STRENGTH P)RCED CONCRETE
BEAM

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ABSTRACT

Nowadays, price of construction materials was increase. That is one of important factor in order to reduce the construction cost. One method in reducing this cost is by removing the concrete volumes in structure element, for example hollow section beam. An empty space that left can be used for various functions especially in building finishing. The space can be used as a route of electrical wire or as a route for ventilation system. One of the problems encountered in this idealization is the strength prediction of beam after the concrete volume has been removed. This study will investigated the effect of cavity introduced in rectangular concrete beam on its bending as well as its maximum stress. Besides that, this study also wants to determine an optimum size of cavity in rectangular concrete beam that can be provided. Several high of cavity will be considered and analysed using LUSAS. There are 10 models analysed using LUSAS modeller include one solid beam as a control model. Based on the results, an optimum cavity size that can be provided in a rectangular hollow concrete beam having size 200mm x 350mm x 2000mm was 135 mm. It's because the maximum stress obtains is almost same as obtain from solid beam. As a conclusion, the maximum stress will increase with increasing a cavity size in a hollow rectangular concrete beam.

ABSTRAK

Harga bahan mentah binaan yang semakin meningkat dewasa ini merupakan salah satu faktor terpenting dalam usaha untuk mengurangkan kos pembinaan bangunan. Salah satu cara untuk mengurangkan kos berkenaan adalah dengan cara membuang isipadu konkrit dalam struktur bangunan sebagai contoh struktur rasuk. Ruang kosong yang yang tinggal di dalam struktur rasuk selepas isipadu konkrit dibuang boleh digunakan untuk pelbagai fungsi terutamanya dalam kemasan bangunan dalam. Sebagai contoh, ruang tersebut boleh digunakan sebagai laluan wayar elektrik atau laluan sistem pengudaraan. Satu masalah yang didapati di dalam penganalisaan adalah jangkaan kekuatan rasuk selepas isipadu konkrit dibuang. Kajian ini akan menyiasat kesan pengenalan rongga dalam rasuk konkrit segiempat tepat pada lentur dan tegasan maksimum. Selain itu, kajian ini juga ingin menentukan saiz optimum rongga dalam rasuk segiempat tepat konkrit yang boleh disediakan. Saiz beberapa rongga akan dipertimbangkan dan dianalisis mengunakan LUSAS. Terdapat 10 model yang telah dianalisis dalam kajian ini termasuk satu rasuk pepejal sebagai model kawalan. Berdasarkan keputusan kajian, saiz rongga optimum yang boleh disediakan dalam rasuk konkrit berongga segiempat tepat yang mempunyai saiz 200mm x 350mm x 2000mm adalah 135 mm. Ia adalah kerana tegasan maksimum yang terhasil daripada LUSAS hampir sama seperti dalam rasuk pepejal. Secara kesimpulannya, tegasan maksimum akan meningkat dengan peningkatan saiz rongga dalam rasuk konkrit berongga segiempat.

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CHAPTER 1

INTRODUCTION

1.1 Background

A beam is horizontal structural member that carry a load, with or with-out moments. Beam support a loads from the floors and roof and transmit this loads to the columns and foundations base on its position. The load carrying capacity of a beam depends on the materials, length, shape of beam cross-section and the restraints applied to its ends. Failure of a beam in a critical location can cause the progressive collapse of the floors.

For design purposes, beam are divided into four major types which is cantilever beam, over hanging beam, simply supported beam and also continuous beam. These types depend on a type of support that used.

Nowadays, in a construction industry, cost reduction is needed in order to minimum a total cost. In order to reach the objective, it was suggest some part in a solid concrete need to remove and hollow without reduce its strength. It will reduce and save a material cost. Furthermore, the hollow part or section can be used for others benefits in future.

There are many research has been done by outside researcher about hollow section. But most of the research has focus more on hollow section in steel. In many applications, stainless steel structural hollow sections were taking a share as structural elements covering square, rectangular and circular cross-sections. It was developed in Europe, Australia and North America by different research and development projects. The research was not only focus on the strength characteristic but also in others characteristics such as its fire resistance and others.

1.2 History of Hollow Structural Section

A hollow structural section (HSS) is a type of metal profile with a hollow tubular cross section. In some countries they are referred to instead as a structural hollow section (SHS). Most HSS are of circular or rectangular section, although other shapes are available, such as elliptical. HSS is only composed of structural steel per code.

