IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 16, Issue 2 Ser. IV (Mar. - Apr. 2019), PP 39-45
www.iosrjournals.org

Effect of Opening on Behavior of Lightweight Concrete Deep Beams

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Abstract: *This research presents an experimental study to examine the effect of opening on shear behavior of self-compacting lightweight concrete (SCLWC) deep beams. Five medium scale beams were statically tested to failure under a concentrated load and one medium scale beam tested under four concentrated loads. The test parameters were beam type (solid, with opening), opening dimensions and places, shear reinforcement, loading type.*

Keywords: *opening, shear behavior, lightweight concrete, deep beams, shear reinforcement, concentrated load, solid beams, diagonal crack.*

Date of Submission: 03-04-2019 Date of acceptance: 18-04-2019

I. Introduction

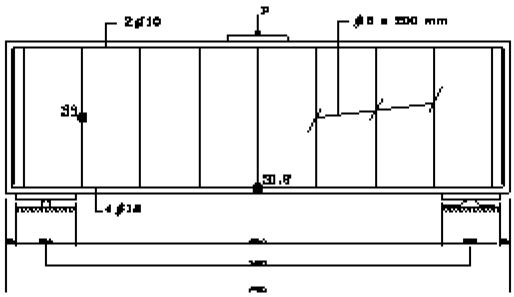
Lightweight concrete (LWC) has, in recent years, become an important structural material and the demand for it is increasing [1]. Because of the practical advantages which is possesses, like saving in the weight of the super structural means that foundations can be reduced in bulk, and time and expenses saved in erection and handling of components, so that smaller lifting equipment can be employed .

The low density results in high thermal insulation of buildings [2]. Nearly LWC is fire resistant, being light weight, it is easy for the workers to handled, and another advantage is the demolition cost. It takes less energy to demolish, as smaller equipment be used compared to normal concrete.

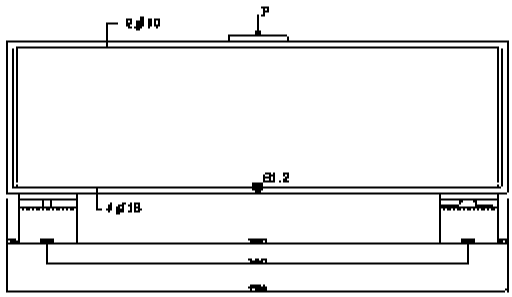
The principal mode of failure in deep beams having adequate reinforcement is diagonal tension cracking [3]. As depth of the beam increased, diagonal crack became predominant and one of the causes of failure in deep beams. The inclusion of steel fibers in concrete deep beams improves the crack and deformation characteristics [4]. If opening was located in the tension region, it is necessary to reinforce properly around the opening to avoid crack propagation [5].

II. Description of the Tested Specimen

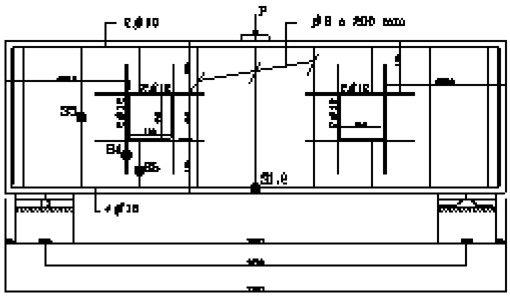
Figure (1) and table (1) show concrete dimensions, supports and loading conditions as well as reinforcement details of tested beam specimens. All six specimens (B1to B6) have the same rectangular cross-section with constant breadth of 120 mm, constant height of 520 mm ,overall length of 1720 mm and a clear span 1450 mm. Specimens (B1,B2) are solid beams (without openings), while specimens (B3,B4) are with two openings of 150*150 mm at the mid span between point of loading and center of supports. Specimen (B5) is with two openings of 150*150 mm located at the quarter span between points of loading and center of supports and finally specimen (B6) is with two opening of 200*200 mm in size located at the mid span between points of loading and center of supports. The same bottom reinforcement of (4Y18) and top reinforcement of (2Y10) are used for all beams, as shown in Figure (1) . All longitudinal bars are high grade deformed bars, and stirrups are made from smooth mild steel. All specimens are simply supported at the two ends of the beams. Specimens (B1, B2, B3, B5 and B6) are loaded by concentrated load acting at the mid span while specimen (B4) is loaded by four concentrated loads. All specimens have compressive concrete cube strength of 25 MPa. Specimens (B1, B3, B4, B5 and B6) have vertical stirrups of 8 mm diameter spaced by 200 mm while specimen (B2) has no vertical stirrups. Specimens (B3, B4, B5 and B6) have vertical & horizontal reinforcement (2Y12) around the openings.



