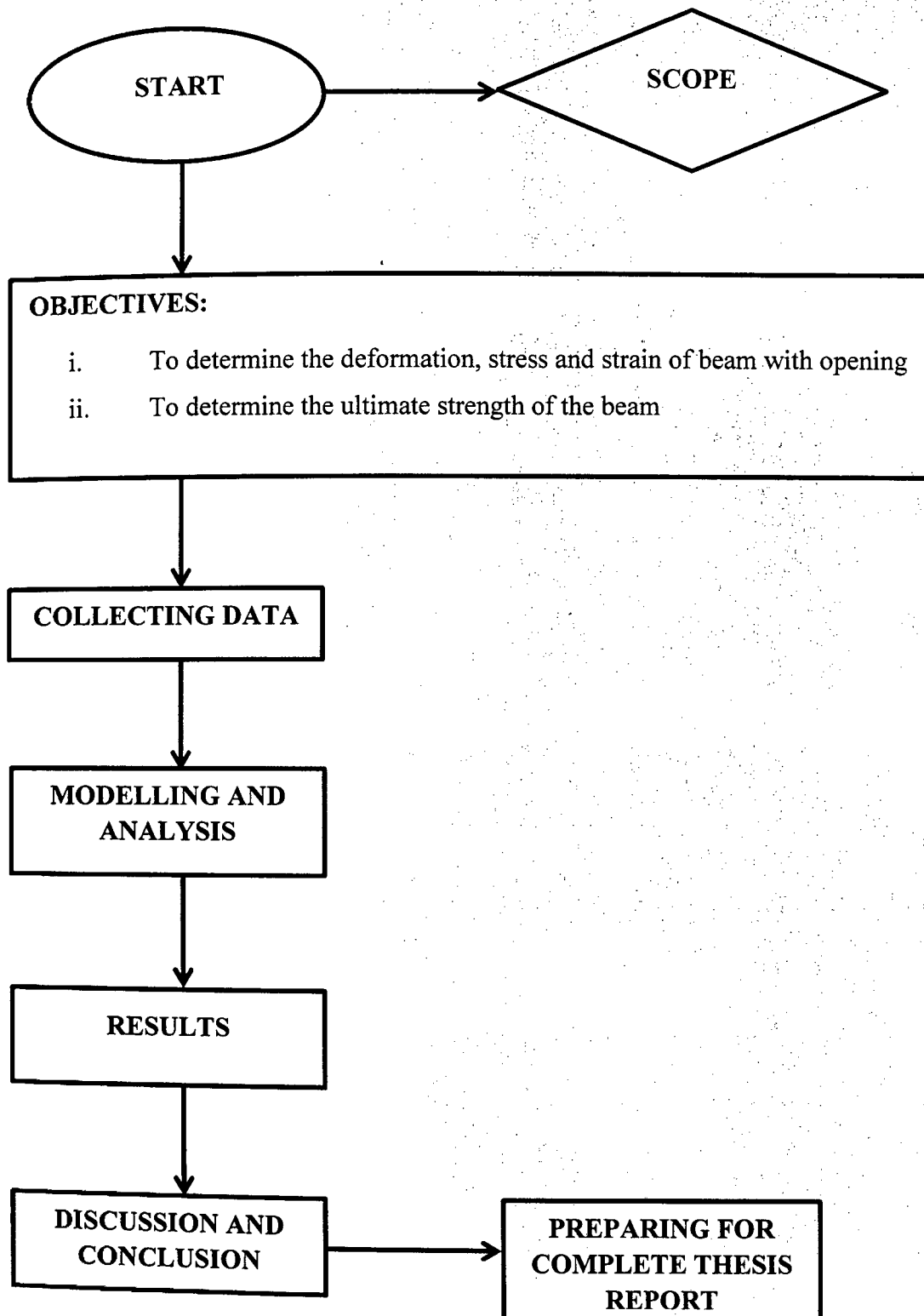
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│ OBJECTIVES:                                                  │
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│   i.     To determine the deformation, stress and strain of  │
│          beam with opening                                   │
│   ii.    To determine the ultimate strength of the beam      │
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      │   CONCLUSION       │        │ COMPLETE THESIS    │
      └───────────────────┘        │    REPORT          │
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Figure 3.1: Simplified Research Methodology for this Study

