Journal of Engineering and Sustainable Development

Vol. 23, No.04, July 2019
ISSN 2520-0917
https://doi.org/10.31272/jeasd.23.4.4

BEHAVIOR OF HYBRID REINFORCED CONCRETE DEEP BEAMS WITH WEB OPENINGS UNDER REPEATED LOADING

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Received 7/12/2017 Accepted 23/4/ 2018 Published 1/7/2019

Abstract: This research aims to study experimentally behavior of hybrid deep beams when subjected to two point's monotonic and repeated loading in presence or absence of web openings. All tested deep beams have the same reinforcement in flexural (ρ= 0.0184) and web (ρ_w=0.003) and same dimensions of (1500mm length, 150mm width and 350 mm 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 wings against shear failure (diagonal strut failure). To achieve the aim, twelve deep beams were cast and tested. Six of them were tested under monotonic loading as control beams to the other six beams tested under repeated loading at levels of 55% of the ultimate load of their control beams. The variables attempts were: loading type (either monotonic or repeated), beam type (either hybrid or non-hybrid), steel fiber (SF) ratio, and finally web opening sizes. The results illustrate that the ultimate load of deep beam with web openings under monotonic loading increases as the SF ratio increases. When SF was added to shear spans with a ratios of 1% and 2% under monotonic loading system, the ultimate load percentages increase are 37.5% and 68.75%, respectively compared with ultimate loads of beams which are without SF. Also, using fiberous concrete in casting the entire length of beams leads to an increase in the ultimate load of 4.55% as compared with deeps beams with the same SF ratio of 1%, and 43.75% as compared with beams cast with conventional concrete. The results using different opening size of square shapes, it was found that the ultimate load decrease as size of web openings increases from 0.61% of beam size to 1.37% of beam size by 10.17% and 25.42%, respectively as compared with hybrid deep beam without openings.

Keywords: *Deep Beam, Hybrid, Web Openings, Repeated Loading, Strengthen, Shear Span.*

سلوك العتبات الخرسانية الهجينة العميقة بوجود فتحات وترة تحت الاحمال التكرارية

الخلاصة: هذا البحث يهدف الى دراسة سلوك العتبة العميقة الهجينة تحت تأثيرنقطتي حمل رتيب وتكراري مع وجود وعدم وجود الفتحات. تمتلك جميع العتبات العميقة المفحوصة نفس التسليح 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 جناحي القص ضد فشل القص. لتحقيق الهدف، تم صب وفحص اثني عشر عتبة عميقة، فُحصت ست منها تحت تأثير الحمل الرتيب كمرجعية للعتبات الست الاخرى تحت تاثير الحمل التكراري بمستوى 55% من الحمل الاقصى للعتبات المرجعية. تضمنت المتغيرات: نوع الحمل (رتيب او تكراري)، نوع العتبة (اما هجينة او غير هجينة)، نسبة الاليف الحديدية وأخيرا حجم وشكل الفتحات. بيّنت النتائج انه اقصى حمل للعتبة العميقة المحتوية على فتحات تحت تأثير الحمل الرتيب يزداد بزيادة نسبة الالياف الحديدية. ووجد انه بإضافة الالياف الحديدية إلى فضاءات القص بنسبة 1% و 2% تحت تأثير الاحمال الرتيبة يؤدي زيادة الحمل الأقصى بنسبة 37.5% و 68.75% على التوالي مقارنة مع العتبات التي لا تحتوي على الالياف الحديدية. ولوحظَ إيضا ان استخدام الخرسانة الليفية في صب العتبات العميقة بالكامل، يزداد الحمل الأقصى بنسبة 4.55% مقارنة العتبات العميقة الهجينة بوجود فتحات مع نسبة إلياف 1%،

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وبنسبة 43.75% مقارنة مع العتبات العميقة ذات الفتحات المصبوبة باستخدام الخرسانة الاعتيادية بالكامل. وجد ان الحمل الأقصى يقل كلما بر حجم الفتحة من0.61% من حجم العتبة إلى 1.37% من حجم العتبة بمقدار 10.17% و 25.42% على التوالي مقارنة مع العتبة العميقة الهجينة بدون فتحات.

