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Experimental Study For The Behavior Of Flanged Lightweight Concrete Beams Under Combined Stresses

Ahmed Awad[1]*, Ahmed Deifalla[2],Hosam Seleem[3],Amr Abdelrahman[4]
1 Research Assistant, Structural Engineering Department, Ain Shams University, Cairo, EGYPT
2Associate Professor, Department of Structural Engineering and Construction Management,Future University in Egypt, Cairo, Egypt
3 Professor, properties and Strength of Materials, Building National Research Center, Cairo, EGYPT
4Professor, Concrete Engineering Department, Ain Shams University, Cairo, EGYPT
*Corresponding author: *Ahmed Awad*

ABSTRACT:*This paper presents an experimental investigation for the behavior of flanged reinforced lightweight concrete (LWC) under combined stresses. LWC was obtained through the use of polystyrene foam as a partial aggregate's replacement to reduce the concrete dry unit weight from 23.0 kN/m3 to 18.1 kN/m3. The experimental work was consisted from two phases; The first phase quantified the mechanical properties of lightweight concrete; namely the compressive and tensile strengths as well as the tension stiffening capability of the concrete mix and The second phase was concerned with testing specimens of LWC beams (L and T-shaped) under combined stresses for determination of the ultimate resistance, mode of failure, ultimate angle of twist, and load-deflection curve for all tested beams.The experimental program consisted of ten full scale T &L beams with cross-section of (150 x 400 mm.).T-sections having a width of slab 550 mm and slab thickness of 150 mm with varying spans (1200 and 450 mm). L-sections having a width of slab 350 mm and slab thickness of 150 mm with varying spans (1200 and 450 mm).The main variables of this study were the span to depth (a/d) ratio, and load eccentricity. The observed behavior of the light weight concrete specimens up to failure greatly encourages the use of light weight concrete in all structural elements. The shear resistance increases with the decrease of (a/d) ratio. When the ratio of a/ddecrease from 3.5 to 1.2 the shear failure loads increases by ratio 40 %.*
KEYWORDS*— Light-weight concrete; Beams; Combined Stresses; T and L-beams; (a/d) ratio; Load Eccentricity*

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I. INTRODUCTION

Structural lightweight concrete mixtures can be designed to achieve similar strengths as normal weight concrete. The same is true for other mechanical and durability performance requirements. Structural lightweight concrete provides a more efficient strength-to-weight ratio in structural elements. In most cases, the marginally higher cost of lightweight concrete is offset by size reduction of structural elements, less reinforcing steel and reduced volume of concrete, resulting in lower overall cost could have impact on the design of the foundations. Use of reduced unit weight concrete could also lead to great advantages for the precast industry by reducing the transportation cost. Furthermore, the reduced mass will reduce the lateral load that will be imposed on the structure during earthquakes, hence simplifying and reducing the lateral load carrying system.

Therefore, the latter material can be produced using standard methods familiar to the construction industry with a dry unit weight of 18 KN/m3, which in turn leads to dead load reduction by 15 – 20 % and the associated decrease in the structure's overall cost, hence, providing a feasible challenge to normal density concrete (NDC) with a dry unit weight of 25 KN/m3. Shear and flexural behavior of R.C. beams has been frequently investigated over the last decades due to the several parameters affecting the concrete shear and flexural resistance.

The study of shear resistance in the case of T and L-beams is limited. In design codes such as ACI Building Code and the Euro code, shear force in a T and L-beams is assumed to be carried only by its web. This simplified assumption, which has prevailed in the shear design practice, requires more investigation, especially in the case of using Light-weight concrete, (LWC) mixes.

II. EXPERIMENTALPROGRAM

Test specimens

The performed experimental work consisted of ten light weight concrete T &L beams. The beams were fixed supported from only one end and free supported from the other end. The beams were tested under the effect of one concentrated load acting at the free end with different load eccentricity. According to the shape of beam cross section (T or L-beam), the beams were divided into two groups G1, and G2 as shown in Table I & Fig.1a and Fig.1b.

