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Effect of hollow core using plastic bottle to the flexural behaviour of RC beam

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Abstract. This study aims to analyze the behaviour of hollow core placing in the tension zone of reinforced concrete beams. The hollow was filled with plastic bottle waste.. The partial replacement of concrete below the neutral axis by using a different layer of plastic bottles was discussed. The cross-section is filled with plastic bottles, in order to get a lighter structure, reduce the volume of concrete/cement and the reduction of environmental pollution. This study used RC beams with concrete strength of 25 MPa and dimensions of 150 x 350 mm, with 3D16 mm longitudinal reinforcement with the yielding strength of 475 MPa. Four type specimens are tested, consisting of control beam and hollow beams type with the height variation of 600 mm (BR1C), and 1800 mm (BR3C). The length of the hollow for each type was 1760 mm (8 bottles) The results indicated that the flexural capacity of the reinforced concrete beam with hollow-core using plastic bottles was almost same with the normal beam. Moreover, the effect of the height of the hollow core was also insignificant on the flexural capacity, where the beam with higher hollow-core showed similar flexural capacity with the beam having a lower hollow. However, the stiffness of reinforced concrete beam was affected by the height of the hollow core, inherent the higher the hollow core, the smaller the stiffness of the beams.

1. Introduction

Nowadays, research efforts are continuously developed to obtain a new, better and efficient construction material and method. The aesthetic qualities and the versatility of reinforced concrete have made it a popular choice for many architects and structural engineers. Therefore, the exploration of natural materials such as gravels and sands as well as lime-stone for cement production is increasing to produce a concrete material. The exploration must affect to the environment. Therefore, the using of the concrete materials should be as efficient as possible. Unfortunately, the manufacture of cement which is the base material of making the concrete mixture, giving a contribution to CO₂ emission. The source of CO₂ in cement production may come from the energy consumed in the heating process and transportation of cement from the manufacturer to the concrete production facilities. Massive exploration of the natural materials for producing concrete effect to the environment condition and global warming that may cause disasters such as flooding and land-slides. Research efforts are continuing to find new, better and efficient construction materials and methods. According to the natural behaviour of concrete material, it is strong in compression and weak in tension, the calculation of RC beams under the simply supported



condition and bending moment as shown in figure 1, it was the compressive stress is borne by the concrete while in the tension was fully borne by the reinforcing steel.

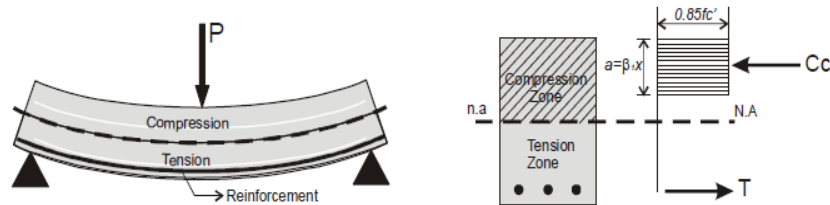


Figure 1. Flexural action of reinforced concrete beam.

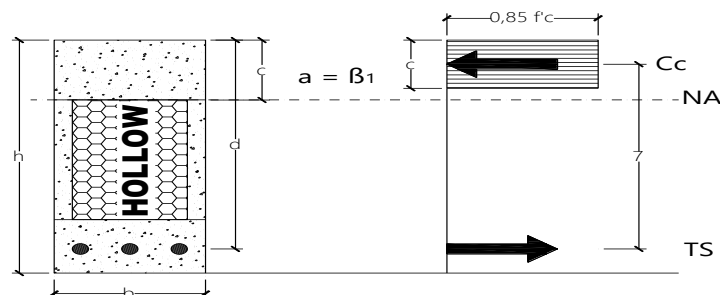


Figure 2. Stress block model of the hollow beam.