HSS are also called tube steel or structural tubing. Circular HSS are sometimes mistakenly called steel pipe though true steel pipe is actually dimensioned and classed differently than HSS. The corners of HSS are heavily rounded, or chamfered, at radii approximately twice the wall thickness. The wall thickness is uniform around the section. In the United Kingdom UK, the terms are circular and rectangular hollow section (CHS and RHS). However, the dimensions and tolerances differ slightly from HSS.

1.3 Problem Statement

Nowadays, in construction method, it's familiar to see a solid structure has been used in a building. It's been used because the strength of concrete is high and can carry more loads depending on its size and shape. If look inside the building in term of finishing, it's looking good because it's already cover by something such as asbestos or something else.

When the building need to install mechanical and electrical equipment, it will somehow cause the building seem scatter which the equipment such as electrical cable or wire and ventilation equipment. That's the reason why a structure needs to be hollowed in order to provide a space for this equipment. This is especially for a beam because there a lot of the equipment was put horizontally rather than vertically in a building.

Even though the structures need to be hollowed, the strength of the structure was same as the solid structure. Therefore, the research of the size of cavity in beam has been done. The useful of this cavity is it can be used as a route of ventilation system, as a route of electric cable, as a route of rainwater and others. Furthermore, the rainwater can be recycled and used it again.

1.4 Objective

The objectives of this research are:

i) To investigate the effect of cavity introduced in rectangular beam on its bending as well as maximum stress.
ii) To study what is the optimum cavity size in rectangular beam that can be provided using linear analysis.

1.5 Scope of Study

The scopes of study of this research are as follows:

i) To make a hollow section in a simply supported beam which is can withstand a load of 50 kN
ii) To justify the high of hollow that can withstand the load on the beam using finite element method (LUSAS software)

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In structure engineering, beam can be classified as a super structure elements. It will carry a load from slab and transfer to the column. Normally beam is in rectangular solid shape. A hollow space may be provide in a beam. Rectangular hollow beam is a type of structure that has a cavity that can found in a rectangular beam. It will give some space in a beam. This space can be used for any method such as wiring route, ventilation system route or others.

Apparently, the research is more to hollow in a steel structure. There are many research has been done by others researcher about this hollow section. This is because there are easier to make a hollow section in steel rather than in concrete. The research has been done on all a types of super structure such as column, beam and slab.

The characteristic that consider was the strength. The strength of structure must be able to carry a load that imposed on it. This is important to make sure the serviceability of the building can withstand any force.

2.2 Finite Element Method

The Finite Element Method (FEM) of analysis is a very powerful and modern computational tool. This method has been used successfully to solve very complex structural engineering problems. FEM has also been widely used in other fields such as thermal analysis, fluid mechanics, and electromagnetic fields. Since the method involves a large number of computations, therefore it requires computer to solve a problem.

The finite element method represents the extension of matrix method for skeletal structures to the analysis of continuum structures. In FEM, all the model will be analyze in discretization which is the model has been dividing into an equivalent system of smaller bodies or units called finite element that interconnected at points common to two or more elements in nodal points or nodes and or boundary lines and or surface.

2.2.1 Background of Finite Element Method

Since in the 1980s, structural analysis was performed including material nonlinearity in the study and design of civil engineering structures, engineers gained access to detailed information regarding phenomena occurring material elastic limit. This information typically describes the state of the material on a point by point basis, but is not easy to extrapolate to the entire structure nor offers sufficient indications about its general state. Furthermore, the relevance to overall structural stability and serviceability of the fact that a certain part of a structure is more or less damaged is difficult to infer from the local information provided by classical nonlinear constitutive models.

The study at macroscopic scale of concrete behavior was traditionally founded on crack models for tension and crush models for compression. A latter-day popular viable alternative are the damage models that bring about a unified treatment of concrete behavior under both tension and compression. Damage models may be classified mainly into two families: those employed mostly in seismic engineering for beam structures, evaluating damage indices from parameters like sectional forces, ductility or deformational energy of structural members. The second family is made up by the continuum mechanics damage models that describe the material state of a point of the structure and are based on the principles of thermodynamics (Alex D. H, 2002).

