# THE EFFECT OF HOLLOW SECTION TO THE FLEXURAL STRENGTH OF THE BEAM

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## ABSTRACT

The idea of providing hollow section to the beam in order to reduce the weight of the structure was generally one of the solutions for lightweight beam structure. The concept introduced was the same as hollow slab panels which been widely used in bridge and highway construction. The reduction of the surface area of the beam 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 flexural strength, deflection profile and crack pattern of the hollow beam samples. Beam dimension of (150x200x3000)mm were sampled into Beam 1, Beam 2, Beam 3 and Beam 4. Beam 1 was solid beam with no hollow while Beam 2, Beam 3 and Beam 4 were beam sample with hollow size of (45x45)mm, (70x70)mm and (95x95)mm respectively. For flexural strength, the beam samples were tested under 4-point flexural test and Linear Variable Displacement Transducer (LVDT) were used to measure the deflection of the samples. The crack pattern of beam samples were observed throughout the experiment and the cracking were then analyzed accordingly. The result shows that the flexural strength of the samples reduced to certain degree of percentage of 12.64%, 16.14% and 17.16% for Beam 2, Beam 3 and Beam 4 respectively. Result for deflection shows that Beam 2, Beam 3 and Beam 4 deflected more compared to Beam 1 with percentage increment of 6.27%, 3.19% and 15.74% respectively. As for deflection profile, Beam 1, Beam 2, Beam 3 and Beam 4 show the same profile. Cracking pattern result shows same behavior between all samples while first crack loading result for Beam 1, Beam 2, Beam 3 and Beam 4 was 31kN, 28kN, 23kN, and 21kN respectively.

# ABSTRAK

Cadangan menyediakan ruang berongga di tengah struktur rasuk adalah salah satu cara untuk menghasilkan struktur konkrit ringan bagi rusuk. Konsep yang diperkenalkan adalah sama seperti panel papak berongga yang digunakan dalam pembinaan jambatan. Namun apabila mengurangkan permukaan konkrit bagi rasuk, ia akan turut mengurangkan kekuatan rasuk tersebut. Justeru, ujikaji perlu dijalankan bagi mengenal pasti dan mengetahui kekuatan lenturan, bentuk pesongan dan corak keretakan sampel. Saiz rusuk (150x200x3000)mm dibahagi kepada sampel Rusuk 1, Rusuk 2, Rusuk 3 dan Rusuk 4. Rusuk 1 adalah sampel pepejal tanpa rongga manakala Rusuk 2, Rusuk 3 dan Rusuk 4 merupakan sampel dengan saiz rongga (45x45)mm, (70x70)mm dan (95x95)mm berturutan. Bagi kekuatan lenturan, sampel rusuk diujikaji menggunakan kaedah Ujian Lenturan 4-titik dan *"Linear Variable Displacement Transducer (LVDT)"* digunakan untuk mengukur bentuk pesongan sampel. Corak keretakan sampel rusuk diperhatikan ketika ujikaji dijalankan. Hasil ujikaji menunjukkan kekuatan lenturan berkurangan sebanyak beberapa peratus iaitu 12.64%, 16.14% dam 17.16% bagi Rusuk 2, Rusuk 3 dan Rusuk 4 berturuan. Hasil ujikaji bagi bentuk pesongan pula menunjukkan Rusuk 2, Rusuk 3 dan Rusuk 4 memesong lebih jika dibandingkan dengan sampel Rusuk 1 dengan peratusan kenaikan 6.27%, 3.19% dan 15.74% berturutan. Bentuk pesongan juga menunjukkan bentuk yang sama antara Rusuk 1, Rusuk 2, Rusuk 3 dan Rusuk 4. Corak keretakan juga menunjukkan corak yang sama antara kesemua sampel. Daya keretakan pertama bagi Rusuk 1, Rusuk 2, Rusuk 3 dan Rusuk 4 adalah 31kN, 28kN, 23kN dan 21kN berturutan.