The flexural capacity (MR) was calculated as follows:

$$MR = 0.85 f'_c \beta_1 C_c b (d - \frac{1}{2} a) \quad (1)$$

To efficiently use the concrete materials, the compressive strength of the concrete on the tension zone may be reduced or can be removed. Some advantages are using hollow in the tension section, such as the structure will be lighter, the production of cement as the main material to make concrete will be reduced and providing a place for utility facilities. Several studies have been conducted about hollow reinforced concrete beam [4], [12], [1] did research by replacing the concrete section below the neutral line with PVC pipe. Joy et al, (2014), using a PVC with diameter 40 mm and 50 mm, Varghese, et al (2016), using 50 mm diameter PVC at various depths (160 mm, 180 mm, 200 mm and 240 mm depth) and Dinesh, et al. (2017), using PVC pipe with 40 mm diameter at various depths (75 mm depth, 116 mm depth and 75 mm +116 mm depth) from top. The result of the test showed that there was no significant difference in the load capacity of the hollow beams at below the neutral axis compared to the normal beam. The same results were also on the deflection. Another study of hollow reinforced concrete beams using bottles PET [9], [7] and [10]. Rahardyanto (2017), using hollow plastic bottle placed in the mid-span of the beam, with concrete quality variation, K.400 and K.300. Compared with solid beam K.400. The test result showed that moment capacity of hollow beam K.400 98% of the solid beam K.400 and hollow beam K300 and K400 was similar. Mathew, et al (2016), using 10 PET bottles located on neutral axis (N10B0), 10 PET bottles located below the neutral axis (N0B10) and 10 PET bottles on neutral axis + 10 PET bottle below the neutral axis (N10B10). The result of the test showed N10B0 has 3% reduction in ultimate load-carrying capacity. N0B10 and (N10B10) has 12.9 % reduction in load-carrying capacity. Sariman, et al (2018) using 2 layer bottle PET at RC beams T shape with a variation of effective width. The normal T Beam width: 200 mm (TSNS) compared with the hollow T beam width: 200 mm (TSBS) and the normal T Beam width : 500 mm (TMNS) compared with the hollow T beam width 500 mm (TMBS). The test result showed that TSNS vs TSBS and TMNS vs TMBS showed the moment capacity was similar. Related to this matter, in this research, there is bending testing of the

beam, to enlarge the cross section capability in carrying the compressive stress and making the hollow variation of height by using a plastic bottle in the tension zone.

2. Research methods

2.1 Specimen and material properties

The dimensions of beams were 3300 mm length with 150 x 350mm cross-section, respectively according to figure 1. The specimen used three of D16 steel bar as tensile reinforcement and two of $\phi 8$ steel reinforcement at the compression side for assembly purpose only. For shear reinforcement used $\phi 8$ -100mm in the support area and $\phi 8$ -200 mm along the tested span. All beam had the same tensile reinforcement ratio. Table 1 and figure 3 present the specimen variable.

Table 1. Specimen variable.

No	Specimen	Hollow length		Hollow height	
		mm	No of bottles	mm	No of bottles
1	BN	0	-	0	-
2	BR1C	2640	12	60	1
3	BR3C	2640	12	180	3

