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SHEAR STRESSES OF HOLLOW LIGHTWEIGHT CONCRETE BEAMS MADE WITH WOOD WASTE

SALAM SALMAN CHIAD ALHARISHAWI[1] , NAGHAM RAJAA[2], LINA ABDULSALAM SHIHAB[3]

Abstract: Hollow Lightweight Concrete (HLC) beams are gaining popularity due to low cost and low weight as compared with the Solid Lightweight Concrete (SLC) beams. HLC and SLC beams decrease in weight, without losing strength and durability. Flexural and shear behavior of reinforced HLC and SLC beams made with sawdust under two-point load is investigated in this study. The ultimate deformation efficiency and shear resistant mechanism of HLC beams are discussed experimentally and compared with other SLC beams. The beams, tested in this research, are rectangular. Beams were designed and constructed as 12 * 23 * 100 cm. Six concrete beam models were prepared including three SLC beams without the hollow and the other three HLC beams poured hollow 50 * 7.5 cm throughout the all beam of 100 cm. All beams were split according to the distance between vertical stirrups, these stirrups were divided into three specimens 45, 13, and 6 cm. By analyzing six experimental test beams, in this research, investigated the effect of diverse factors on the shear of beams. On comparison with normal concrete beams, this work describes the failure of mechanism, process, and ductility. The first crack loads, ultimate loads, load-deflection behavior, crack patterns and shapes of failure were investigated in this study. The experimental results show the ultimate performance of HLC beams are pure shear and controlled by yielding tension and compression steel bars. Also, it is found that the measured size and configuration of the hollow opening had an effect on the load-carry capacity and mid-span deflection of HLC beams. Thus, the design and construction details of beams can be additionally customized to reduce the total cost and weight of the HLC beams.

Keywords: Reinforced lightweight concrete, hollow beams, flexural behavior, shear behavior, cracks, hollow lightweight concrete (HLC), solid lightweight concrete (SLC).

[1] PhD., Eng., Mustansiriyah University, College of Engineering, Environmental Engineering Department, Baghdad, Iraq, e-mail: dr.salam.chiad@uomustansiriyah.edu.iq
[2] Assist Lecturer., Eng., Mustansiriyah University, College of Engineering, Highway and Transportation Engineering Department, Baghdad, Iraq, e-mail: Nagham_z77@uomustansiriyah.edu.iq
[3] Lecturer., Eng., Mustansiriyah University, College of Engineering, Civil Engineering Department, Baghdad, Iraq, e-mail: a.linaabdulsalam@uomustansiriyah.edu.iq

1. INTRODUCTION

With the growing economic, engineering structures often contain the unprecedented size, height, and span. Requirements for economic capacity and durability have pushed concrete towards becoming a multi-function material. The useful conditions of concrete have to meet the condition of lightweight concrete. Lightweight aggregate concrete is prepared by using sand, gravel, cement, wood waste and water. the density is less than 2200 kg/m^3 [1]. Lightweight aggregate concrete can considerably decrease the structural weight of building and the load of building elements. It can decrease loads, obtain the economic advantage, and better structural performance like strength, thermal insulation and ductility [2]. In the design of reinforced concrete bridge piers, the hollow section is approved to rise flexural rigidity and decrease the weight of piers. Shear behavior of solid reinforced concrete hunched (RCH) beams has been widely investigated in the past over loading [3-7]. Stefanou et al, 1983 achieved the shear behavior of beams with differ depth. Additionally, the research described the determination of the ultimate shear strength to beams with BS, ACI [5]. Tena et al, 2008 recognized the behavior of concrete beams subjected to shear loading. In comparison to the solid beams, hollow beams (or thin-walled box girders) are gaining more common in the industry because low cost and less weight [8]. With the important weight decrease, hollow beams have almost similar strength. Because of that reason, hollow beams have the ability of long-spanning lengths, which leads to an excessive amount of decrease in steel and concrete. Hollow bunched beams have been used for monorail bridge girders in the past few years [9-13].

By analyzing six test beams, the mainly aim of this research is to study the effect of different factors on the shear of beams, the flexural response of the HLC beams and SLC beams representing the structural details; the effects of the existence of hollow part of the HLC beams on flexural and behavior under load; the shear resistance mechanism of the HLC beams and SLC beams under combined shear and flexure. Also, the experimental results of this study, were compared with hollow normal weight concrete beams and solid normal weight concrete beams.

