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Original Article

Behaviour Analysis of Shear Strength in Hollow Reinforced Beams: A Laboratory Experimental Test

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Abstract - *The strength of a reinforced beam in carrying loads is determined by two factors, namely; (1) the ability to bear bending loads due to moments, and (2) the ability to bear shear forces due to shear forces. Tests carried out by the research team have previously proven that with certain cavity formations, the flexural capacity of hollow concrete beams is the same as that of normal reinforced concrete beams. This study aims to obtain the effect of shear force on the shear capacity of hollow reinforced concrete beams. In this study used hollow reinforced concrete beams with a cross-section size of 175x350mm and a length of 3000mm. main reinforcement 3D16mm, stirrup reinforcement D8mm, spacing 150mm, material quality f'c = 25 MPa and fy = 400 MPa as control beams. (BN15). Next, blocks are made with the same size and material quality with the stirrup spacing of 10 cm (BN10), then given a cavity using a plastic bottle with a length of 3240mm (12 bottles), cavity height: 180mm/3 bottles. 2 hollow concrete beams were made with a variation of stirrup spacing, namely 150mm (BR15) and 100mm (BR10). The load distribution was regulated by a 2-point load system, namely (a): 50 cm from each position, so the value a/d = 1.6; thus, according to the Nawy theory, a shear failure will be obtained. The loading is given gradually and gradually increased until failure occurs in the beam. The aim of the research is to obtain the shear capacity of hollow reinforced concrete beams. Thus, the ability of hollow reinforced concrete beams to carry loads can be relied upon.*

Keywords - *Bending moment, Latitude force, Hollow reinforced concrete beam, Material quality, Shear failure.*

1. Introduction

The rationale for the emergence of hollow reinforced concrete beam structures begins with the behaviour of reinforced beam structures in carrying bending loads. As a result of the bending moment, the upper layer will be compressed, and the lower layer will be tension. Under balanced conditions, the reinforcing steel's tensile strength equals the compressive strength carried by the concrete section above the neutral line. Thus there is a part of the concrete below the neutral line which is not taken into account to carry the compressive force, so that part can be removed or made hollow [1].

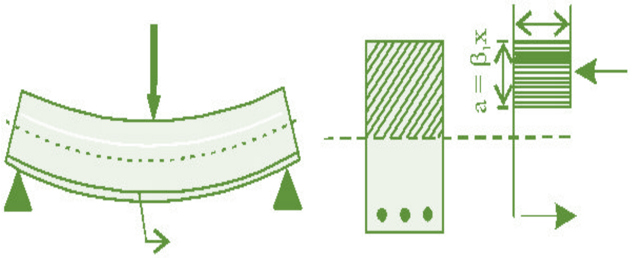


Fig. 1 Flexural action of reinforced concrete beam

Hollows can be formed with waste plastic bottles. Rahardyanto's research (2013) has the specific aim of how to place bottles when casting concrete because of the floating nature of the bottles due to the upward pressure from the newly released concrete. In addition, this test also uses different concrete qualities, namely K-300 and K-400, with three plastic bottles arranged in the middle of the span. The load test results confirm the theory, which states that the cavity formed by the PET bottles placed in the Tensile area does not reduce the flexural strength of the beam [4]. Research by Ima Mathew (2016) includes the combined effect of placing voids on the neutral axis and partially replacing concrete below the neutral axis by creating air voids with plastic bottle waste. The test results show that the bending behavior is similar for all beams. Compared to the ability to carry loads by reducing their weight, beams with cavities on the neutral axis are more effective than other beam variants [5]. Research by Syahrul Sariman et al. (2019) used square beams with dimensions of length 3300 mm, body width b = 150 mm, total height: 350 mm, effective height = 300 mm, using 3D16mm for tensile reinforcement, 2D8 mm for compressive reinforcement, cavities are made from plastic bottles with a length of 2760 mm (12 bottles) and varying heights of 60 mm (1 bottle) and 180 mm (3 bottles), below the neutral line, concrete quality f'c: 25 MPa and steel quality fy: 400 MPa. The results showed that the flexural capacity of hollow reinforced concrete beams using plastic bottles was not significantly different. The purpose of hollows in reinforced concrete beams is to make the structure lighter, reducing cement production as the primary material for making concrete.

