FLEXURAL BEHAVIOUR OF REINFORCED CONCRETE WITH RECTANGULAR HOLLOW SECTION

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JUNE 2013

ABSTRACT

Beam is a structural member which spans horizontally between supports, made of steel, reinforced concrete, wood or composite. In Malaysia, reinforced concrete beam is the preferred choice as structure. However, the self-weight of reinforcement beam quite significant to the overall dead load in the structure which transferred to the foundation. Thus, the idea of providing hollow section to the beam was to reduce the weight of the beam as overall structure weight structure was generally. The concept introduced was the same as hollow slab panels which been widely used in bridge and highway construction where this will reduce the cost and material wastage at the same time. Referring to the second moment of inertia law, the reduction of the surface area of the beam due to the hollow will give an effect on the bending moment and shear resistance of the beam. Therefore, an experimental testing was necessary in order to identify the reduction of beam sample strength, deflection profile and the crack pattern. Four sample of beam with hollow size varies from 20 mm to 110 mm were prepared as well as a solid beam as a control and tested with four point flexural test to determine the flexural strength, deflection and crack pattern. Three LVDT were placed under the beam to measure the deflection and the cracks were marked to indicate the propagation and type of crack. From the results, each of the specimens was test with the four point test. The result shows that the flexural strength of the concrete beam depends on the surface area. Result shows, flexural strength decreases when the size of the rectangular hollow were increasing. Rectangular hollow of the beam make the total surface area decreases. It also decreased the second moment of inertia at the beam. Beam tend to fail and produce crack pattern in small load because the decreased of the second moment inertia.

ABSTRAK

Rasuk adalah struktur yang memanjang secara melintang diantara konkrik tetulang. Biasanya rasuk diperbuat daripada keluli, konkrit tetulang, kayu atau komposit. Di Malaysia, rasuk konkrit tetulang adalah pilihan utama sebagai struktur. Jentera berat digunakan untuk mengangkat (pre casting) rasuk konkrit ke bahagian atas. Salah satu cara untuk mengurangkan berat rasuk konkrit adalah dengan membuang sebahagian konkrit. Bahagian yang perlu dibuang adalah berbentuk segi empat pada bahagian tengah rasuk konkrit. Ia akan dapat mengurangkan pengendalian pembinaan. Dengan mengurangkan sebahagian konkrit, kekuatan rasuk konkrit akan semakin berkurang. Terdapat beberapa saiz yang di ketengahkan untuk membuang konkrit tersebut. Kekuatan dan profil pesongan lenturan akan diambil kira pada setiap spesimen yang di tetapkan. Corak retak juga perlu diambil kira bagi mengenalpasti sama ada kegagalan rasuk adalah berpunca daripada lentur atau ricih. Corak retak diambil kira hanya daripada sebelah permukaan rasuk sahaja. Papan lapis digunakan untuk membuat segi empat bagi mengelakkan konkrit masuk kedalam bahagian segi empat yang telah dibuang. Kekuatan rasuk dipengaruhi oleh tetulang dan konkrit. Setiap spesimen akan diuji dengan menggunakan mesin khan untuk mendapatkan kekuatan sebenar setiap spesimen.

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LIST OF SYMBOLS

f_t	Concrete tensile capacity under unaxial tension
f_c	Concrete compression capacity under unaxial tension
f_{tt}	Concrete tensile capacity under biaxial tension
f_{tc}	Concrete tensile stress/capacity under biaxial tension-compression
f_{ct}	Concrete compression stress/capacity under biaxial compression-tension
f_y	Yield strength of steel reinforcement
f_{ck}	Strength of concrete
Σ	Flexural strength
Mm	Measure of length in milimeter

LIST OF ABBREVIATIONS

OPC	Ordinary Portland Cement
T	Type of the reinforcement bar
R	Type of the shear link
LVDT	Linear variable displacement transducer
C	Cover
D	Depth
d	Diameter
M&E	Mechanical and Electrical
F	Force applied to the beam
N	Newton
K	kilo
B	Width of the beam
L	Length
Fs	Shear Force

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Concrete beam is use to support and distributed loadings from floor to the column and foundation. Length of the concrete beam affects the beam weight itself. Tension occurs at the bottom of the beam. Compression occurs at the top of the beam. Reinforcement was support the beam at the bottom. Some of the concrete were not used at the bottom of the beam. How to remove the concrete without reduce the strength of the concrete beam?