2. EXPERIMENTAL PROGRAM

In this study, reinforced concrete beams were made, using wood waste (Sawdust (SD)), sand as fine aggregate, gravel as coarse aggregate, reinforcing bars, box plastic with cement content (326) kg/m^3.

This experimental work explains the major details of materials used, characteristics, mixed details, and methods of testing used in this study.

2.1. MATERIAL PROPERTIES

- Cement: normal Portland cement from the northern cement manufacturing plant (Tasluja-Bazian) was utilized.
- Fine Aggregate: Natural sand was used in the experimental work as fine aggregate.
- Coarse Aggregate: The gravel must be clean and 100% crushed. Coarse aggregates got from the Al-Nibaee region.
- Wood Waste: Sawdust (SD) is also known as wood dust. It is the by-product of cutting or drilling wood with a saw or any other tool as shown in (Fig. 1).
- Reinforcing Bars: Ribbed longitudinal steel bars are used in this work with a nominal diameter of 12 mm, 16 mm and 6 mm as shown in (Fig. 2). The mechanical properties of steel bars in terms of average yield tensile strength, ultimate tensile strength and maximum elongation are given in Table 1.
- Plastic Box: Box plastic has been used plastic dimensions of 5 * 7.5 * 100 cm for the purpose of hollow concrete beams as shown in (Fig. 2).
- Mixing Water: Use of tap water to cast and cure all the specimens of the HLC beams and SLC beams.

Table 1. Mechanical Properties of Steel Bars

Diameter (Steel Bar) mm	Type of Bar	Yield Strength (fy) MPa	Ultimate Strength (fu) MPa	Maximum Elongation (%)
6	Round	443	474	28
12	Ribbed	617	731	20
16	Ribbed	516	613	18

Fig. 1. Wood Waste

Fig. 2. Photo Showing Reinforcing Bars with Plastic Box for Specimen

2.2. MIX DESIGN

Table 2.shows the concrete mix.

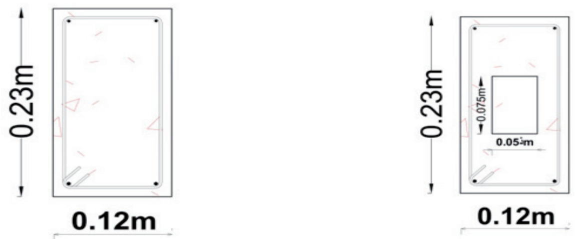
Table 2. Mix Proportions by Weigh

Mixture No.	Portland Cement (C),	Fine sand (F.S) (kg/m^3)	Coarse Aggregate (kg/m^3)	Wood Waste (kg/m^3)		Water (w) (kg/m^3)	w/c	Density (kg/m^3)
				Sand Replacement of Wood Waste (%) by weight	Sawdust			
Group 2	326	440	978	10%	49	163	0.5	1956

2.3. MOULDS AND SPECIMENS DESCRIPTION

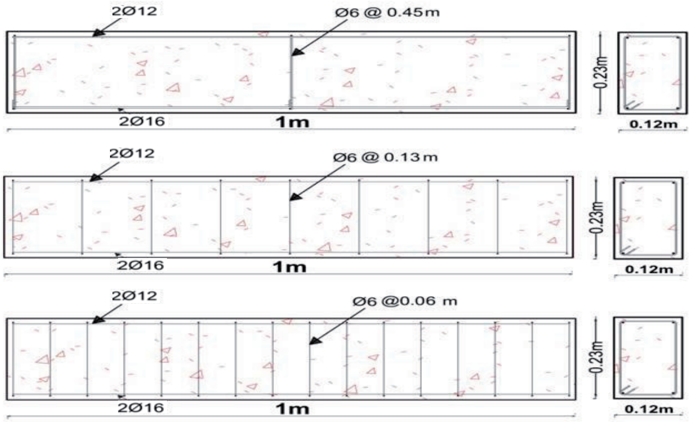
Specimens used are reinforced HLC beams having a cross-section of width * full depth = 23 * 12 cm. In the center of the section of these specimens, the hollow part 7.5 * 5 cm is organized.