Cement production emits carbon dioxide gas (CO2), which can cause a greenhouse effect but can also be reduced [7]. However, the question arises whether the reduction in the volume of the beam due to voids will not cause problems in its capacity to carry shear forces? Several studies have been carried out relating to hollow reinforced concrete beams, including using PVC pipes such as those conducted by Joy and Rajeev (2014) [8], Kumar and Joy (2015) [10], Varghese et al. (2016) [11], Dhinesh and Satheesh (2017) [13] and Parthiban and Neelamagem (2017) [15], have yet to investigate how hollows affect the shear capacity of beams.

As an objective of the study, there are 3 behaviors of concrete blocks to be analyzed, namely:

- Comparing the shear capacities between theoretical calculations and test results.
- Comparing the shear capacity of normal reinforced concrete beams with hollow reinforced concrete beams with the same stirrup spacing.
- Obtain the shear load capacity of hollow reinforced concrete beams with different stirrup spacings.

From the theory of theoretical bending capacity, it can be explained that the stress diagram at the boundary conditions corresponds to the Whitney diagram, shown in Figure 2 [16].

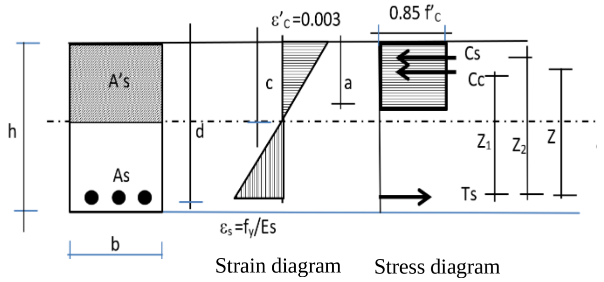


Fig. 2 Strain and Stress Diagrams of reinforced concrete

Where :

Cc = 0.85 f'c. a. b and Cs = As. fy

Ts_1 = As_1. f_y and Ts_2 = As_2. f_y

Cc = Ts

$$a = \frac{As.fy}{0.85\,f'c.b} = \frac{692.97 * 481.78}{0.85 * 27.09 * 175} = 72.12mm$$

$$c = \frac{a}{\beta_1} = \frac{72.12}{0.85} = 84.85\ mm$$

The height of the hollow maximum (h_{max}) can be shown in Figure 3 as follows:

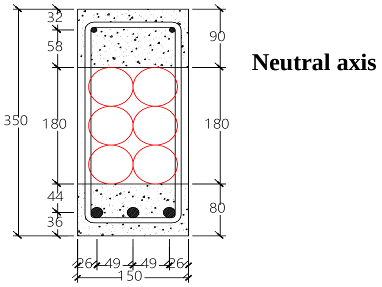


Fig. 3 Height of hollow max

h_{rmax} = h – 80 – c = 350 – 80 – 85 = 185 mm

Calculation of the capacity of the cross-section to carry out of the moment.

Mnc = 0.85 f'c*a*b (d – ½ a) = 87 857 682,71 Nmm

Mns = As' * f's (d – d') = 7 369 529.27 Nmm

Mu = Mnc + Mns = 95 227 211,98 Nmm

From the beam mechanic obtained the relationships between the moment and the load as follows **:**

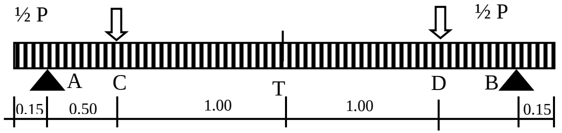


Fig. 4 Loading sketch

The calculated resume of the moment and Shear force can be seen in Table 1

Table 1. Moment and shear force

Point	Moment	Shear Force
A	-0.0143	1.9060 + 0.5 P
C	1.3581 + 0.6 P	0.3812 + 0.5 P
T	1.4152 + 0.6 P	0
D	1.3581 + 0.6 P	0.3812 + 0.5 P
B	-0.0143	1.9060 + 0.5 P