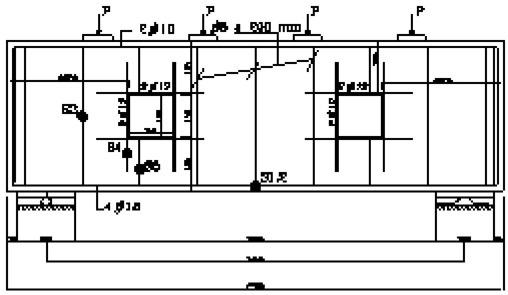
Detailing of beam (B1)



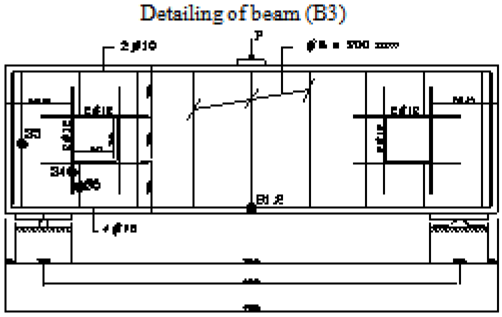
Detailing of beam (B2)



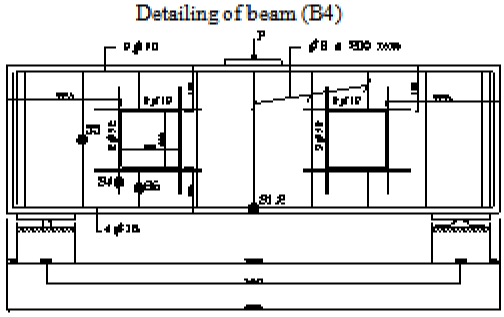
Detailing of beam (B3)



Detailing of beam (B4)



Detailing of beam (B5)



Detailing of beam (B6)

Figure (1): Details of the tested beam specimens

Table (1): Details of tested beam specimens.

Beam	Beam type	Opening size (mm)	Position of opening	Type of loading	Lower reinforcement	Upper reinforcement	Shear RFT
B1	Solid beam	No opening	No opening	Single point load at mid span	4 Y 18	2 Y 10	R8@200 mm
B2	Solid beam	No opening	No opening	Single point load at mid span	4 Y 18	2 Y 10	No stirrup
B3	Beam with opening	150x150	At mid distance between loading and support	Single point load at mid span	4 Y 18	2 Y 10	R8@200 mm
B4	Beam with opening	150x150	At mid distance between loading and support	Four point load	4 Y 18	2 Y 10	R8@200 mm
B5	Beam with opening	150x150	At quarter distance between loading and support	Single point load at mid span	4 Y 18	2 Y 10	R8@200 mm
B6	Beam with opening	200x200	At mid distance between loading and support	Single point load at mid span	4 Y 18	2 Y 10	R8@200 mm

III. Test Results of the tested beam specimens

Table (2) shows a summary of the test results for each of tested deep beam specimen, includes the load of shear cracking, load of shear failure, the mid-span deflection at failure, the maximum strain in opening RFT, and the maximum strain in the vertical stirrups at failure. Also figure (2) shows the crack pattern of the tested beam specimens.