Make concrete beam with hollow are one way to reduce the concrete. It also was reduce the weight of the beam. Reduced weight is important because of transportation cost and less cost of material (concrete). The most important thing is to make labor easy to handle it on site. The hollow beam concrete between the holes contains the materials that provide bending resistance to bending momentum from loads. There is some comparison between the solid beam and the hollow beam concrete with the same cross section and same reinforcement fail almost at the same load when subjected to pure torsion with minimal effect of the internal concrete core.

Cost and time saving, more economic in bearing supports and environment caring are the point of the advantage of hollow core beam concrete. Cost and time saving can make the different fields of this kind of production are really unlimited and suitable for private, Administrative, Commercial, and industrial buildings. The beams are laid quickly and independently of the weather. The hollows in the beams can be used for pipe and other electric wire purposes.

More economic in bearing support up to 50% of cross section area of beams is voids which reduce the weight of beams distinctly. In return it is possible to eliminate rows of supports to increase costs, save money and achieve constructional advantages. Environment caring means that sand, gravel, and cement are used on economic base, thus the pollutions is reduced and environment protections is achieved due to the extruder technique used in these production which means essentially less water consumption, less steel, aggregate and cement.

In the construction of modern buildings, 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 and, for aesthetic reasons, are 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 savings thus achieved may not be significant, but for multistory buildings, any saving in story height multiplied by the number of stories can represent a substantial saving in total height, length of air-conditioning and electrical ducts, plumbing risers, walls and partition surfaces, and overall load on the foundation. It is obvious that inclusion of openings in beams alters the simple beam behavior to a more complex one.

1.2 PROBLEM STATEMENT

Beam, slab and column are familiar in the construction. To operate it at the top level is not easy as it looks. It related to the material usage and the manpower. The problem occurs because labors need to install the pre casting at the top. They need heavy machine to bring up it. Waste of money to rent the heavy machinery. For the large project, this kind of the problem do not occurs.

To overcome the problem, rectangular hollow section were applied at the concrete beam. This application were minimized the construction handling, transportation, and the number of workers. This research wants to determine how to reduce the weight of the beam without disturbing the strength and structure of the beam. To reduce the weight of the beam, we must reduce the materials used in the concrete beam. One way to reduce the weight of the beam is make the solid beam to be a hollow beam. Strength of the beam becomes lower.

1.3 OBJECTIVE OF STUDY

I. To determine the flexural strength and deflection profile of hollow beam design with the different size of the rectangular hollow.

II. To observe the crack pattern of hollow beam design.

1.4 SCOPE OF STUDY

In this experimental study, the effect of hollow section size of the beam on its flexural strentgh will be focused. Five beams with dimension of 200mm height, 150mm width and 3 meter span will be prepared. Solid beam with no hollow section will be designated as beam a for a control parameter and beam with hollow opening (110x60, 90x40, 70x20, 20x20)mm will be designated as Solid Beam, Beam 1, Beam 2, Beam 3 and Beam 4 respectively.

The hollow section was designated to be located at the centre of the beam surface area. Thin plywood will be support the hollow of the beam. Strength of the plywood will be neglected. Therefore, the strength of the hollow beam influence by the reinforcement and the concrete.

Material such as Ordinary Portland Cement (OPC), sand, coarse aggregates, concrete reinforced bar and links bar will be used. A concrete of grade 30N/mm^2 and uncrushed coarse aggregate with maximum size of 20mm will be used. Ready mixture were ordered with specification. As for the reinforcement, reinforcement bar of size 12mm and shear link bar of size 8mm will be used. The reinforcement design used for the beam is 2T12 at the top and 2T12 at the botttom and for shear link reinforcement of R6-250.

The beam samples will be tested for the flexural strength test to determine which beam will have the more flexural strength. Then, all of this sample beam also will be compare in term of deflection and crack pattern.

The method chosen for this experiment is 4 point test (flexural test) and Linear variable displacement transducer, LVDT will be fixed to observe the deflection of the beam. Figure 1.4 were shown the arrangement of the beam design.