1. Introduction

Deep beams are structural elements loaded as simple beams in which a significant amount of the load is carried to the supports by a compression force combining the load and the reaction. As a result, the strain distribution is no longer considered linear, and the shear deformations become significant when compared to pure flexure [1]. Reinforced concrete deep beams are typically used as members in high rise structures due to their high resistance capacity. Also, they often have a function to convert the structural system between upper and lower part of the structure. Its structural behavior can influence the stability and safety if the structure remarkably. Because the stress distribution in the section of the deep beam is nonlinear, the linear elastic theory for the general beam analysis cannot be applied. Therefore, ACI 318M-14 Code requires that deep beams be designed via non-linear analysis or by Strut and Tie Method (STM) [2].

2. Designation of Specimens

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.

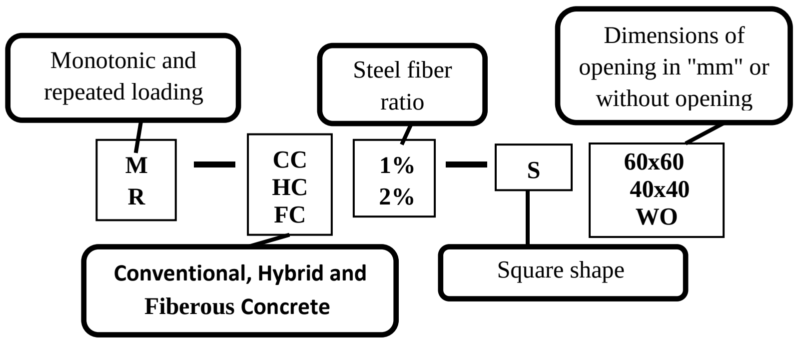

Figure 1. Symbol of Specimens

3. Experimental Program

A total of twelve 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 and web reinforcement. The reinforcement of flexure for all the tested beams are 2Ø 20mm and 1Ø 16mm ($\rho = 0.0184$ where ρ is the ratio of the flexural reinforcement). The clear span between supports was 1230mm Which gives an a/d 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. 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.

The proportions of concrete mix were (1: 1.82: 2.73) (Cement: Sand: Gravel) with water cement ratio=0.5, Table (1) shows details of the twelve tested reinforced concrete deep beams. The main variables investigated and details of the web reinforcement are also shown.

Table 1. Beam Specimens Detail*.

Beam No.	Beam designation	Type of Beams	Type of Load	SF (%)	Vertical And Horizontal Web. Reinforced
1	M-CC-S60x60	Non-Hybrid (CC)	Monotonic (Control)	0	Φ4 mm@ 80 mm c/c
2	R-CC-S60x60	Non-Hybrid (CC)	Repeated (55% of Control Ultimate Load)	0	Φ4 mm@ 80 mm c/c
3	M-FC-S60x60	Non-Hybrid (FC)	Monotonic (Control)	1	Φ4 mm@ 80 mm c/c
4	R-FC-S60x60	Non-Hybrid (FC)	Repeated (55% of Control Ultimate Load)	1	Φ4 mm@ 80 mm c/c
5	M-HC1%-S60x60	Hybrid	Monotonic (Control)	1	Φ4 mm@ 80 mm c/c
6	R-HC1%-S60x60	Hybrid	Repeated (55% of Control Ultimate Load)	1	Φ4 mm@ 80 mm c/c
7	M-HC2%-S60x60	Hybrid	Monotonic (Control)	2	Φ4 mm@ 80 mm c/c
8	R-HC2%-S60x60	Hybrid	Repeated (55% of Control Ultimate Load)	2	Φ4 mm@ 80 mm c/c
9	M-HC1%WO	Hybrid	Monotonic (Control)	1	Φ4 mm@ 80 mm c/c
10	R-HC1%-WO	Hybrid	Repeated (55% of Control Ultimate Load)	1	Φ4 mm@ 80 mm c/c
11	M-HC1%-S40x40	Hybrid	Monotonic (Control)	1	Φ4 mm@ 80 mm c/c
12	R-HC1%-S40x40	Hybrid	Repeated (55% of Control Ultimate Load)	1	Φ4 mm@ 80 mm c/c

*All Beam Specimens have same a/d ratio=1.14 and ρ_w=0.003.

Details of dimension and reinforcement for the beams tested specimens and the location of web opening with different size are shown in Figures (2).