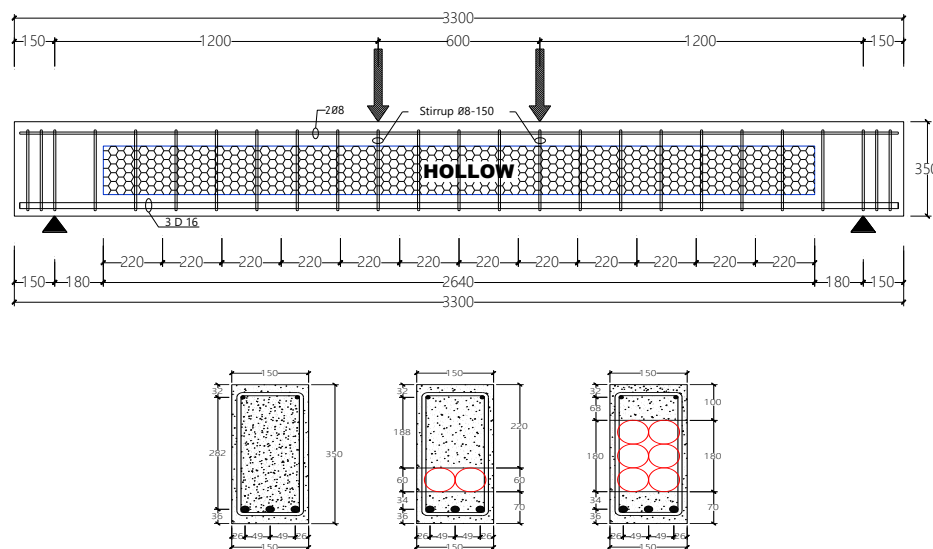


Figure 3. Detail of specimen.

The material properties of concrete and steel reinforcement used in this study are presented in table 2.

Table 2. Properties of materials.

Concrete		Steel reinforcement	
Compressive strength	25 MPa	Compressive strength	470 MPa
Tensile strength	3.9 MPa	Tensile strength	470 MPa
Young Modulus	23 GPa	Young Modulus	200 GPa

2.2 Fabrication of specimen

Figure 4 shows the casting of the specimen. The concrete casting was started from the bottom and was stopped until 80 mm height of the beam. After that, the plastic bottles were put on the concrete surface.

The concrete casting was continued again which the height depends on the variation of the specimen. All specimen was cured for 28 days in the moisturing condition before testing.



Figure 4. Casting of specimen.

2.3 Test set up

Several strain gauges were attached at the longitudinal reinforcement and shear reinforcement. Strain gauges also were attached at the concrete. Strain gauge was used to measure the strain of the steel and concrete. The location of attached strain gauges is shown in figure 5.

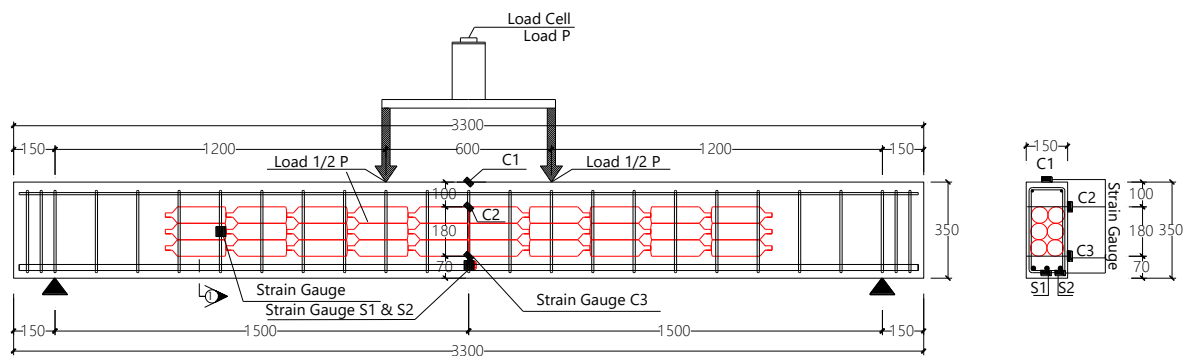


Figure 5. Location of strain gauge.



Figure 6. Setup of specimen.

Figure 6 shows the loading set up. All the beams were subjected to four-point bending test using actuator with a maximum load of 1500 kN. A load cell with 200 kN capacity was used to measure the applied load. The load measured using load cell was applied gradually with the rate of 2 kN per step until the first crack of concrete occurred. Further loading, the load was applied with the rate of 5 kN until the maximum load. Several LVDT (Linear Variable Displacement Transducer) were used to measure the displacement of the beams. Two LVDT were also installed under the loading point and one LVDT were installed at the midspan of the beam. All the data were recorded automatically using data logger.

