3. Stiffness, Ductility and Moment Capacity of the Hollow RC Beam 2022

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Stiffness, Ductility and Moment Capacity of the Hollow RC Beam

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Abstract- This study aims to analyze the Stiffness, ductility and moment capacity of hollow core that placing in 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 different length 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 27MPa and dimensions of 150x350mm, with 3D16mm longitudinal reinforcement with the yielding strength of 487MPa. Five type specimens are tested, consisting of control beam (BN) and hollow beams type with length variation of 880mm (BR3A), 1760mm (BR3B) and 2640mm (BR3C). The height of the hollow for each type was 1800mm (three layer bottles).

All beams were tested for their flexural characteristics with 4 loading points using an actuator with a maximum load of 1500kN. A load cell with a capacity of 200kN is used to measure the load. Three LVDT (Linear Variable Displacement Transducers) are used to measure beam deflection. All data is recorded automatically using a data logger. The results indicated that the moment capacity of reinforced concrete beam with hollow core using plastic bottles was almost same with the normal beam. Moreover, the effect of the length of the hollow core was different significant of the stiffness and ductility. The stiffness of the BR3A, BR3B and BR3C, respectively 93.40 %, 79.00 % and 67.53 % to stiffness of BN and the ductility of the BR3A, BR3B and BR3C, respectively about 96.1%, 91.0% and 84.2 % to ductility of the BN.

Keywords – Stiffness, Ductilty, Momen capacity, Hollow RC Beam

I. INTRODUCTION

Reinforced concrete was the dominant structural material in engineering construction due to its advantages such as workability, low cost and fire resistance as well as low maintenance costs. Unfortunately, the reinforced concrete structure has its own heavy weight, besides in the manufacture of cement which is the base material of making concrete mixture, giving contribution to CO_2 emission. The source of CO_2 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 concretes affect to the environment condition and global warning that may cause disasters such as flooding and land-slides. Related to that, research efforts are continuously looking for new, better and efficient construction material and method. The concrete should be used as efficiently as much as possible.

Flexural action depend on compressive stress of concrete on compression side and tensile stress of steel on tension zone. In reinforced concrete (RC) beams concrete on tension zone has no effect on the flexural action. Figure 1. shown the flexural action of Reinforced concrete beam due to flexure load.

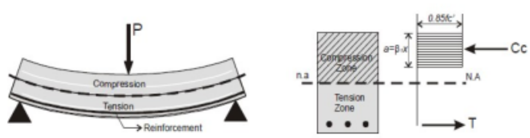


Figure 1. Flexural action of Reinforced concrete beam.

The flexural capacity (MR) of the beam is influenced only by compression stress of the concrete and the tensile stress of the steel reinforcement, as follows :

$$MR = 0.85\, f'c\, \beta_{1.}\, c.\, b\, (\, d - \tfrac{1}{2}\, a\,) \qquad (1)$$

Several studies have been conducted on this subject, which were [1] to analyze the flexural behaviour of Styrofoam-filled Concrete (SFC) by adding Styrofoam 30 % to replace the concrete volume on tension area. The results indicate that the strength of normal concrete (NC) and SFC has decreased with addition of 30% Styrofoam. However, when the SFC beam was combined with deformed bar, the ultimate bending strength of SFC specimens increase 12.6% compared to the NC specimens. [2] to analyse the flexural behaviour of the beam with eliminated concrete parts below neutral axis then used truss system as external Reinforced Concrete Beams. Hollow reinforced concrete beam referred to in this paper is which on the tension zone made hollow by using plastic bottles waste 60 mm diameter. There are some advantages using hollow in the tension section, i.e : the structure will be lighter, the production of cement as the main material to make concrete will be reduced.

In order to efficiently use the concrete materials, then the compressive strength of the concrete on the tensile stressed section may be reduced or the concrete on the tensile stressed section may be removed.

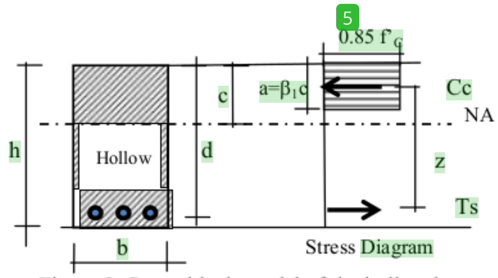


Figure 2. Stress block model of the hollow beam

There are some advantages using hollow in the tension section, i.e : the structure will be lighter, the production of cement as the main material to make concrete will be reduced, providing place for utility facility and it can be used to accommodate waste Related to this matter, in this research, there is bending testing of beam, with the aim of enlarging the cross section capability in carrying the compressive stress and making the hollow by using plastic bottle in the section of the tensile section.

