ANALYSIS (BEAM WITH SMALL
CII ING ANSYS

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ABSTRACT

The provision of transverse openings in prestressed concrete beams of floor to facilitate the passage of utility pipes and service ducts results not only in a more systematic layout of pipes and ducts, it also translates into substantial economic savings in the construction of a multi-storey building, increase the usable area of building. In this thesis, to investigate the problem of openings in beams, choose small circular opening as consideration. By using manual calculation and personal computer software (ANSYS) to analysis the beam behaviours under point loads. The aspects will analyse the beam with opening through four input variables which are the density of prestressed cable, modulus of elasticity, point load 1 and point load 2, and then gain the output of parameters. The results include general situations of stress, strain, and deflection. Base on the past research and experimental test of literature, conclude manual results getting from software calculation, analysis the characteristics and the behaviours of the prestressed concrete beam with small circular opening. The objective of this project is based on the four input variables which are point load 1, point load 2, modulus of elasticity, and density of prestressed cable, to gain the three output parameters which are maximum deflection, maximum stress, and maximum strain. The statistic for the random input variables and output parameters had been computed by using the ANSYS software and illustrate the properties of the output parameters using histogram plots, cumulative distribution curves, and history plots. The influence of random input variables on the individual output parameters. Hence, the analysis was success and results collected were accurate and fit into use.

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CHAPTER 1

INTRODUCTION

1.0 General

As the construction of modern buildings developing and advancing, the requirement of people is more and more, a network of pipes and ducts is necessary to accommodate essential services like water supply, sewage, air-conditioning electricity, telephone, and computer network. Usually, these pipes and ducts are placed underneath the beam soffit, for aesthetic reasons, and it is covered by a suspended ceiling, thus creating a dead space. Passing these ducts through transverse openings in the floor beams leads to a reduction in the dead space and results in a more compact design. For small buildings, the saving may not be significant, however for multi-storey buildings, any saving in storey height multiplied by the number of stories can represent a substantial saving in all length, height of electrical ducts, plumbing risers, air-conditioning, partition surfaces and walls, and total load on the foundation.

Comparison the behaviours of a simple beam and a beam with opening, the beam with opening are more complex than another one, it is obvious. Due to abrupt changes in the sectional configuration, opening corners are under a high tress concentration that may lead to cracking unacceptable from aesthetic and durability viewpoints. The reduced stiffness of the beam may also give rise to excessive deflection under service load and result in a considerable redistribution of internal forces and moments in a continuous beam. Unless special reinforcement is provided in adequate quantity with suitable detailing, the strength and serviceability of such a beam may be seriously affected.

In this thesis, focus on the beam with small circular web opening through using ANSYS software to analysis the beam behaviours such as deflection, stress, and strain.

ANSYS is a general purpose software, used simulate interactions of all disciplines of physics, structural, vibration, fluid dynamics, heat transfer and electromagnetic engineers. The finite element analysis is a numerical technique. It was an extension of matrix method of structural analysis. In finite element method, actual component is replaced by a simplified model, identified by a finite number of elements connected at common point called nodes, with an assumed behaviour of each element to the set of applied load, and evaluating the unknown variable such as displacement, temperature at this finite number of points. In this method all the complexities of the problems, like varying shapes, boundary conditions and loads are preserved, but the solution obtained are approximate. Nowadays civil engineers used this method extensively for the analysis of beam, space frames, plates, shells, foundations and etc. Finite element analysis can handled both static and dynamic problems.

In this research, Finite Element Method (FEM) models were used to stimulate the behaviour of the cellular beam structure's ability using ANSYS 12.1 program. This program is capable of predicting deflection and stress in concrete concepts and also includes model's constitutive laws for concrete material, based on smeared crack concepts and for high strength composite materials.