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# CHAPTER 1

# INTRODUCTION

## 1.1 INTRODUCTION

For this research, the original theory was base from Industrial Building System (IBS) that introduced by Construction Industry Development Board Malaysia (CIDB) for construction field in Malaysia. This IBS used widely in other country such as Europe and United State. Since that, CIDB was taking an approach to introduce the IBS method into the construction field in Malaysia. IBS method simplified the construction work as a well as it reduced time consuming also reducing the cost for the construction.

In IBS construction method, precast solid beam is commonly used by the contractor in order to reduce time consume. Problems occur for the F class contractors which acknowledging that the precast beam was too heavy to lift without any machinery support. Therefore, the solution of lightweight beam structure introduced. The idea of providing hollow section to the beam in order to reduce the weight of the structure was generally one of the solutions for lightweight beam structure.

The concept introduced was the same as hollow slab panels which been widely used in bridge and highway construction. Referring to the second moment of inertia law, the reduction of the surface area of the beam 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 strength of the beam, which resulted from the hollow section implemented on the beam.

## 1.2 PROBLEM STATEMENT

A beam is a structural element that is capable of withstanding load primarily by resisting bending. The bending force induced into the material of the beam as the result of the external loads, own weight, span and external reactions to these loads is called a bending moment. Beams are traditionally descriptions of building or civil engineering structural elements, but smaller structures such as truck or automobile frames, machine frames, and other mechanical or structural systems contain beam structures that designed and analyzed in a similar fashion.

The solid beam structure was used widely nowadays and become the major problem as it carry lot of weight and it lead to difficulty for the contractors to lift and move the structure to the higher section. Therefore, the hollow section introduced in order to reduce the weight of the beam. However, since the reduction of the surface area of the beam will result in the reduction of the strength of the beam itself. Hence, a theoretical calculation and experimental testing made in order to find the percentage of strength lost and to provide better recommendation and suggestion for hollow section beam.

## 1.3 OBJECTIVES OF STUDY

The main objectives of this study:

I. To determine the flexural strength of hollow reinforced concrete beam with different hollow size.

II. To determine the deflection profile of hollow reinforced concrete beam

III. To observe the crack pattern of hollow reinforced concrete beam

## 1.4 SCOPE OF STUDY

In this experimental study, the effect of hollow section size of the beam on its flexural strength focused. Four beams with dimension of 200mm height, 150mm width and 3 meters span were prepared. Solid beam with no hollow section designed as Beam 1 as a control parameter and beam with hollow opening 23%, 35% and 48% was designed as Beam 2, Beam 3 and Beam 4 respectively. The hollow size for Beam 2, Beam 3 and Beam 4 were (45x45)mm, (70x70)mm, and (95x95)mm respectively. The hollow section designed to be located at the center of the beam surface area. Table 1.1 shows the proposed hollow size for the beam and Table 1.2 shows the weight reduction of the beam.

Material such as Ordinary Portland Cements (OPC), sand, coarse aggregates, concrete reinforced bar and links bar were used. A concrete of grade 30 and uncrushed coarse aggregate with maximum size of 20mm used. Table 1.3 shows the mix proportion for $1m^3$ concrete. As for the reinforcement, reinforcement bar of size 12mm and shear link bar of size 8mm used. The reinforcement design used for the beam is 2T12 and for shear link reinforcement of H8-250.The beam samples tested for the flexural strength test to determine which beam will have the more flexural strength. All beam samples were compared in term of deflection and crack pattern.

The method chose as an experimental testing was 4-point test (flexural test) and Linear Variable Displacement Transducer (LVDT) used to observe the deflection of the beam. Figure 1.1 shows the details of 4-point test that needs to be done, referring to BS 1881-Part 118-83.