Specimens without a hollow section called SLC beams were also made for comparison. The details of the cross-section of these specimens are shown in (Fig. 3) and all dimensions are in mm. The average cube compressive strength (*fcu*) of normal concrete was equal to (30 MPa) and (23 MPa) for lightweight concrete. All beams were deformed into steel reinforcing bar with (12 mm and 16 mm) diameter used longitudinal reinforcement top and down. And reinforcing bar with (6 mm) diameter vertical stirrups were arranged at the spacing of 45, 13, 6 cm as shown in (Figures 4 and 5) and all dimensions are in mm.

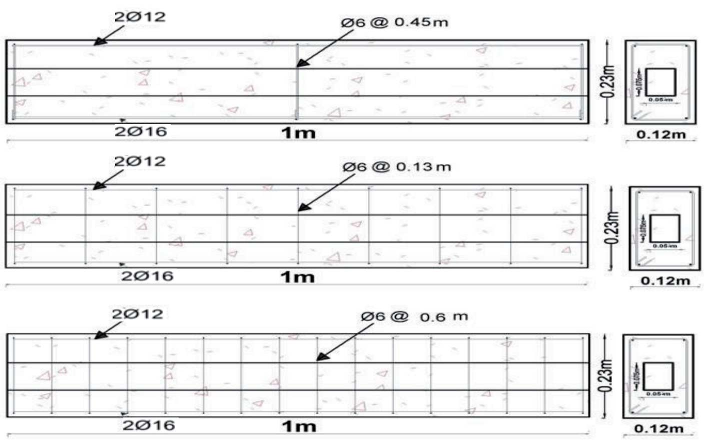


a. Solid Lightweight Concrete Beam b. Hollow Lightweight Concrete Beam

Fig.3. Sectional Details of Beam [Cross Section]: a) SLC Beam and b) HLC Beam

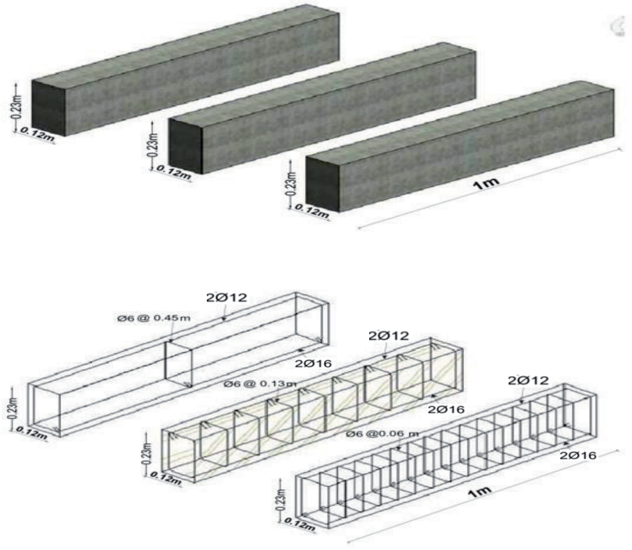


a. Solid Lightweight Concrete Beam

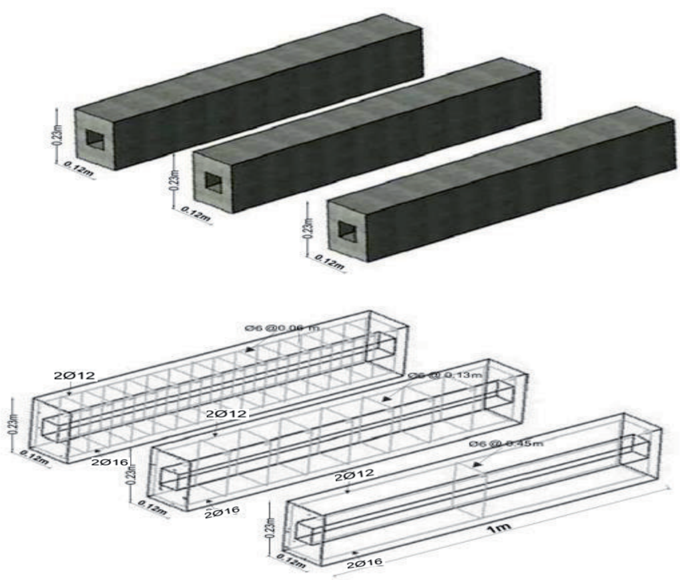


b. Hollow Lightweight Concrete Beam

Fig. 4. Elevation Details of Beam [Cross Section] (2- Dimensions): a) SLC Beam and b) HLC Beam



a. Solid Lightweight Concrete Beam



b. Hollow Lightweight Concrete Beam

Fig. 5. Elevation Details of Beam [Cross Section] (3- Dimensions): a) SLC Beam and b) HLC Beam

