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Effect of Using Lightweight Concrete on the Behavior of L and T- 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
2 Associate 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
4 Professor, Concrete Engineering Department, Ain Shams University, Cairo, EGYPT

ملخص البحث

شهد إستخدام الخرسانة خفيفة الوزن ازديادا كبيرا في الاونة الاخيره لما لها من فوائد ومزايا عديدة سواء من حيث قدرتها العاليه علي العزل الحراري, أو من حيث جدواها الإقتصادية نظرا لخفة وزنها مما يقلل من التكلفة الإجمالية للمنشآت التي يتم استخدامها فيها. كما ان تخفيض وزن الخرسانة له مردود ايجابي في صناعة الخرسانة الجاهزة وتقليل تكلفة المناولة والنقل. وقد تم هذا البحث بهدف التحقق من سلوك الخرسانة خفيفة الوزن عن طريق الاستبدال الجزئي للركام بحبيبات البوليسترين لخفض وزن وحده الخرسانه الجافه من 23 كيلونيوتن/متر3 الي 18.1 كيلونيوتن/متر3.

وفقا لذلك ، تم تنفيذ برنامج عملي شمل على مرحلتين. المرحلة الأولى تتضمن التعرف على بعض الخواص الميكانيكية لـلخرسانه خفيفه الوزن وهي تحديدًا الكثافة والضغط ومقاومة الشد. المرحلة الثانية تضمنت اختبار4 كمرات ذات الشفه خفيفه الوزن التي تم إختبارها تحت إجهادات مركبه للتعرف علي سلوك الكمرات.

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 lightweight and normal-weight concrete 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 four full scale T & L beams with cross-section of (150 x 400 mm.). Two T-sections having a width of slab 550 mm and slab thickness of 150 mm, span of 1300 mm, load eccentricity of 50mm, with varying material type (LWC, and NWC). Two L-sections having a width of slab 350 mm and slab thickness of 150 mm, span of 1300 mm, load eccentricity of 50mm, with varying material type (LWC, and NWC).The main variables of this study were the material type, and the shape of cross section. The observed behavior of the light weight concrete specimens up to failure greatly encourages the use of light weight concrete in all structural elements.

Keywords— Light-weight concrete; Beams; Combined Stresses; T and L-beams; Normal-Weight Concrete

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 weight concrete (NWC) 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 design of reinforced concrete members under combinations of bending, torsion, and shear continues to be a complex problem despite the availability of data on the behavior of members under individual loadings. Several investigators have explored the field over the past decades, testing and reporting several hundreds of beams, but the problem is far from solved. In particular, the design engineer requires further information on the behavior of concrete elements under combined loadings to enable him to proceed confidently in the design of more economical and aesthetically pleasing structures.

II. EXPERIMENTAL PROGRAM

Test specimens

The performed experimental work consisted of four 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
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