95 227 211,98 = 1.4152 + 0.6 P

P = 156.3533 kN

From theoretical shear capacity, it can be explained that intact reinforced concrete beams with a stirrup spacing of 100mm. Shear carrying capacity of concrete =

$$Vc = 1/6\sqrt{f'_c}.bw.d = 39.25kN$$

The ability of the stirrup reinforcement to withstand shear

$$Vsv = \frac{Av.fy.d}{s} = 82056{,}91N = 82.06\ kN$$

Vc + Vsv = 39.25 + 82.06 = 121.31 kN

Pu = 2 x 121.31 = 242.62 kN

While the capacity to carry theoretical shear forces for other types of beams can be seen in the following table.

Table 2. Theoretical shear capacity of the specimen

No	Beam Notation	Shear Capacity (kN)
1	BN-10	242.62
2	BN-15	179.52
3	BR-10	217.37
4	BR-15	154.27

2. Materials and Methods

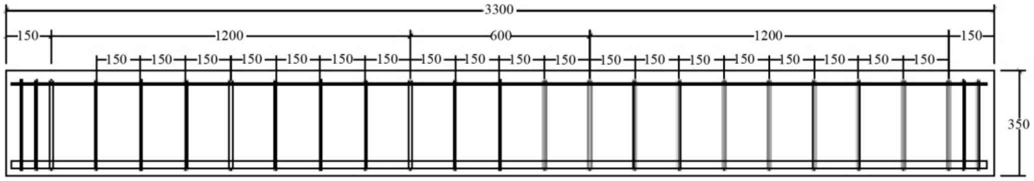
2.1. Materials

The length of the beams was 3300 mm with 175×350 mm cross-sections, respectively. Effective height = 314 mm. The specimen used three D16 steel bars as tensile reinforcement and two D8 steel bar reinforcements at the compression side for assembly purposes only. For shear reinforcement, used D8-100mm in the support area and D8-200 mm along the tested span.

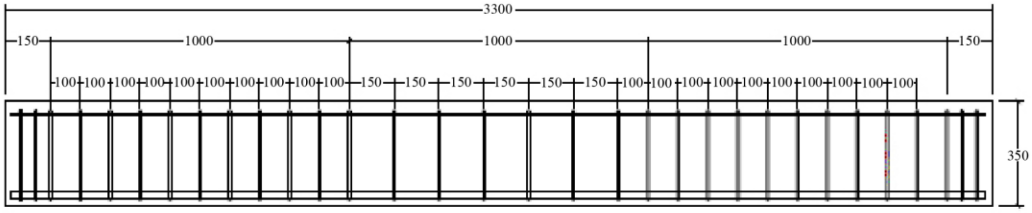
Hollow length 2760 mm = 12 bottles @ 220 mm, Hollow Height 180 mm (3 layer bottle, 60 mm diameter).

Based on the theory of beam cracking due to load, to cause compressive shear cracking, the ratio between the distance between the load catchment point and the bearing axle (= a) and the effective beam height (=d) is taken = 500/314 = 1.59 between 1 – 2.5.

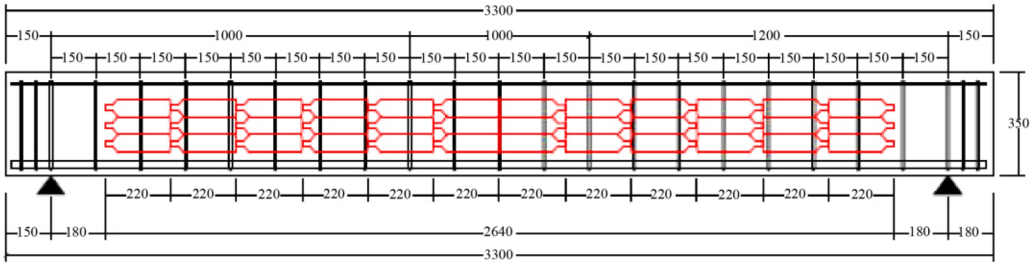
The hollow reinforced concrete beam specimens consist of 4 types, which can be described as follows :