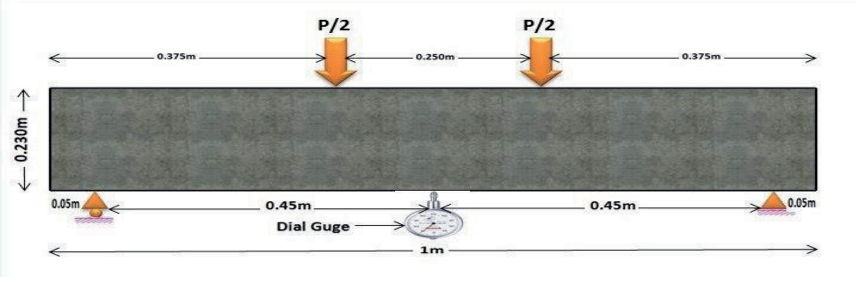
2.4. PREPARATION OF SPECIMENS (MIXING, CASTING, COMPACTING AND CURING PROCEDURE)

All test specimens were prepared at the lab. Steel bars were properly bent and anchored with stirrups to prepare steel cage of beams as shown in Fig. 5. Plastic box was used to create an internal opening in all beams. For this purpose, the Plastic box was properly cut into the desired shape and placed inside a steel cage as shown in figure 2. Also, a special formwork was fabricated before the casting to ensure the proper dimensions of beams. Mixed concrete was used to cast all hollow HLC beams and SLC beams. After 24 hours, beams were removed from the formwork and properly cured for 28 days in water. Standard cube concrete specimens (150 * 150 mm) were also cast to obtain compressive strength of the concrete at testing age and then tested as shown in (Fig. 6).

Fig. 6. HLC Beams out of the Water

3. TEST SETUP AND INSTRUMENTATION DETAILS

In order to accurately observe the structural responses of the HLC beams and SLC beams, one dial gauge (ELE type) and (30 mm) capacity was installed under the beam at the middle to recorded downward deflection as shown in (Fig. 7). The load was applied using the hydraulic universal testing machine (MFL system) to test HLC beams and SLC beams specimens as well as control specimens. One end of the beam was supported over the hinged support whereas the second end of the beam was supported over the roller support.



a. Side View of Beam

b. Universal Testing Machine (MFL System)
Fig. 7. Test Instrumentation: a) Side View and b) Universal Testing Machine

4. ANALYSIS RESULTS

4.1. GENERAL

In this study, six reinforced lightweight concrete beams specimens were tested. The beams were identical in length, width and thickness, but different in steel reinforcement bar with (6 mm) diameter vertical stirrups were arranged at the spacing of 45 cm, 13 cm, 6 cm as web reinforcement. six reinforced lightweight concrete beams models including three SLC beams without a hollow (S 45 LWC, S 13 LWC, S 6 LWC) and the other three HLC beams poured cavity 5 x 7.5 cm along the Al-beam of 100 cm (O 45 LWC, O 13 LWC, O 6 LWC). According to these variables, ultimate loads, crack patterns as well, as shapes of failure, are different from each beam to another. Beams were divided according to the distance vertical stirrups bar reinforcement (6 mm diameter) and hollow were divided into six specimens, (S 45 LWC, S 13 LWC, S 6 LWC) and (O 45 LWC, O 13 LWC, O 6 LWC).

4.2. MECHANICAL PROPERTIES (CRACK PATTERNS, FIRST CRACK LOADS, ULTIMATE LOADS)

The experimental test results of cracking and ultimate loads are described in Table 3. The load was applied to the HLC beams and SLC beams specimens, the first cracks formed at about (17.4 - 29.5) % of the ultimate load for the beam specimens.

For beams models including three SLC beams without a hollow (S 45 LWC, S 13 LWC, S 6 LWC), The values of the first crack load (Pcr) are (12.5, 13.5 and 14.5) kN, and other three HLC beams (O 45 LWC, O 13 LWC, O 6 LWC) are (13, 15 and 17) kN respectively.

