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EFFECT OF WEB OPENING'S SHAPE ON THE BEHAVIOR OF HYBRID REINFORCED CONCRETE DEEP BEAMS UNDER REPEATED LOADING

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Abstract: This research aims to study experimentally behavior of hybrid deep beams with web openings when subjected to two points' monotonic and repeated loading in effect of web openings shape. All tested deep beams have the same flexural (0.0184) and web reinforcement (ρ_w=0.003) and same dimensions of (1500mm length, 150mm width and 350mm height). In this research, the idea of hybridity was achieved by reinforcing the two shear spans with steel fiber keeping the middle span free from this fiber. The aim was to strengthen shear region against shear failure (diagonal strut failure). To achieve the aim, six deep beams were cast and tested. Three of them were tested under monotonic loading as control beams to the other three beams tested under repeated loading at levels of 55% of the ultimate load of their control beams. The variables studied were: loading type (either monotonic or repeated) and web opening shapes. The results indicated that using different opening shapes (rectangular, circular or square) with an equivalent shape of 1.37% of beam size show that the ultimate load of beams with rectangular opening decreases by 10% as compared with beams with square web openings of the same area. Also, the ultimate load of beams with circular openings increases by 6.8% as compared with beams with square web openings of the same area. Also, it can be concluded that deep beams haves circular openings are increasing in ultimate loads by 17.5% as compared to rectangular web openings shapes with equivalent area.

Keywords: *deep beam, hybrid, web openings, repeated loading, strengthen, shear span.*

تأثير شكل فتحات الوترة على سلوك العتبات الخرسانية الهجينة العميقة تحت الاحمال التكرارية

الخلاصة: يهدف هذا البحث الى دراسة سلوك العتبات العميقة الهجينة مع فتحات وترة تحت تأثيرنقطتي حمل رتيب وتكراري بتأثير شكل فتحات مختلفة بحجم مكافئ. تمتلك جميع العتبات العميقة المفحوصة نفس تسليح الانحناء والقص (ρ_w =0.003) وبنفس الابعاد (1500 ملم طول، 150 ملم عرض و 350 ملم ارتفاع). في هذا البحث، تتحقق فكرة التهجين بتسليح فضائي القص بالياف الحديد مع بقاء الفضاء الوسطي بدون إلياف. ان الهدف من ذلك هو تقوية منطقة القص ضد فشل القص. لتحقيق الهدف، تم صب وفحص ستة عتبات عميقة، فُحصت ثلاث منها تحت تأثير الحمل الرتيب كمرجعية للعتبات الثلاث الاخرى تحت تاثير الحمل التكراري بمستوى 55% من الحمل الاقصى للعتبات المرجعية. تضمنت المتغيرات: نوع الحمل (رتيب او تكراري) وشكل الفتحات. اظهرت النتائج عند استخدام فتحات ذات اشكال مختلفة (مستطيلة أو دائرية أو مربعة) بحجم مكافئ 1.37% من حجم العتبة ان الحمل الأقصى للعتبات العميقة الهجينة تحت تأثير الاحمال الرتيبة مع فتحة مستطيلة يقل بنسبة 10% ويزداد بنسبة 6.8% للعتبات العميقة الهجينة ذات الفتحة الدائرية ذات نفس المساحة ، مقارنة مع العتبة العميقة الهجينة ذات الفتحة المربعة. وإيضا، إن الحمل الاقصى للعتبات العميقة الهجينة تحت تأثير الاحمال الرتيبة ذات الفتحة الدائرية تزداد بنسبة 17.5% مقارنة مع ذات الفتحة المستطيلة.

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1. Introduction

Deep beams constitute elements of structure with loading as simple beams, in which a compression force made up of the load and reaction conveys a substantial proportion of the load to the supports, generating a non-linear strain distribution and more marked shear deformations than pure flexure [1].

Because they have high resistance capacity, the most common application of RC deep beams is as members in tall structures. Furthermore, conversion of the structural system between the superior and inferior parts of a structure is also a task frequently undertaken by these beams. How stable and safe a structure is depends greatly on how it behaves structurally.

The linear elastic theory for general beam analysis is inapplicable due to the lack of linearity of the stress distribution in the deep beam section. Hence, non-linear analysis or the Strut and Tie Method (STM) is suggested by the ACI318M-14 code as the preferred approach for the design of deep beams [2].

2. Experimental Program

A total of six deep beams have been tested under two-point loads and support as a simply supported to investigate the behavior of reinforced concrete deep beams under monotonic and repeated loading.

The tested beams have been designed to ensure shear failure under monotonic loading according to STM of the ACI 318M-14 Cod**e [3]**. All beams had the same dimensions 1500mmx 350mm x 150mm (length, height and width), respectively and flexural reinforcement. The reinforcement of flexure for all the tested beams are $2\emptyset\, 20\text{mm}$ and $1\emptyset\, 16\text{mm}$ ($\rho = 0.0184$ where ρ is the ratio of the flexural reinforcement).

