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SHEAR CAPACITY OF THE HOLLOW- REINFORCED CONCRETE BEAM WITH STIRRUP DISTANCE

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ABSTRACT

The ability of reinforced beams to carry loads is determined by two factors, namely the ability to carry bending loads due to moments and the ability to carry shear forces. Previous tests have proven that 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 reinforced concrete beams with a cross-section size of 175x350mm with a length of 3000mm. main reinforcement 3D16mm, stirrup reinforcement □8mm, 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 a stirrup spacing of 10 cm (BN10) then the beams are given cavities using plastic bottles with a length of 3240mm (12 bottles), cavity height: 180mm/3 bottles. 2 hollow concrete beams were made with variations in the spacing of stirrups, 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 research aims 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: hollow RC beam, distance of stirrup, shear force capacity.

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1. INTRODUCTION

1.1 General

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 tensile strength carried by the reinforcing steel is made equal to 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].

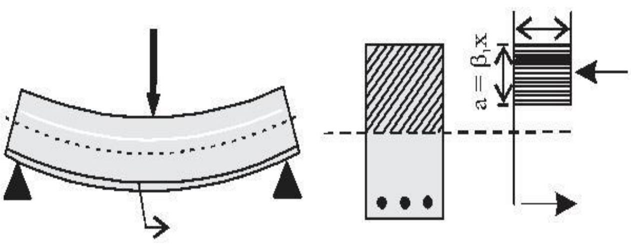

Figure-1. Flexural action of reinforced concrete beam.

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, which emits carbon dioxide gas (CO_2), which can cause a greenhouse effect, can also be reduced [2]. 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? Hollows can be formed with waste plastic bottles. Rahardyanto's research (2013) with 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 [3]. 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 behaviour 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 [4]. 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, 3D16mm tensile reinforcement, 2ϕ8 mm 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 from. 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, which

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emits carbon dioxide gas (CO_2), which can cause a greenhouse effect, can also be reduced [5]. 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)[6], Kumar and Joy (2015)[7], Varghese *et al* (2016) [8], Dhinesh and Satheesh (2017) [9] and Parthiban and Neelamagem (2017) [10] have yet to investigated how hollows affect the shear capacity of beams

1.2 Objective of the Study

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.

2. LITERATURE REVIEW

2.1 Theoretical Bending Capacity

The stress diagram at the boundary conditions corresponds to the Whitney diagram, shown in Figure-2 [11]

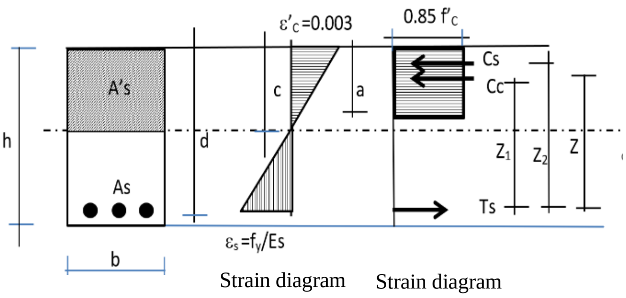

Figure-2. Strain and stress diagrams of reinforced concrete.

$Cc = 0.85\ f'_c.\ a.\ b$ and $Cs = As.\ fy$;

$Ts_1 = As_1.\ f_y$ and $Ts_2 = As_2.\ f_y$

$Cc = Ts$

$$a = \frac{As.fy}{0.85f'c.b} = \frac{602.97*481.78}{0.85*27.09*175} = 79.50\text{mm}$$

$$c = \frac{a}{\beta_1} = 92.35\text{mm}$$

2.2 The Height of Hollow Maximum (hmax)

Sketch of the cross section specimen can be seen at Figure-3.