1.1 Problem Statement

In the modern day, beam was be used to construction building as an important part to transfer the loading from the upper segments and it also can used for others multiple service such as water supply, sewage, air-conditioning electricity, telephone, and computer network base on the ducts in the beam. Because of that, beam structures must be designed well with appropriate calculation to make sure it can support the loads so that it is safe for long period of time. Even though there are several methods can be used to analyse the behaviour of beam structure, in order to make the procedure easily and specifically finite element method (FEM) would be used through ANSYS software.

Most of the times, engineers need to find out an accurate data of deflection and stress for the structure before they start design. A lot of time had been wasted for that works. By applying the probabilistic analysis, a range of result can be obtained by input the variables values only. So engineer's works can be easy and save more time for focus others.

1.2 Research Objective

The basic purpose of this thesis was to gain a better understanding on how a beam with six circular opening web behave at subject loading by using ANSYS which a finite element analysis software.

To achieve this purpose, first step is to determine the result of static structural analysis that can be used to the prestressed beam with small circular web opening, which are maximum deflection and loading of the beam. Then probabilistic analysis shall be applied to get the range of the result based on different loading, so the design procedure of an engineer can be simplified.

Finally, the objective of this study is to propose a prestressed concrete beam with small circular web opening recommendation for a residential apartment.

1.3 Scope of Study

First of all, download and install the software of finite element modelling package, the ANSYS. Complete all ANSYS tutorials from the website of Alberta to learn the skill on doing all structural analysis, either static or dynamic. The tutorials included basic tutorials which outlining basic structural analysis using ANSYS, intermediate tutorials which taught about complex skills such as dynamic analysis and nonlinearities, advanced tutorials which explored the advanced skills such as sub-structuring and optimization.

Secondly, define the properties of the prestressed concrete beam with small circular web opening, which include the dimensions and the sections of the beam structure. Determine the type of the structure by referring plans or assumptions. Base on the details collected or assumed, model the prestressed concrete beam, the pre-processing state is the steps to define key-points and lines, geometric data and mesh. It shall be finish to continue to next step.

When the pre-processing state is done, the data is saved there are few kinds of analysis to be carried out. Loads and supports will be assign and determine the solution of the prestressed concrete beam which is deflection and stress. After that, carry out probabilistic analysis to observe the change of results. Finally, proceed with the thesis writing.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

In recent years, super high-rise buildings constructed with prestressed concrete structure have sharply been on the increase. In the field of multiple dwelling housing, in particular, prestressed concrete construction has become the most popular form. In order to secure sufficient resistance and toughness of the structural members, which are subject to a large shearing force, efforts have been made to increase the strength of shear reinforcement bars. This is due to it being difficult to secure required volumes of reinforcement bars if conventional reinforcing bars of ordinary strength are to be used. For the same reason, increasing the strength of shear reinforcement for web-opening has been called for. Beams and other structural members are provided with web-openings through which to pass piping, ducts, etc.

Shear reinforcement for web-openings comprise of the reinforcing bars that are arranged around those web-openings. When there is a web-opening in a beam, a concentration of stress occurs around the opening. This stress concentration can cause deterioration in the shear strength and deformation-performance the beam and cause cracks in it around the opening, etc. Shear reinforcements for web-openings are arranged to prevent those problems from occurring.

It is due to economy and a growing trend toward the use of systems approach to building design that structural engineers are often required to keep provisions for transverse openings in beams. Most engineers permit the embedment of small pipes, provided some additional reinforcement is used around the periphery of the opening. But when large openings are encountered, particularly in reinforced or pre-stressed concrete members, they show a general reluctance to deal with them because adequate technical information is not readily available. There is also a lack of specific guidelines in building codes of practice (ACI, 1995; BS 8110-97), although they contain detailed treatment of openings in floor slabs. As a result, designs are frequently based on intuition, which may lead to disastrous consequences. There is at least one case on record, described by Merchant (1967), in which the failure of a large building was averted when severe distress at a large opening in the stern of a beam was discovered and mitigated in time.