3.2   ANSYS Modeller Software

ANSYS is software that is able to do simulation of model for nonlinear static analysis that simply provides stresses or deformations. In non-linear stress analysis is becoming increasingly important for designers employing a wider variety of materials in a multitude of applications. The model analysis is then able to determine the deformation, shear and bending of the model. Simulation using ANSYS is a great step ahead which allows precise prognosis and optimization of the performance of model, with the flexibility of adjusting the dimensions, materials and loading. In ANSYS, the analysis may be broken into three stages, model which is pre-processing, solution and post-processing. In pre-processing stage, the model will build to define key points, element type, and material and mesh lines. In solution stage, the loads and constraints will specify and solve the resulting set of equations. On the other hand, the processing stage involve further processing and view of the results such as deformations, element forces and moments and stress contour diagrams.

3.3   Pre-processing

In this initial step, it is about define the key point, element type, material and meshing of lines/area or volume required. The amount of detail required depends on the dimension of analysis.

3.3.1   Specified the Title

In order to specify the title, go to the 'Utiliy menu bar' and select 'File" followed by 'Change Title' and edit the desired title. It has been shown in the figure below.
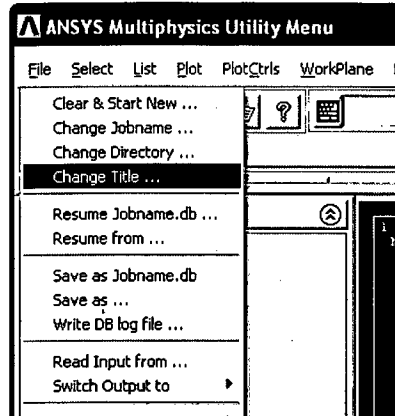
Figure 3.2: Change Title Steps

Although this step is not required for the analysis process but it has been recommended to do so in order to identify the file whenever the file has been saved.

3.3.2 Element Types

The reinforcement bar, link and stirrup used for the beam opening model is considered as Link 8 and it is assumed to elastic-plastic material and identical in tension and compression. Solid 65 will be used as modelling for concrete and it is three-dimensional with three degree of freedom at each node. The figure below shows the element types used in this study
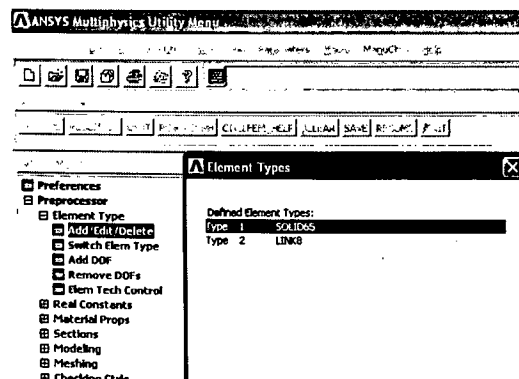

Figure 3.3: Element Types

3.3.3 Real Constant

Real constant in ANSYS is described as element reference. Basically element type BEAM4 is used in ANSYS for the 3-D beam element. Real constant consist of cross-sectional area, area moments of inertia, thicknesses in the z and y directions. The real constants can be specified using the following steps:

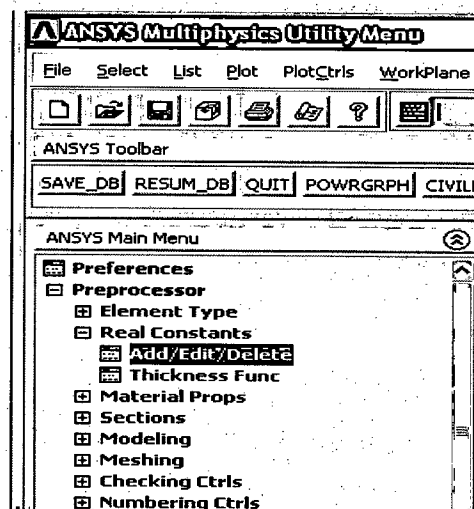Main Menu > Preprocessor > Real Constants > Add/Edit/Delete

Figure 3.4: Real Constant

3.3.4 Material Properties

Basically the type of material will be used in analysing the beam opening using ANSYS consist of concrete and reinforcement bar. The type of materials used will be inserting into the ANSYS before creating the model. Material properties definition is performed by CivilFEM command. This command will automatically defines the ANSYS material properties and the CivilFEM material properties necessary for code checking. In this stage, a material property was specifying by select material in the 'Civil Preprocessor' menu bar.