By using this finite element method, the size of cavity that need to provide in a beam can be predict in order to make sure the strength of the beam still the same as solid beam. The analysis by section need to do in order to know the limit concrete compression and reinforcement tension in a beam.

2.2.2 Definition of Finite Element Method

The finite element method (FEM) is a numerical method for finding approximately solutions for partial differential equations as well as integral equations of engineering and mathematical physics (Daryl, 2007). Each element is of simple geometry and therefore is much easier to analyze than the actual structure. In essence approximate a complicated solution by a model that consists of piecewise continuous simple solutions. The elements are called "Finite" to distinguish them from differential elements used in calculus.

2.2.3 Advantages of Finite Element Method

When numerical analyses were first introduced in engineering practice in the1960s, many analysis methods such as boundary element method and finite difference method, were in use. Over a time, these methods were dominated by the FEM because of its inherent generality and numerical efficiency. Although other methods retain advantages in certain applications, they are difficult or impossible to employ to other types of analyses. At the same time, the FEM has wider applicability. The versatile analysis tool can be applied to almost any types of engineering problems. For this reason, the FEM has widespread adoption for increasingly diverse problems and dominated the market of commercial analysis software.

This method has a various of advantages that can help to solve a problem that occur. Firstly, this method can model irregularly geometry shaped bodies easily. Besides, FEM can handle general load conditions without difficulty. It also can vary the size of elements easily using coordinate systems that was introduced. Furthermore, FEM has a dynamic effects where it will show a real condition of element when some load was appoint into an element. Nevertheless, this FEM can handle a nonlinear behavior which it's very difficult to analyze (Kenneth H.H et al., 2001).

2.2.4 Types of finite Element

A classification according to the way the element represents the displacement field in three dimensions distinguishes among solid, shell, membrane and joint elements. Solid element fully represents all three dimensions. The solid element models the 3-D displacement field with three variables.

The shell elements are used to model 3-dimensional structures whose behavior is dependent upon both flexural and membrane effects. Normal stress to the shell cross section are usually assumed to have linear distribution which is consequently the shell element can model bending. The shell element models the displacement field with two variables.

The membrane element is used to model 2 and 3-dimensional structures whose behavior is dominated by in-plane membrane effects. The membrane element can model only membrane stresses but not bending stresses.

The joint elements are used to model the flexibility of joints between other LUSAS elements. It was incorporates a variety of joint elements which are designed to match the nodal freedoms of their associated elements. It may also be used to model point masses which is plastic hinges or smooth and frictional element contact.

2.2.5 Fundamental Requirement

There are three basic conditions that must be observed which are equilibrium of forces, the compatibility of displacements and the material behavior law. The first condition requires is the internal forces balance the external applied loads. Compatibility condition requires that the deformed structure fits together to the deformations of the member are compatible. It is also necessary to know the relationship between load and deformation for each component of the structure such as material behavior law. This relationship in linear elasticity is the Hook's law.

2.2.6 Meshing

The need to split the solution domain or model geometry into simply shaped subdomains called "finite elements" was a requirement of the FEM. This is a discretization process commonly called "meshing" and elements are called "finite" because of their finite, rather than infinitesimally small size having infinite number of degrees of freedom. Thus the continuous model with an infinite number of degrees of freedom (DOF) is approximated by a discretized both of FE model and finite DOF. This allows for reasonably simple polynomial functions to be used to approximate the field variables in each element. Besides that, meshing the model geometry also discretizes the original continuous boundary condition. The loads and restraints are represented by discrete loads and supports applied to element nodes (Kurowski, 2004).

The three major factors which define the choice of discretization are element order which is order of the element shape function, element mapping where element shape may distort from the ideal shape after mapped to the actual shape in the FE mesh and element size.

2.2.7 Verification of Result

Finite element analysis software has become a famous tool in the hands of design engineers. The results of the finite element analysis need to be verified so that it does not contain errors such as applying wrong boundary conditions and loads, wrong input data, selecting inappropriate types of elements, size after meshing and poor element shape. Experimental testing of the model is one of the best ways for checking the results, but it may take a long time and quite expensive. Therefore, it is always a good practice to start by applying equilibrium conditions and energy balance to different portions of a model to ensure that the physical laws are not violated.