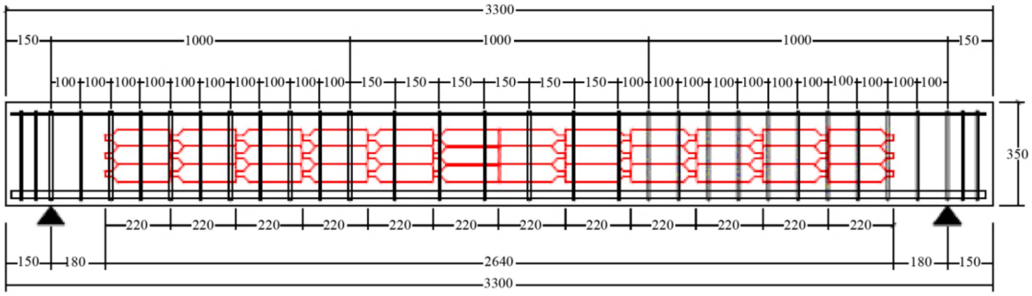
(a). BN-15



(b). BN-10



(c). BR-15



(d). BR-10

Fig. 5 Sketch of Specimen

Table 3. Number and notation of specimen

No	Hollow Length Height	Hollow Height	Distance of stirrup	Specimen Notation	Amount of Sample
1	0 bottle (0 mm)	0 layer (0 mm)	100	BN-10	1
2	0 bottle (0 mm)	0 layer (0 mm)	150	BN-15	1
3	12 bottles (2640 mm)	3 layers (180 mm)	100	BR-10	1
4	12 bottles (2640 mm)	3 layers (180 mm)	150	BR-15	1

2.2. Methods

Casting starts from the base of the specimen and is stopped at a height of 70 mm. After that, the plastic bottles are placed on the concrete surface according to the predetermined height and length variations. Casting is then continued until the formwork is complete. All test beams were treated for 28 days before testing.

All beams were tested with four loading points using actuators with a maximum load of 1500 kN. A load cell with a 200 kN capacity is used to measure the magnitude of the load. Loading is done at 5 kN per step until the maximum load. Three Dial gauges are used to measure the deflection of the beam.

Fig. 6 Set up specimens for testing

3. Results and Discussions

3.1. Results

The weight of the test object is obtained by weighing it with a digital scale**.** The result of the weighing can be seen in the following table **:**

Table 4. Weight of specimen

No	Specimen Notation	Weight (kg)
1	BN - 10	482.0
2	BN - 15	459.8
3	BR - 10	387.4
4	BR - 15	371.2

The results of testing the shear load capacity of the beam can be seen in the following table:

Table 5. Shear capacity of beam

No	Type of Beam	Max shear force (kN)
1	BN - 10	260
2	BN - 15	190
3	BR - 10	230
4	BR - 15	165

The graph of the load and deflection test results can be seen in the following figure :

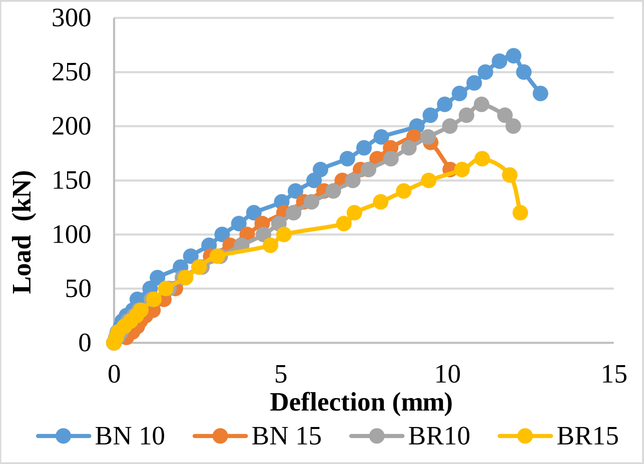


Fig. 7 Correlation of Load vs Deflection

3.2. Discussions

Of the three study objects carried out in this study, some of the test results that can be discussed include:

a) Comparison of shear capacity of hollow reinforced concrete beams between theoretical calculations and experimental tests.