The clear span between supports was 1230mm Which gives an a/h ratio of 3.5 which is less than 4.0 as recommended by the provisions of the ACI 318M-14 Code**[3]** for deep beam requirements. The Proportions of Concrete Mix were (1: 1.82: 2.73) (432.43Kg: 787.02Kg: 1180.54Kg) (Cement: Sand: Gravel) with water cement ratio=0.5.

Also, bearing plates were designed with dimension 40mmx 80mmx 150 mm under each load and above each support to avoid any local crushing in concrete. Also, with each mix of specimen, eight of control specimens (five cylinders and three prisms) for CC and the same eight models for FC have been casted at the same time and same concrete batch of the cast specimen beam for control testing of concrete and the results of compressive strength show that no significant different between CC and FC in magnitude of *(fc*').

And a symbol for each deep beam has been set to distinguish it from the rest of the deep beams, which includes (beam's number, type of loading, type of beam with steel fiber ratio if it found, shape of openings and size of opening), Figure (1) explains the meaning of the symbol.

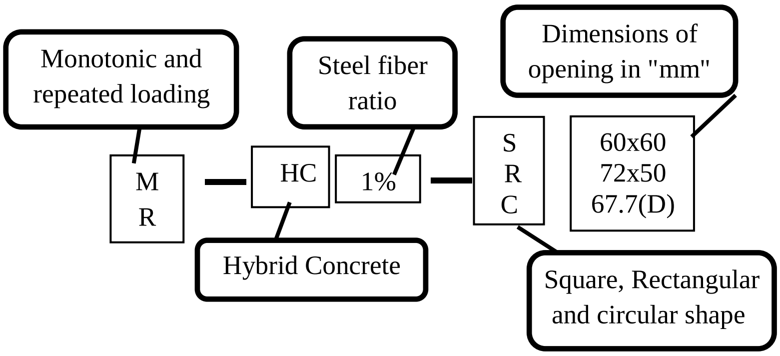

Figure (1) Symbol of Specimens

Table (1) shows details of the six tested reinforced concrete deep beams. The main variables investigated and details of the web reinforcement are also shown.

Table 1. Beam Specimens Details*.

Beam designation	Shape of Opening	Dimension of Openings (mm)	Type of Load	Vertical And Horizontal Web. Reinforced
M-HC1%-S60x60	Square	60x60	Monotonic (Control)	Φ4 mm@ 80 mm c/c
R-HC1%-S60x60	Square	60x60	Repeated (55% of Control Ultimate Load)	Φ4 mm@ 80 mm c/c
M-HC1%-R72x50	Rectangular	72x50	Monotonic (Control)	Φ4 mm@ 80 mm c/c
R-HC1%-R72x50	Rectangular	72x50	Repeated (55% of Control Ultimate Load)	Φ4 mm@ 80 mm c/c
M-HC1%-C67.7	Circular	Φ 67.7	Monotonic (Control)	Φ4 mm@ 80 mm c/c
R-HC1%-C67.7	Circular	Φ 67.7	Repeated (55% of Control Ultimate Load)	Φ4 mm@ 80 mm c/c

*all beams are Hybrid, a/h=1.14, SF=1% and ρ_w =0.003

Details of dimensions and reinforcement for the tested beams are shown in Figures (2) to (4).

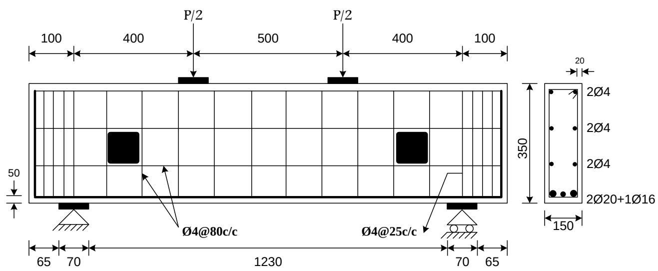

Figure 2. Details of Beams HC1%-S60x60 (All Dimensions are in mm)

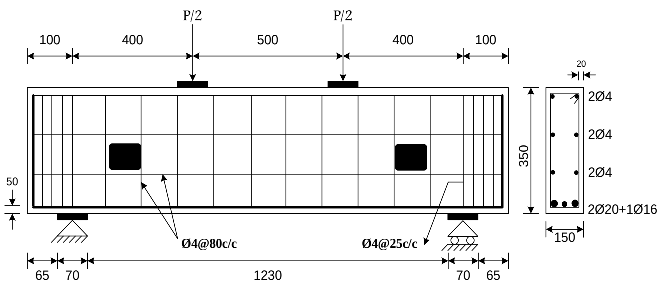

Figure 3. Details of Beams HC1%-R72x50 (All Dimensions are in mm)

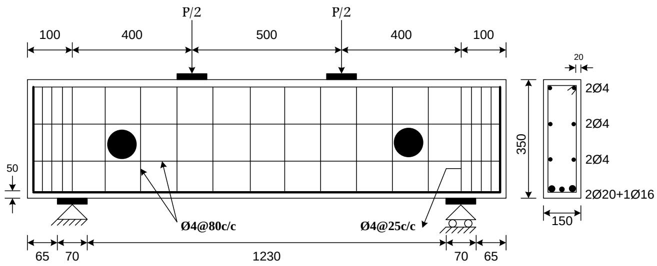

Figure 4. Details of Beams C67.7 (All Dimensions are in mm)

2.1 Materials

Properties and description of used materials are show in Table (2).