Table I: Details of the Tested Specimens

Group	Specimen	Type	Steel Reinforcement	Effective Span(a) mm	(a/d) Ratio	Eccentricity (e) mm
G1	TB	NWC	3Ø16 at the bottom of the web, and 5Ø10+3Ø16 in the flange	1300	3.5	50
	TB-3.5-5	LWC		1300	3.5	50
	TB-3.5-15	LWC		1300	3.5	150
	TB-1.2-5	LWC		450	1.2	50
	TB-1.2-15	LWC		450	1.2	150
G2	LB	NWC	3Ø16 at the bottom of the web, and 3Ø10+3Ø16 in the flange	1300	3.5	50
	LB-3.5-5	LWC		1300	3.5	50
	LB-3.5-15	LWC		1300	3.5	150
	LB-1.2-5	LWC		450	1.2	50
	LB-1.2-15	LWC		450	1.2	150

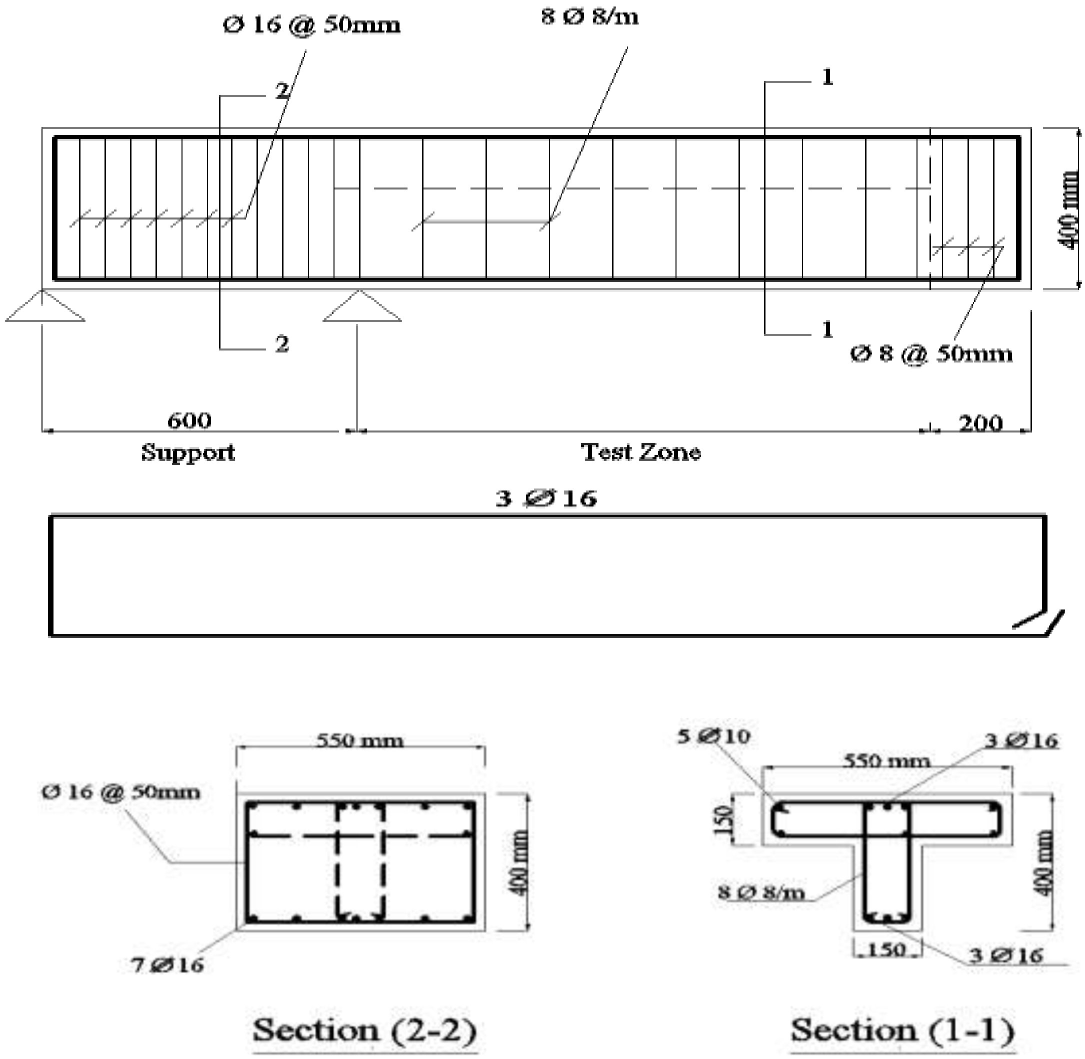

Fig.1a Typical dimensions and reinforcement of group G1

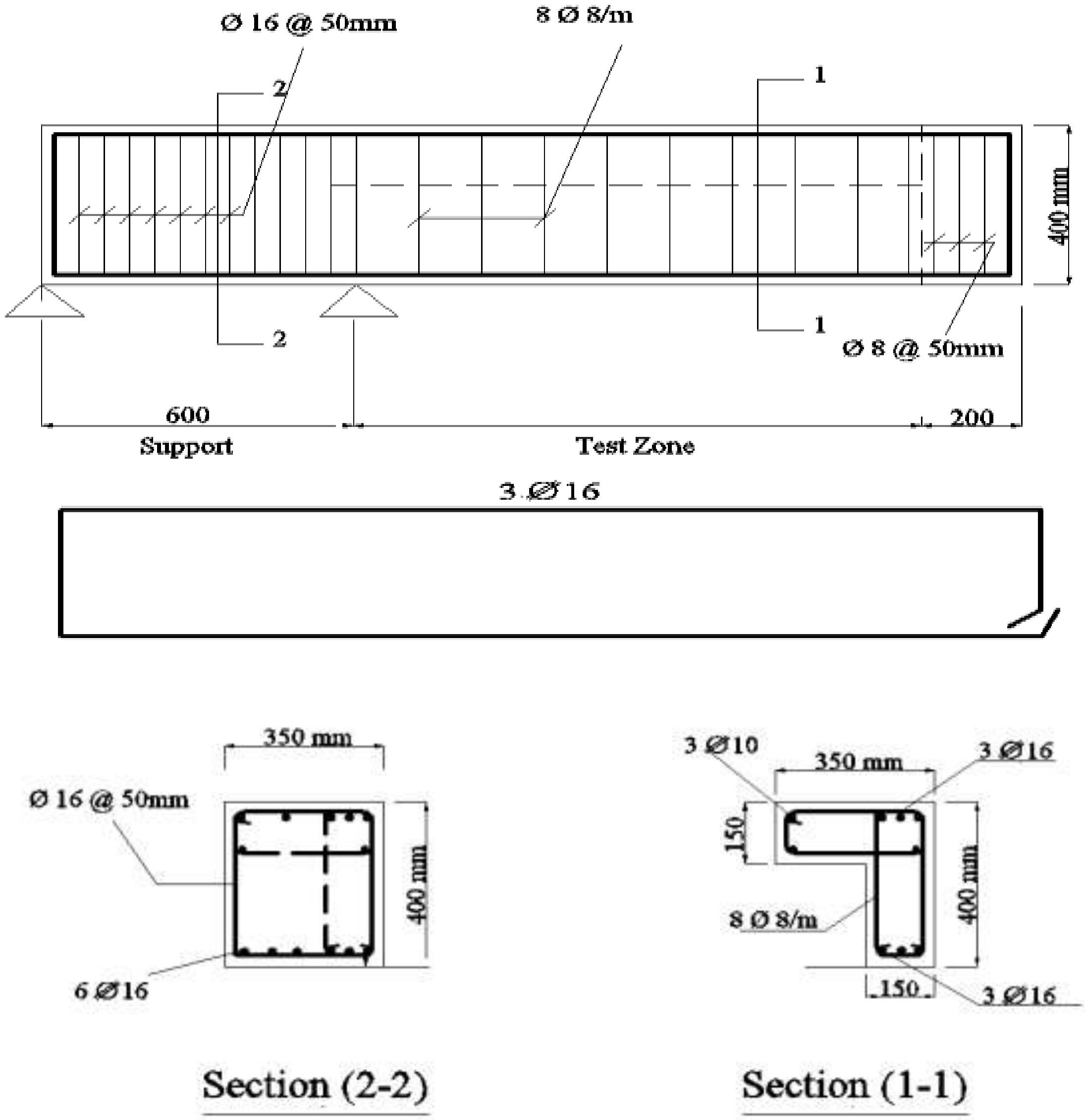

Fig.1b Typical dimensions and reinforcement of group G2

Mix Composition

From the mix design, the quantities required by weight for one cubic meter of fresh concrete for the L.W.C specimens are as given in Table II. The longitudinal reinforcement for the beams were high-grade steel bars (fy=400 N/mm2). Table III shows the mechanical properties of L.W.C mix.