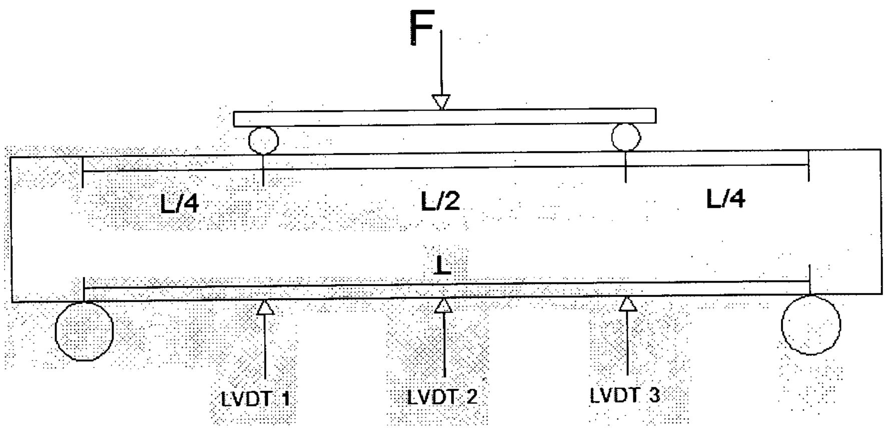


**Figure 1.1:** 4-point test

**Table 1.1:** Proposed hollow section size

| Beam | % of opening | Hollow Size (mm) | Hollow Area ($mm^2$) | Bar Reinforcement | Link Reinforcement |
|---|---|---|---|---|---|
| **Beam 1** | Solid | - | - | 2T12 | H8-250 |
| **Beam 2** | 23% | 45x45 | 2025 | 2T12 | H8-250 |
| **Beam 3** | 35% | 70x70 | 4900 | 2T12 | H8-250 |
| **Beam 4** | 48% | 95x95 | 9025 | 2T12 | H8-250 |

**Table 1.2:** Weight reduction for hollow concrete beams

| | Beam 1 (Solid) | Beam 2 (45x45) | Beam 3 (70x70) | Beam 4 (90x90) |
|---|---|---|---|---|
| **Weight (kg)** | 225 | 210 | 188 | 157 |
| **Weight Reduction (kg)** | - | 15 | 37 | 68 |

**Table 1.3:** Mix proportion for concrete mixing

| Quantities | Water (kg) | Cement (kg) | Fine aggregate (kg) | Coarse aggregate (kg) |
|---|---|---|---|---|
| **per 1 $m^3$** | 180 | 360 | 445 | 1335 |
| **per 0.184$m^3$** | 33.12 | 66.24 | 81.88 | 254.64 |
| **Ratio** | 1 | 2 | 2.5 | 7.5 |

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 INTRODUCTION

Research and study in comparing the strength between solid beam and hollow beam with the same cross-section and reinforcement had been made before. Some research found that hollow beam couldn't resist an extra loadings compared to solid beam which can resist and carry extra load. Therefore this chapter review on the characteristic strength of hollow beam and how much the strength is reduced dependent on the size of the hollow sections. The strength of the beam was known to reduce depending on the hollow size on the beam and this chapter will review the explanations on the hollow beam behaviour and from those the suggestion and recommendation to increase the concrete hollow beam strength was observed.

Although the literature covers a wide variety of such theories, this review is focusing on five major themes which emerge repeatedly throughout the literature reviewed. This review focused on cracking, deflection and bending. Although the literature presents these themes in variety of contexts, this review is primarily focus on the explanation in reduction of hollow beam strength toward bending, crack, deflection and shear.

## 2.2 BENDING

The bending of the structure is depending on the load that acting on the structure such beam. Solid rectangle beam can resist the bending when the beam is design with applying the bar and link based on the load acted on the beam. For hollow beam, "The hollow beam will failed near the design loads while the solid beam will failed more than the design loads", Alnuaimi et.al. (2007). This statement was supported by Fouad et.al. (2000) which found that hollow and solid beam with the same reinforcement is having different strength in term of flexural. This shows that hollow beam bend with small load acted compared to solid beams that can withstand from bending with higher load applied. According to Alnuaimi et al. (2007) again, beam resisted more load so the maximum displacement measured was higher in the solid beam than the hollow beam. With this review, the hollow beam proved to have lower strength than the solid beam.