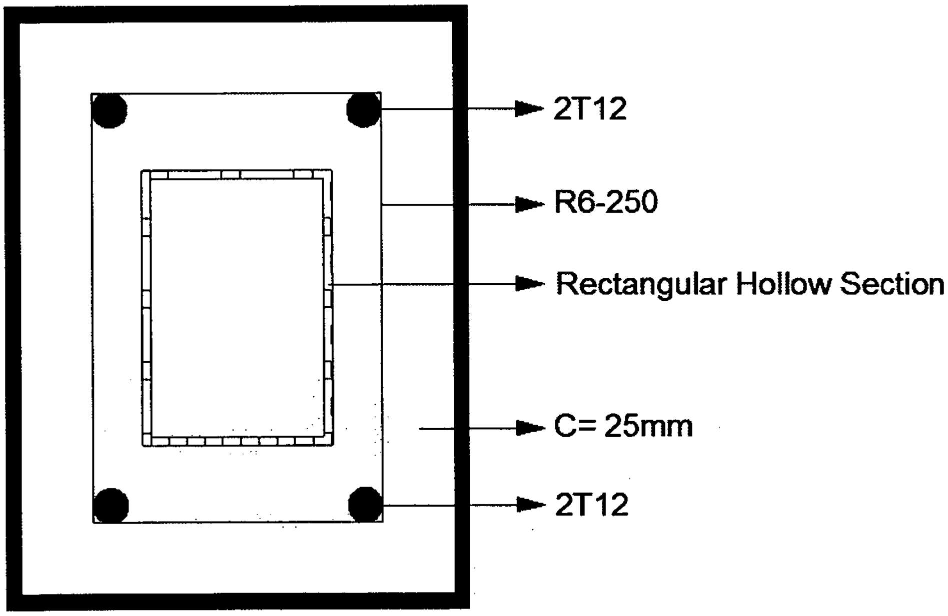

Figure 1.4: Design of the Beam With Size of The Reinforcement and Size of The Hollow Section

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The degree of change in the beam behavior as a result of the presence of an opening depends on many factors. There are shape and size of the opening, position of the opening, weight of the beam. These factors refer to the studies that have been done earlier. To make this investigation easier to refer, a number of inputs such as size hollow, hollow position, and so on refer to previous studies.

2.2 SHAPE AND SIZE OPENING

The size of the opening is the most important parameter that effect the beam behavior. Strength of the beam is influenced by the strength of solid concrete reinforcement already. Some concrete at the bottom of the beam does not affect the strength of the beam. The part has to be removed to reduce the weight of the concrete beam. The strength are affected only at the top, while the bottom is supported by reinforcement. But, how much and in which positions need to be removed must be determine. (Mansur and Tan,1996)

Hollow beam were classified according to their size into two main categories, there are small opening and large openings. Shaped were considered circular and square openings as small ones. Square opening may be considered large when its diameter exceeds 0.25 times the depth of the beam web. Although no clear-cut line was found in the literature between the two categories. The classification of an opening to either small or large depends on the effect of such opening in the structural response of the beam. (Mansur and Huang, 1992)

An opening may be considered small when the presence of such opening does not change the beam type behavior. On the other hand, when the presence of the opening leads to change in the beam type behavior to a frame type behavior then such opening will be considered as large one. Other, opening that are circular, square may be considered as small openings provided that the depth or diameter of the opening proportion to the beam size about less 40% of the overall beam depth. In practice, openings are located near the supports where shear is predominant. In such a case, tests have shown that a beam with insufficient reinforcement and improper detailing around the opening region fails prematurely in a brittle manner. (Siao and Yap, 1990)

Simple design procedure for reinforced concrete beams with large web openings. The openings should be provided so that chords have enough concrete area to develop the ultimate compression block in flexure and sufficient depth to provide efficient shear reinforcement. They should not be deeper than one-half the beam depth and should be located not closer than one-half the beam depth from supports or concentrated loads. (Kiang-Hwee and Mansur, 1999)

2.3 POSITION OF THE OPENING

External strengthening of T-beams provided with small square openings close to the support. The type of material used was FRP plates in the form of a truss around the position of the opening. External strengthening of reinforced concrete beams having a large rectangular opening in the shear zone. (Mansur and Huang, 1992)

Openings should preferably be positioned flush with the flange for ease in construction. In the case of rectangular beams, openings are commonly placed at mid depth of the section, but they may also be placed eccentrically with respect to depth. Care must be exercised to provide sufficient concrete cover to the reinforcement for the chord members above and below the opening. The compression chord should also have sufficient concrete area to develop the ultimate compression block in flexure and have adequate depth to provide effective shear reinforcement.