Table 2. Properties of Construction Materials.

Material	Descriptions
Cement (according to I.Q.S No.5, 1984) [4]	Ordinary Portland Cement (Type I)
Sand (according to I.Q.S. No. 45/1984)[5]	Natural sand from Al-Ukhaidher region with maximum size of(4.75)
Gravel (according to I.Q.S. No. 45/1984)[5]	Crushed gravel of maximum size (14mm)
Steel Fiber	Hooked ends mild steel fibers are used in construction of fiberous concrete with volumetric (*vf*) of 1%, tensile strength =1130mpa, length=50mm, nominal diameter=0.5mm aspect ratio=100.
Reinforcing Bars (according to ASTM C370-05a) [6]	(Φ20mm) deformed steel bar, having (491MPa) yield strength (fy) (Φ16mm) deformed steel bar, having (507MPa) yield strength (fy) (Φ4mm) deformed steel bar, having (698MPa) yield strength (fy)
Water	Clean tap water

The horizontal length of all longitudinal flexural reinforcement was 1460mm and a vertical length of 250mm to make 90^o standard hook to provide sufficient anchorage as shown in plate (1).

Plate 1. Steel Reinforcement Cage Used for Deep Beams.

2.2 Molds and Casting

Four steel molds were designed and fabricated for casting two hybrid deep beams for each batch as shown in Plate (2). The inside dimensions for each mold were 1500mm x 150mm x 350mm (length x width x depth), respectively. After they were positioned vertically, the moulds were oiled sparingly. The preparation of the reinforcing bars had been done beforehand, so the reinforcement cage was positioned. And the producer of casting was done as a three stages, the first by cast FC in the lower gate and the second by cast CC in the middle gate and finally cast FC in upper gate with closed every gate before the stage of casting.

Plate 2. Details of Molds.

2.3 Test Procedure

After 28 days, the specimens were removed from curing. To enable visualisation of how cracks propagated, cleaning and white painting of the beam specimens were undertaken prior to the testing day. Proper labelling of all beam specimens was done as well as the location of the support points, loading points and dial gauge was clearly indicated on the beam surface.

As illustrated in Plate (3), the beam models were positioned on a machine with a clear span of 1230mm. To provide a requirement for the openings in deep beams' specimen through casting operation, wooden parts were used with the same dimensions of the openings required. To prevent stress from concentrating on the superior beam face during loading, two 150mm×70mm×40mm steel plates were placed over the support points and beneath the load points. The testing of every beam model was done under two-point loading.

To make contact with the bottom of the beam centre, the dial gauge was placed in the location defined by the two points. In the case of monotonic testing, the beam specimens were loaded to failure in a single cycle, while in the case of repeated loading testing, they were loaded in six cycles (each cycle of loading was up to 55% of ultimate load of static test).

The loading of the beam specimens was done in 10kN increments, at a load increment rate of 1.5kN/sec. The resulting cracks for each cycle were noted on the beam surface in terms of location and widths. Occurrence of failure involved unexpected failure of the beams at the same time as the load indicator ceased to record or return and the deflection increased rapidly. After recording it, the ultimate load was removed to enable photographic documentation of the pattern of cracks and the manner in which failure occurred.

Plate 3. Details of Molds and Casting Procedure.

3. Experimental Results

In monotonic loading, during the applied load and at the low load level, all the tested beams behaved in an elastic manner and the deflection at mid span were small proportion to the applied loads.

When increase the applied load, first crack occurred, then numbers of cracks were observed at the region of the pure bending moment. At continuously increasing loads, first shear crack appeared and more cracks appeared at the shear span region of the beams.

These cracks (pure shear cracks) began to appear in region between the support and the point of the applied load; starting from the support area toward the applied load area passing through the corner of the opening.

These diagonal cracks began as one crack and increased in number as the load increased, the inclined cracks widened and extended toward the support and load positions.

And in the deep beams tested under repeated loading, at the first cycle, the behavior of deep beam specimens were similar to the behavior of deep beams under monotonic loading, and also the cracks began from the support toward the applied load's point, and at the end of this stage at least two cracks appeared.

At unloading, the crack width was decreased as the crack disappeared and appeared again when the load increased in the next cycle. In the other cycles; another cracks were appear and increase.

Finally, in the all tested deep beams failure occurred by splitting the inclined line joining the edge of steel plates at the supports and loading positions (strut of the deep beam). In beams tested under repeated loading, if the specimens did not fail after six cycles, the loading was allowed to be increased up to failure. Details of the tested beams and results obtained are shown in Table (3).