On the other hands, according to Yang et al. (2006), mentioned that the beam with opening is influencing the concrete compressive strength on the capacity of the load carrying by decreasing the strength significantly with the deep and size of the opening. The load carrying related to the flexural of the concrete. When the load carrying capacity is lower, then the beam deflected more. This review have the significant with the research done by Shanmugam & Swaddiwudhipog (1988), which mentioned that the opening located at the tension zone affected more on the strength and behavior of the beams compare to opening that located at the compression zone. The strength of the beam was mostly related with the bending and flexural of the beam. The less strength of the beam meant that the beam is bending more. The strength of the beam came from the concrete and reinforcement bar of the concrete. Additionally, from the research done by Barney et al. (1977), stated that the opening segment is producing the shear force affecting the flexural strength simultaneously with the deflection of the beam.

## 2.3 DEFLECTION

The opening or hollow in the structure such as beam required in nowadays building design for the satisfaction of requirements of placing of ventilation, heat, water and electricity pipe Nie et al. (2005). However, the hollow beam deflected more than the solid beam. Therefore, the behavior of the deflection of the hollow beam or an opening beam required to investigate. Benitez et al. (1998) made a research about the deflection of the composite beam with web opening. They also describe and come out with the procedures to calculate the deflection of the beam. However, the equation from Benitez et al. (1998) not included in this literature due to incapability and too conservative. According to Nie et.al. (2005), to produce the equation to calculate the deflection of the opening beam, two assumption were applied which is the maximum deflection is located at the mid-span of the beam and the effect of the hollow or opening of the beam were neglected. The equation is not in use for this study since the opening was transverse of the beam while the opening for this study was on longitudinal opening. The assumption can be use in determining the deflection of the hollow beam in this study.

On the others hand, according to Ding et al. (2010), in order to investigate the crack width opening and the deflection behavior, The crack inside the core or hollow of the beam was measured simultaneously with the deflection of the beam. Therefore, three types of graph need to construct in order to get the data, which graph of deflections against crack, load against deflection and load against crack. According to Benitez et.al (1998) again mentioned that when there have an opening of the beam, the strain compatibility is reduced and there are loss of material to carrying the shear that is effecting on the vertical deflection between the ends of the hollow which was subjected to the shear. This review shows that the hollow of the beam is affecting the deflection profile of the beam.

For the other context, according to Campione & Minafo (2012), they did the research about strength the opening beam by using the vertical strut. Based on the result, they found that the hollow beam with vertical strut has deflected 15 % greater than the solid beam. While the other hollow beam without the strut was 20 % to 22%. The present of the strut is less effective, which only increase about 5% of the deflection. However, the present of the strut still can help increasing the deflection profile of the beam.

Furthermore, based on research done by Maaddawy & Sherif (2009) stated that the deflection of the beam is depending on the size of the opening. The larger the size of the opening inside the concrete beam, the more the beam deflected.

## 2.4 CRACKING

According to Al Nuaimi et. al. (2007), hollow beams cracked at lower loads than the solid beams and there were larger number of cracks in hollow beam than the solid because the core of the concrete for hollow beam reduce the load on the reinforcement bar which is leads to the higher cracking load. This proved that the solid beam is stronger than the hollow beam in term of cracking because solid beam can withstand the higher load before crack than the hollow beam. Similarly, Mitchell & Collins (1979) mentioned that the solid beam cracked at a higher load than the hollow, which also one of the factors that can leads to cracking. Mitchell et al. (1979) also mentions and explains that the earlier cracking of the hollow sections may be due to stress concentrations at the sharp corners.

Furthermore, from the experiment that been conducted by Al Nuaimi & Bhatt (2005), they have found that all the tested hollow beam was failed in ductile manner where the steel yielded or reached near yield before the concrete crushed. Both hollow beam and solid beam failed in a ductile manner with steel yield before crushed. However, from the studied conducted by Alnuaimi et al. (2007), the beam with high flexural and displacement leads to failure before crushing. In this context, the hollow beam have high flexural and displacement than the solid beam. In other context, Wegian & Almottiri (2007) state that the hollow beam specimen cracked near mid-span and started from bottom to top. These cracks indicate clearly that the lightly reinforced beam specimens failed due to pure flexure. This proves that the hollow beam cannot withstand with the high load and may produce crack and finally failed.