It is obvious that inclusion of openings in beams alters the simple beam behaviour to a more complex one. Due to an abrupt change in the cross-sectional dimensions of the beam, the opening corners are subject to high stress concentration that may lead to wide cracking that is unacceptable from aesthetic and durability viewpoints. The reduced stiffness of the beam may also give rise to excessive deflection under service load and result in a considerable redistribution of internal forces and moments in continuous beam may be reduced to a critical degree.

2.1 Beam with Web Openings

Openings that are circular, square, or nearly square in shape may be considered as small openings provided that the depth (or diameter) of the opening is in a realistic proportion to the beam size, say, about less than 40% of the overall beam depth. In such a case, beam action may be assumed to prevail. Therefore, analysis and design of a beam with small openings may follow the similar course of action as that of a solid beam. The provision of openings, however, produces discontinuities or disturbances in the normal flow of stresses, thus leading to stress concentration and early cracking around the opening region. Similar to any discontinuity, special reinforcement, enclosing the opening close to its periphery, should therefore be provided in sufficient quantity to control crack widths and prevent possible premature failure of the beam.

In 1910, Horton, who was a member of the Chicago Bridge and Iron works, for the first time proposed cutting the beam web and reassembling the two halves to increase the section modulus, (Das and Seimaini, 1985). The idea of castellated beam was proposed later in 1935 by Geoffrey Boyd who was a structural engineer in the British Structural Steel Company (Knowles, 1991). Invention of castellated beams which were previously known as 'Boyd beams', brought him the British Patent award in 1939. Following the developments, cellular beams were first introduced to the steel construction Industry in 1987 by the steel manufacturer Westok (Westok, 1985) who are the current world-wide patent holders of cellular beams. These beams seem to be a significant development in steel construction in the past 20 years. Since 1997, these beams have been used in over 4000 projects and 20 countries.

Within this range Arcelomittal (Arcelormittal, 2001) has also introduced another product called 'Angelina Beam' which is similar to castellated beams but with a slightly different cut as shown in Figure 2.1. Beside these beams, which are categorised as beams with multiple openings, it is also common to have beams with single openings or multiple but isolated openings in which openings are too far apart to worry about the failure of the web post or the interactions between the openings.

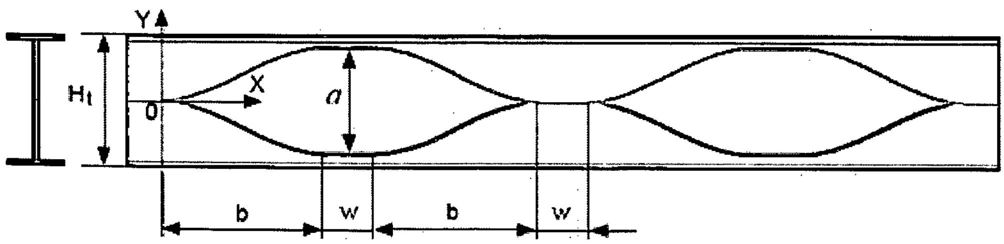

Figure 2.1 Angelina beam produced by Arcelomittal

2.2 Classification of Openings

Transverse openings in beams may be of different shapes and sizes, Prentzas (1968), in his extensive experimental study, considered openings of circular, rectangular, diamond, triangular, trapezoidal and even irregular shapes, as shown in Figure 2.2. Although numerous shapes of openings are possible, circular and rectangular openings are the most common ones. Circular openings are required to accommodate service pipes, such as for plumbing and electrical supply. On the other hand, air-conditioning ducts are generally rectangular in shape, and they are accommodated in rectangular openings through beams. Sometimes the corners of a rectangular opening are rounded off with the intention of reducing possible stress concentration at sharp corners, thereby improving the cracking behaviour of the beam in service.