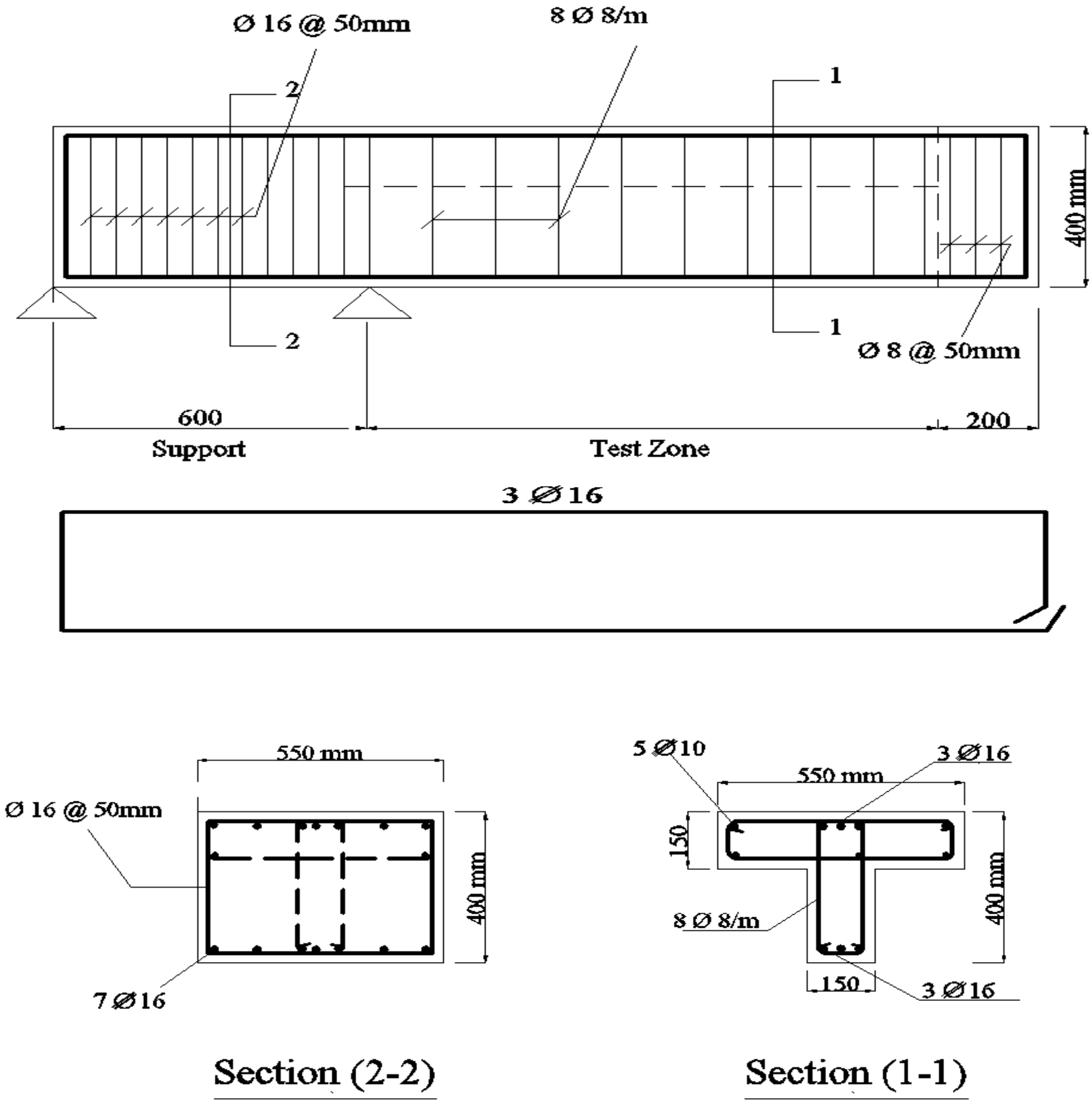


Fig.1a Typical dimensions and reinforcement of group G1

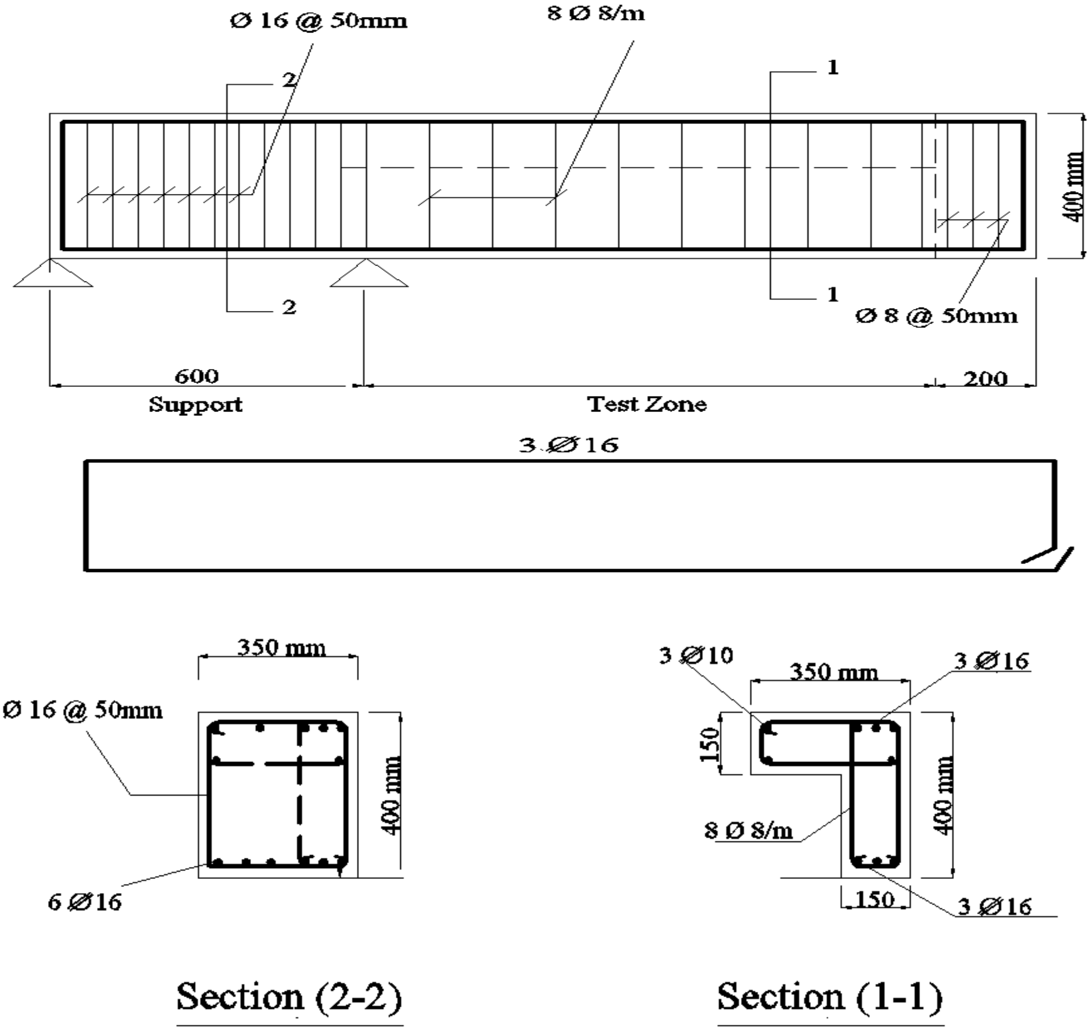


Fig.1b Typical dimensions and reinforcement of group G2

Mix Composition

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

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; Material Quantities in kg/m3 for The NWC Specimens

Materials	Cement Kg/m^3	Sand Kg/m^3	Gravel Kg/m^3	Water Liter	w/c ratio
Quantity	460	935	820	205	0.45

Table IV, and V shows the average the values of the obtained results for lightweight and normal weight concrete mix respectively.

Table IV: 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