Several studies have been conducted about hollow reinforced concrete beam. **[3]** did a research by replacing the concrete section below the neutral line that does not bear the load with PVC pipe. The characteristic of PVC were not tested because it was only used as the filling material in the concrete. There were nine beams casted and tested. Three of the specimen are reference beams (CB1, CB2, CB3). Three tested beams were using PVC pipe with 40 mm diameter (HW1, HW2, HW3) and the other three used placed at 63 mm from the top section. The length of the pipe in the neutral line of the beam was 620 mm. All beams being tested had 150 mm x 230 mm x 980 mm dimension with 800 mm effective range. The single reinforcing beams 2 ϕ 20mm and 2 ϕ 12mm were the top reinforcement and 8- 150 were the shear reinforcement. The result of the test showed that there was no significant difference in the load supporting ability between the controlling solid beams and the cavity beams at the neutral line, and so was the deflection. At the maximum load 100 KN, the controlling beam CB showed 4.28 mm deflection while the tested beams HW 40. The CB control beam shows a deflection of 4.28 mm, while the HW 40 mm test beam: 4.30 mm and HW 50 mm: 4.90 mm. Based on the test results can be concluded that the behavior of reinforced concrete beams with PVC pipe cavity diameter 40mm and 50 mm placed on neutral lines not much different from conventional reinforced concrete beams.

[4], 2017, conducted a bending test on cavity reinforced beams. Eight tested beams of 150 x 150 x 1000mm consisted of two tested beams with top PVC pipe depth of 34 mm from the compression fiber, two beams with 75 mm depth PVC pipe axis position (the pipe axis coincided with the cross-section axis), two beams with the bottom part of the PVC pipe at 116 mm from the compression fiber (34 mm from the tension fiber) and two beams with the PVC pipe at 75 mm depth and 116 mm from the compression fiber. The beams were designed with weak reinforcement with bottom reinforcement of 2 ϕ 8mm and the top reinforcement of 2 ϕ 8mm. The shear reinforcement used cross bar of ϕ 6 - 150 mm. The relation between the loads and the deflection showed various values. The beams with 34 mm of pipe depth showed 22 KN maximum load value and 3.4mm deflection. The 75 mm of pipe depth showed 22 KN maximum load value and 5.8 mm deflection. Then, the 166 mm of pipe depth showed the highest value of load which was 26 kN with 5.7 mm deflection. The last, for the pipes at two points which were at 75 mm and 116 mm of depth showed 24 kN maximum load and 5.5 mm deflection.

[6], conducted a study using polythene spheres recycled plastic waste with varying diameters, 75 mm, 65 mm and 35 mm. There are 7 test beams made by each control beam 2 pieces (CB1 and CB2), 1 test beam filled with diameter 75 mm (UN1- volume 10% volume control beam), 1 test beam filled 65 mm diameter beam (UN2 - volume 6% of control beam volume), 1 test beam filled 65 mm diameter beam (UN3 - volume 12% of control beam volume) 1 test beam filled 35 mm diameter beam (UN4 - volume 3% of control beam volume), 1 test beam filled 35 mm diameter beam (UN5 - volume 6% volume control beam) All use M30 quality concrete, 100mm x 200mm x 1200mm, effective range 900 mm. Fe415 steel quality, tensile reinforcement 2 ϕ12 and 2ϕ8 above reinforcement with stirring ϕ10-100 mm. The test results show that (a) hollow beam behavior and control beam are slightly different. (b). Partial replacement of concrete in the tensile zone shows no significant difference in load carrying capacity. (c). beam UN5, show greater load capacity and deflection better than control beam.