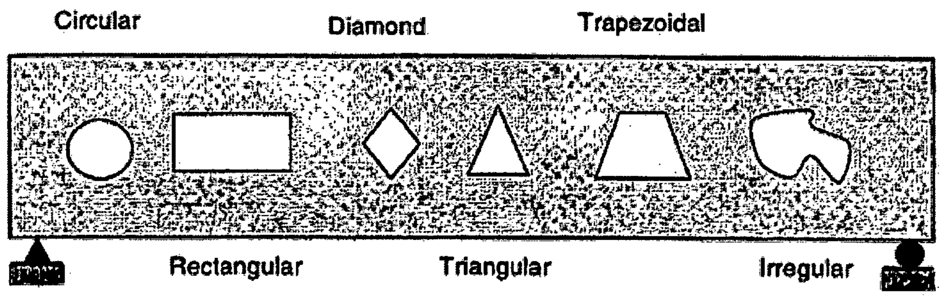

Figure 2.2 Opening shapes considered by Prentzas (1968)

With regard to the size of openings, many researchers use the terms small and large without any deflection or clear-cut demarcation line. Mansur and Hasnat (1979) have defined openings circular, square, or nearly square in shape as small openings, whereas, according to Somes and Corley (1974), a circular opening may be considered as large when its diameter exceeds 0.25 times the depth of the beam web. However, Mansur and Kiang-Hwee Tan (1999) consider that the essence of classifying an opening as either small or large lies in the structural response of the beam. When the opening is small enough to maintain the beam-type behaviour or, in other words, if the usual beam theory applies, then the opening may be termed a small opening. When beam-type behaviour ceases to exist due to the provision of openings, then the opening maybe classified as a large opening.

According to the above criterion, the definition of an opening being small or large depends on the type of loading. For example, if the opening segment is subject to pure bending, then beam theory may be assumed to be applicable up to a length of the compression chord beyond which instability failure takes place. Similarly, for a beam subject to combined bending and shear, test data reported in the literature (Prentzas, 1968; Mansur et al.1985, 1990; Nasser et al., 1967) have shown that the beam-type behaviour transforms into a Vierendeel truss action as the size of opening is increased. Some guidelines for identifying whether an opening is large or small are given in subsequent chapters when dealing with different types of loading and load combinations.

2.3 Behaviour of Beam in Shear

In a beam, shear is always associated with bending moment, except for the section at inflection point. In a homogeneous elastic beam, such as a concrete beam prior to cracking, the presence of shear changes the direction of principal tensile stress from a horizontal direction to a direction inclined to the longitudinal axis of the beam. Since concrete is weak in tension, this diagonal tensile stress eventually leads to what is basically known as diagonal tension failure of a beam. When the beam is provided with too much shear reinforcement, failure may also occur by crushing of the concrete in a diagonal direction, known as diagonal compression failure. The full details of the behaviour of a solid beam in shear can be found in any standard textbook on structural concrete.

When a small opening is introduced in the web of beam under-reinforced in shear, test data reported by Hanson (1969), Somes and Corley (1974), Salam (1977), and Weng (1998) indicate that the mode of failure remains essentially the same as that of a solid beam. Since the opening represents a source of weakness, however, the failure plane always passes through the centre of the opening, except when the opening is very close to the support so as to bypass the potential inclined failure plane. Figure 2.3 shows schematically some typical shear failures of beams containing square and circular openings as reported by [Hanson (1969) and Somes and Corley (1974), respectively, and summarized by Mansur (1998).