Table V: Mechanical Properties of Tested NWC Mix

Concrete strength *(Kg/cm2)*	**Cube strength *(Kg/cm2)***		**Cylindrical compressive strength *(Kg/cm2)* after 28 days**
	7 days	**28 days**	
350	257	357	290

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.

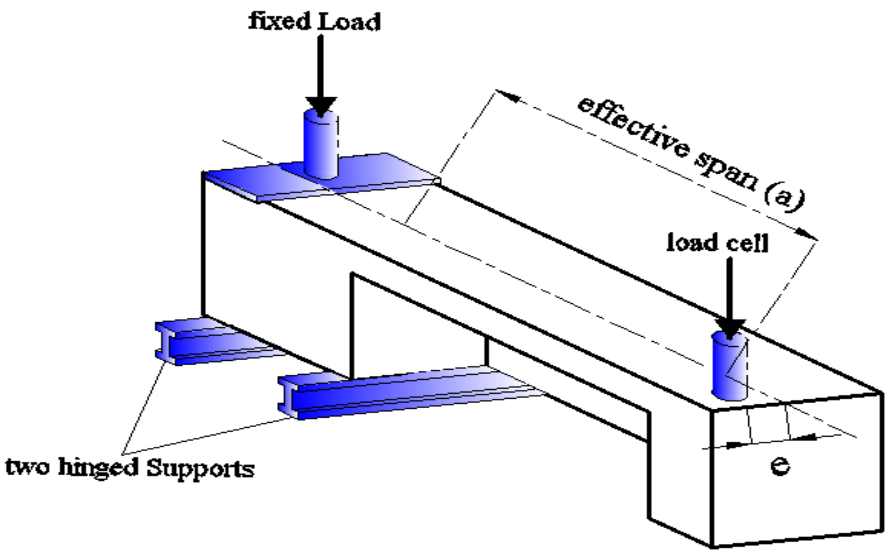


Fig.2 Test setup

III. EXPERIMENTAL RESULTS AND DISCUSSION

The four 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.6 show the failure mode of all the tested specimens. From the figures, 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 combined shear and flexure failure or flexure failure only. Table VI shows flexural cracking, shear cracking and failure loads for all tested beams.