While the study of hollow reinforced concrete beams using PET plastic bottles, conducted by **[7]**, with the aim to find an easy method of implementation and learn the flexibility of hollow beam by using PET bottles. T he test beam measures 200 x 400 x 3850 mm, 3 (three) specimens of reinforced concrete beam K-400 as control beam, then as test beam consists of each 3 beams of hollow plastic bottle placed in the middle of span, with quality of concrete K.400 (PET K-400) and K.300 (PET K-300). The test results show that PET K-400 has the ultimate moment of 98 % compared to solid beam with the same quality of concrete. Research also shows that PET beams PET K-300 has the ultimate moment 1.017 compared to beam PET K-400. **[8],** conducted a hollow beam research using a test beam of size 20x30x200 cm. Normal beam capacity (N0B0) compared to hollow beam with 10 PET bottles located on neutral lines (N10B0), Hollow beam with 10 PET bottles located below the neutral line (N0B10) and Hollow beam with 10 PET bottles on neutral lines and below the neutral line (N10B10). The test results show that the ultimate load capacity on Beam N10B0 = 97.66% of the normal beam. As for the beams and N0B0 and N10B10 the ultimate moment capacity is relatively the same and range only differently whereas the N0B0 beam is also relatively the same as the N10B10 beam and its value is 90% of the ultimate moment capacity of the normal beam. Whereas in terms of weight ratio, N10B0 and N0B10, the weight is about 97.9% of the weight of the Normal beam (N0B0), while the weight of the N10B10 beam is 95.8% of N0B0. **[9]**. The aim of this study is to compare the ultimate load of normal beam and beam with plastic waste. The beams were T shaped, with two conditions which were apparent T shaped beam and the neutral T shaped beam The result showed that there is not significantly different between two sample. It means that their ability to sustain the loads is not significantly different.

These studies examine (1), moment bearing capacity, (2). load deflection relationship and (3) crack pattern of hollow reinforced concrete beams. This research complements this research by analyzing the stiffness and ductility of hollow reinforced concrete beams

II. PROPOSED ALGORITHM

2.1. Specimen and material properties

The dimensions of beams were 3300mm length with 150 x 350mm cross section, respectively. The specimen used three of D16 steel bar as tensile reinforcement and two of ϕ8 steel reinforcement at the compression side for assembly purpose only. For shear reinforcement used ϕ8-100mm in support area and ϕ8-200mm along the tested span. All beam had the same tensile reinforcement ratio.

Material properties of concrete and steel reinforcement used in this study are presented in Table 1

Table 1. Material properties

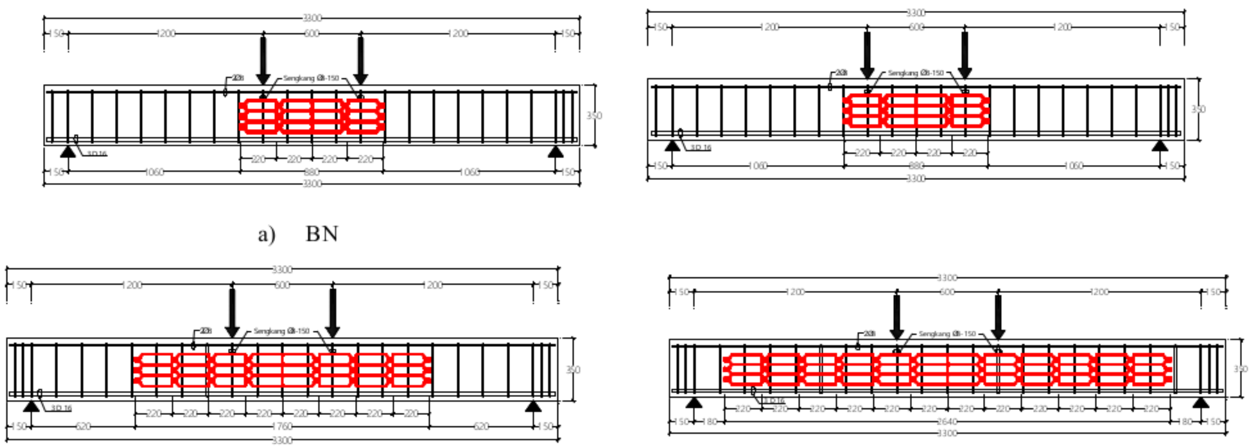
Concrete		Steel Reinforcement	
Compressive strength	27.09 MPa	Yield strength	450 MPa
Tensile strength	3.9 MPa	Tensile strength	487 MPa
Young Modulus	23 GPA	Young Modulus	200 GPa

Table 2. Specimen variable

No	Specimen	No's Specimen	Hollow Length		Hollow Height	
			mm	**No of bottles**	**mm**	**No of bottles**
1	BN	3	0	0 bottles	0	0 bottles
2	BR3A	3	880	4 bottles	180	3 bottles

3	BR3B	3	1670	8 bottles	180	3 bottles
4	BR3C	3	2640	12 bottles	180	3 bottles

The detail of the specimen can be seen at Figure 3.



a) BN

b). BR3A

c). BR3C

Figure. 3. Details of the specimen.