The value Ultimate Load (Pu) for three SLC beams (S 45 LWC, S 13 LWC, S 6 LWC) were (56, 75 and 83) kN, but Ultimate Load (Pu) for three HLC beams (O 45 LWC, O 13 LWC, O 6 LWC) were (44, 55 and 64) kN.

For beams models including three SLC beams (S 45 LWC, S 13 LWC, S 6 LWC), and three HLC beams (O 45 LWC, O 13 LWC, O 6 LWC), the flexural cracks widened drastically after yielding of steel reinforcement and the concrete in the compression zone crushes finally, shown in (Fig. 8). all these test results from less than about 15%, when compared with the six reinforced normal weight concrete beams [9].

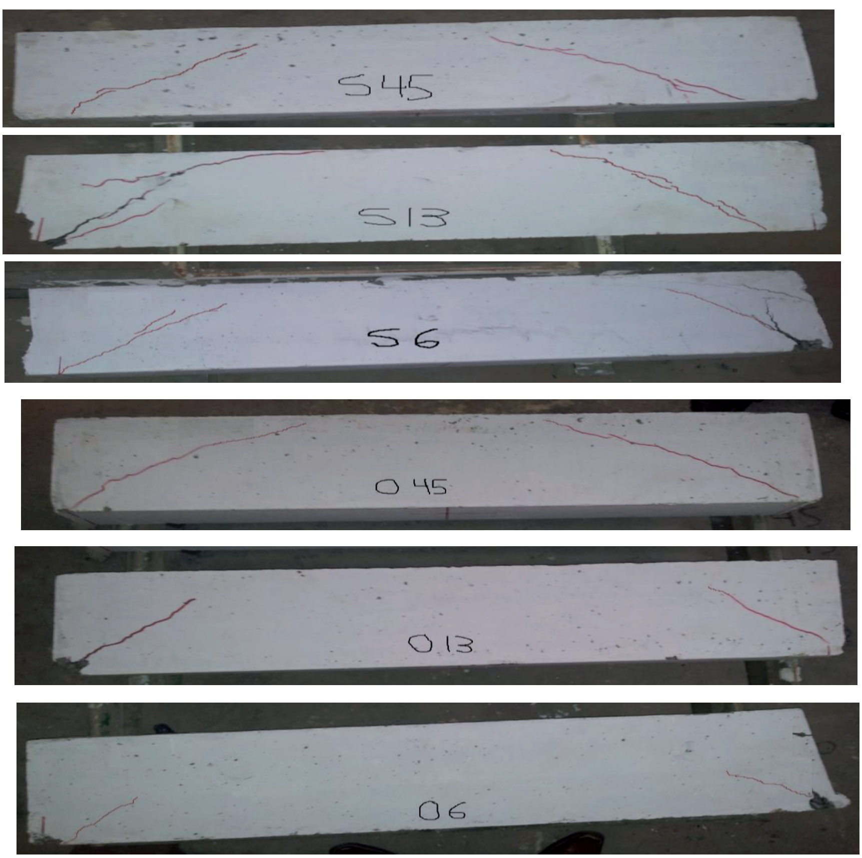


Fig. 8. Crack Patterns at Ultimate Failure (HLC Beams and SLC Beams)

Table 3. First Crack and Ultimate Loads (HLC Beams and SLC Beams)

Group Name	Beam Designation	f_{cu} (MPa)	First Crack Load (P_{cr}) (kN)	Ultimate Load (P_u) (kN)	$\frac{P_{cr}}{P_u}$ (%)
Solid Lightweight Concrete Beam	S 45 LWC	23	12.5	56	22.3
	S 13 LWC	22.5	13.5	75	18
	S 6 LWC	22	14.5	83	17.4
Hollow Lightweight Concrete Beam	O 45 LWC	22.5	13	44	29.5
	O 13 LWC	21.5	15	55	27.3
	O 6 LWC	23	17	64	26.5