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

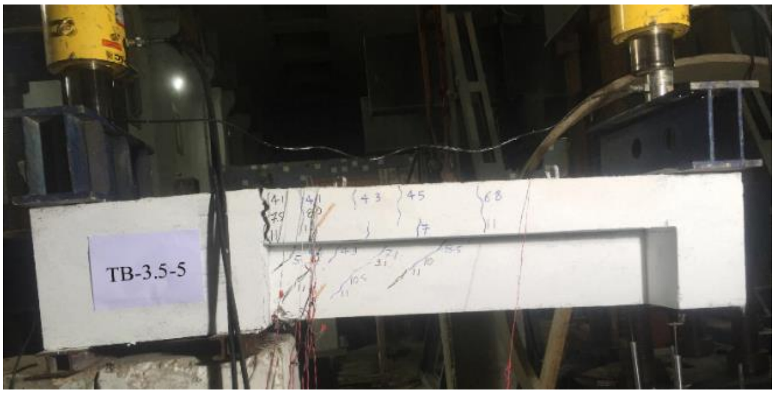
Group	**Specimen**	**Failure load (KN)**	**Shear and torsion Cracking load (KN)**	**Moment Cracking load (KN)**	**Failure Mode**
G1	TB	120	60	30	tension flexure failure
	TB-3.5-5	110	50	25	tension flexure failure
G2	LB	97	51	25	compression failure due to shear and moment
	LB -3.5-5	86	45	22	compression failure due to shear and moment

a) Left Side

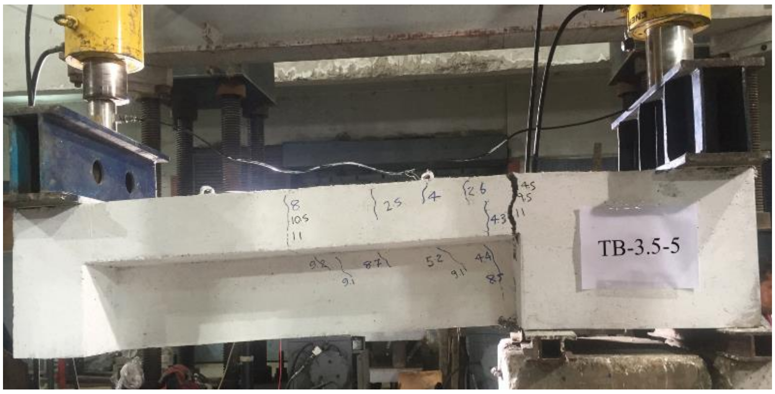
b) Right Side

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

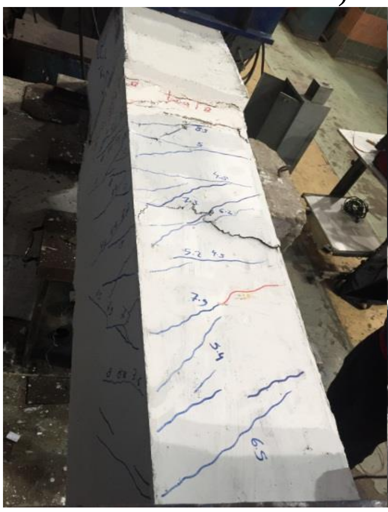
c) Top Side

d) Bottom Side

Fig.5 Failure Mode for Specimen LB

a) Left side

b) Right side



c) Top Side

d) Bottom Side

Fig.6 Failure Mode for Specimen LB-3.5-5

The following load behavior was observed in the experiment:

By using lightweight concrete (TB-3.5-5), it was found that the ultimate load has decreased 8.3% more than the control specimen TB which casted using normal weight concrete. The ability to sustain inelastic deformations for specimen (TB-3.5-5) decreased by approximately 5.6% more than the control specimen.

By using lightweight concrete (LB-3.5-5), it was found that the ultimate load has decreased 8.2% more than the control specimen LB which was casted using normal weight concrete. The ability to sustain inelastic deformations for specimen (LB-3.5-5) decreased by approximately 8% more than (LB) specimen.