Simple design procedure for reinforced concrete beams with large web openings. The openings should be provided so that chords have enough concrete area to develop the ultimate compression block in flexure and sufficient depth to provide efficient shear reinforcement. They should not be deeper than one-half the beam depth and should be located not closer than one-half the beam depth from supports or concentrated loads. (Teng and Fong, 1997)

In continuous beams that generally occur in practice, reduction in stiffness due to the provision of opening through webs causes a redistribution of internal forces and moment, the amount of which needs to be evaluated before a design can proceed. Based on the review of literature on the behavior and strength of the beams with web openings, the following guidelines can be introduced to facilitate the selection of the size and location of the web openings, openings should preferably be positioned flush with the flange for ease in construction.

In the ease of rectangular beams, openings are generally positioned at mid-depth of the section; however, they may also be placed eccentrically with respect to depth. The sufficient concrete cover should be provided for the reinforcement of the chord members above and below the openings. The compression chords should also have enough concrete area to develop the ultimate compression block in flexure and sufficient depth to provide efficient shear reinforcement.

Openings should not be positioned closer than one-half the beam depth D to the supports in order to avoid the critical region for shear failure and reinforcement congestion. Moreover, positioning of an opening closer than 0.5 D to any concentrated load should be avoided. Depth of the openings should be limited to 50% of the overall beam depth. When multiple openings are used, the post separating two adjacent openings should not be less than 0.5 D to insure that each opening behaves independently. (Collins and Bentz, 2008)

2.4 PURE BENDING

In the case of pure bending, placement of an opening completely within the tension zone does not change the load-carrying mechanism of the beam because concrete there would have cracked anyway in flexure at ultimate. The ultimate moment capacity a beam is not affected by the presence of an opening as long as the minimum depth of the compression chord is greater than or equal to the depth of ultimate compressive stress block. (Mansur and Tan, 1999)

However, due to reduced moment of inertia at a section through the opening, cracks will initiate at an earlier stage of loading. The effects on maximum crack widths and deflection under service load have been found to be only marginal, and may safely be disregarded in design.

2.5 COMBINED BENDING AND SHEAR

In a beam, shear is always associated with bending moment, except for the section at inflection point. When a small opening is introduced in a region subjected to predominant shear and the opening is enclosed by reinforcement. From solid lines test data indicate that the beam may fail in two distinctly different modes. (Collins and Mitchell, 1996)

The first type is typical of the failure commonly observed in solid beams except that the failure plane passes through the center of the opening. In the second type, formation of two independent diagonal cracks, one in each member bridging the two solid beam segments. Labeled respectively as beam-type failure and frame-type failure these modes of failure require separate treatment. (Bentz and Collins, 2004)

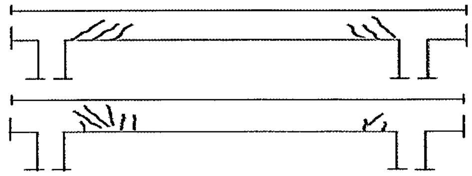

Figure 2.6: Concrete beams due to increased shear stress (Cause III)

Source: Rigotti 2002

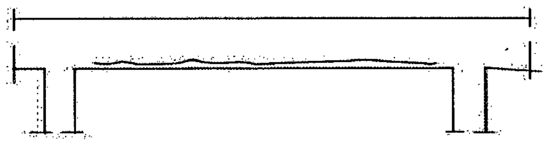

Figure 2.7: concrete beams due to corrosion or insufficient concrete cover

Source: Rigotti 2002

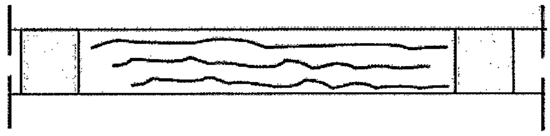

Figure 2.8: Parallel to main steel in case of corrosion in beams

Source: Rigotti 2002

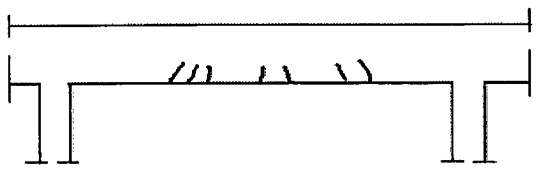

Figure 2.9: Increased bending stress in beams (Cause I)

Source: Rigotti 2002

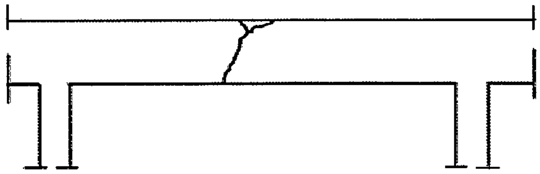

Figure 2.10: Compression failure in beams (Cause II)