The Flow chart analysis of research can be seen at figure 4

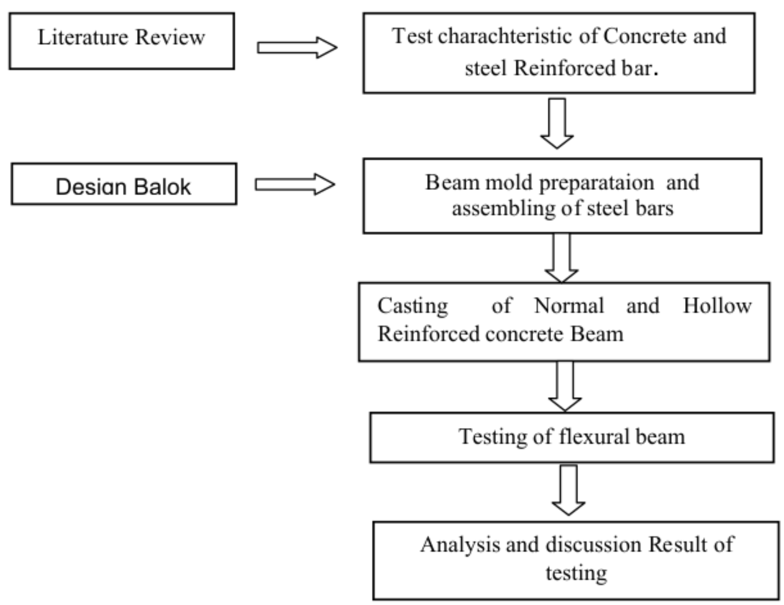


Figure 4 Study of algorithm Block Diagram

III. EXPERIMENT AND RESULT

3.1. Fabrication of Specimen

Figure 4 shows the casting of specimen. Concrete casting was started from the bottom of the specimen and was stopped until 70 mm height. After that, the plastic bottles were put on the concrete surface. The concrete casting was continued again which depends of the specimen variation. All specimen were cured for 28 days in the moisturing condition before testing.

Figure. 5. Casting of specimen.

3.2. *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 6.

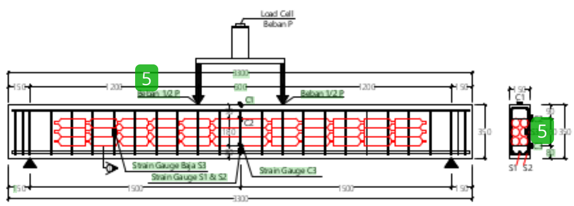


Figure 6. Location of Strain gauge.

Figure **7.** Setup of Specimen (BN).

Figure 7 shows the loading set up. All the beams were subjected to four point bending test using actuator with 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 first crack of concrete. Further loading, the load was applied with the rate of 5 kN until maximum load. Several LVDT (Linear Variable Displacement Transducer) were also used to mesure the displacement of the beams. Two LVDT were 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.

III. Experiment and Result

Ultimate Capacity

Result test of the specimen is presented in Table3.

Table 3. Weight and Load capacity of Specimen Test

Type of Beam	Initial		Yield		Ultimate	
	Pcr kN	Mcr kN m	Py kN	My kN m	Pu kN	Mu kN m
BN	16.06	11.05	126.28	77.18	136.08	83.06
BR3A	16.19	10.89	126.35	76.99	139.48	84.86
BR3B	15.93	10.50	124.55	75.75	135.55	82.35
BR3C	15.93	10.51	125.35	76.16	136.81	83.03

Table 3 presents the load capacity of the tested specimens. Initially, all beams were un-cracked beams. Further loading, the cracks occurred. As the result the beam stiffness decreased

In the Initial crack, Beam BN shows a 16,06 kN load higher than the theoretical calculation of 13,38 kN. The load value at the initial crack for BR3A beam is 16.19 kN, approximately equal to the theoretical calculation value or 96,7% to BN. For BR3B beams the load value at the initial crack of 15,93 kN, or 71.50 % to the value of BN. While the beam BR3C load value at the initial crack of 25.93 kN or 76,30% to BN

Load-Deflection Relationship

The relationship between the applied load and deflection at the mid span centre is presented in Fig.7.

