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Effect of Different Positions of Hollow Section on the High Strength Concrete Beam

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Effect of Different Positions of Hollow Section on the High Strength Concrete Beam

O Rokiah[1], S Mohd Arif[1], B W Chong[1], C W Wong[1], D Youventharan[2], P J Ramadhansyah[2] and A A G Nadiatul Adilah[2]

[1]Faculty of Civil Engineering Technology, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia
[2]Department of Civil Engineering, College of Engineering, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia

Corresponding author: rokiah@ump.edu.my

Abstract. Today, the construction industry is continuously looking for lighter and high strength concrete (HSC) beams especially for high rise building. This research reported the effect of different positions of hollow section on the HSC beam containing eggshell powder (ESP) as partial cement replacement and tire crumb (TC) as partial sand replacement. Sustainable and high strength concrete is now widely used as a structural component like beam, slab and wall due to environmental impact. The hollow section also can reduce the dead loads which contribute to seismic effect in high rise buildings. Furthermore, eggshell is an agricultural waste that is generally considered worthless and is mostly disposed of because it leads to pollution, but it has similar properties as lime that used to be raw material to produce cement. In this study, 10% TC is used as partial sand replacement to produce a green concrete to make it more sustainable in construction. The experimental program consists of casting and testing high strength concrete beams of size 150 x 200 x 1500 mm with different positions of circular hollow sections. To study the flexural behaviour, all beams are tested after 28 days of curing subjected to four-points bending test in order to analyse the effect of different position of hollow section on the strength, deflection and mode of failure of HSC beam. Based on the experimental result, solid beam (SB) exhibits the higher strength with maximum loading of 156.45kN and flexural strength up to 39.11N/mm². Besides, one hollow beam (OHB) and two vertical hollow beams (TVHB) show a better result in deflection compared to solid beam (SB). However, the two horizontal hollow beam (THHB) exhibits better performance in strength, with nearly 6.5% less than the SB. Conclusively, the position of the hollow beam affects the strength and deflection of the beam. All the beams experienced shear crack and flexural crack. The two horizontal hollow beams (THHB) can be used as a light structure beam of a building especially for the roof beam which receives less loading from the roof.

1.0 Introduction

In construction, a beam is a flexural member that acts as support for slab and vertical wall and distributes the loading by bending. During bending of the beam that will happen in two zones which are the compression zone at top and tensile zone at bottom in reinforced concrete beam [1]. Hence, a hollow beam is introduced by removing part of the concrete that helps to reduce the cost of the construction through reducing the use of formwork while casting for secondary beam. Lesser the formwork required to support the curing system due to the less weight of hollow beam that needed to support. The idea of making hollow beams is the same as the introduction of concrete hollow-core panels which are widely used for parking structure, bridge and concrete buildings [2].

Recently, the use of high concrete strength (HSC) has been increased and especially high rise buildings have been used in many parts of the world. Due to structural shapes and including deterioration, long-term poor performance of a conventional concrete or known as normal concrete with compressive strength around 30 N/mm^2 the development of high-resistance concrete has been accelerated. HSC performs better in compressive strength, durability, affordability and thus allows low maintenance buildings to be built in a sustainable and economical way. ACI 318-08 [3] and also BS EN 12390-3:2019 [4], HSC can be defined as the concrete that strength more than 55 MPa at 28 days. It is widely used for the construction of bridges and hollow beams [5]. HSC provides excellence performance and durability than normal concrete [6].

Concrete is flexible and durable and became very popular and the demand was increasing throughout the past few years due to the rapid development. Materials that needed to produce concrete are cement, sand, gravel and water that trigger the hydration process [7]. Cement is the main material but the production caused environmental issues. It is estimated 900 kg of carbon dioxide (CO_2) will be produced when 1 ton of cement is produced [8]. CO_2 emission from the combustion of fossil fuel in cement industry but also by calcination of limestone to produce clinker, the main ingredient of cement. The raw material for cement production is limestone which only can serve the cement industry for more than 15 years if no action was taken [9]. Thus, research was utilizing the quarrying of the limestone by replacing other materials that consist of the same chemical contain especially the waste materials that will cause environmental issues. Eggshell has a very similar chemical component with limestone which has a high content of calcium oxide [10]. Use of eggshell to replace cement in concrete instead of natural lime can help in reducing the use of cement in concrete production, conserving natural lime and utilizing waste material [11]. It also reduces the amount of global CO_2 emission by minimizing the consumption of cement in concrete production. Also, using eggshell waste in concrete production will reduce the waste landfill problems. Nowadays, rubber waste is becoming a problem for the environment due to it will end up as landfill. The disposal tire reached 1000 million every year and half of it was dumped with no further action [12]. If the rubber waste continues to dump uncontrollably, it will use the space on earth and also cause landscape pollution. This is because the rubber cannot be decomposed and it will release toxic gases while burning. Thus, this study is to investigate the effect of different hollow section beams on the high strength concrete containing eggshell as partial cement replacement and tire crumb as partial sand replacement under flexural behaviour.