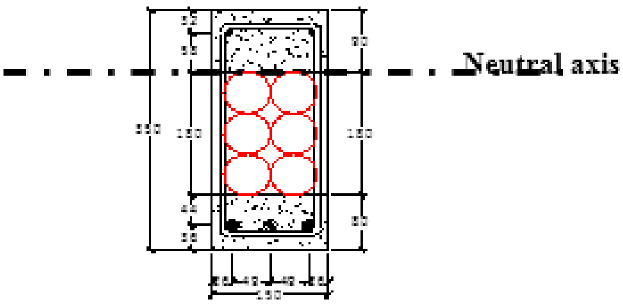

Figure-3. Height of hollow max.

h_{rmax} = h - 80 - c = 350 - 80 - 90 = 180 mm

2.3 Moment Capacity and Maximum Loads

Calculation of the capacity of the cross-section to carry out 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 burden as follows:

Mu = 1.4152 + 0.6 Pu

Pu = 156.3533 kN

2.4 Theoretical Shear Capacity

Intact reinforced concrete beams with 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

Vu = 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-1. 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

3. MATERIALS AND METHODS

3.1 Specimen and Material Properties

The length of beams was 3300 mm with 175×350 mm cross section, respectively. Effective height=314mm. The specimen used three of D16 steel bar as tensile reinforcement and two of φ8 steel bar reinforcement at the compression side for assembly purpose only. For shear

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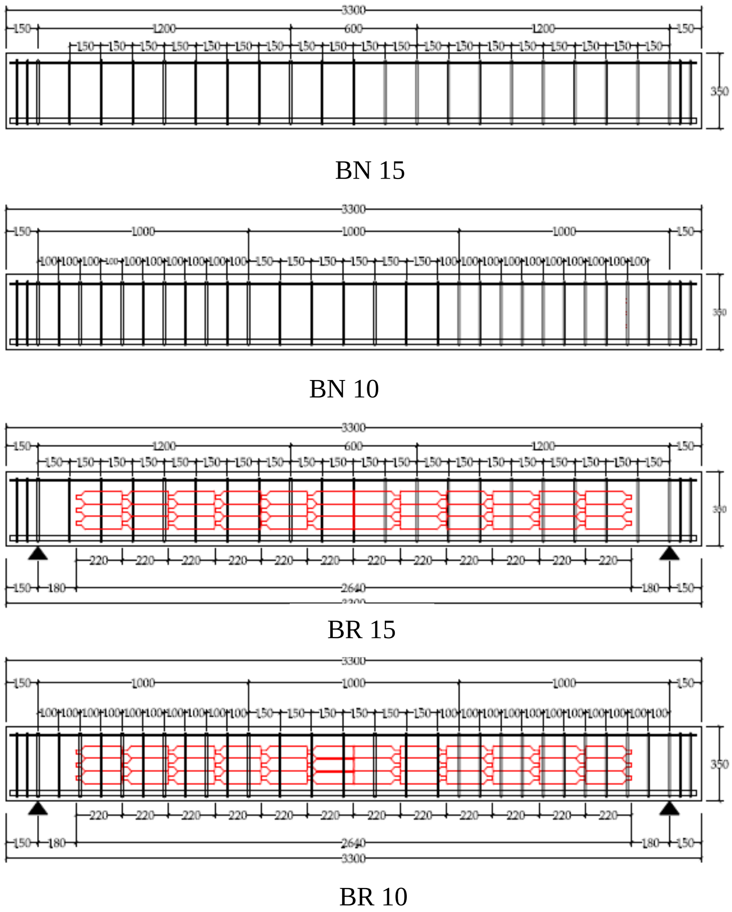
reinforcement used φ8-100mm in the support area and φ8-200 mm along the tested span.

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

Table-2. Number and notation of specimen.

No	Hollow Length Heght	Hollow Height	Distance of stirrup	Specimen Notation	No of sample
1	0 bottle (0 mm)	0 layer (0 mm)	150	BN-15	1
2	0 bottle (0 mm)	0 layer (0 mm)	100	BN-15	1
3	12 bottles (2640 mm)	3 layers (180 mm)	150	BR3-15	1
4	12 bottles (2640 mm)	3 layers (180 mm)	100	BR3-10	1

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.



BN 15

BN 10

BR 15

BR 10

Figure-4. Sketch of specimen.

3.2 Specimen Fabrication

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.

3.3 Test Setup

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.

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Figure-5. The test setup.

4. RESULTS AND DISCUSSIONS

4.1 Result of the Test

a. Weight of specimen

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.

Tabel-3. Weight of Specimen.

No	Type of Beam	Weight (kg)
1	BN - 10	482.0
2	BN - 15	459.8
3	BR -10	387.4
4	BR - 15	371.2

4.1.2 Shear Capacity

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

Table-4. Beam Shear Capacity.