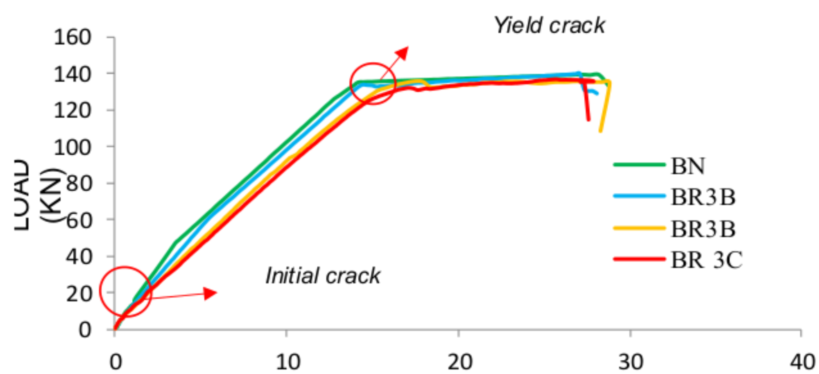


Figure 7. Load – Deflection relationship

Generally all the beams showed similar behaviour, where the stiffness of load – deflection curve reduced at the first cracking load (Pcr) and reduced again at the yielding load (Py). However, the stiffness of the beams was different which depends on the variation of each beam.

3.1 *Stiffness of specimen*

The value of the stiffness is calculated by the equation $k = \frac{P_{cr}}{\delta_{cr}}$. Calculation of beam stiffness can be seen in table 4

Table 4. Calculated of the stiffness value

Type of Beam	Pcr (N)	Δ_{cr} (mm)	k (N/mm)
BN	16060.60	1.19	13439.83
BR3A	16193.50	1.29	12553.10
BR3B	15927.00	1.50	10618.00
BR3C	16927.80	1.86	9076.57

Comparison of the value of the stiffness of the BR3A, BR3B and BR3C cavity beams against normal beams can be seen in Figure 8.

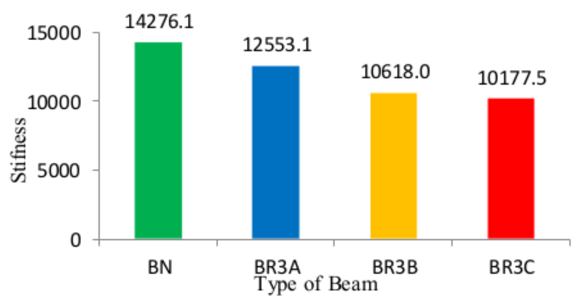


Figure 8. Comparison of Stiffness

From figure 8 it can be calculated that the stiffness of BR3A is 93.40% of the normal beam stiffness while the stiffness of the BR3B and BR3C beams is 79.00% and 67.53% of the normal beam stiffness, respectively

3.2. Ductility of specimen

Beam ductility values can be calculated based on the equation $\mu = \Delta_{max}/\Delta_y$

Table 5 shows the calculation of the ductility of normal beams (BN) and hollow beams (BR3A, BR3B and BR3C).

Tabel 5. Calculation of the ductility

Type of Beam	Pmax kN	□max (mm)	□y (mm)	□
BN	136.079	28.860	14.025	2.058
BR3A	139.478	27.050	13.260	2.040
BR3B	135.546	27.100	14.028	1.932
BR3C	136.812	25.696	14.840	1.732

While the comparison of the ductility values of the BR3A, BR3B and BR3C cavity beams against normal beams can be seen in Figure 9

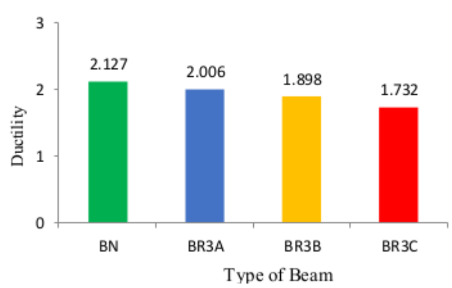


Figure 9. The ductility value of the specimen

From figure 9 it can be calculated that the BR3A ductility is 99.14% of the normal beam ductility, while the BR3B and BR3C beam ductility are 93.88% and 84.15%, respectively, against the normal beam ductility.

IV. CONCLUSIONS

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 same with the normal beam. Moreover, the effect of the length of the hollow core was also insignificant on the flexural capacity, where the beam with longer hollow core showed similar flexural capacity with the beam having a shorter hollow.
2. The stiffness of reinforced concrete beam with hollow core was affected by the length of the hollow core. The longer the hollow core, the smaller the stiffness.
3. The Ductility of reinforced concrete beam with hollow core was affected by the length of the hollow core. The longer the hollow core, the smaller the ductility

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