2.0 Materials

2.1 Cement

The cement used in this study is localize Orang Kuat Ordinary Portland Cement (CEM I 42.5 N) manufactured by YTL Cement that conforming to BS EN Specification for Portland Cement (BS12/BS EN 197-1:2000 and ASTM C 150-95 Type I.

2.2 Aggregate
Coarse aggregate used in this study was crushed stone with a nominal size of 10mm. Meanw hile, the fine aggregate used within the range size of 75 µm to 4.76mm. In this study, the fine aggregate was dried in the oven at a temperature of 110 °C for 24 hours to remove its uncertain moisture. Then, aggregate was kept in dry condition and free from impurities and the aggregate used in this study was conforming to BS Specification for Aggregates for Concrete (BS EN 12620).

2.3 Tire Crumb
The tire crumb (TC) with the size 1.18 mm was immersed with saturated sodium hydroxide (NaOH) aqueous solutions for 20 minutes and cleaned with water. This process is to enhance the hydrophilicity of the rubber surface.

2.4 Eggshell Powder
The eggshell waste was supplied by Egg Tech Manufacturing Sdn Bhd, Puncak Alam, Selangor. The eggshell was carefully rinsed and washed to eliminate the organic residue of the egg. Then, the eggshell was dried in the oven with temperature 105 °C for 24 hours. Clean eggshell was collected and ground by a grinding machine. The ground eggshell powder (ESP) was prepared by sieving through sieve size 150µm. Figure 1 show the eggshell powder used in this study as filler in the concrete mixing. The chemical composition of ESP and OPC is shown in Table 1.

Figure 1. Eggshell Powder

Table 1. Chemical composition of ESP and OPC

Element	OPC	ESP
Calcium Oxide (CaO)	60.1	52.10
Magnesium Oxide (MgO)	2.1	0.06
Silica Dioxide (SiO_2)	21.8	0.58
Alumina (Al_2O_3)	6.6	0.06
Ferric Oxide (Fe_2O_3)	4.1	0.02
Chloride (Cl)	-	-
Sulphur Trioxide (SO_3)	2.2	0.62
Potassium Oxide (K_2O)	0.4	0.25
Sodium Oxide (Na_2O)	0.4	0.15
Loss on Ignition (LOI)	2.4	45.42

2.5 Super plasticizer

Super plasticizer used in this study is Sika Viscocrete. It used to reduce the water content in concrete and maintain the workability performance.

2.6 Water

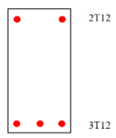
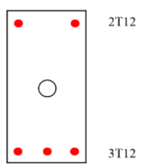
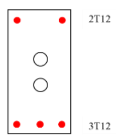
According to ASTM C1602 (2012), potable and non-potable water is permitted to be used as mixing water in concrete. In this study, water is used for concrete mixing and curing regime.

3.0 Methodology

3.1 Sample Preparation

In this research, four types of beam specimens were prepared with three sets for each specimen. The summary details of beam specimens are shown in Table 2. Specimen 1 represents a controlled solid beam (SB) with reinforcement. Specimen 2 is designed with one hollow beam (OHB) which is the position of circular hollow (35mm) at the centre of the beam in the view of the x-axis. Specimen 3 is designed with two vertical hollow beams (TVHB) which is the position of two circular hollows (35 mm) at 75mm from both top and bottom respectively in the view of the x-axis. Specimen 4 is designed with two horizontal hollow beams (THHB) which are the two circular hollow sections (35 mm) at 50mm from both left and right in the view of the x-axis. Besides that, all specimens were reinforced with 2T12 for top and 3T12 for bottom of the beam; and shear reinforcement R6 with a range of 150 mm. All the beam specimens were casted with high strength concrete containing 10% of ESP as partial cement replacement and 10% of TC as partial sand replacement for C60 concrete. All the beam specimens were water cured with a gunny bag for 28 days and painted to ease the observation of cracking patterns.