4.3. ULTIMATE LOADS

- The experimental results of ultimate loads to all beams as listed in Table 4 show that the ultimate loads for HLC beams (O 45 LWC, O 13 LWC, O 6 LWC), were less strength than the ultimate loads for SLC beams (S 45 LWC, S 13 LWC, S 6 LWC) respectively, shown in (Fig. 9). As shown in Figures 10 and 11, the compared between lightweight concrete beams and normal weight concrete beams [9].
- The distance vertical stirrups bar reinforcement (6 mm diameter) decreases the ultimate loads for all beams (SLC beams and HLC beams) increase shown in (Fig. 12 and 13). As shown in Figures 14 and 15, the comparison between lightweight concrete beams and normal weight concrete beams [9].
- The reductions in the ultimate loads for solid beams (S 45 LWC, S 13 LWC, S 6 LWC), are about (average 25) % smaller than the ultimate loads of hollow beams (O 45 LWC, O 13 LWC, O 6 LWC), respectively, shown in (Fig. 9).

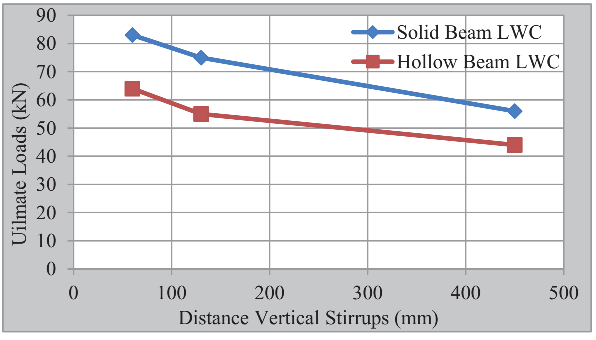


Fig. 9. Ultimate Load-Distance Vertical Stirrups Bar Reinforcement (6, 13, 45) cm Relationships for Lightweight Concrete Beam with Solid and Hollow Beam.

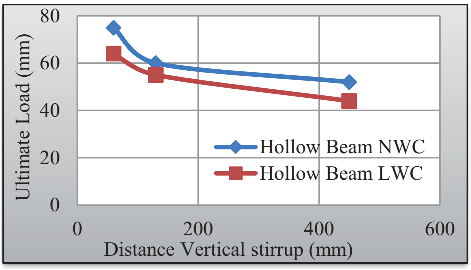


Fig. 10. Ultimate Load-Distance Vertical Stirrups Bar Relationships for Hollow Beams Between Lightweight Concrete and Normal Concrete

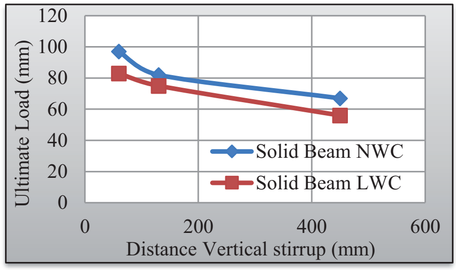


Fig. 11. Ultimate Load-Distance Vertical Stirrups Bar Relationships for Solid Beams Between Lightweight Concrete and Normal Concrete

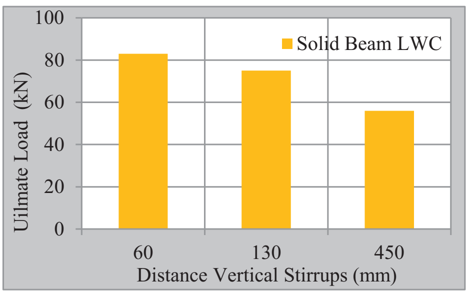


Fig. 12. Ultimate load-Distance Vertical Stirrups Bar Reinforcement Relationships with Solid Lightweight Concrete Beam.

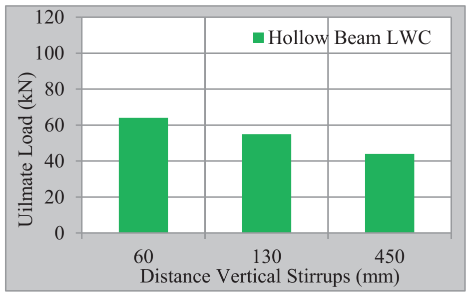


Fig. 13. Ultimate Load-Distance Vertical Stirrups Bar Reinforcement Relationships with Hollow Lightweight Concrete Beam.