3. Result and discussion

3.1 Ultimate capacity

The weight of the beams shows a significant decrease. BR1C, weight 92.8% of the weight of BN. BR2C weight 82.3% of BN and BR3C was only 73.6% of BN. The results show that the ultimate load capacity of the beam not affected by the hollow. The ultimate capacity hollow beam was almost similar with normal beam. This result indicated that the variation of hollow height was insignificant on the ultimate capacity. The Result of the test of the specimen is presented in table 3 should be centred unless they occupy the full width of the text.

Table 3. Weight and load capacity of the specimen test

Specimen	Weight (kg)	Ultimate Capacity (P_u) (kN)	Remarks
BN	425,5	136.08	Flexural failure
BR1C	395	137.88	Flexural failure
BR3C	313	138.41	Flexural failure

3.2 Load - deflection relationship

Table 4 presents the load capacity of the tested specimens. Initially, all the beams were un-cracked beams. On the specimen BN, the concrete resisted both compression and tension forces. On the specimens BR, the concrete resisted the compression stress while the steel reinforcement resisted tension stress. When the applied load reached to the rupture strength of the concrete, the concrete started to crack. In the Initial crack, BN shows a 12,60 kN load lower. The load value at the initial crack for BR1C beam is 10.33 kN, or 82.0 % to BN. While the beam BR3C was 10.20 kN or 81.0 % to BN. This caused a decreasing of beam flexural stiffness. Once the tension zone of concrete cracked, its tensile force resistance becomes negligible. At yield and ultimate stage, the applied load of all specimen was similar because of the steel reinforcement as same.

Table 4. Relation load vs deflection of the specimen each condition

Specimen	Bottle layer	Initial crack		Yield of steel		Ultimate capacity	
		P_{cr} (kN)	Δ_{cr} (mm)	P_y (kN)	Δ_y (mm)	P_u (kN)	Δ_u (mm)
BN	-	12.60	0.50	120.68	12.39	136.08	27.11
BR1C	1	10.33	0.63	121.88	11.75	137.88	30.31
BR3C	3	10.20	0.49	114.89	13.34	138.41	30.94

The relationship between the applied load and deflection at the mid-span was presented in figure 7.

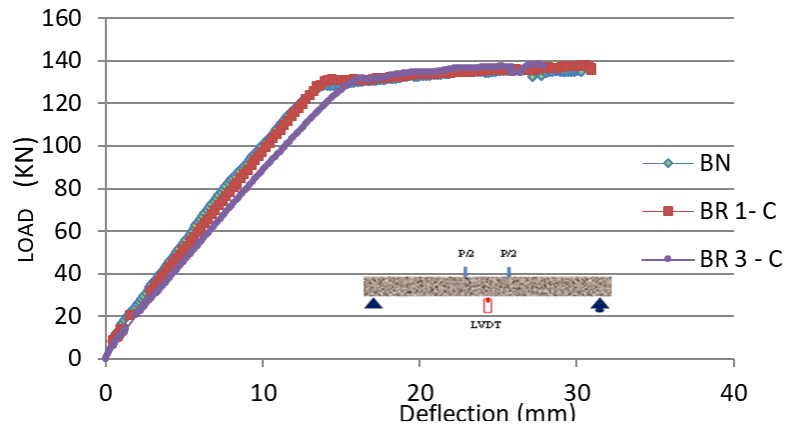


Figure 7. Load -deflection relationship.

Generally, all the beams showed similar behaviour, where the stiffness of the load-deflection curve reduced at the first cracking load (P_{cr}) and reduced again at the yielding load (P_y). However, the stiffness of the beams was different which depends on the variation of each beam.