Table (2): Summary of test results of tested beam specimens

Beam	Load at shear Cracking (ton)	Load at failure (ton)	Mid-span deflection at failure (mm)	Max strain in stirrups (micro strain)	Max strain in opening RFT (micro strain)
B1	10	35	3.65	1450	-
B2	10	22	2.60	-	-
B3	8	22	2.90	1300	1123
B4	16	43	4.70		1215
B5	10	20	3.00	1190	
B6	8	21	3.75	693	820

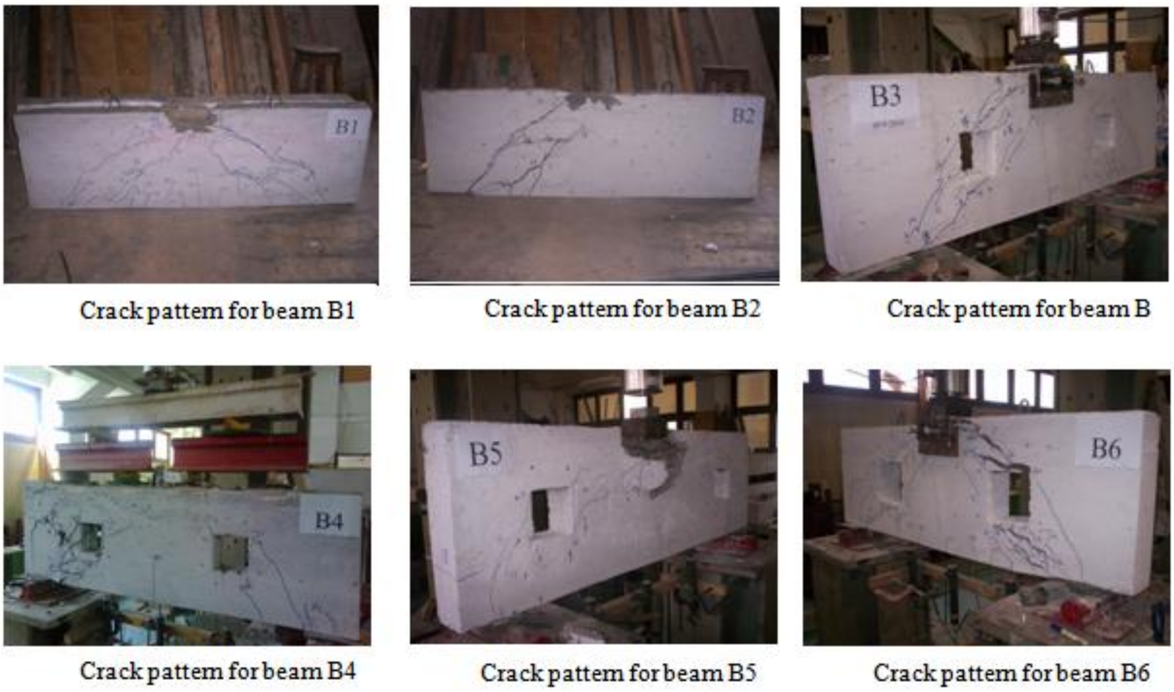


Fig. 2: Crack pattern of tested beam specimens

IV. Comparative Discussion of Experimental Results

1. General

The tested specimens were divided into four groups depending on different parameters. The first group consisted of two beams (specimen B1, B2) where B1 solid beam with shear reinforcement, B2 solid beam without shear reinforcement. The second group consisted of three beams (specimen B1, B3, B5) where B1 without opening, B3 with openings at mid of shear span shear, B5 with openings at quarter of shear span. The third group consisted of two beams (specimen B3, B4) where B3 loaded with single concentrated load, B4 loaded with four concentrated loads. The fourth group consisted of two beams (specimen B3, B6) where B3 with opening dimensions 150x150 mm; B6 with opening dimensions 200x200 mm.

2. Cracking and crack propagation:

For group (1): At low load level the behavior of LWC deep beams (B1&B2) was linear elastic with no crack occurrence. As the load increased, the extreme fiber concrete tensile stress reached its limiting concrete strength and hair shear cracks occurred. The first crack was nearly under the position of the loaded plate area. As the load increased above the first cracking load, the cracks widened and started to propagate diagonally towards from loading plate to support plate up to failure and some flexural cracks also propagated.