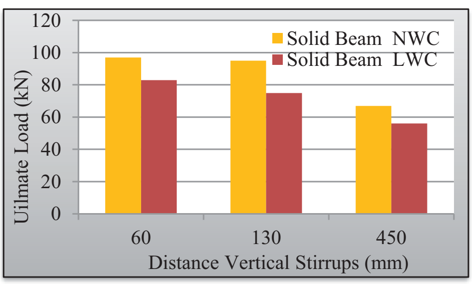


Fig. 14. Ultimate Load-Distance Vertical Stirrups Bar Reinforcement Relationships with Solid Lightweight Concrete and Normal Concrete Beam.

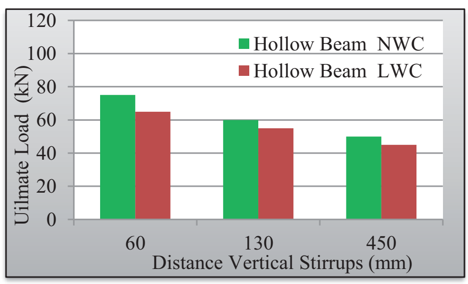


Fig. 15. Ultimate load-Distance Vertical Stirrups Bar Reinforcement Relationships with Hollow Lightweight Concrete and Normal Concrete Beam.

4.4. LOAD-DEFLECTION RELATIONSHIPS

The deflection experimental results of SLC beams and HLC beams are showed in Table 4. The experimental test results presented that for SLC beams the maximum deflection at ultimate load occurs when the distance vertical stirrups bar reinforcement (6 mm diameter) equals 6 cm, while the minimum deflection at 45 cm, similar to the HLC beams. (Figures 16 and 17) show the load-deflection relationships for the beams (SLC beams and HLC beams). As shown in Figures 18 to 23, the comparison between lightweight concrete beams and normal weight concrete beams [9].

Table 4. The Deflection Value at First Crack and Ultimate Loads

Group Name	Beam Designation	Deflection at First Crack (mm)	Deflection at Ultimate Load (mm)
Solid Lightweight Concrete Beam	S 45 LWC	0.07	1.7
	S 13 LWC	0.08	1.83
	S 6 LWC	0.09	2.78
Hollow Lightweight Concrete Beam	O 45 LWC	0.09	1.8
	O 13 LWC	0.1	2.3
	O 6 LWC	0.11	3.4

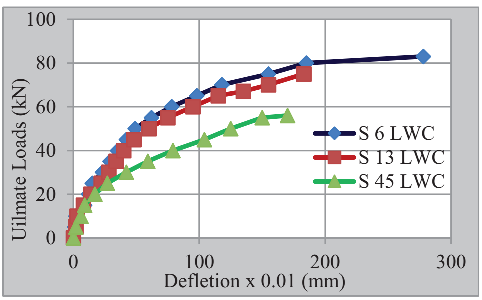


Fig. 16. Load-Deflection Relationships for Solid Lightweight Concrete Beam (S 6, S 13, S 45)

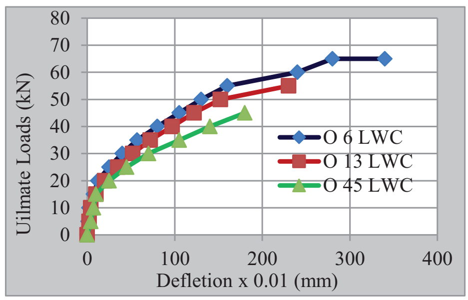


Fig. 17. Load-Deflection Relationships for Hollow Lightweight Concrete Beam (O 6, O 13, O 45)

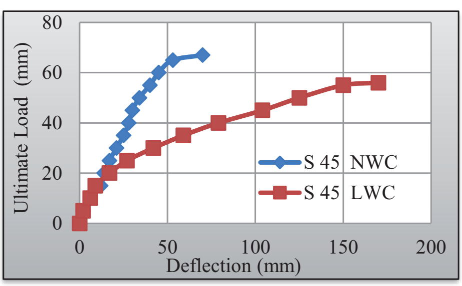


Fig. 18. Load-Deflection Relationships for Solid Lightweight and Normal Concrete Beam (S 45)