Table II: Material Quantities in kg/m3 for The LWC Specimens

Materials	Cement Kg/m^3	Sand Kg/m^3	Gravel Kg/m^3	w/c ratio	Super-Plasticizer $Liter/m^3$	Silica fume Kg/m^3	Polystyrenes Foam $Liter/m^3$	Fiber Polypropylenes $(gm/m^{3)}$
Quantity	450	630	630	0.308	13.5	40	330	900

Table III: Mechanical Properties of Tested LWC Mix

Concrete strength (Kg/cm2)	**Cube strength(Kg/cm2)**		**Cylindrical compressive strength (Kg/cm2) after 28 days**
	7 days	**28 days**	
350	253	356	287

Test procedure

The specimens were tested by using a hydraulic jack. At the beginning of each test, the specimen was installed as a beam with cantilever. The tested zone included the cantilever only and the other zone was very rigid (acting as fixed support) as illustrated in Fig.2. The reading of the hydraulic jacks and the steel strain gauges were taken by special instruments.

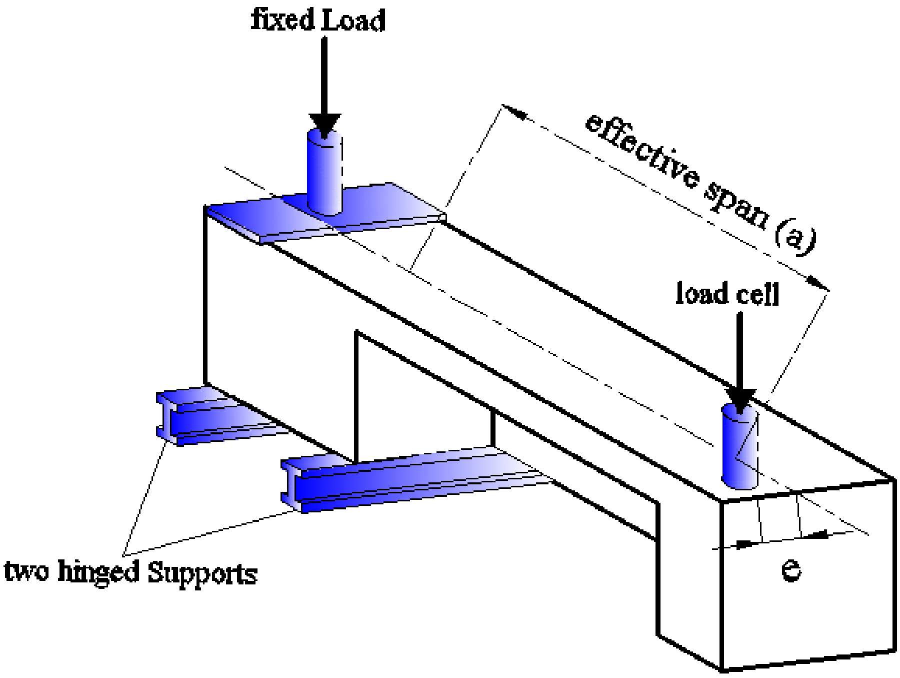

Fig.2 Test setup

III. EXPERIMENTAL RESULTS AND DISCUSSION

The ten tested models behaved in a different manner and the following remarks were noticed:

Crack Pattern and Failure Mode of Tested Beams

At the end of testing each beam, the marked crack pattern was used to provide necessary information required for defining the failure mechanism of each specimen. Fig.3 through Fig.12 show the failure mode of all the tested specimens. From the figures, for specimens with (a/d) ratio equal to 3.5, the specimens experienced the formation of vertical cracks near support and then fine cracks diagonally started in critical shear zones; left and right sides of beam span. With the extension of the cracks in the beam under higher load increments, the final failure mode was characterized by shear failure or flexure failure.For specimens with (a/d) ratio equal to 1.2, the specimens experienced the formation of fine cracks diagonally near the acting load and then fine cracks vertically started in critical flexure zones. With the extension of the cracks in the beam under higher load increments, the final failure mode was characterized by shear compression failure. Table IV shows flexural cracking, shear cracking and failure loads for all tested beams.

Table IV: Failure and Cracking loads due to flexure, shear, and torsion

Group	Specimen	Failure load (KN)	Shear and torsion Cracking load (KN)	Moment Cracking load (KN)	Failure Mode
G1	TB	120	60	30	tension flexure failure
	TB-3.5-5	110	50	25	tension flexure failure
	TB-3.5-15	100	45	25	compression failure due to shear, torsion, and moment
	TB-1.2-5	180	80	100	compression failure due to shear
	TB-1.2-15	130	67	90	compression failure due to shear and torsion
G2	LB	97	51	25	compression failure due to shear and moment
	LB -3.5-5	86	45	22	compression failure due to shear and moment
	LB -3.5-15	79	40	22	compression failure due to shear, torsion, and moment
	LB -1-5	145	65	80	compression failure due to shear
	LB -1-15	110	55	70	compression failure due to shear and torsion