For groups (2,3&4): At low load level the behavior of LWC deep beams (B3,B4,B5&B6) was linear elastic with no crack occurrence. As the load increased, the extreme fiber concrete tensile stress reached its limiting concrete strength and hair shear cracks occurred. The first crack was nearly under the position of the loaded plate area. As the load increased above the first cracking load, the cracks widened and started to propagate diagonally towards from loading plate to opening corners and from opening corners to support plate up to failure and some flexural cracks also propagated.

3. Failure loads:

For group (1): At failure, it was found that the ultimate load of beam (B1) was higher than that of (B2) by about 37%. This could be attributed to the fact that increase shear reinforcement increases the ultimate shear strength against failure. For group (2): At failure, it was found that the ultimate load of beam (B1) was higher than that of (B3&B5) by about 37% &43%. This could be attributed to the fact that the position of opening in quarter of shear span decreases the ultimate shear strength against failure. For group (3): At failure, it was found that the ultimate load of beam (B4) was higher than that of (B3) by about 49%. This could be attributed to the fact that loading by four concentrated loads makes confining for shear and increases the ultimate shear strength against failure. For group (4): At failure, it was found that the ultimate load of beam (B3) was higher than that of (B6) by about 5%. This could be attributed to the fact that increase opening dimensions decrease the ultimate shear strength against failure.

4. Deflection:

Figures (3 to 6) show the mid-span deflection relation through the load history for the four groups of tested deep beams until failure.

For group (1): The first part of the load versus mid-span deflection was similar for all beams representing the behavior of the un-cracked beam utilizing the gross moment of inertia of the concrete cross section. In this part the load deflection relationship was linear. For the second part, post cracking up to failure, represents the cracked beam with reduced moment of inertia. The load deflection relationship for (B1) varied about 18% than (B2), this significant decrease in the deflection of (B2) compared with that of (B1) may be attributed to the absence of shear reinforcement. Approaching failure, the deflection for (B2) was lower than B1 by about 29% which mean that shear reinforcement (stirrups) have significant effect on deflection (refer to figure (3)). For group (2): The first part of the load-deflection had no significant change in deflection for the three beams. In this part the load-deflection relationship was linear. At post cracking stage, deflection of (B3) was lower than B1, and deflection of (B3 & B1) was lower than (B5). This decrease in deflection of (B3) compared with that of (B1) may be attributed to the position of openings when it is in the mid of shear span. In addition, decrease in deflection of (B1) compared with that of (B5) may be attributed to the position of opening when it is in quarter of shear span. Approaching failure, the deflection of (B3) was lower than (B5), which means that the opening in quarter of shear span increased deflection than when it is in mid of shear span so that opening position have significant effect on deflection, and deflection of (B3&B5) was lower than that of (B1),which mean that opening decreased beam stiffness (refer to figure (4)). For group (3): The first part of the load-deflection had no significant change in deflection for the two beams. In this part the load-deflection relationship was linear. At post cracking stage, deflection of (B3) was lower than that of (B4). This decrease in deflection of (B3) compared with that of (B4) may be attributed to the loading type. Approaching failure, the deflection of (B3) was lower than (B5), which means that four concentrated load type increased deflection more than single concentrated load type (refer to figure (5)). For group (4): For The first part of the load-deflection, no significant change in deflection for the two beams was found. In this part the load-deflection relationship was linear. At post cracking stage, deflection of (B3) was lower than (B6), This decrease in deflection of (B3) compared with that of (B6) may be attributed to the opening size. Approaching failure, the deflection of (B3) was lower than that for (B6), which means that when opening size increased, the deflections increased also (refer to figure (6)).

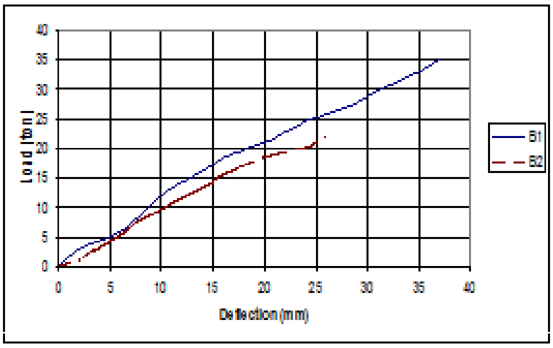


Fig. 3: Effect of vertical stirrups presence on mid-span deflection (Group 1)