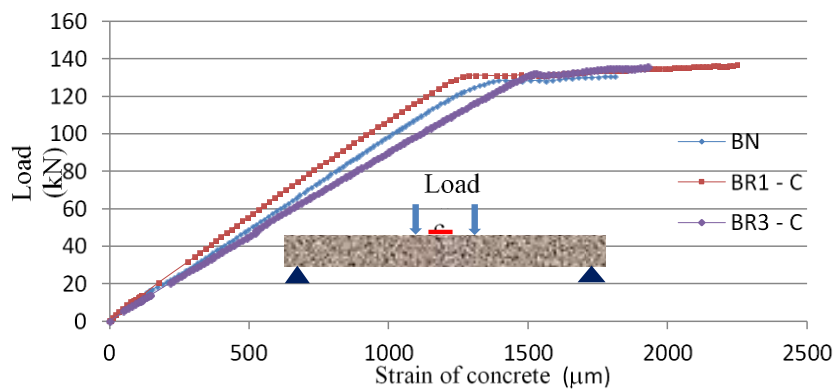


Figure 8. The strain of concrete on the top beam.

3.3 Load vs strain

The value strain of concrete on compression area shows relationship between applied load and strain of concrete for specimen BN, BR1C, and BR3C. This indicates that the failure of the three beams is an under reinforced failure. The relationship about load and strain of concrete was presented in Figure 8.

The strain of the tensile reinforcement increased more than 2100×10^{-6} on all specimens indicated it has yielded. The relationship between load and strain of steel reinforcement was presented in Table 5 and figure. 8

Table 5. Strain of steel reinforcement at ultimate load.

No	Specimen	Pu (kN)	ϵ_s
1	BN	136.08	8872.3
2	BR 1C	137.88	8540.8
3	BR 3C	136.81	9056.3

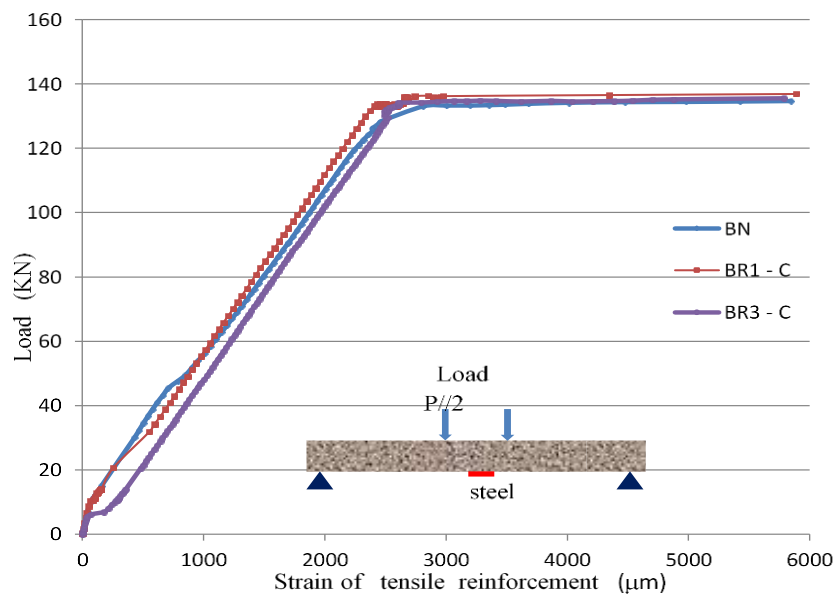
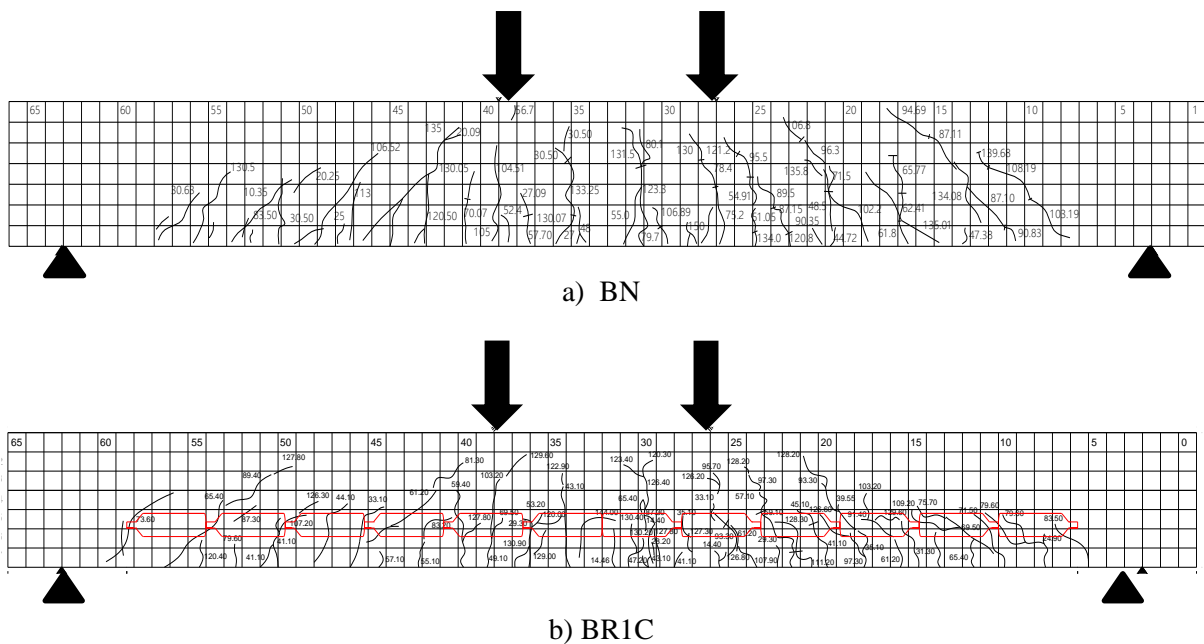