Table 2: Summary detail of specimens

Specimen	Hollow section (mm)	Shear Link	Details
1 Solid Beam (SB)	-	R6-150mm	
2 One Hollow Beam (OHB)	35	R6-150mm	
3 Two Vertical Hollow Beam (TVHB)	35	R6-150mm	

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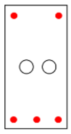
4 Two Horizontal Hollow Beam (THHB)	35	R6-150mm	

Figure 2. Beam specimen

3.2 Testing Setup

All the specimens were tested using four-points bending test to collect the data of maximum loading, deflection and cracking pattern. The load was applied constantly until the beams failed to resist loading. Three Linear Variable Differential Transformer (LVDT) were used to record the deflection of the beams. Two of the LVDT were placed under the loading point while one LVDT was placed to the centre of the beams. The supports were placed 150 mm from both ends of the beam. Meanwhile, the loading points were set to 200 mm from the centre of the beam to the both sides. The data was recorded and analysed to obtain the result of testing. The testing was according to the ASTM D6272 where the span of loading was one third of the support span. The details of the four-points bending test is shown in Figure 3. Figure 4 shows the testing set up of four-points bending tests. Then, the setup of LVDT under the beam is shown in Figure 5. While, the flexural strength of the beam was calculated for four point bending test which involved the ultimate loading of the beam.

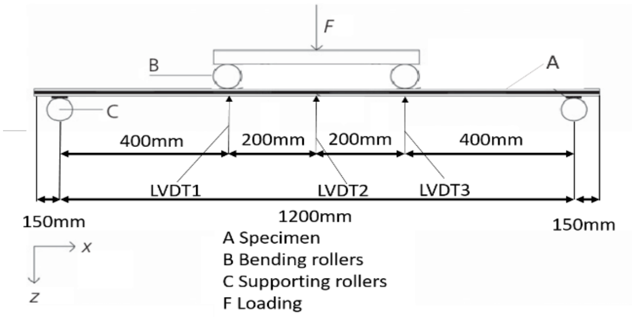


Figure 3. Setup of four-points bending test

Figure 4. Testing set up for four-points bending test

Figure 5. Setup of LVDT under the beam

4.0 Result and Discussion

4.1 Flexural Strength

Table 3 shows the summary of maximum loading obtained from testing and the flexural strength calculated using equation 1. It can be seen that the solid beam specimen (SB) can resist the highest loading of 156.45 kN and followed by THHB, OHB and TVHB with 146.14 kN, 133.89 kN and 121.90 kN respectively. In addition, the values of flexural of each beam specimen were 39.11 N/mm², 33.47 N/mm², 30.48 N/mm² and 36.54 N/mm² respectively. Generally, the flexural strength is also called modulus of rupture (MOR) is a measure of concrete tensile strength. Because it affects the flexural cracking, shear strength, deflection characteristics and concrete brittleness ratio, it is an important characteristic in structural concrete design [13].

Table 3. Summary of maximum loading and flexural strength of specimens

Specimen	Maximum Loading (kN)	Flexural Strength (N/mm^2)
1 (SB)	156.45	39.11
2 (OHB)	133.89	33.47
3 (TVHB)	121.90	30.48
4 (THHB)	146.14	36.54

Figure 6 shows the maximum load and flexural strength for each beam specimen. From the analysis, among the different positions of hollow section beam, the THHB exhibits the highest flexural strength which is 6.59% lower than SB. While, the flexural strength of OHB and TVHB was 14.42% and 22.08% lower than SB respectively. It is indicated that the position of the hollow beam will affect the strength of the beam with the same arrangement of reinforcement. In this study, SB specimen resists the highest loading compared to the hollow section beam. However, the THHB has resisted more loading compared to OHB and TVHB. Thus, the best position of the hollow section is THHB due to better load resistance. This is consistent with a similar study that the flexural strength of the hollow beam was less compared with solid beam [14]. The solid beam can resist more loading compared to the hollow beam.