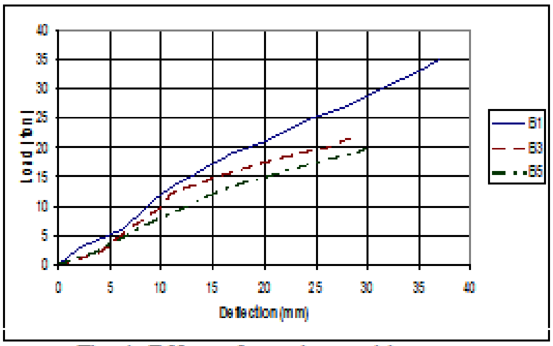


Fig. 4: Effect of opening position on mid-span deflection (Group 2)

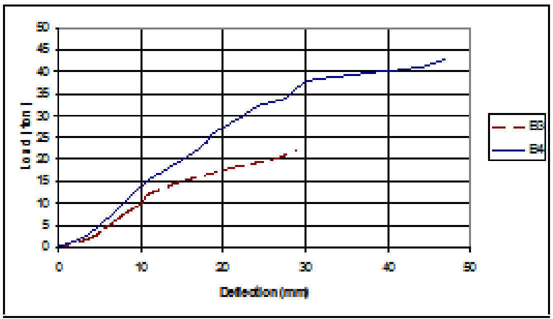


Fig. 5: Effect of loading type on mid-span deflection (Group 3)

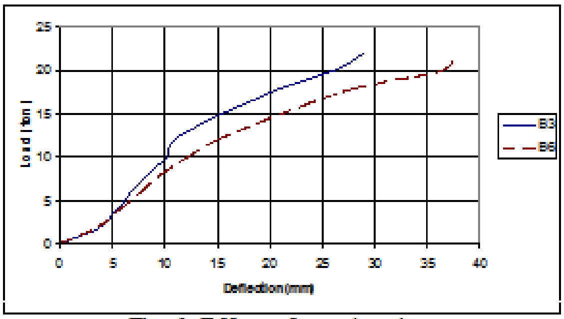


Fig. 6: Effect of opening size on mid-span deflection (Group 4)

5. Steel Strains:

Figures (7 to 15) show the steel strain variation through the load history for the four groups of tested beams.

For group (1): For beam (B2), flexural steel reached its yield strength earlier than that of beam (B1). This is attributed to the presence of vertical stirrups of beam (B1) than that of beam (B2) (refer to figure (7)).

For group (2): For beam (B3), flexural steel reached its yield strength earlier than that of beams (B1&B5). This could be attributed to the opening position that when it was in mid of shear span, the flexural strength of beam decreased. For tensile strain in stirrups, for beam (B5), steel reached its yield strength earlier than that of beams (B1, B5). This could be attributed to the opening position that when it was in quarter of shear span, the shear strength of beam decreased (refer to figures (8,9 and 10)).

For group (3): The tensile strain in bottom bars as well as bars around opening, for beam (B3), reached its yield value earlier than that of beam (B4). This could be attributed to that when the loading type was four concentrated loads, flexural and shear strength of beam increased (refer to figures (11 and 12)).

For group (4): The tensile strain in bottom bars, for beam (B6), steel reached its yield value earlier than that of beam (B3), this could be attributed to opening dimensions, as when increasing the opening dimensions, flexural strength of beam decreased. For tensile strain in stirrups and bars around the openings, for beam (B6), steel reached its yield strength earlier than that of beam (B3), this could be attributed to the opening dimensions, as when increasing the opening dimensions shear strength of beam decreased (refer to figures (13, 14 and 15)).