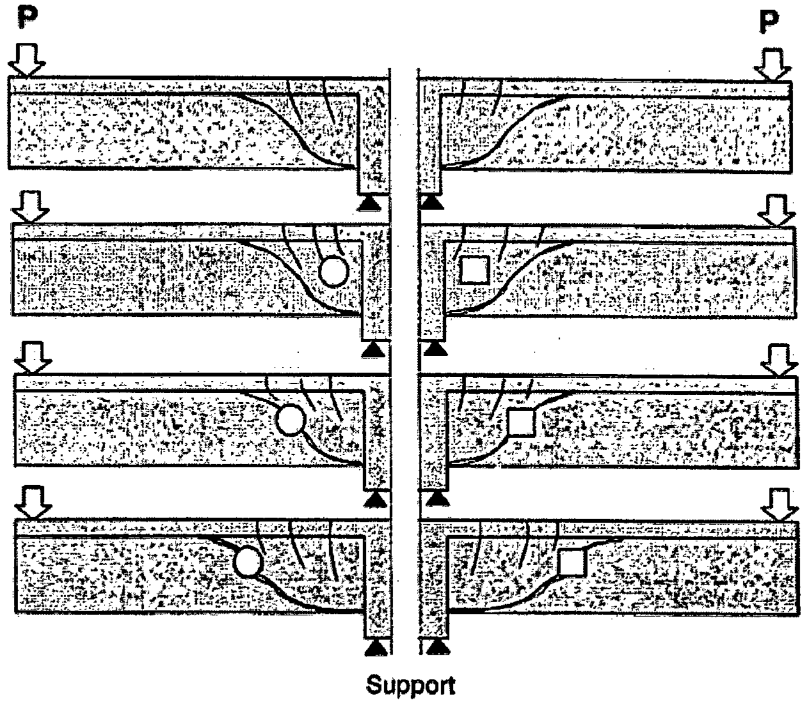

Figure 2.3: Typical shear failure of a beam without shear reinforcement (Mansur, 1998).

Hanson (1969) at PCA laboratory tested a series of longitudinally reinforced T-beams representing a typical joist floor. The specimens contained square openings and were tested in an inverted position under a central point load to simulate the joists on either side of a continuous support. The major parameters considered in the study were the size, do, and horizontal (from the edge of the central stub) and vertical (from the compression face of the beam) locations, X and Y, respectively, of the opening. A similar study was reported by Somes and Corley (1974) but, in that case, the openings were circular in shape.

Salam (1997) conducted an investigation on reinforced concrete perforated beams of rectangular cross section tested under two symmetrical point loads. The study was mainly aimed at devising a reinforcement scheme suitable for restoring the strength to the same level as that of the corresponding solid beam. The reinforcement schemes and the beam details employed are shown in Figure 2.4.Slam found that, in addition to the longitudinal reinforcement above and below the opening and full depth stirrups by its sides, short stirrups in the members both above and below the opening (as in Beam B6) are necessary to eliminate the weakness due to the provision of opening. In his study, Salam (1997) also noted that when sufficient reinforcement (as in Beam B4) is provided to prevent a failure along a diagonal crack passing through the centre of opening and traversing the entire depth (see Figure 2.4), the failure is then precipitated at the minimum section. In such a case, formation of two independent diagonal cracks in the members above and below the opening splits the beam into two separate segments, thus leading to the final failure. Figure 2.5 shows the cracking pattern of beam B4 that failed in this manner.

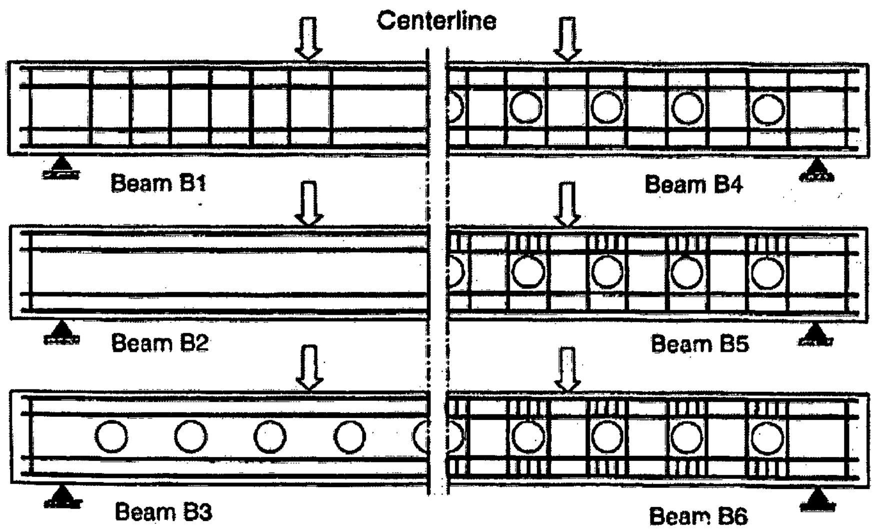

Figure 2.4: Reinforcement schemes for beams with opening (Salam, 1997).