Particularly, there also have some of the researchers do the study on crack pattern. According to Alnuaimi et al. (2007), beam that subjected to the small load by flexural test crack almost vertical crack pattern. By the adding of more loads, the crack pattern is changing the angle from vertical to 45° to 60°. This show that the more the load, the crack pattern become more inclined. This crack pattern called vertical bending crack and inclined torsional crack. On the other hand, from the research conducted by Yang & Chen (2005) mentioned that there have two type of crack pattern which is smeared crack and discrete crack which able provided satisfactorily the load displacement responses and the crack path or pattern. Smeared crack modes and discrete crack modes is process where the works of meshing the crack pattern is carrying on when the crack start to propagated. This type of crack pattern is when the crack started to appear at mid-span and propagate upward with increasing crack width. As the load is increasing, the crack is propagate half of the beam and gradually curved towards the loading point.

Besides, Toussaint et al. (2004) in their research mentioned that the crack pattern can indicates the degradation of stiffness and the plastic part of the stress/strain responses. Besides, from their research also described the method of checking the crack pattern. The loading value was taken immediately as soon as the crack started to develop and propagate. Then the cracks numbered in order of the appearances. The crack pattern can be achieved by constructing the Flu curve according to the loads when the crack is appear with the width of the crack. Therefore, the crack pattern were determined by drawing back the appearing crack pattern to the actual dimension graph. From the Flu curve, the bond strength between reinforcement bar and concrete can be determined.

In addition, the crack propagation that developed on the beam also can determine whether the crack developed by subjected to bending or shear. According to Behzad & Ebrahimi (2008), mentioned that when the beam develop crack at the edge, the beam is not in plane shape anymore after the deformation. This is due to the shear stress near the crack tip, which also leads to the warping of the plane section. Any crack propagate at the edge of the beam or at near the rolling support for this study is expected to undergo the crack which subjected by the shear stress. Besides, from their research also mentioned that any crack propagated at the mid-span of the beam is may subjected by bending stress.

## 2.5 HOLLOW SECTION SIZE

As stated by M.A Mansur (2006), the 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, about less than 40% of the overall beam depth. In such a case, beam action can 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 provided in sufficient quantity to control crack widths and prevent possible premature failure of the beam.

# CHAPTER 3

# METHODOLOGY

## 3.1 INTRODUCTION

This chapter will explain about the research that conducted and explain the study carried out. In this chapter, explanation about the materials used, the research planning and the testing conducted to determine the characteristic of hollow concrete beam included. This part also will give the clear point of view about the research and clearly shows how the objective of this research achieved. At the early stage, the data and the literature review were collected from the previous study. The source of the study such as books, journals, magazine, research papers, articles, symposium papers and internet. The discussion between was crucial in order to improve and gain the knowledge and information regarding the scope of the research. For this study, the materials used are Portland cement, coarse aggregate, fine aggregate and polystherene used to create hollow section of the beam. After casting and curing part done, the specimen will be tests by using flexural test (4-point test).

## 3.2 RESEARCH PLANNING

Figure 3.1 shows the research experimental flow for this study.