2.3 London University Stress Analysis System (LUSAS)

LUSAS is one of the world's leading structural analysis systems. The LUSAS system uses finite element analysis techniques to provide an accurate solution for all types of linear and nonlinear stress, dynamic, and thermal problems. It is an associative feature-based modeler. The model geometry is entered in terms of features which are sub-divided or discretized into finite element in order to perform the analysis. Increasing in accuracy of the solution is depends on increasing the discretization of the features, but with a corresponding increase in solution time and disk space required. The features in LUSAS form a hierarchy that is volumes are comprised of surfaces, which in turn are made up of lines or combined lines, which are defined by points (LUSAS Modeller, Theory Manual, Version 14.0, 2004).

2.3.1 Characteristic of LUSAS Software

LUSAS software can analysis and organize a complex structure problems and shapes including 3 dimensional structures. This software also can be used in dynamic structural analyses with temperature changes. LUSAS software can solve problems up to 5000 number of elements.

2.3.2 Analysis Procedure

There are 3 steps in the finite element analysis using the LUSAS software. Firstly, a pre-processing phase which involves creating a geometric representation of the structure, assigning properties, outputting the information as a formatted data file that suitable for processing by LUSAS. (LUSAS Modeller, Theory Manual, Version 14.0, 2004).

Next is finite element solver. It is a sets of linear or nonlinear algebra equations where solved simultaneously to obtain nodal results such as displacement values at different nodes. The last step was a result processing. In this final process, the results can be processed to show the contour of displacements, stresses, strains, reactions and other important information. Graphs as well as the deformed shapes of a model can be plotted.

2.4 Concrete

Concrete materials have a sufficient compressive strength, so are widely used in civil engineering, reactor buildings, bridges, irrigation works and blast resistant structures, etc. Concrete has its first modern record as early 1760, when John Smeaton used it in Britain in the first lock on the river Calder. In 1796, J.Parker discovered Roman natural cement and 15 year later, Vicat burned a mixture of clay and lime to produce cement (M.Nadim Hassoun, 2002)

Concrete is a construction material that consists of coarse aggregate, fine aggregate, cement, water and sand. Besides that, concrete nowadays was added by other chemical and pozzolanic admixtures such as superplasticizer, air entraining, retarder, fly ash and others in order to improve it properties. It has a very wide variety of strength, and its mechanical behavior is varying with respect to its strength, quality and materials. The strength and the durability are two important factors in concrete.

It's usually will design for a high strength grade which is 30 and above depending on its type of function. This is to make sure the beam can resists the entire load that appoint to it. As the load is applied, the ratio between the stresses and strains is approximately linear at first and the concrete behaves almost as an elastic material with virtually a full recovery of displacement if the load is removed.

2.4.1 Stress- Strain Relation of Concrete

Concrete has an inconsistent stress-strain relation depending on its respective strength. Compressive strength of concrete depends on the cement content, the cement-water ratio, the age of concrete and also the type of aggregate. However, there is a typical patent of stress-strain relation for the concrete regardless the concrete strength, as shown in Figure 2.1.

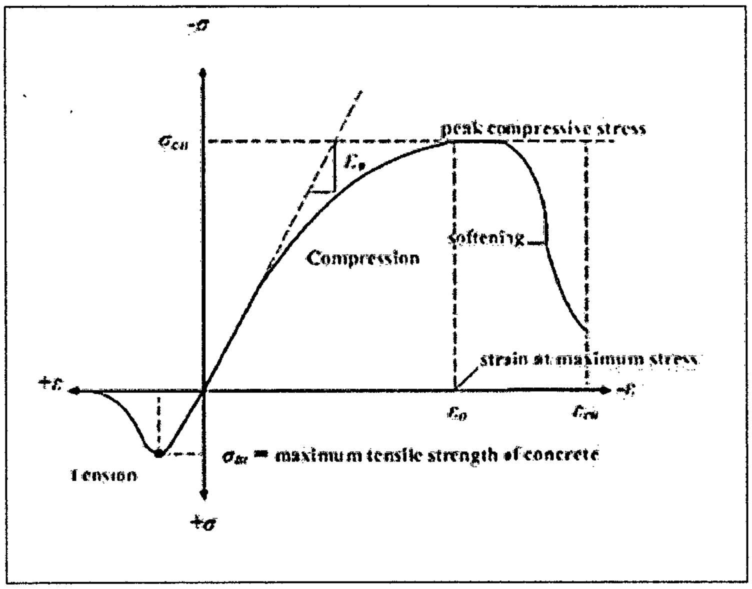

Figure 2.1: Stress-strain curve of concrete (Mosley et al., 1999)