This aims to obtain the shear capacity of reinforced concrete beams that are intact or hollow between theoretical calculations and experimental test results. As previous calculations regarding the shear capacity of the beam consisting of the shear capacity of the concrete and the shear capacity of the reinforcement, it can be compared between the shear capacity of the beam and its flexural capacity, as shown in the following table and graph.

Table 6. Comparison between theoretical calculations and experimental tests

No	Type of specimen	Theoretical shear capacity	Experimental shear capacity	Different	
		(kN)	(kN)	(kN)	(%)
1	BN - 10	242.62	260	17.38	7.16%
2	BN - 15	179.52	190	10.48	5.84%
3	BR - 10	217.37	230	12.63	5.81%
4	BR - 15	154.27	165	10.73	6.96%

From the table above, it can be obtained that the shear capacity of reinforced concrete beams based on theoretical calculations is 6 – 7 % smaller than the compressive strength of the experimental test results.

This shows that the theoretical calculation has been given a safety factor from the actual capacity of both intact and hollow reinforced concrete beams. The same is true for the difference in the distance between stirrups.

If the shear capacity is compared with the results of the flexural capacity test of the same reinforced concrete beams, the data shows that BN 10, BN 15 and BR 10 are still higher than their flexural capacities. However, in the BR-15 beam, the shear capacity is not significantly different from the flexural capacity. This shows that the beams BN 10, BN 15 and BR 10 will experience flexural failure before shear failure. Only BR 15 beams need attention to the possibility of shear failure.

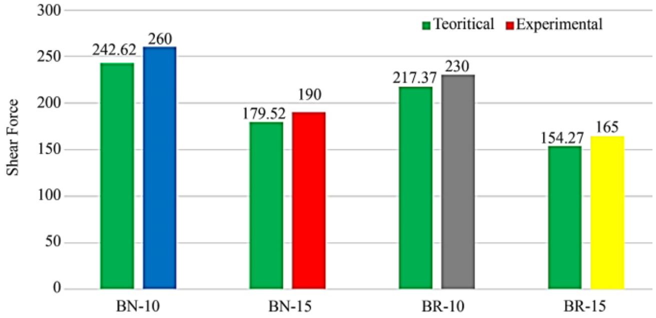


Fig. 8 Comparison of the Theoretical and Experimental Shear force

b) Comparison of the shear capacities of intact reinforced concrete beams and hollow reinforced concrete beams.

The following table shows a comparison of the shear capacity of intact and hollow reinforced concrete beams.

Table 7. Differences in the shear capacities of intact and hollow reinforced concrete beams

No	Type of Beam	Shear capacity (kN)	Differences (%)
1	BN - 10	260	88.5
2	BR - 10	230	
3	BN - 15	190	86.8
4	BR - 15	165	

From Table 7 can be seen that the shear capacity of normal concrete beams compared to hollow concrete beams ranges from 86 – 89 % on average.

c) Comparison of shear capacity due to the difference in stirrup spacing.

Meanwhile, to see the comparison of shear strength due to variations of stirrup reinforcement can be seen in the following table.

Table 8. Comparison of the shear capacity of the beam due to the difference in the spacing of the stirrups

No	Type of Beam	Shear capacity (kN)	Differences (%)
1	BN - 10	260	73.08
2	BN - 15	190	
3	BR - 10	230	71.74
4	BR - 15	165	

From the table, it can be seen that the shear capacity of normal concrete beams compared to hollow concrete beams is an average of 72%.

The performance of reinforced concrete beams is determined by the ratio between shear capacity, and it is weight.

Table 9 and Figure 9 show a comparison of the shear capacity and weight of the beam, which can show the performance of the beam.