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

4.1.3 Load - Deflection relationship

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

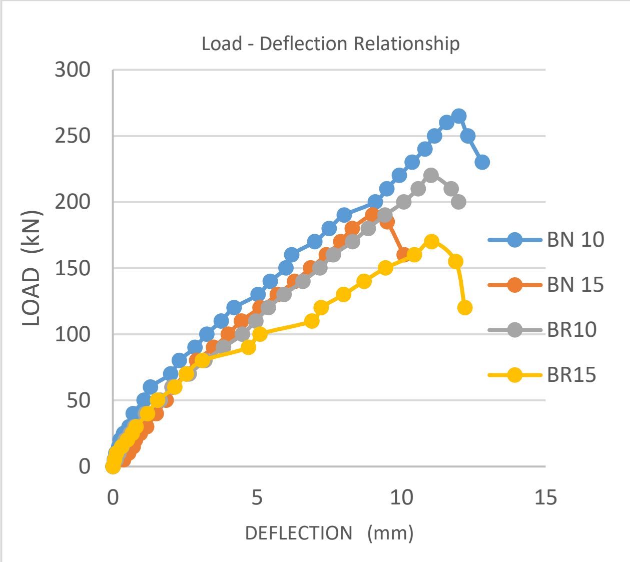

Figure-6. Load - deflection relationship.

4.2 DISCUSSIONS

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-5.

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%

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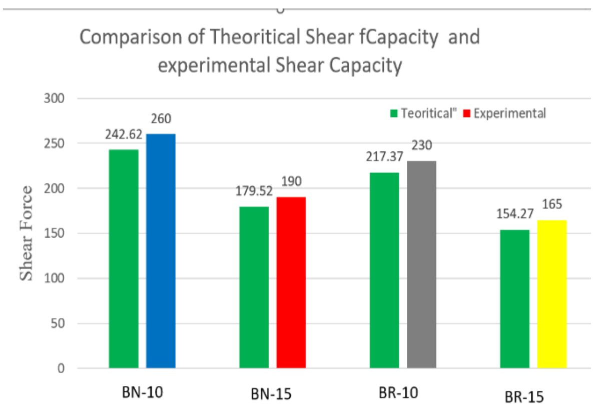

Figure-7. Comparison of the theoretical and experimental shear force.

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.

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

A comparison of the shear capacities of reinforced concrete beams intact and hollows can be seen in Table-6.

Table-6. 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-6 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

Table-7. Comparison of the shear capacity of the beam due to the difference in the spacing of the stirrups.

No	Jenis Balok	Kapasitas Geser (kN)	Selisih (%)
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%.

d. Ratio of shear strength and beam weight

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

Table-8 and Figure-8 show a comparison of the shear capacity and weight of the beam which can show the performance of the beam.

Table-8. 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

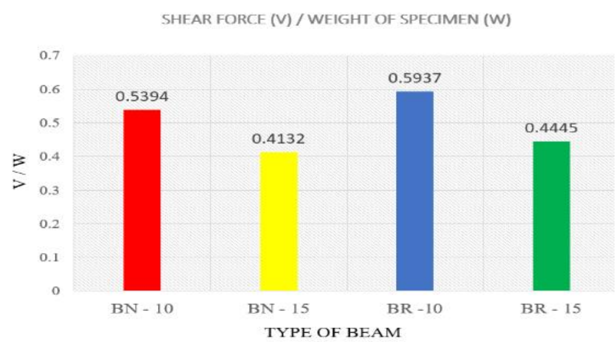

Figure-8. Performance of specimen.

Tables 8 and Figure-8 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 beam with a cavity height of 3 layers of bottles and a cavity length of 12 bottles. With a ratio of Mu/W = 0.263 [12]