Table 3. Summary of test Results for Tested Deep Beams[*]

Beam Designation	Type of Loading	No. of Cycles	Ultimate Load (kN)	Modes of Failure
M-HC1%-S6x6	Monotonic (Control)	-	440	Diagonal Shear Failure
R-HC1%-S6x6	Repeated (55% of Control Ultimate Load)	6	300	Diagonal Shear Failure
M-HC1%-R72x50	Monotonic (Control)	-	400	Diagonal Shear Failure
R-HC1%- R72x50	Repeated (55% of Control Ultimate Load)	6	290	Diagonal Shear Failure
M-HC1%-C67.7	Monotonic (Control)z	-	470	Diagonal Shear Failure
R-HC1%- C67.7	Repeated (55% of Control Ultimate Load)	6	310	Diagonal Shear Failure

[*]1. All beams have the same (a/h) ratio = 1.14, SF=1% and hybrid

2. All beams have same Min. web reinforcement ratio = 0.003 for all tested beams.

3. $\boldsymbol{\rho}_w = \Sigma \frac{A_{si}}{b_w s_i} sin_{\alpha_1}$

Plates (4) to (9). Shows modes of failure and the crack Patterns of the tested deep beams.

Plate 4. Beam M-HC1%-S60x60

Plate 5. Beam R-HC1%-S60x60

Plate 6. Beam M-HC1%-R72x50

Plate 7. Beam R-HC1%-R72x50

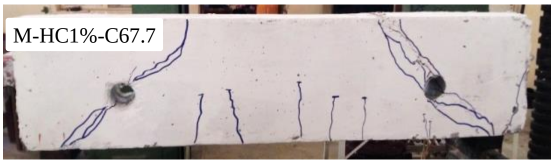

Plate 8. Beam M-HC1%-C67.7

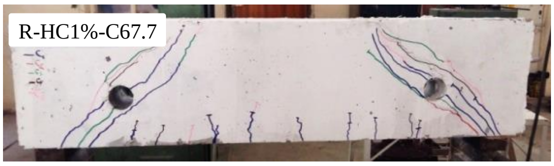

Plate 9. Beam R-HC1%-C67.7

4. Effect of Many Parameters on Ultimate Load of Tested Beams

4.1 Effect of Loading Type

Table (4) explains the effect of loading type, monotonic or repeated with load level of 55% of its control deep beams ultimate load. Beams that are tested under monotonic loading considered as control beams for identical beams tested under repeated loading as a percent of their control monotonic load beams. Generally, the ultimate loads of deep beams subjected to repeated loading are lower than the ultimate loads of corresponding beams tested under monotonic loading.

Table 4. Effect of Loading Type for All Tested Deep Beams*

Beam No.	Type of Loading	No. of Cycles	Ultimate Load (kN)	% Percentage Decrease
M-HC1%-S60x60	Monotonic (Control)	-	440	31.81
R-HC1%-S60x60	Repeated (55% of Control Beam Load)	6	300	
M-HC1%-S72x50	Monotonic (Control)	-	400	27.5
R-HC1%-S72x50	Repeated (55% of Control Beam Load)	6	290	
M-HC1%-C67.7	Monotonic (Control)	-	470	34.04
R-HC1%-C67.7	Repeated (55% of Control Beam Load)	6	310	
				Means = 31.12

*1. All beams have the same (a/h) ratio = 1.14, SF=1% and hybrid concrete

2. All beams have same Min. web reinforcement ratio = 0.003 for all tested beams.

3. $\rho_w = \Sigma \frac{A_{si}}{b_w s_i} sin_{\alpha_I}$

From the observation of Table (4), the following points can be noticed:

1. The percentages decrease in ultimate load according to repeated loading of hybrid deep beams with square web openings of size (60mmx60mm) is 35.59%.
2. The percentages decrease in ultimate load according to repeated loading of hybrid deep beams with circular web openings of diameter 67.7mm (1.37% of beam size) is higher than hybrid deep beams with rectangular web opening with equivalent size (72mmx50mm) which are 34.04% and 27.5%, respectively.

4.2 Effect of shape of Web Openings

4.2.1Under Monotonic Loading

The effect of shape of web openings is studied under constant ratio of SF on ultimate load. The results are drawn in Figure (5) and also listed in Table (5).

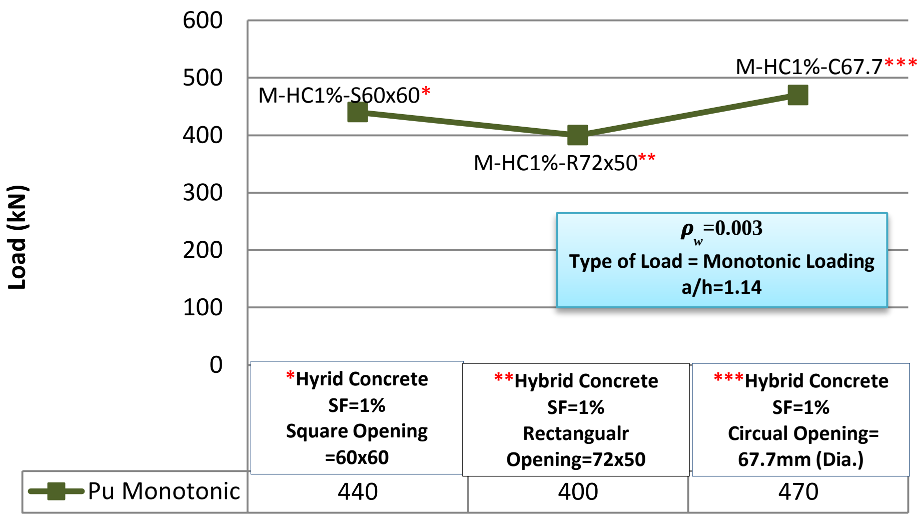

Figure 5. Effect of web openings' shape on Ultimate Load of Beams under Monotonic Loading.