Table 9. Comparison of shear capacity and beam weight

No	Type of beam	Shear capacity (V) (KN)	Weight (W) (kg)	V/W
1	BN - 10	260	482.0	0.53
2	BN - 15	190	459.8	0.41
3	BR -10	230	387.4	0.59
4	BR - 15	165	371.2	0.44

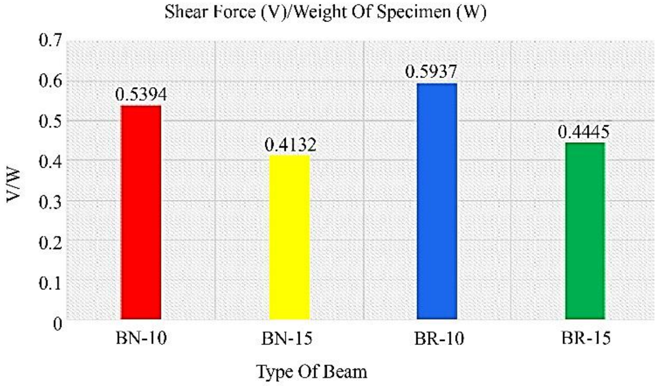
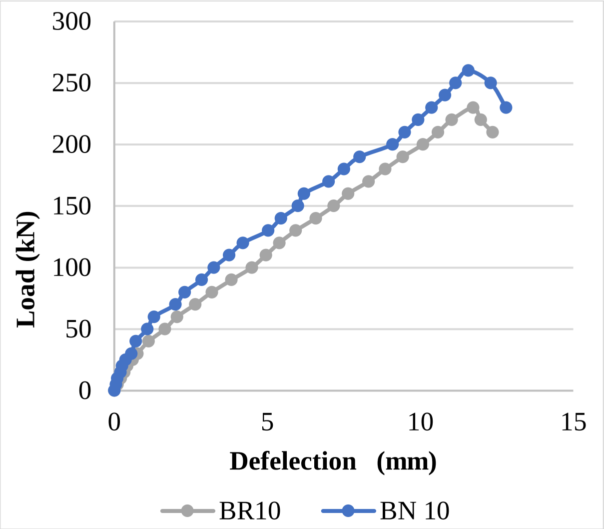


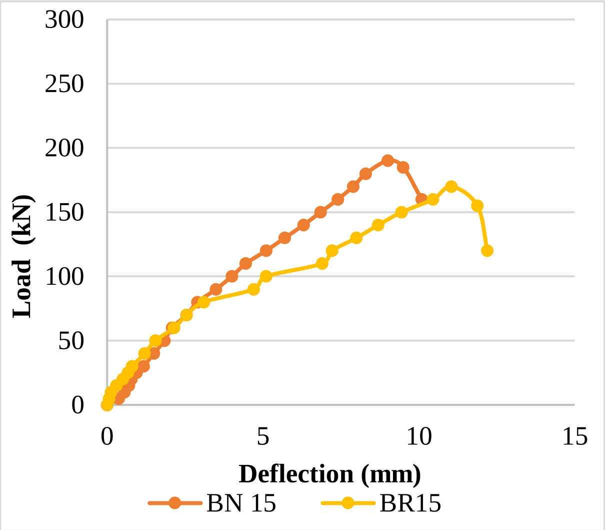
Fig. 9 Performance of specimen

Table 9 and Figure 9 show that the best beam performance in this test is a hollow beam with a stirrup spacing of 10 cm (BR 10). This research is in line with previous research conducted by Sariman et al. on hollow beams with a cavity height of 3 layers of bottles and a cavity length of 12 bottles. With a ratio of Mu/W = 0.263 [17].