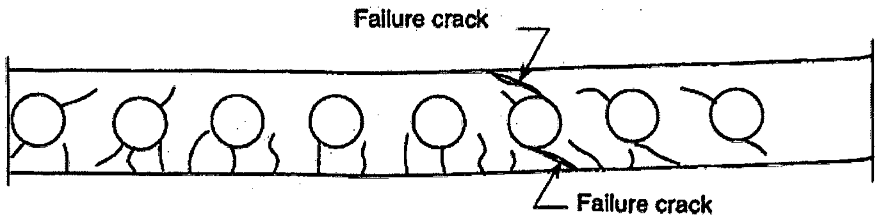

Figure 2.5: Shear failure of Beam B4 at the throat section (Salam, 1977).

2.4 Finite Element Analysis

Finite element analysis (FEA) is consists of computer model of a material or design that is stressed and analysed for specific results. It is used in new product design, and existing product refinement. In other words, FEA is a numerical method to find out an approximate solution for variables in a problem which is difficult to obtain analytically. The calculation of potential design changes such as temperature, buckling and deflection are usually complicated. A numerical method that is able to solve these engineering problems of the element analysis. In case of structural models failure, FEA may be used to help determine the design modifications to meet the new condition.

The concept of the finite element analysis is solving a continuum by a discrete model. It is done by dividing the problem into small several elements. Each element is in simple geometry and this is easier to be analysed than the actual problem or the real structure. Each element is then applied with known physical laws. The equation which is formed by each element or parameters then will combined to form a global equation. The new equation can be used to solve the field variables such as displacement, buckling, temperature and so on.

Figure 2.6 Unstrengthen Pretension Inverted T-beam with Nine Circular Web Openings

2.4.1 History of Finite Element Analysis

The finite element method or analysis (FEA) originated from the need for solving complex elasticity and structural analysis in civil and aeronautical engineering. It was developed by two persons that are Alexander Hrennikoff (1941) and Richard Courant (1942). Hrennikoff assumed that the plan elastic medium as a set of bars and beams (Giuseppe Pelosi, 2007).

In 1943, R. Courant introduces the piecewise continuous functions for the element. He used a set of triangular elements to study the St Venant torsion problem. He had been using the Ritz method of numerical analysis and minimization of various calculus to obtain approximate solutions to vibration systems. The formal introduction of finite element was published in paper by Argyris and Kelsey, Tunner, Clough, Martin, and Topp. Clough became the first person to use in term of finite element in 1960. Since then, the finite element application has been developed greatly (Strang and Fix, 1973).

The aeronautics, automotive, defence, and nuclear industries had started using the finite element application since early 70's. However, this is limited to expensive mainframe computer. Zienkiewicz and Cheung is the important person in developing the finite element technology at that time. But later, Hinton and Crisfield carried out the finite element into modelling and solution of nonlinear problems (Reddy, 1993).

With the development of the CAE technology, engineering drawing can be produced. Besides, the analysis can be carried out and also the finite element modelling can be done. The finite element becomes more and more important today which can simplify and solves various types of engineering problems.

2.4.2 How Does Finite Element Analysis Work

FEA uses a complex system of points called nodes which make a grid called a mesh. This mesh is programmed to contain the material and structural properties which define how the structure will react to certain loading conditions. Nodes are assigned at a certain density throughout the material depending on the anticipated stress levels of a particular area. Regions which will receive large amounts of stress usually have a higher node density than those which experience little or no stress. Points of interest may consist of: fracture point of previously tested material, fillets, corners, complex detail, and high stress areas. The mesh acts like a spider web in that from each node, there extends a mesh element to each of the adjacent nodes. This web of vectors is what carries the materials properties to object, creating many elements (Peter Widas, 1997).