Figure 9. Strain of the tensile reinforcement

3.4 Crack pattern

Figure 10 presents typical crack patterns of each specimen. Specimens BN indicated the typical crack pattern of the normal under reinforced concrete beams. Further loading after the first crack, the other cracks appeared while the existing cracks propagated. The propagation of the cracks moved toward to the compression concrete. The long cracks were concentrated in the constant moment region at span center. While on the hollow beam, after the initial crack, the addition of the load results in the spread of cracks which tend to continue up to the level of the hollow in each specimen. Generally, the crack shows that failure type was diagonal crack and similarly of all specimen.



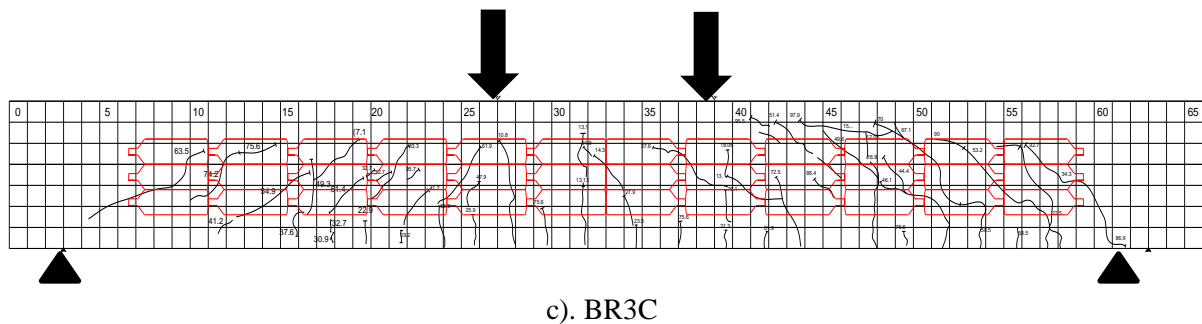


Figure 10. Typical crack pattern of specimen.

4. Conclusion

Based on the experimental test, it can be concluded that:

1. The flexural capacity of reinforced concrete beam with hollow core using plastic bottles was almost the same with the normal beam. Moreover, the effect of the height of the hollow core was insignificant on the flexural capacity.
2. The stiffness of the reinforced concrete beam with hollow core was affected by the height of the hollow core. The higher the hollow core, the smaller of the stiffness however insignificant.
3. The crack pattern of hollow beam, tend to the level of the hollow.

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