Table 5. Effect of Web Openings' Shape on Ultimate Load of Beams under Monotonic Loading.

Beam Designation	Ultimate Load (kN)	% Increase Ultimate Load*
M-HC1%-S60x60	440	-
M-HC1%-R72x50	400	-10
M-HC1%-C67.7	470	6.8**

*The percentage of increase is measured with respect to beam M–HC1%–WO.
**The percentage increase of load of beam M-HC1%-C67.7 is 17.5% with respect to beam M-HC1%-R72x50.

From the results it can be seen that the ultimate load for the hybrid deep beam with rectangular web openings of size 72mmx50mm (1.37% of beam size) M-HC1%-R72x50 is decreases by 10% compare with the hybrid deep beam with equivalent square web openings of size 60mmx60mm (1.37% of beam size) M-HC1%-S60x60. It can be concluded that deep beams haves circular openings has the highest ultimate loads as compared to the other two shapes with equivalent area (rectangular and square) which are 17.5% and 6.8%, respectively.

4.2.2 Under Repeated Loading

The effect of shape of web openings on ultimate load for hybrid deep beams under repeated loading of level 55% of their corresponding control monotonic loading are shown in Figure (6) and listed in Table (6).

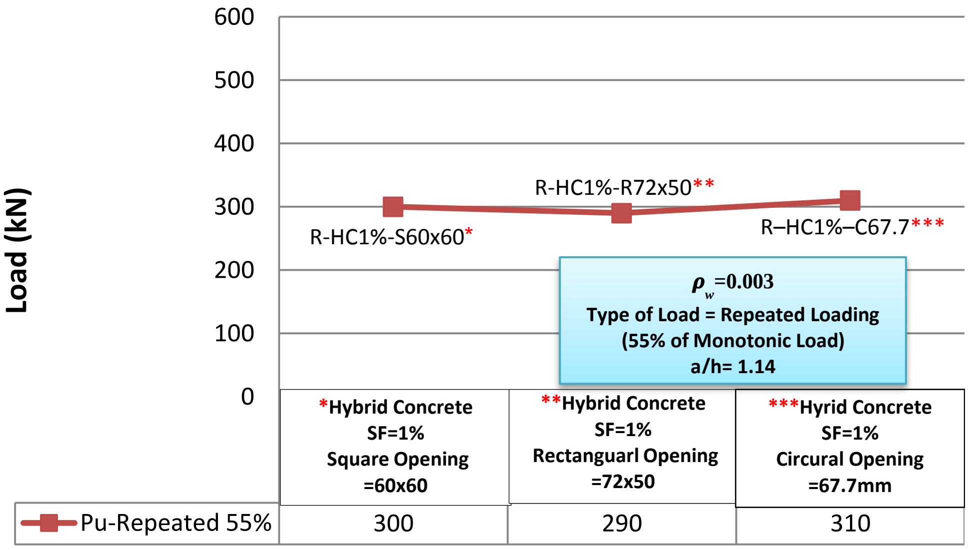

Figure 6. Effect of shape of web openings shape on Ultimate Load of Beams under Repeated Loading.

Table 6. Effect of shape of web openings on Ultimate Load of Beams under Repeated Loading.

Beam Designation	Ultimate Load (kN)	% Increase Ultimate Load*
R-HC1%-S60x60	300	-
R-HC1%-R72x50	290	-3.33
R-HC1%-C67.7	310	3.33**

*The percentage of increase is measured with respect to beam R–HC1%–WO.
**The percentage increase of load of beam R-HC1%-C67.7 is 6.9% with respect to beam R-HC1%-R72x50.

From Figure (6) and Table (6), it can be seen that no significant change in ultimate load for different shape of web openings with equivalent area of openings, which the change was ±3.33%.

Also, it can be seen that slightly increases in the percentage of hybrid deep beams with circular web openings compared to hybrid deep beams with equivalent area of square opening which is 6.9% under repeated loading of level 55% of their control beam monotonic ultimate load.

Also, it can be seen that the values of ultimate repeated loading of deep beams with web openings size 60mmx60mm (1.37% of beam size) are lower than their corresponding monotonic loadings.

5. Load-Deflection Response

Figures (7) through (12), show the load versus mid-span deflection curves obtained for all tested deep beam specimens which were tested under monotonic and repeated loading.

The load versus mid-span deflection curves are initiated in a linear form with a constant slope.

After initiating cracks, the load- deflection response takes a nonlinear form with variable slope where the deflection is increased at an increasing rate as the applied load is increased.

The load versus mid-span deflection curves appeared to be dependent on type of loading.