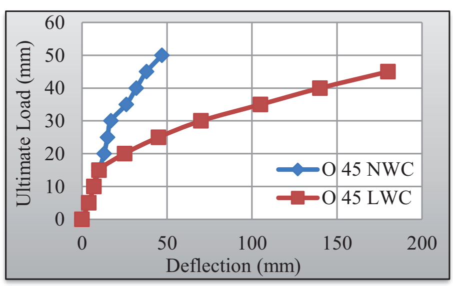


Fig. 19 Load-Deflection Relationships for Hollow Lightweight and Normal Concrete Beam (O 45)

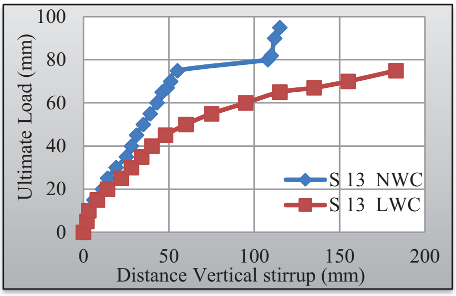


Fig. 20. Load-Deflection Relationships for Solid Lightweight and Normal Concrete Beam (S 13)

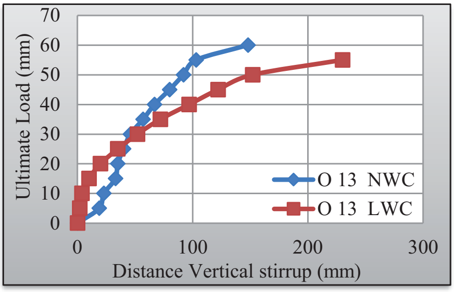
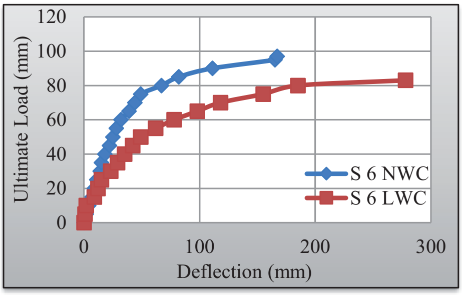


Figure 21. Load-Deflection Relationships for Hollow Lightweight and Normal Concrete Beam (O 13)



Fig, 22. Load-Deflection Relationships for Solid Lightweight and Normal Concrete Beam (S 6)

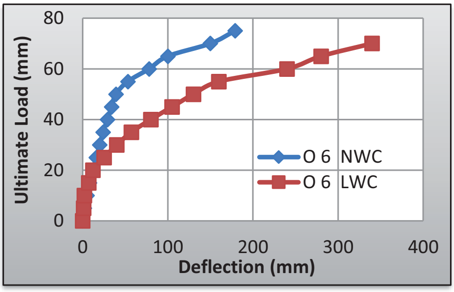


Fig.23. Load-Deflection Relationships for Hollow Lightweight and Normal Concrete Beam (O 6)

5. CONCLUSIONS

This research presents the results of an experimental investigation conducted on reinforced HLC beams. A total number of six reinforced lightweight concrete beams were constructed and tested under a two-point bending scheme. Research parameters included the size and configuration of the reinforced HLC beams. The ultimate deformation capacities are compared with those of the reinforced SLC beams without the hollow part. The shear resistance mechanism of HLC beams and SLC beams is discussed by mainly on the deterioration of concrete shear resistance. Based on test observations, the following conclusions are drawn:

1- The HLC beams represent the details of the failed beam at an ultimate load of 44, 55, 64 kN and corresponding midspan deflection of 0.09, 0.1, 0.11 mm. The load versus deflection response was a pure flexural and the ultimate failure was mainly due to the crushing of the concrete at the compression zone.

2- The experimental results also proved that the configuration of the hollow opening had a negligible effect on the load-carrying capacity and mid-span deflection of hollow HLC beams.
3- The yielding of both tension and compression longitudinal steel bars weren't observed in all HLC beams. However, tensile and or compressive yielding of vertical stirrups was observed in any HLC beam. This is an indication that HLC beams in shearing cracks have failed.
4- The HLC beams and SLC beams maximum deflection at ultimate load happens when the distance vertical stirrups bar reinforcement is minimum.
5- The distance vertical stirrups bar reinforcement (6 mm diameter) decreases the ultimate loads for all HLC beams and SLC beams.

The limitations persist and hence future research is required in the area. More studies should extend to other parts of the building (columns and slabs).

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LIST OF FIGURES AND TABLES:

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