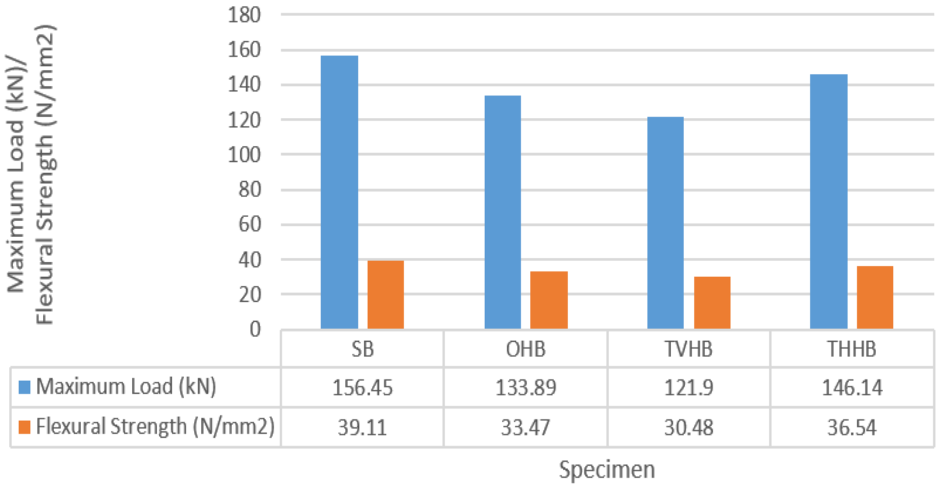


Figure 6. Maximum load and flexural strength of beam specimen

4.2 Deflection

In this study, linear variable displacement transducer (LVDT) is used to obtain the deflection of beam under four point loading test. Table 4 shows the deflection data for all beams specimens. Figure 7 shows the loading against deflection for all beam specimens. From the analysis, the maximum deflection for SB, OHB, TVHB and THHB were 8.37 mm, 6.99 mm, 6.9 6mm and 9.28 mm respectively. It can be seen that OHB and TVHB exhibit less deflection as compared to SB even though those two specimens have hollow sections. Besides, THHB exhibits the higher deflection compared to solid beams with 10.87% increase. It is indicated that the deflection of beam decreased with beam with hollow section [15]. It should be noted that the beam with hollow section exhibits less deflection compared to solid beam [16]. According to Balaji & Vetturayasudharsanan [17] the deflection of hollow beams with single openings have lesser deflection at the ultimate stage and yield stage than hollow beams than with double openings. Other than that, the beam cracks at the mean time of test loading which means that the beam is not cracking at the full load. It was indicated that the reinforcement resisted the deflection after beam crack.

Table 4. Summary of deflection data

Specimen	Deflection (mm)
1 (SB)	8.37
2 (OHB)	6.99
3 (TVHB)	6.96
4 (THHB)	9.28

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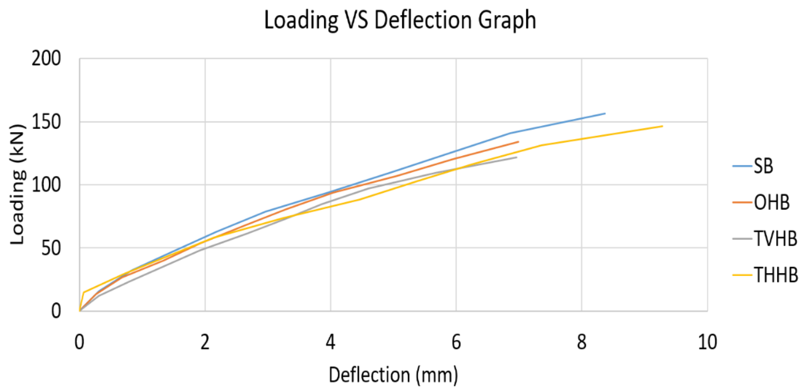


Figure 7. Loading vs Deflection

4.3 Crack Pattern

Figure 8 shows the crack pattern in all the tested beams. The beams were cracked while it reached the limit to resist the loading. The crack pattern of the beam was observed after the loading test. The crack pattern for all the specimens was in slanting crack as shown in Figure 8. The slanting crack was also known as a shear crack which the beams failed in shear due to insufficient shear reinforcement designed to the beam. The mode of failure in all has been identified as a failure in flexure-shear. First crack was found in the bending-moment region and then in shear zone. All four specimens observed the same crack pattern.

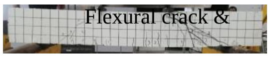
Specimen	Cracking Pattern	Failure Mode
1 (SB)		Flexural crack & Shear crack
2 (OHB)		Flexural crack & Shear crack
3 (TVHB)		Flexural crack & Shear crack
4(THHB)		Flexural crack & Shear crack

Figure 8. Crack pattern of beam

5.0 Conclusion

a) In terms of strength, two horizontal hollow beams (THHB) can resist maximum loading of 146.14kN and flexural strength of 36.54N/mm² which is 6.59% lower compared to the solid beam (SB).
b) Deflection of THHB was 9.28mm which was 10.87% higher than the solid beam (SB). However, OHB and TVHB had 16.49% and 16.85% lower deflection than the solid beam (SB) respectively. The deflection of THHB has higher deflection but its maximum loading is lower than the SB. It is believed that deflection is higher if the THHB was affected by the position of the hollow section when load applied.
c) All the specimens, SB, OHB, TVHB and THHB were crack in flexural first then continuous by shear crack and finally end up as combined failure after reaching ultimate load of beam.
d) The size of the hollow can increase to have a more significant effect on the maximum load, deflection and crack pattern. The position of hollow can be implemented on the tension zone and compression zone to analyse the effect of hollow on the flexural behaviour. However, the THHB can be used as a structure beam of a building especially for the roof beam which receives less loading from the roof.

6.0 References

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