The behavior of concrete is almost elastically when the load is applied to the concrete. According to the stress, the strain of the concrete is increasing approximately in a linear manner. Finally the relation will be no longer linear and the concrete tends to behave more as a plastic material. Therefore the displacement cannot complete after the removal of the loadings. As a result, permanent deformation will incur. (Mosley et al., 1999)

Generally, the strength of concrete depends on the age, the cement-water ratio, type of cement and aggregate, and the admixture added to the concrete, an increment in any of these factors producing an increase in strength. Assumption the concrete can reach its strength at the age of 28-day because usually the increment of concrete strength is insignificant after the age of 28-day.

2.4.2 Elastic Modulus of Concrete

The stress-strain relationship for concrete is almost linear provided that the stress applied is not greater than one third of the ultimate compressive strength. A number of alternative definitions are able to describe the elasticity of the concrete, but the most commonly accepted is E = Ec, where Ec is known as secant or static modulus as shown in a Figure 2.2. The modulus of elasticity of concrete is not constant and highly depends on the compressive strength of concrete.

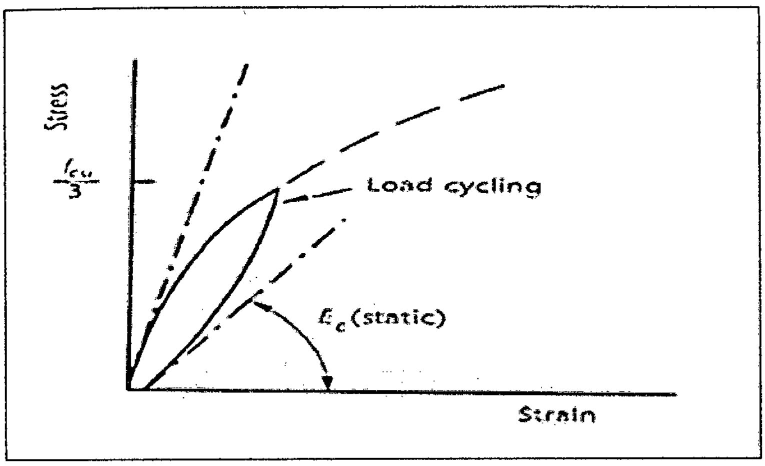

Figure 2.2: Static modulus of concrete (Mosley et al., 1999)

2.5 Steel Reinforcement

Steel is a material that has a great tensile strength and often use in the concrete because concrete does not act in tension well alone. Besides that, there is a good bond between concrete and reinforcement. The reinforcement steel has a wide range of strength. It has more consistent properties and quality compared to the concrete, because it is manufactured in a controlled environment. There are many types of steel reinforcement. The most common are plain round mild steel bars and high-yield stress deformed bars. The typical stress-strain relations of the reinforcing steel can be described in the stress-strain curve as shown in Figure 2.3.