Source: Rigotti 2002

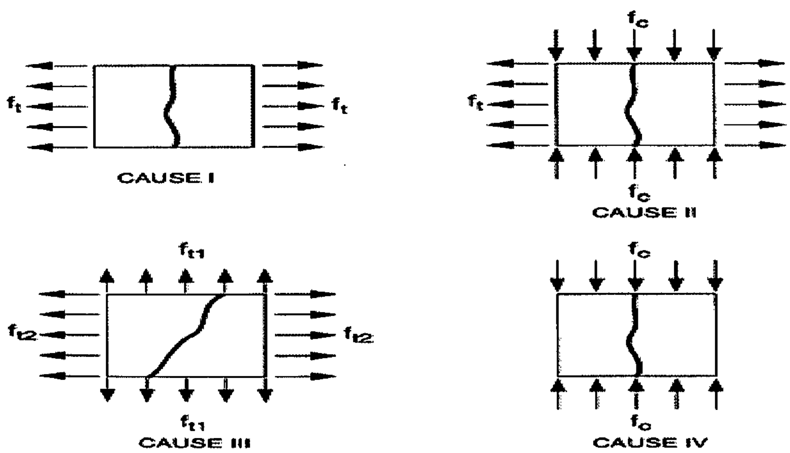

Figure 2.11: Basic failure modes of concrete

Source: Rigotti 2002

2.6 EFFECTS OF CREATING OPENINGS

It is obvious that transverse openings through beams are a source of potential weakness. When the service systems are preplanned and the sizes and locations of openings required to achieve the necessary layout of pipes and ducts are decided upon well in advance, adequate strength and serviceability may be ensured by following the method described in the preceding section.

However, this is not always the case. While laying the ducts in a newly constructed building, the M&E contractor frequently comes up with the request to drill an opening for the sake of simplifying the arrangement of pipes. When such a request comes, the structural designer finds it difficult to give a decision. Of course, from the owner's viewpoint, creating an opening may represent some financial savings, but the structural engineer would have to take the risk of jeopardizing the safety and serviceability of the structure.

Another situation arises in an old building where concrete cores are taken for structural assessment of the building. In this case, however, the holes are generally filled in by no shrink grout. If the structure is to stay, then the question is whether or not such repair is adequate to restore the original level of safety and serviceability of the structure. In a recent study an attempt was made to answer some of these frequently asked questions of the effect of drilling holes in an existing beam. (Mansur, 1999)

As part of the study, four prototype T-beams simulating the conditions that exist in the negative moment region of a continuous beam were tested. All beams were 2.9 m long and contained a central stub to represent the continuous support. The cross section consisted of a 400mm deep and 200mm wide web and, a 100mm thick and 700mm wide flange. For symmetry, one opening, 150 mm in diameter, was created on each side of the central stub at a distance 525 mm from the face of the central stub, and all beams contained the same amount and arrangement of reinforcement. (Mansur, 1999)

2.7 CRACKING PATTERNS AND FAILURE MODES

Different cracking patterns and failure modes were observed for different beams. For the solid beam the first flexural crack was observed at the position of the maximum positive bending moment between the two concentrated loads. As the applied load was further increased more flexural cracks appeared. Then at higher load diagonal shear cracks were observed. Finally, the beam failed in a flexural mode of failure.

With increasing the applied load two main diagonal shear cracks were observed at the upper and lower chords of the opening and more flexural cracks were formed within the middle part of the beam. The main diagonal crack in the upper chord of the opening started very close to the position of right inner vertical edge of the opening and extended on an angle of about 45 degrees towards the lower edge of the upper chord of the opening.

On the other hand, the main diagonal crack in the lower chord started also very near to the inner vertical edge of the opening and extended towards the lower edge of the lower chord approximately along the diagonal line of the lower chord. Finally, the beam failed in a shear mode at the opening along the two previously formed diagonal cracks at its chords.

2.8 STRENGTH OF THE PLYWOOD

Plywood is among the strongest of all building materials. The strength is a result of individual grain layers placed perpendicular to each other bonded with glue under high pressure in the manufacturing process. This makes plywood virtually split-proof. Other properties that can add strength to plywood are type of glue, species and thickness.

Thickness of the plywood shown the strongest of all plywood is used for concrete forms, stair risers and industrial flooring. This 1-inch-thick fir plywood is also available with tongue and groove patterns that lock together for even more strength. Other widely used plywood types include 3/4 inch, which is one of the most widely used of all plywood thicknesses. A 12 by 36 inch piece of 3/4 inch fir plywood can support up to 50 lbs. without