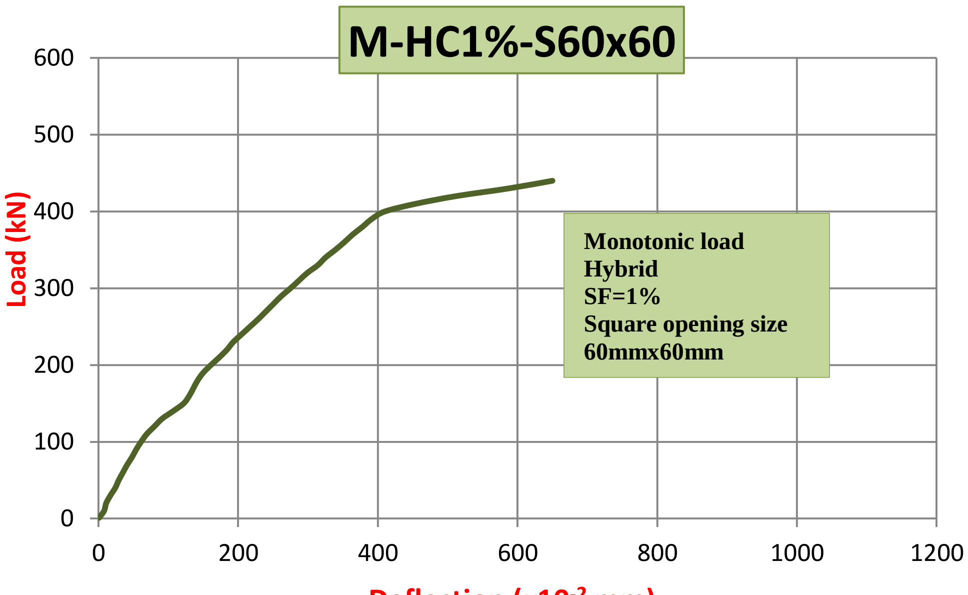

Figure 7. Load Versus mid-span Deflection Response for Beam M-HC1%-S60x60

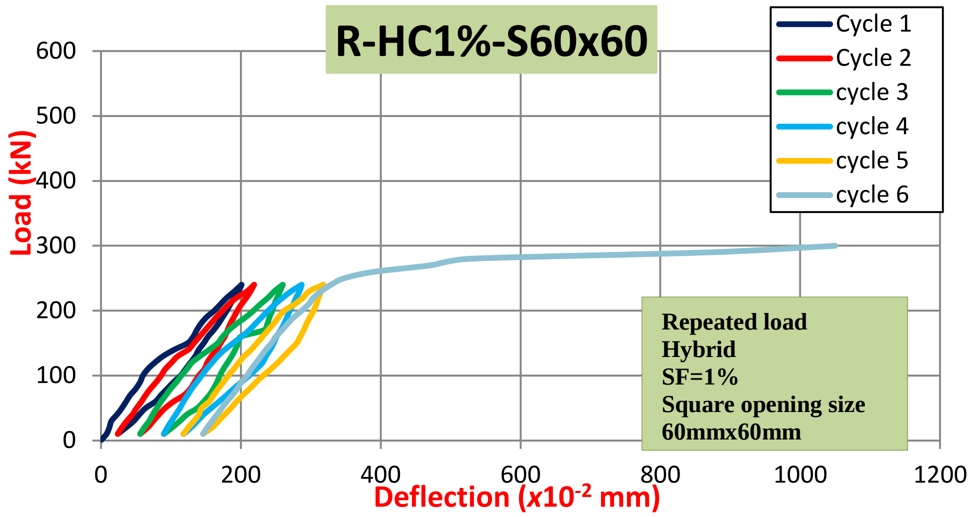

Figure 8. Load Versus mid-span Deflection Response for Beam R-HC1%-S60x60

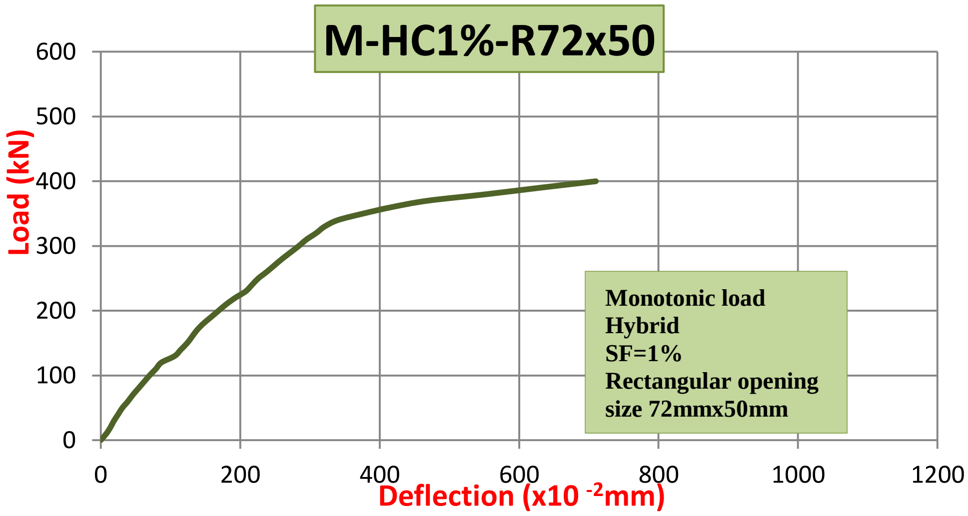

Figure 9. Load Versus mid-span Deflection Response for Beam M-HC1%-R72x50

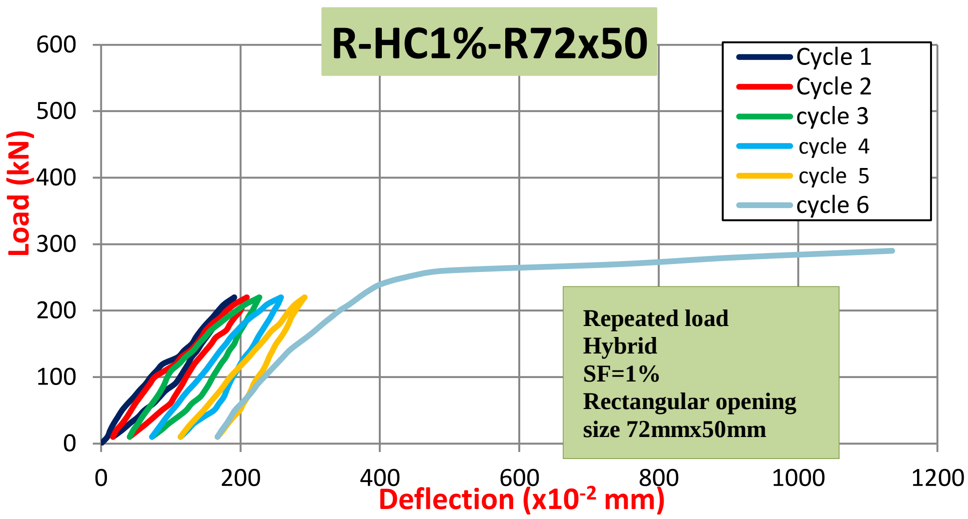

Figure 10. Load Versus mid-span Deflection Response for Beam R-HC1%-R72x50

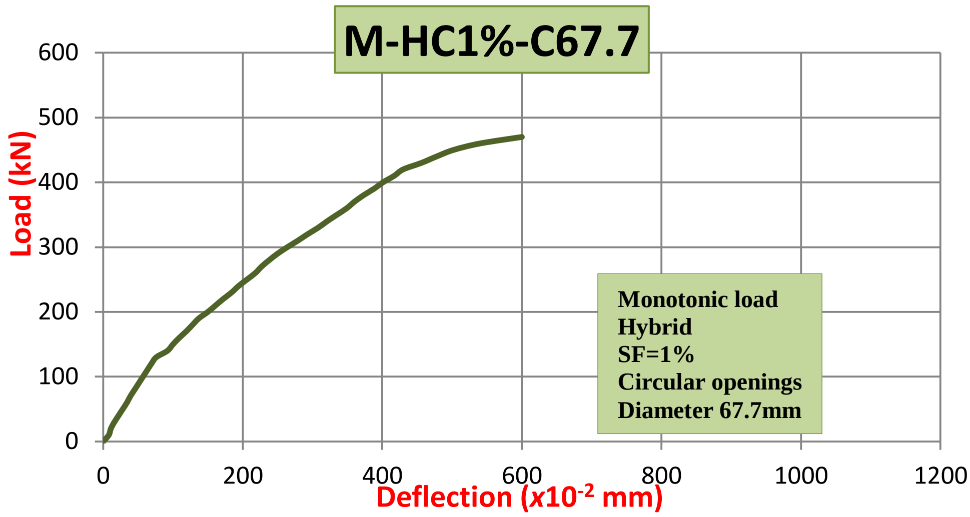

Figure 11. Load Versus mid-span Deflection Response for Beam M-HC1%-C67.7

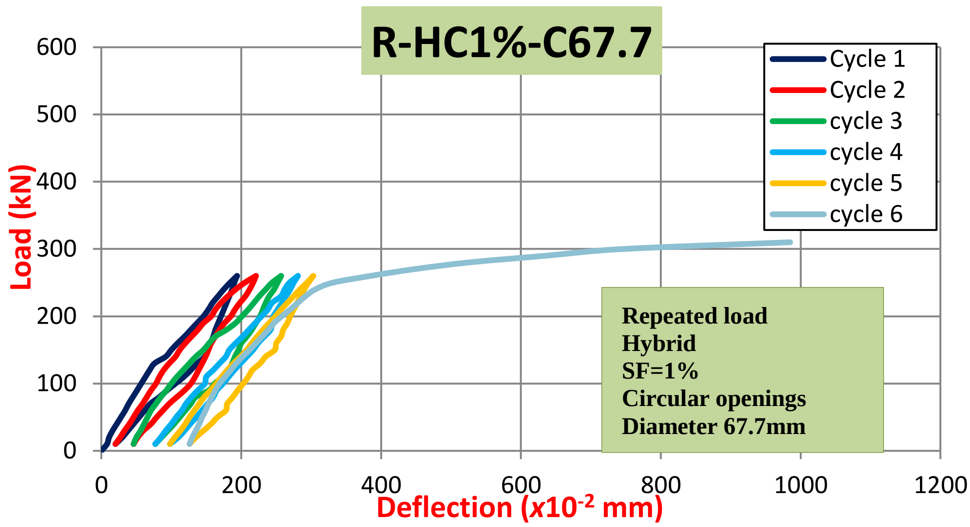

Figure 12. Load Versus mid-span Deflection Response for Beam R-HC1%-C67.7

6. Effect of Shape of Web Openings

Figure (13) shows effect of shape of web openings with equivalent area on load versus mid-span deflection for beams (controls) which are tested under monotonic loading.

The shape of openings are square of size 60mmx60mm in beam M-HC1%-S60x60, rectangular of size 72mmx50mm (1.37% of beam size) in beam M-HC1%-R72x50 and circular of diameter 67.7mm (1.37% of beam size) in beam M-HC1%-C67.7.