a) Left Side b) Right Side

c) Top Side

Fig.3 Failure Mode for Specimen TB

a) Left Side b) Right Side

c) Top Side

Fig.4 Failure Mode for Specimen TB-3.5-5

a) Left Side b) Right Side

c) Bottom Side

Fig.5 Failure Mode for Specimen TB-3.5-15

a) Left Side b) Right Side

Fig.6 Failure Mode for Specimen TB-1.2-5

b) Left Side b) Right Side

Fig.7 Failure Mode for Specimen TB-1.2-15

a) Left Side b) Right Side

Fig.8 Failure Mode for Specimen LB

a) Left Side b) Right Side

c) Bottom Side

Fig.9 Failure Mode for Specimen LB-3.5-5

a) Left Side b) Right Side

c) Bottom Side

Fig.10 Failure Mode for Specimen LB-3.5-15

a) Left Side b) Right Side

Fig.11 Failure Mode for Specimen LB-1.2-5

a) Left Side b) Right Side

Fig.12 Failure Mode for Specimen LB-1.2-15

The study of experimental results indicates that the load carrying capacity at different levels for each beam increases with the decrease of (a/d) ratio. The following points can be made:-

- By using specimen (TB-1.2-5) with a/d ratio equal to 1.2, it was found that the ultimate load has increased 39% more than the specimen (TB-3.5-5) with a/d ratio equal 3.5.
- By using specimen (LB-1.2-5) with a/d ratio equal to 1.2, it was found that the ultimate load has increased 41% more than the specimen (LB-3.5-5) with a/d ratio equal to 3.5.
- By using specimen (TB-1.2-15) with a/d ratio equal to 1.2, it was found that the ultimate load has increased 15.4% more than the specimen (TB-3.5-15) with a/d ratio equal to 3.5.
- By using specimen (LB-1.2-15) with a/d ratio equal to 1.2, it was found that the ultimate load has increased 28.2% more than the specimen (LB-3.5-15) with a/d ratio equal to 3.5.

The comparison of the results for the specimen s in groups G1 with specimens of group G2 indicates that the flange width contributes significantly to the shear carrying capacity of LWC beams at different levels. The comparative study highlights the following points:

- By using specimen (TB-3.5-5), it was found that the ultimate load has increased 21% more than specimen (LB-3.5-5).
- By using specimen (TB-1.2-5), it was found that the ultimate load has increased 19% more than specimen (LB-1.2-5).
- By using specimen (TB-3.5-15), it was found that the ultimate load has increased 21% more than specimen (LB-3.5-15).
- By using specimen (TB-1.2-15), it was found that the ultimate load has increased 15.4% more than specimen (LB-1.2-15).

The experimental results indicates that the load carrying capacity at different levels for each beam decreases with the increase of load eccentricity. The following points can be made:-

- By using specimen (TB-3.5-15) with load eccentricity 15cm, it was found that the ultimate load has decreased 9% more than specimen (TB-3.5-5) with load eccentricity 5cm.
- By using specimen (LB-3.5-15) with load eccentricity 15cm, it was found that the ultimate load has decreased 8.2% more than specimen (LB-3.5-5) with load eccentricity 5cm.
- By using specimen (TB-1.2-15) with load eccentricity 15cm, it was found that the ultimate load has decreased 28% more than the specimen (TB-1.2-5) with load eccentricity 5cm.
- By using specimen (LB-1.2-15) with load eccentricity 15cm, it was found that the ultimate load has decreased 24% more than the specimen (LB-1.2-5) with load eccentricity 5cm.

Deflections

During testing of each Specimen, the deflection at the end of the effective span (at the free end) was measured at the end of each load increment. The measured load-deflection curve are shown in Fig.13a and Fig.13b. From the figure, the following points are made:

- The load deflection curves for the tested Specimens were nearly linear at the early stages of loading from zero up to the first crack. The great decrease in stiffness due to excessive cracking had resulted in relatively great increase in the deflection values, approaching the failure load, the deflection continued to increase even with the applied load being maintained constant.
- The deflections of specimens at the same load were inversely proportional to the slab width. For beam specimens TB-3.5-5, TB-3.5-15, TB-1.2-5 and TB-1.2-15 have slab width 550mm (T-section), the vertical deflection decreased by about 42%, 41%, 50% and 43% respectively than that for LB-3.5-5, LB-3.5-15, LB-1.2-5 and LB-1.2-15 having L- section with slab thickness 350mm at the same load.
- Using LWC speeds up the cracking process, decreases the beam stiffness at different levels, and consequently increases the measured deflection. For specimen TB-3.5-5 which was casted using LWC, it was found that the vertical deflection increased by about 54% more than control specimen TB at the same load. For specimen LB-3.5-5 which was casted using LWC, it was found that the vertical deflection increased by about 44% more than control specimen LB at the same load.
- Increasing load eccentricity leads to an increase in the applied shear stresses due to torsion on the specimen from the left side. Therefore, the cracks increase and widen up more and rapidly leading to a depression in the stiffness of the specimen cross section and increasing in the deflection values.For specimens in G1,it was found that the vertical deflection in specimens TB-3.5-15 and TB-1.2-15 who have load eccentricity equal to 15cm, increased by about 21% and 49% more than specimens TB-3.5-5 and TB-1.2-5respectively who have load eccentricity equal to 5cm at the same load. For specimens in G2, it was found that the vertical deflection in specimens LB-3.5-15 and LB-1.2-15 who have load eccentricity equal to 15cm, increased by about 20% and 64% more than specimens LB-3.5-5 and LB-1.2-5 respectively who have load eccentricity equal to 5cm at the same load.

Stirrup Strains

Fig.14a and Fig.14b shows the measured load-stirrups strain curves till failure for the specimens in groups G1and G2. From the figure, the following two observations are made:

- The steel strains in stirrups were inversely proportional to the slab width. For beam specimens TB-3.5-5, TB-3.5-15, TB-1.2-5 and TB-1.2-15 have slab width 550mm (T-section), the strains in stirrups decreased by about 56%, 55%, 89% and 49% respectively than that for LB-3.5-5, LB-3.5-15, LB-1.2-5 and LB-1.2-15 having L- section with slab thickness 350mm at the same load.

- The recorded stirrup strain indicates that the strain value at different levels for each specimendecreases with the decrease of (a/d) ratio. This is because a significant portion of the shear transmitted directly to the support by an inclined strut in case of small (a/d) ratio. This mechanism is frequently referred to as arch action and the magnitude of the direct load transfer increases with decreasing a/d-ratios. This mechanism prevents cracks widening and yielding of stirrups. For specimens in G1,it was found that the strain at vertical stirrup in specimens TB-3.5-5 and TB-3.5-15 who have a/d ratio equal to 3.5, increased by about 86% and 71% more than specimens TB-1.2-5 and TB-1.2-15 respectively who have a/d ratio equal to 1.2 at the same load. For specimens in G2,it was found that the strain at vertical stirrup in specimens LB-3.5-5 and LB-3.5-15 who have a/d ratio equal to 3.5, increased by about 78% and 75% more than specimens LB-1.2-5 and LB-1.2-15 respectively who have a/d ratio equal to 1.2 at the same load.
- Increasing load eccentricity leads to an increase in the applied shear stresses due to torsion on the specimen from the left side. Therefore, the cracks processing speeds up leading to a depression in the stiffness of the specimen cross section and increasing in the stirrup strain values. For specimens in G1, it was found that the strain in vertical stirrup in specimens TB-3.5-15 and TB-1.2-15 who have load eccentricity equal to 15cm, increased by about 48% and 90% more than specimens TB-3.5-5 and TB-1.2-5 respectively who have load eccentricity equal to 5cm at the same load. For specimens in G2, it was found that the strain in vertical stirrup in specimens LB-3.5-15 and LB-1.2-15 who have load eccentricity equal to 15cm, it was found that the strain in vertical stirrup increased by about 31% and 75% more than specimens LB-3.5-5 and LB-1.2-5 respectively who have load eccentricity equal to 5cm at the same load.

Longitudinal Steel Strain

Fig.15a and Fig.15b shows the measured load-upper Longitudinal steel strain curves till failure for the beams in groups G1and G2. From the figure, the following two observations are made:

- For specimens with a/d ratio equal to 3.5, Increasing load eccentricity had no significant effect on the upper longitudinal steel bars. These additional torsion stresses effects the shear behavior of the specimen which is resisted mainly by stirrups. For specimens TB-3.5-5 and LB-3.5-5 who has load eccentricity equal to 5cm, it was found that the strain at longitudinal steel bars approximately the same as specimens TB-3.5-15 and LB-3.5-15 respectively who has load eccentricity equal to 15cm at the same load.
- For specimens with a/d ratio equal to 1.2, it was found that increasing load eccentricity had significant effect on the behavior of the specimenswhere the cracks processing sped up and strain in steel bars increased after excessive cracks. The strain at longitudinal steel bars for specimensTB-1.2-15 and LB-1.2-15 increased by about 39%and 60% more than specimens TB-1.2-5 and LB-1.2-5 respectively at the same load.