From these results, the following conclusions can be made:

Cracking patterns and failure modes were similar for LWC and NWC specimens, which where a typical cases of flexure tension failures for TB and TB-3.5-5 Specimens. Also, LB and LB-3.5-5 had typical compression failures due to compressive stresses.

The crack width increased in case of using LWC and a minor depression in the ultimate strength was observed. This is because of Existence of foam on LWC mixture decreases the contribution of aggregate interlock to shear strength and increases the crack width.

Using lightweight concrete instead of normal weight concrete resulted in a rapid widening in the shear cracks, increasing in the ultimate deformation, and finally decreasing in the ultimate failure load.

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.7a and Fig.7b. 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, and TB-3.5-5 who have slab width 550mm (T-section), the vertical deflection decreased by about 35%, and 42% respectively than that for LB, and LB-3.5-5 who 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.

Stirrup Strains

Fig.8a and Fig.8b shows the measured load-stirrups strain curves till failure for the specimens in groups G1 and G2. From the figure, the following two observations are made:

- For specimen TB-3.5-5 which was casted using LWC, it was found that the strain in vertical stirrup increased by about 28% more than control specimen TB at the same load. This is because the cracks increase and widen up more and rapidly in case of using LWC leading to a depression in the stiffness of the specimen cross section. Therefore, the stirrups become more effective on resisting the shear stresses due to shear and torsion and the probability of stirrups to reach yield for specimen TB-3.5-5 is rapid more than control specimen TB.

- For specimen LB-3.5-5 which was casted using LWC, it was found that the strain in vertical stirrup increased by about 25% more than control specimen LB at the same load. This is because the cracks increase and widen up more and rapidly in case of using LWC leading to a depression in the stiffness of the specimen cross section. Therefore, the stirrups become more effective on resisting the shear stresses due to shear and torsion and the probability of stirrups to reach yield for specimen LB-3.5-5 is rapid more than control specimen LB.

Longitudinal Steel Strain

Fig.9a and Fig.9b shows the measured load-upper Longitudinal steel strain curves till failure for the beams in groups G1 and G2. From the figure, the following two observations are made:

- The measured strain values were insignificant before concrete cracking. After concrete cracking, the strain in the steel bars started increasing which shows that the steel bars became effective after cracking.
- For specimen TB-3.5-5 which was casted using LWC, it was found that the strain at longitudinal steel bars increased by about 53% more than control specimen TB at the same load. This is because the flexural cracks initiate and widen up rapidly for LWC more than NWC. This leads to a depression in the stiffness of the specimen cross section and the steel bars become more effective on resisting the normal stresses due to moment.
- For specimen LB-3.5-5 which was casted using LWC, it was found that the strain at longitudinal steel bars increased by about 60% more than control specimen LB at the same load. This is because the flexural cracks initiate and widen up rapidly for LWC more than NWC. This leads to a depression in the stiffness of the specimen cross section and the steel bars become more effective on resisting the normal stresses due to moment.