A comparison graph between the shear capacity of intact reinforced beams and hollow reinforced beams can be made between BR 10 vs BR 10 beams and BN 15 vs BR 15. The comparison graph can be seen in Figure 10 below :

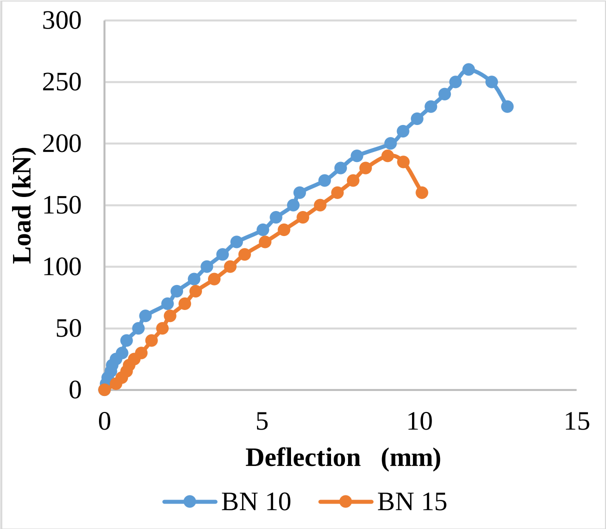


(a) Comparison between BN-10 vs BR-10

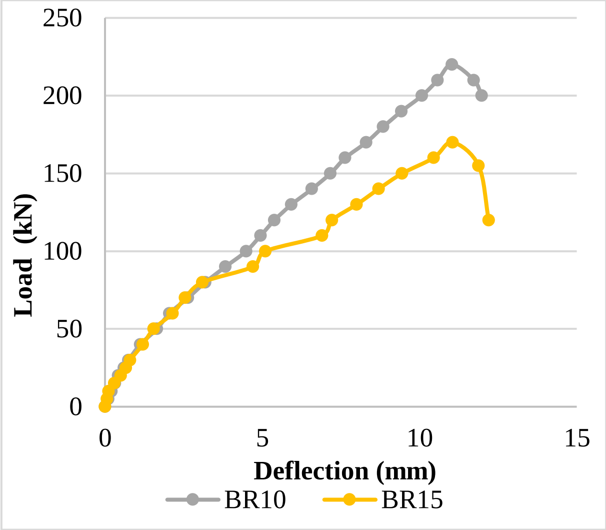


(b) Comparison between BN-15 vs BR-15

Fig. 10 Comparison Load and Deflection between Normal and hollow RC Beam



(a) Comparison between BN-10 vs BN-15



(b) Comparison between BR-10 vs BR-15

Fig. 11 Comparison Load and Deflection relationship effect of stirrup distance

Both graphs in Figure 10 show that the stiffness of reinforced concrete beams is better than that of hollow reinforced concrete beams with the same stirrup spacing. Meanwhile, the influence of the spacing of stirrups made between BN10 vs BN15 and between BR10 vs BR15 can also be seen from the effect on the shear strength of the beam, as shown in Figure 10.

From Figure 11, it can be seen that the shear capacity of reinforced concrete beams with a stirrup spacing of 10 cm is higher than that of reinforced concrete beams with a stirrup spacing of 15 cm. This shows that the spacing of stirrup reinforcement greatly determines the shear capacity of reinforced concrete beams.

4. Conclusion

Based on the results of research and analysis of hollow reinforced concrete beams, several conclusions can be drawn as follows:

- The theoretically calculated shear capacity of reinforced concrete beams is 6 – 7% smaller than experimental tests. Hollow reinforced beams' shear capacity is greater than similar beams.
- The shear capacity of hollow reinforced concrete beams is 86 – 89% smaller than that of intact reinforced concrete beams. This is due to the reduced cross-sectional area of the concrete due to voids.
- Differences in stirrup spacing result in the reduced shear capacity of reinforced concrete beams, both hollow and intact reinforced concrete beams. Beams with a stirrup

spacing of 15 cm have a smaller shear capacity of 71-73% compared to beams with a stirrup spacing of 10 cm.

- The performance of hollow reinforced concrete beams is better than that of intact reinforced beams. The best version of reinforced concrete beams is hollow RC beams with a stirrup spacing of 10 cm.
- The graph of the load-deflection relationship shows that the rigidity of the full beam is better than that of hollow concrete beams, as well as that of beams with a stirrup spacing of 10 cm which are stiffer than beams with a stirrup spacing of 15 cm. Hollow reinforced concrete beams with the stirrup spacing of 10 cm show a stiffness, That is not significantly different from intact reinforced concrete beams with a stirrup spacing of 15 cm.

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