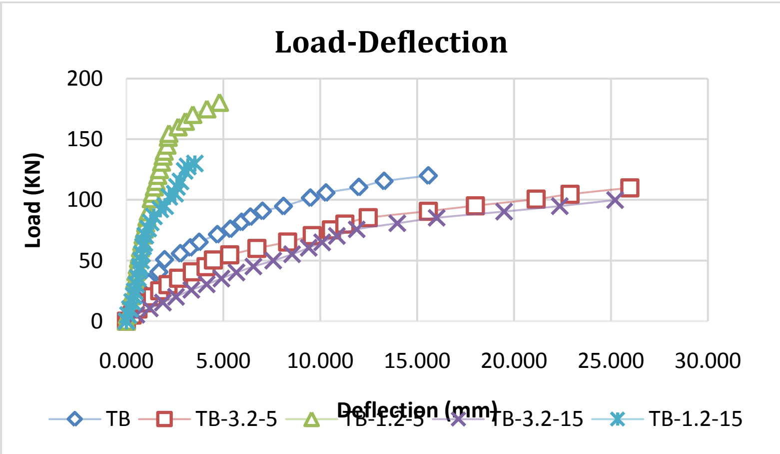

Fig.13a: Load-Deflection Curve for G1 Specimens

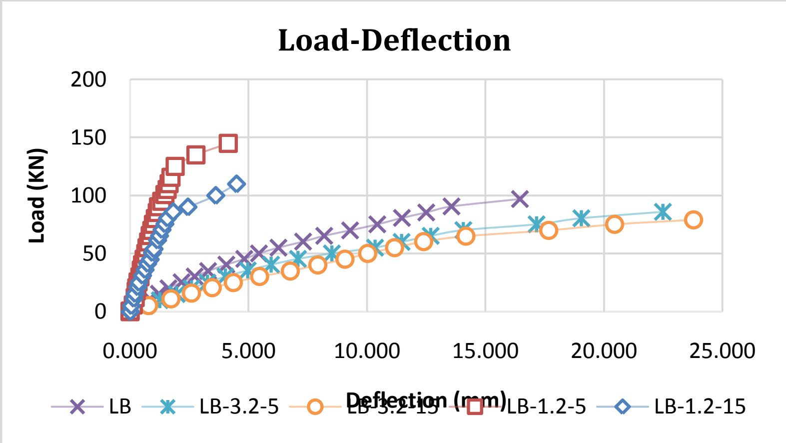

Fig.13b: Load-Deflection Curve for G2 Specimens

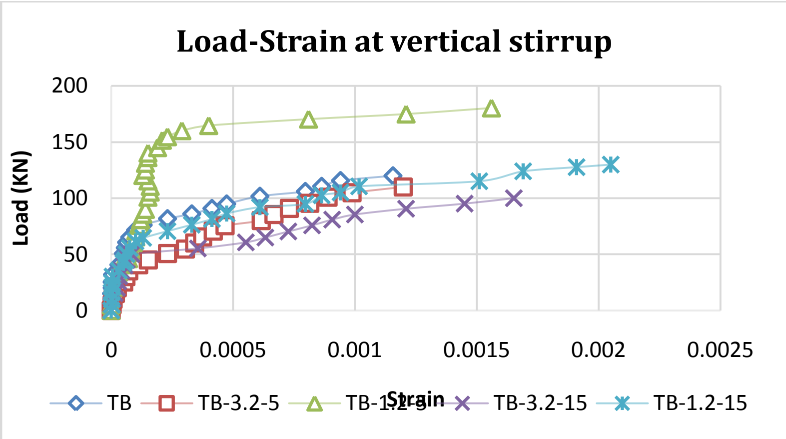

Fig.14a: Load-Strain at Vertical Stirrup Curve for G1 Specimens

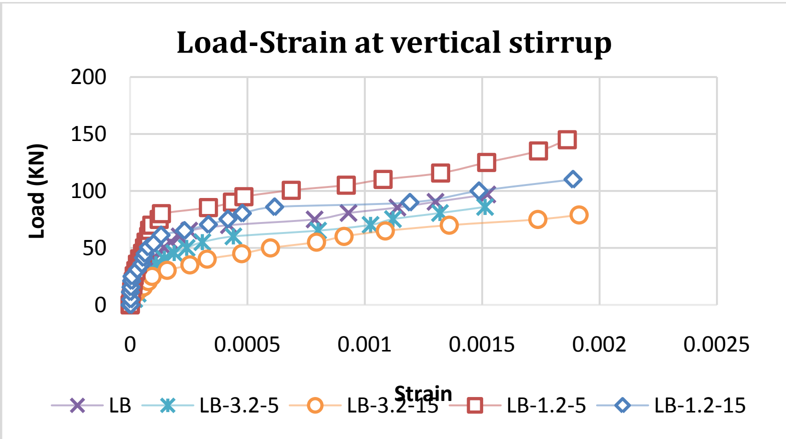

Fig.14b: Load-Strain at Vertical Stirrup Curve for G2 Specimens

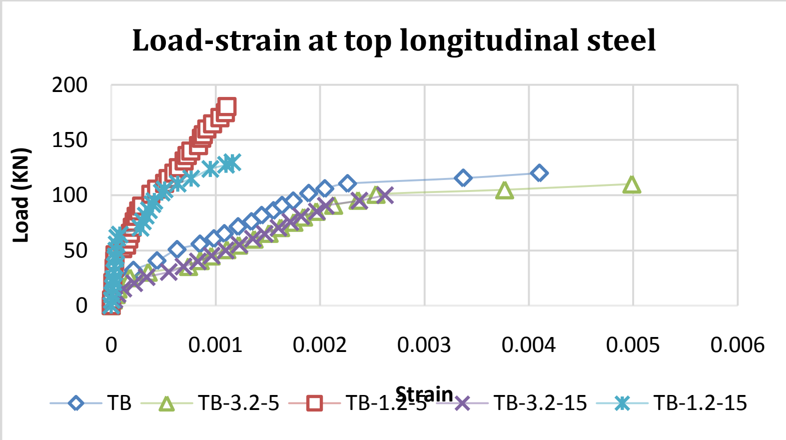

Fig.15a: Load-Strain at Upper Longitudinal Steel Curve for G1 Specimens

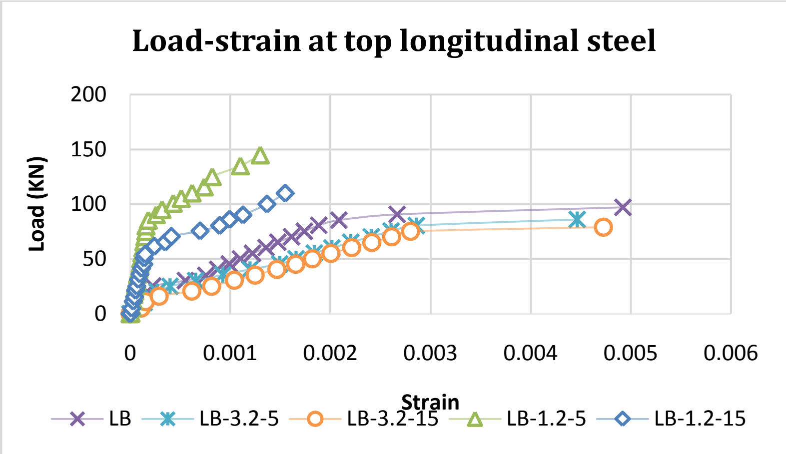

Fig.15b: Load-Strain at Upper Longitudinal Steel Curve for G2 Specimens

IV. CONCLUSIONS

1-Using LWC speeds up the cracking process, decreases the beam stiffness, and consequently increases the measured deflection at the same load compared with NWC.

2- The failure modes of light weight concrete specimens are similar to normal weight concrete specimens.

3- The failure modes of light weight concrete specimens with T-section are similar to light weight concrete specimens with L-section.

4-Increasing the slab width contributed to increase the shear resistance, where the shear failure loads for T-beams increased by about 20 % more thanL-beams.

5- The shear resistance decreases with the increase of load eccentricity. When the load eccentricity increases by 10cm, the shear failure loads decreases by ratio 9 % for specimens with a/d ratio equal to 3.5, and 25% for specimens with a/d ratio equal to 1.2.

6- The shear resistance increases with the decrease of (a/d) ratio.When the span to depth (a/d) decreases from 3.5 to 1.2, the shear failure loads increases by ratio 40% for specimens with load eccentricity equal to 5cm, and 20% for specimens with load eccentricity equal to 15cm.

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