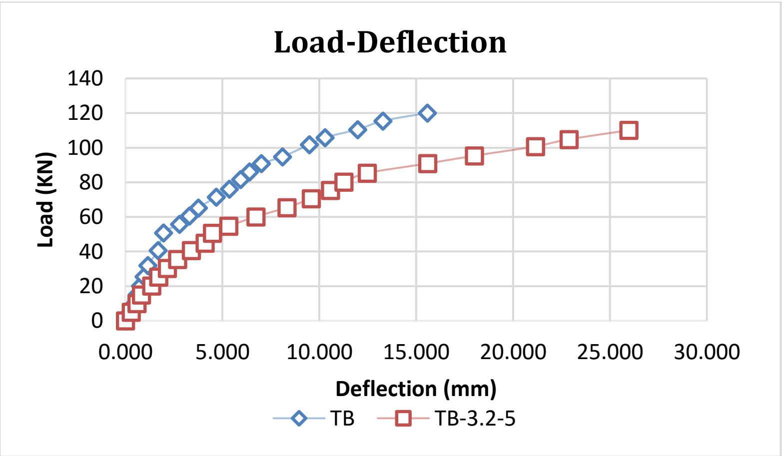


Fig.7a: Load-Deflection Curve for G1 Specimens

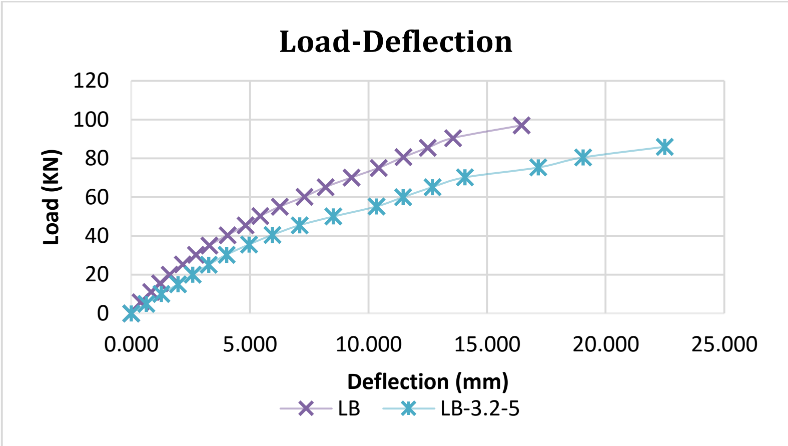


Fig.7b: Load-Deflection Curve for G2 Specimens

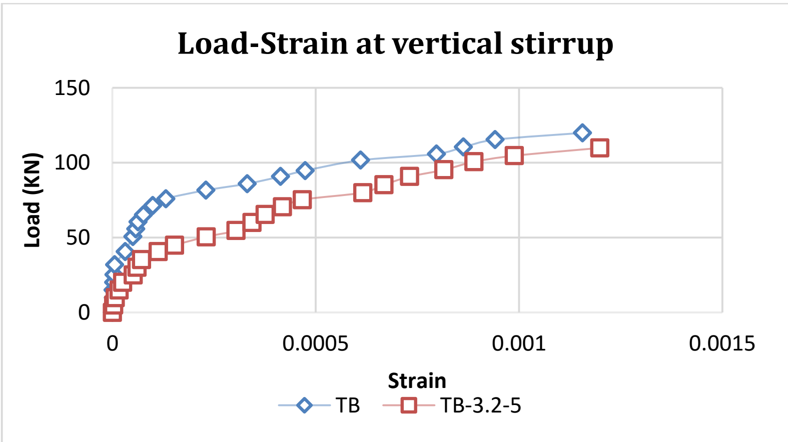


Fig.8a: Load-Strain at Vertical Stirrup Curve for G1 Specimens

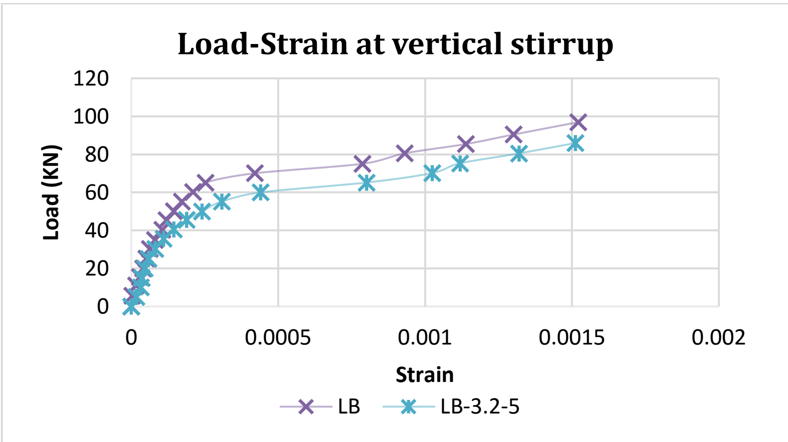


Fig.8b: Load-Strain at Vertical Stirrup Curve for G2 Specimens

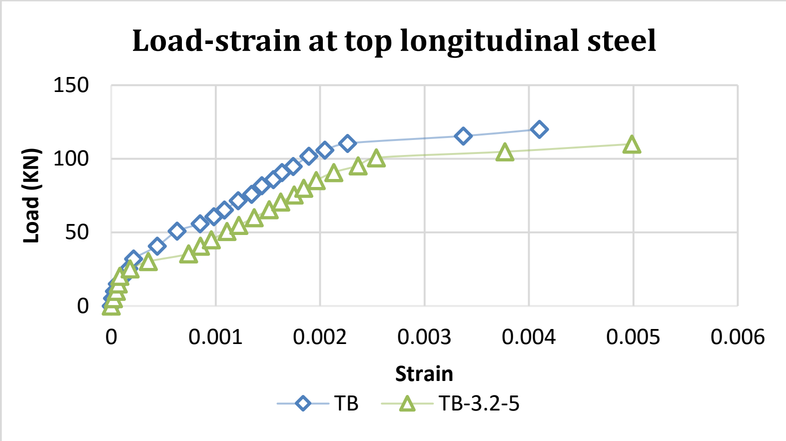


Fig.9a: Load-Strain at Upper Longitudinal Steel Curve for G1 Specimens

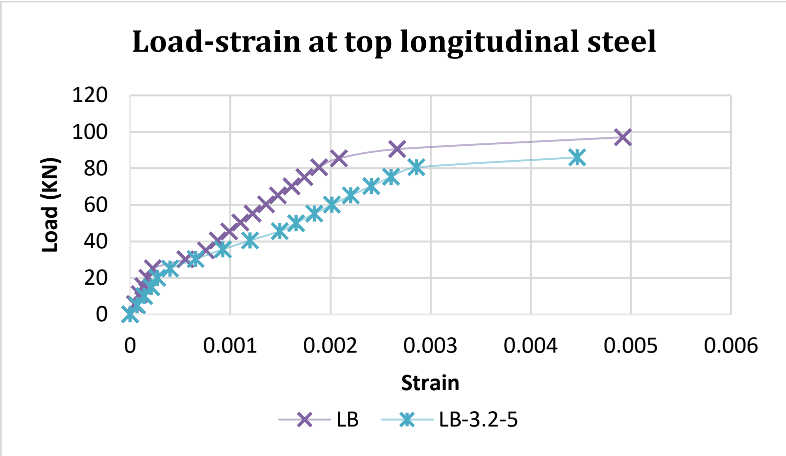


Fig.9b: Load-Strain at Upper Longitudinal Steel Curve for G2 Specimens

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- The flexural strength for beams with lightweight concrete decreased by about 8.3% more than beams with normal weight concrete.

5- For beams with a/d ratio equal to 3.5, The shear strength for beams with lightweight concrete decreased by about 8.2% more than beams with normal weight concrete.

REFERENCES

[1] ACI Committee 213, "Guide for Structural Lightweight Aggregate Concrete", American Concrete Institute, 1987

[2] Aurelio Muttoni, Miguel Fernández Ruiz. Shear Strength of Members without Transverse Reinforcement as Function of Critical Shear Crack Width , ACI STRUCT J Title no. 105-S17 ,2008,163-172