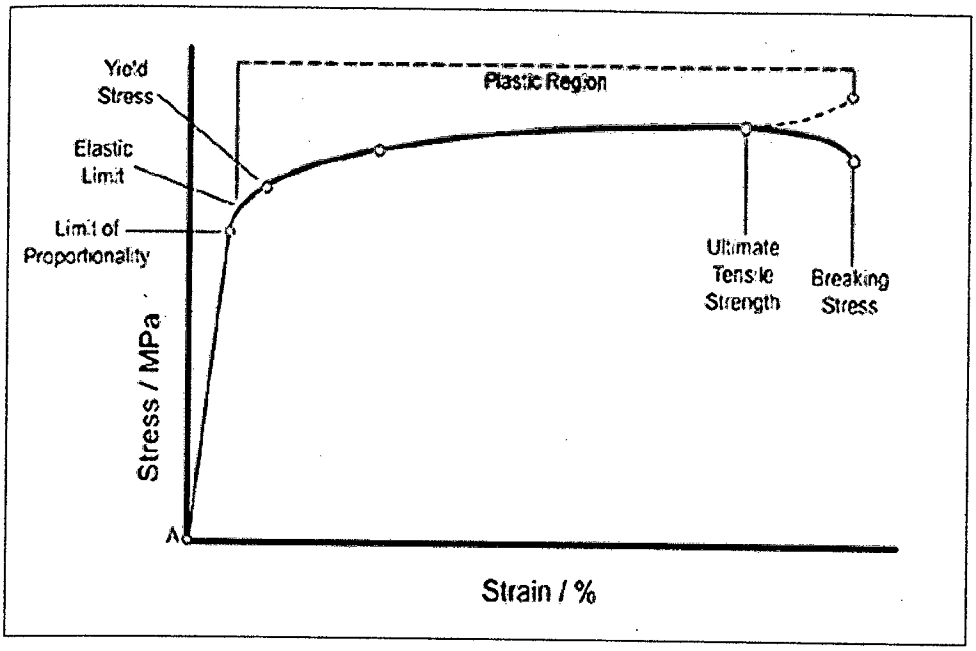

Figure 2.3: Typical stress-strain curve for reinforcing steel (R.C. Hibbeler, 2008)

From the Figure 2.3, the mild steel behaves as an elastic material until it reaches its yield point, finally it will have a sudden increase in strain with minute changes in stress until it reaches the failure point. On the other hand, the high yield steel does not have a limited yield point but has a more gradual change from elastic to plastic behavior.

Steel reinforcement have a similar slope in the elastic region with Es = 200kN/mm^2. The specific strength taken for the mild steel is at the yield stress. For the high yield steel, the specific strength is taken as the 0.2% proof stress. BS 8110 has recommended an elastic-plastic model for stress-strain relationship, which the hardening effect is neglected (British Standards Institution, 1997). The stress-strain curve may be simplified bilinear as shown in Figure 2.4

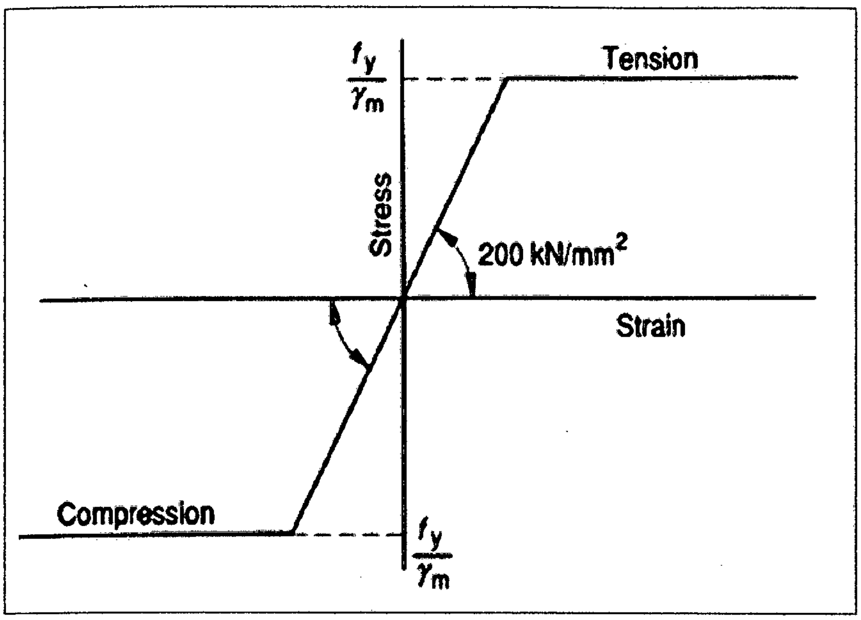

Figure 2.4: Simplified stress-strain curve for reinforcing steel (British Standard, 1997)

2.6 Hollow Section

A hollow section can be classified as a cavity part that exists in a middle of element or section. The Hollow Structural Sections (HSS) is a cold-formed welded steel tube used for welded or bolted construction of buildings, bridges and other structures and a wide variety of manufactured products (Steel Tube Institute, 2005). It is produced in square, rectangular and round shapes to meet design requirements.

There are many kind of structure that can be hollowed. For example, a beam, slab, column and others. This kind of hollow structure is make without reduce the strength of the structure itself. Besides that, the total of the materials also can be reduce when it was hollowed at the bottom section.

Most of this kind hollow structure is found in a steel structure because it's easier to make a hollow in steel materials rather than make it in a concrete form. To make the