It can be seen that the beams suffer convergent deflection values at earlier stages of loading. At latest stages of loading (before failure) the deep beam of circular openings M-HC1%-C67.7 is stiffer than the deep beam with square openings M-HC1%-S60x60 which is stiffer than the beam with rectangular openings M-HC1%-R72x50.

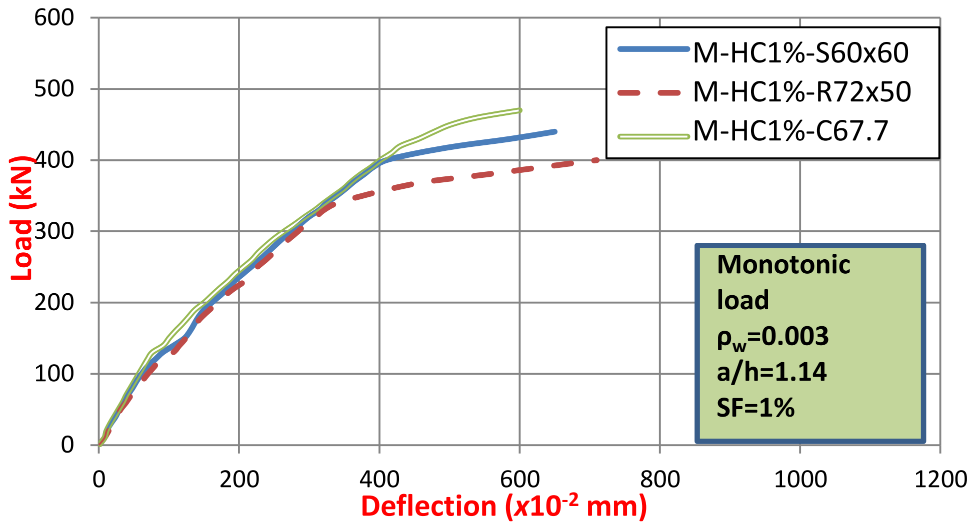

Figure 14. Load Versus mid-span Deflection for Hybrid Beams with Different shape with equivalent area of web openings under Monotonic Load.

7. Conclusions

Based on the results obtained from the experimental work of the research presented, the following conclusions are found:

1. Generally, the ultimate loads of deep beams with web openings subjected to repeated loading (55% of their corresponding monotonic loading per cycle) are lower than the ultimate loads of corresponding beams tested under monotonic loading in the ranges of variables adopted in the present work, as follows:
    i. The percentages decrease in ultimate load according to repeated loading of hybrid deep beams with circular web openings of radius 67.7mm (1.37% of beam size) is higher than hybrid deep beams with rectangular web opening with equivalent size which are 34.04% and 27.5%, respectively.
    ii. The mean value of the percentages decrease of beams subjected to monotonic and 55% repeated loading is 31.12.
2. For shape parameters, from the results it can be found that the ultimate load for the hybrid deep beam with rectangular web openings of size 72mmx50mm under monotonic load is decreases by 10% compare with the hybrid deep beam with equivalent square web openings of size 60mmx60mm (1.37% of beams size), It can be concluded that deep beams haves circular openings of diameter 67.7mm has the highest ultimate loads as compared to the other two shapes with equivalent area (1.37% of beam size) (rectangular and square) which are 17.5% and 6.8%, respectively, while under repeated of level 55% of their control beam monotonic ultimate load it can be seen that no significant change in ultimate load for different shape of web openings with equivalent area of opening, which the change was ±3.33%. Also, it can be seen that slightly increases in the percentage of hybrid deep beams with circular web openings compared to hybrid deep beams with equivalent area of square opening (1.37% of beams size) which are 6.9%.

8. References

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Abbreviations

Symbol	Description
ACI	American Concrete Institutes
ASTM	American Society for Testing and Materials
CC	Conventional Concrete
FC	Fiberous Concrete
SF	Steel Fibers
STM	Strut and Tie Models