[3] C. H. Huang, L. H. Chen, Y. C. Kan, C. H. Wu , T. Yen. Shear behavior of full size reinforced lightweight concrete beam. Dahan Institute of Technology, Hualien, Taiwan. 2011.

[4] Danile F. Jensen. Reliability Analysis for Shear in Lightweight Reinforced Concrete Bridges Using Shear Beam Database, Utah State University, 2014

[5] Hussein O. Okail"flexural behavior of reinforced self-compacting lightweight concrete beams ", Faculty of engineering, ain shams university, 2008.

[6] Lei Yu, Yi Che , Yupu Song. Shear behavior of large reinforced concrete beams without web reinforcement, Advances in structural engineering vol. 16 No.4 2013, 653-665.

[7] M. Hamrat, B. Boulekbache, M. Chemrouk ,S. Amziane. Shear Behavior of RC Beams without Stirrups Made of Normal Strength and High Strength Concretes, Advances in structural engineering vol. 13 No.1 2010, 29-41.

[8] Qiang Yu , Zdeněk P. Bažant , Hon.M.ASCE. Can Stirrups Suppress Size Effect on Shear Strength of RC Beams? , J Struct Eng 2011;137:607-17.

[9] R. PARK and T. PAULAY. " Reinforced Concrete Structures" department of civil engineering, University of Chambery, Christchurch, New Zealand, 1975.

[10] Shuaib H. Ahmad, Shamsoon Fareed ,S.F.A.Rafeeqi. Shear strength of normal and light weight reinforced concrete slender beams without web reinforcement, Civil Engineering and Architecture 2(1):2014, 33-41.