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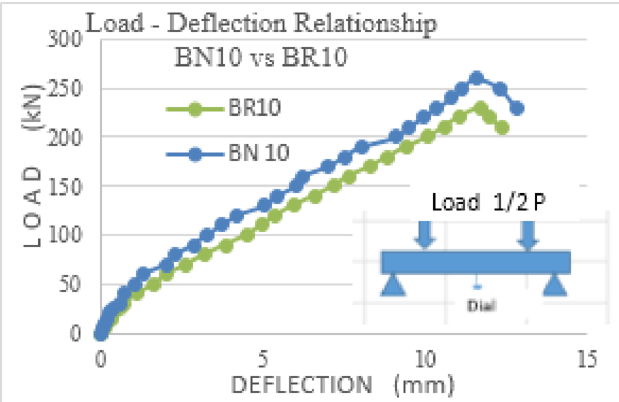
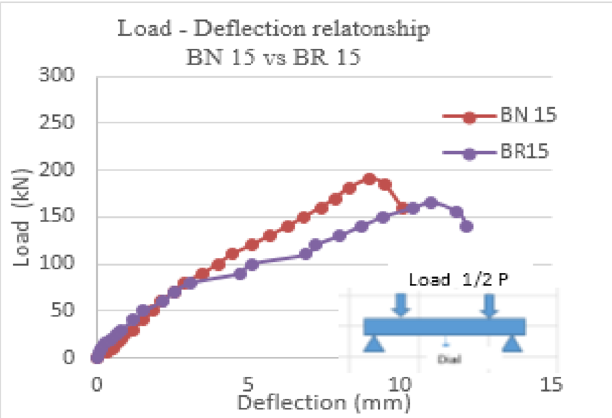
e. Load-Deflection relationship

A.. Graph of comparison of shear capacities of intact reinforced beams and hollow reinforced beams Here we will compare BN 10 with BR 10 and BN 15 with BR 15. The graphs can be seen in Figures 24 and 25



a. BN 10 Vs BR 10



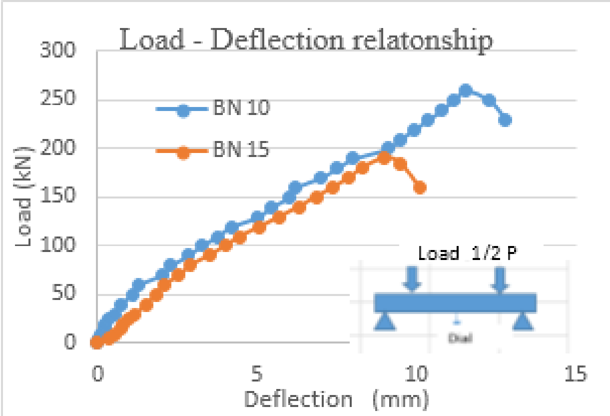
b. BN 15 Vs BR 15

Figure-9a, and b. Comparison Load and Deflection relationship Normal and Hollow RC Beam.

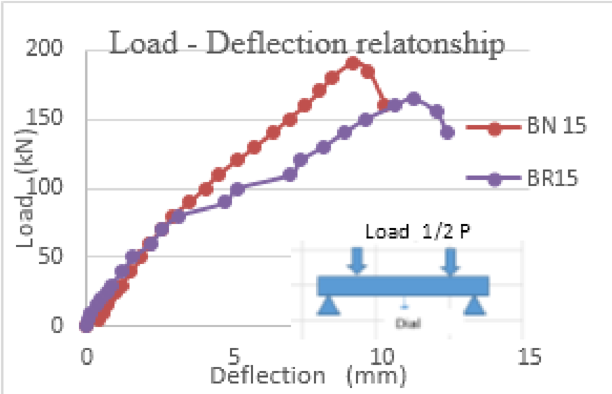
Both graphs in Figure-9 a and b show that the stiffness of reinforced concrete beams is better than that of hollow reinforced concrete beams with the same stirrup spacing.

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

Here we will compare BN 10 with BN15 and BR10 with BR 15. The graphs can be seen in Figures 10a and b.



a. BN 10 vs BN 15



b. BN 10 vs BN 15

Figure-10a and b. Comparison Load and Deflection relationship Effect distance of stirrup.

From Figure-10 a and b, 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

5. CONCLUSIONS

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

a) The theoretically calculated shear capacity of reinforced concrete beams is 6 - 7% smaller than experimental tests. The shear capacity of hollow reinforced beams is greater than that of similar beams.

b) 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.

c) 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

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

d) The performance of hollow reinforced concrete beams is better than that of intact reinforced beams. The best version of reinforced concrete beams is hollow reinforced concrete beams with a stirrup spacing of 10 cm.

e) 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 a 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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