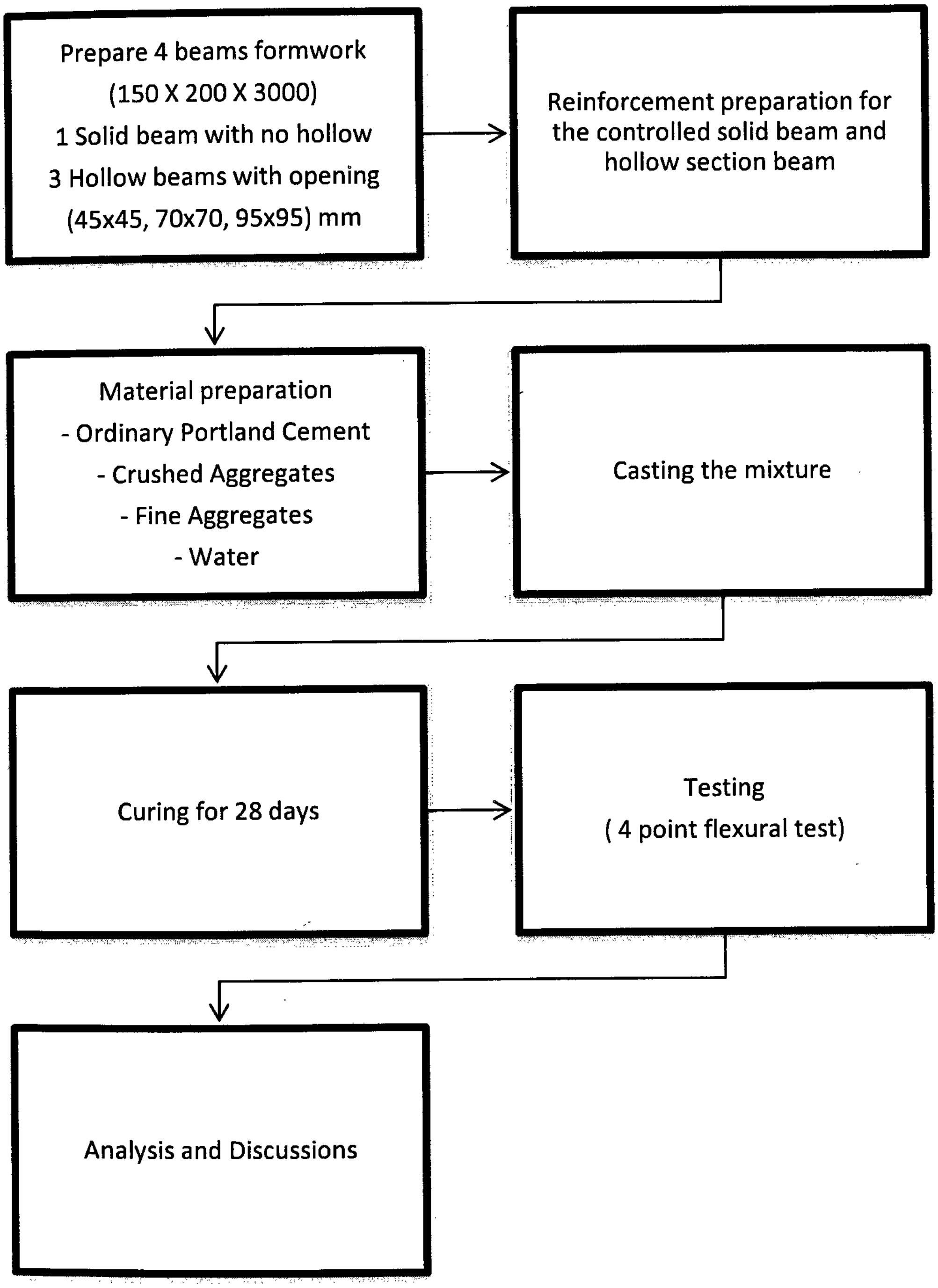


**Figure 3.1:** Research experimental works flow

## 3.3 SAMPLE PREPARATIONS

Sample preparation included the preparation of formwork, reinforcement bar, concrete mixing, casting and curing of sample. This was prepared stage by stage, started with preparations of formwork and last stage was curing the sample.

### 3.3.1 Formwork preparations

Formwork is the term given to either temporary or permanent molds which concrete or similar materials poured. In the context of concrete construction, the formwork supports the shuttering molds

Early stage of sample preparations was to prepare the formwork for 4 beams sample and for this research, timber formwork were used. The formwork was prepared using the same materials and dimension of 150mm x 200mm x 3000mm. The preparation of formwork is one of the crucial part as the defect occur in this part will affect the beam sample. The problem that might occur is uneven size of the beam also concrete segregations.