2.4.3 Meshing

The important requirement of the FEM is need to split the solution domain (model geometry) into simply shaped subdomains called "finite elements". This is a discretization process commonly called meshing and element are called finite because of their finite, rather than infinitesimally small size having infinite numbers of degree of freedom. Thus the continuous model with an infinite number of degrees of freedom (DOF) is approximately by a discretized FE model with a finite DOF. This allows the reasonably simple polynomial functions to be used to approximate the field variables in each element. Meshing the model geometry also discretized the original continuous boundary condition. The loads and restraints are represented by discrete loads and support applied to element nodes.

There are many ways in turning a mathematical model into an FE model by meshing. The three major factors which define the choices of discretization are element size, element order and element mapping (Kurowski, 2004).

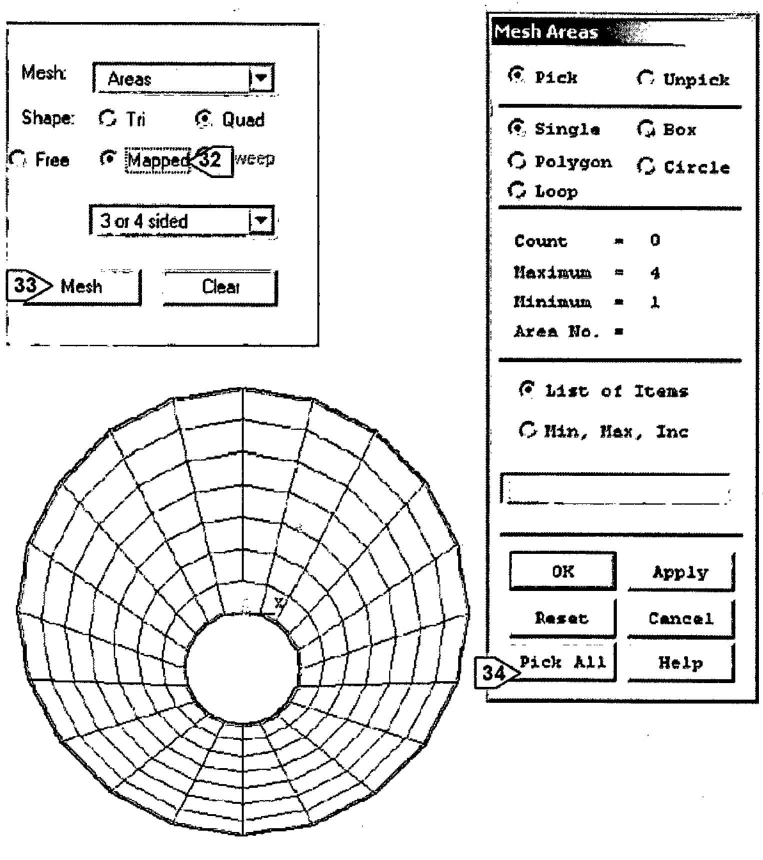

Figure 2.7: Circular solid mesh procedure

2.4.4 Advantages of Finite Element Analysis

Implementing finite element analysis can:

i. Speed development of new products.
ii. Reduce costs of develop product which is less spend due to costs of material of models and testing on it.
iii. Provide greater product reliability.
iv. Improve quality.
v. Assist with development of testing processes.

2.5 ANSYS Parametric Design Language

ANSYS is a finite element analysis package used widely in industry to simulate the response of a physical system to structural loading, and thermal and electromagnetic effects. ANSYS uses the finite element method to solve the underlying governing equations and associated problem-specific boundary conditions (Cornell University, 2002).

APDL are can be known as tools to help designers perform parametric analyses in which simulation software automatically solves for entire ranges of specified variables and generates displays that enable users to readily spot trends and identify an optimal design. Parametric analysis can guide the product development process to a design configuration that can save the time compared if by individual analyses were manual performed. The period of time to set up is required in APDL which a model can increase significantly with the complexity of the geometry.

ANSYS Workbench platform is one of the most efficient ways of deal with geometric parameters which enables parameters of the CAD model to be driven directly form simulation.