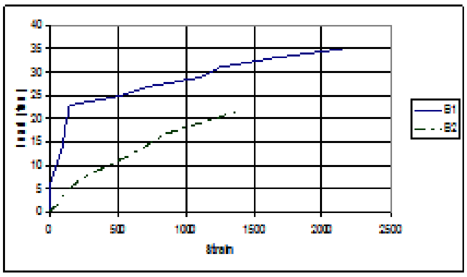


Fig. 7: Effect of the presence of vertical stirrups on flexural steel strain (Group 1)

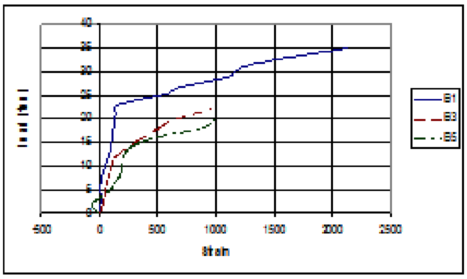


Fig. 8: Effect of opening position on on flexural steel strain (Group 2)

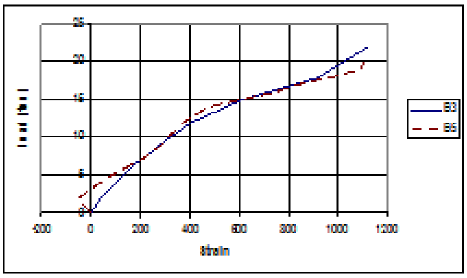


Fig. 9: Effect of opening position on steel strain around the opening (Group 2)

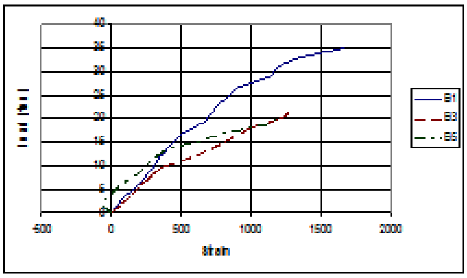


Fig. 10: Effect of opening position on steel strain in vertical stirrups (Group 2)

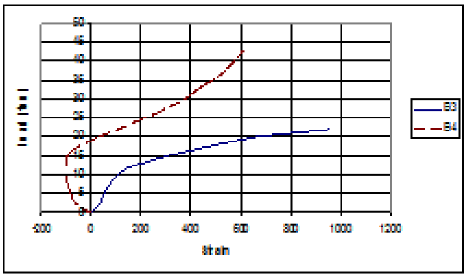


Fig. 11: Effect of loading type on flexural steel strain (Group 3)

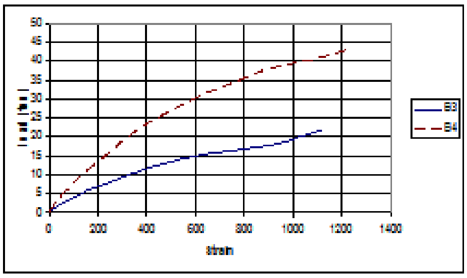


Fig. 12: Effect of loading type on steel strain around the opening (Group 3)

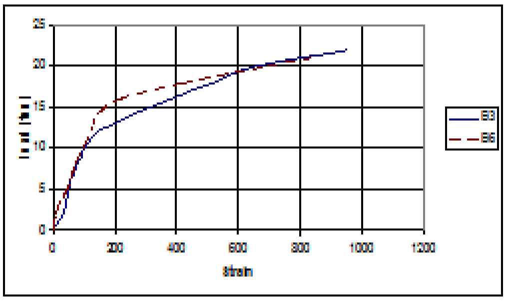


Fig. 13: Effect of opening size on flexural steel strain (Group 4)

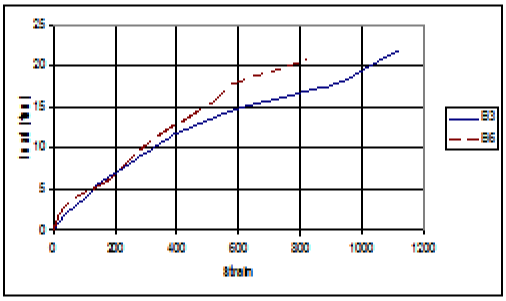


Fig. 14: Effect of opening size on steel strain around the opening (Group 4)

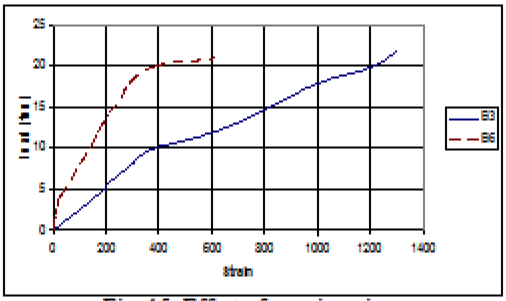


Fig. 15: Effect of opening size on steel strain in vertical stirrups (Group 4)

6. Concrete Strains:

Figures (16 to 19) show the concrete strain variation through the load history for the four groups of tested beams.