For formwork preparations, main materials been used was plywood with 1.25cm of thickness and wood with dimensions of 2.5cm x 5cm. Figure 3.2 shows the formwork sample for the hollow concrete beam. This formwork made up of 3 different part which is the base, the walls and the faces of the beam. The base was the strongest part of the formwork and it supported the overall weight of the concrete and the reinforcement. For wall, it was build both side left and right, and its purpose was to shape and hold the concrete beam into desirable size and dimensions. Formworks face was the last part which purpose to seal the formwork and it is located at the front and end of the formworks.

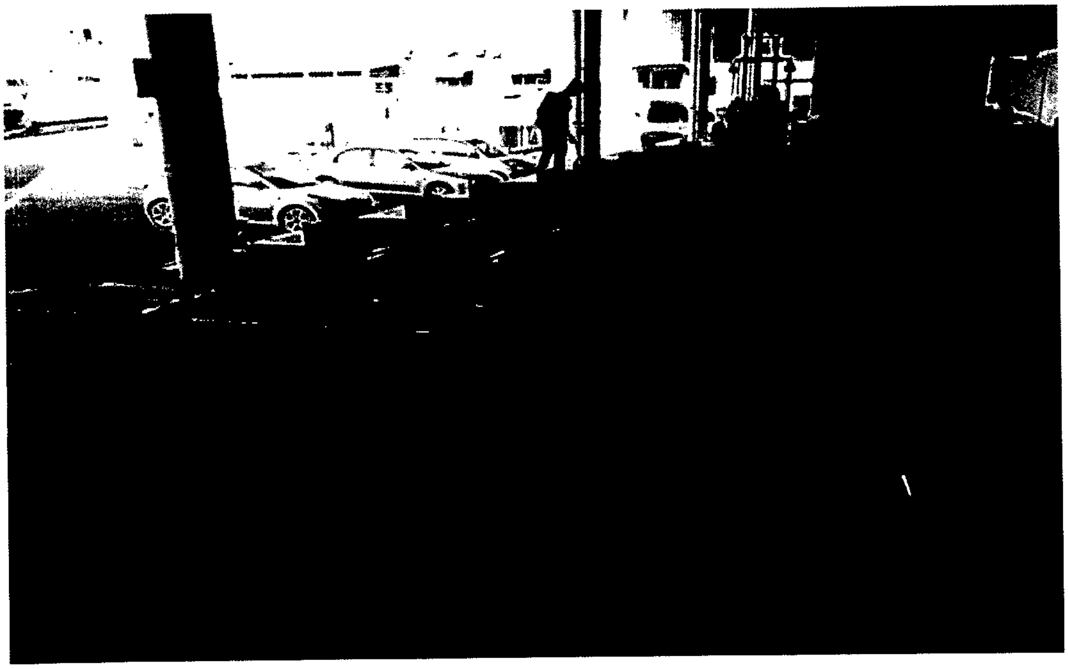

**Figure 3.2:** Formwork preparations

### 3.3.2 Reinforcement preparations

A rebar (short for reinforcing bar), also known as reinforcing steel and is commonly used as a tensioning device in reinforced concrete and reinforced masonry structures holding the concrete in compression. It is usually in the form of carbon steel bars or wires, and the surfaces deformed for a better bond with the concrete.

Steel reinforcement preparations divided into two parts which reinforcement bar preparations and shear link preparations. The reinforcement of the sample provided using concrete reinforcement design method. Code of study Eurocode used for this design and this beam considered for residential usage. From the design calculations, reinforcement bar of 2T12 and shear link of H8-300 provided to the beam sample. Shear link was shaped into rectangular shape with size of 150mmX100mm considering the cover of 25mm both from side, bottom and top. The link and reinforcement bar was tie to a length of 2900mm by considering the cover of 50mm from each end of the formwork.