For group (1), Concrete strain of beam (B2) was higher than that of beam (B1), which means that decreasing shear reinforcement leaded to the increase of concrete strain (refer to figure (16)).

For group (2), Concrete strain of beam (B3) was higher than that of beams (B1&B5), which means that when the opening was in mid of shear span, concrete strain increased (refer to figure (17)).

For group (3), Concrete strain of beam (B4) was higher than that of beam (B3), which means that loading by four concentrated loads increase flexural capacity and therefore concrete strain (refer to figure (18)).

For group (4), Concrete strain of beam (B6) was higher than that of beam (B3). This means that increasing the opening dimensions leaded to the increase in concrete strains (refer to figure (19)).

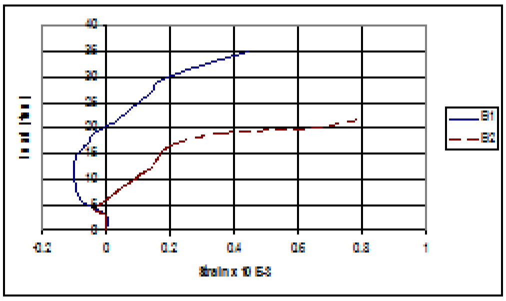


Fig. 16: Effect of the presence of vertical stirrups on concrete strain (Group 1)

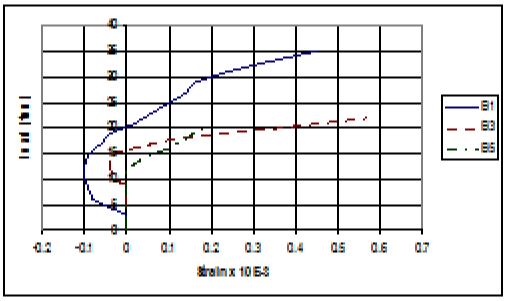


Fig. 17: Effect of opening position on concrete strain (Group 2)

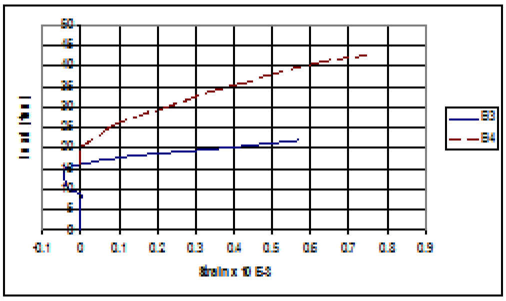


Fig. 18: Effect of type of loading on concrete strain (Group 3)

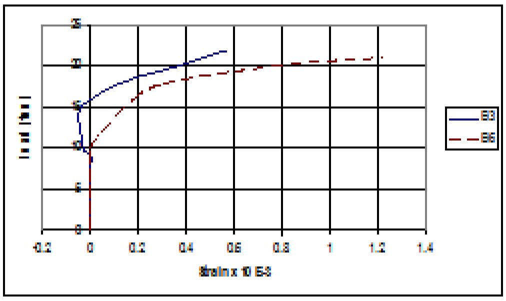


Fig. 19: Effect of opening size on concrete strain (Group 4)

V. Conclusions

From the previous experimental work and the comparative study, the following conclusions can be gained,

1. Omitting shear reinforcement in deep beam, B2, decreased the shear strength.
2. Omitting shear reinforcement reduces deflections and strains near failure.
3. Openings in shear span of deep beams decreased shear strength compared with that for solid deep beam with shear reinforcement (stirrups) and had value of shear resistance near that of solid deep beams without shear reinforcement.
4. Four point loading system enhanced the shear capacity of the tested beam.
5. The location of the web opening is a major factor influencing the shear strength of the deep beam.
6. Increasing opening size decreased shear strength.

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