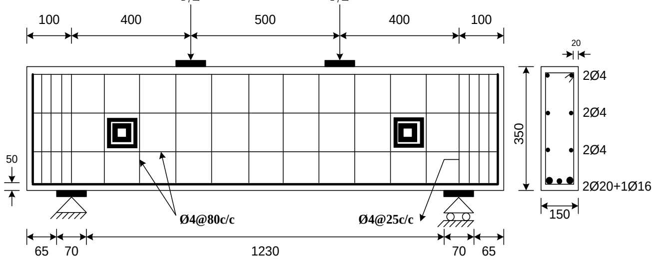

Figure 2. Details of Beams. (All Dimensions are in mm)

4. Materials

Properties and description of used materials are shown 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 0%, 1% and 2%, 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)

4.1 Description of Reinforcement Bars

The horizontal length of all longitudinal 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

4.2 Molds and Casting

Four steel molds were designed and fabricated for casting four 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). 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.

Plate 2. Details of Molds

5. 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 and 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 specimens were positioned on a machine with a clear span of 1230mm.

To prevent stress from concentrating on the superior beam face during loading, steel plates with 150mm length ×70mm width ×40mm height were placed over the support points and beneath the load points.

The testing of every beam specimen was done under two-point loading.

To make contact with the bottom of the beam centre, the dial gauge was placed in the middle under location defined by the two points.

In the case of monotonic testing, the beams specimens were loaded to failure in a single cycle, while in the case of repeated loading testing, they were loaded in six cycles. The loading of the beam specimens was done in 10kN increments, at a load increment rate of 1.5kN/sec.

The resulting cracks for every cycle were noted on the beam surface in terms of location and magnitude.

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 Beam (HC1%-WO) under testing

6. 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 was appears and more cracks appears at the shear span region of the beams. These cracks (pure shear cracks) began to appear in region between the support and the points of the applied load; starting from the support area toward the applied load area passing through the corner of the opening.

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

Other deep beams were 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 well it were began from the support toward the applied load's point, and at the end of this stage at least were two cracks appear.

At unloading, the crack width was decreases as the crack was disappear and appearing again when increased the load in the next cycle. In the other cycles; another cracks were appeared and increased.

Finally, in all tested deep beams failure was 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	Beam Type	SF (%)	Type of Loading	No. of Cycles	Ultimate Load (kN)	Modes of Failure
M-CC-S60x60	Non-Hybrid (CC)	0	Monotonic (Control)	-	320	Diagonal Shear Failure
R-CC-S60x60	Non-Hybrid (CC)	0	Repeated (55% of Control Ultimate Load)	6	240	Diagonal Shear Failure
M-FC-S60x60	Non-Hybrid (FC)	1	Monotonic (Control)	-	460	Diagonal Shear Failure
R-FC-S60x60	Non-Hybrid (FC)	1	Repeated (55% of Control Ultimate Load)	6	320	Diagonal Shear Failure
R-HC1%-S60x60	Hybrid	1	Monotonic (Control)	-	440	Diagonal Shear Failure
R-HC1%-S60x60	Hybrid	1	Repeated (55% of Control Ultimate Load)	6	300	Diagonal Shear Failure
M-HC2%-S60x60	Hybrid	2	Monotonic (Control)	-	540	Diagonal Shear Failure
R-HC2%-S60x60	Hybrid	2	Repeated (55% of Control Ultimate Load)	6	350	Diagonal Shear Failure
M-HC1%-WO	Hybrid	1	Monotonic (Control)	-	590	Diagonal Shear Failure
R-HC1%-WO	Hybrid	1	Repeated (55% of Control Ultimate Load)	6	380	Diagonal Shear Failure
M-HC1%-S40x40	Hybrid	1	Monotonic (Control)	-	530	Diagonal Shear Failure
R-HC1%-S40x40	Hybrid	1	Repeated (55% of Control Ultimate Load)	6	340	Diagonal Shear Failure

*1. All beams have the same (a/h) ratio = 1.14

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

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

Plates (4) to (15) show modes of failure and the crack patterns of the tested deep beams.

Plate 4. Deep Beam M-CC-S60x60

Plate 5. Deep Beam R-CC-S60x60

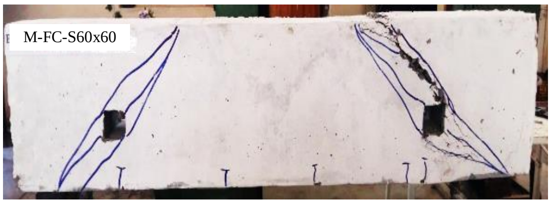

Plate 6. Deep Beam M–FC–S60x60

Plate 7. Deep Beam R-FC-S60x60

Plate 8. Deep Beam M-HC1%-S60x60

Plate 9. Deep Beam R-HC1%-S60x60

Plate 10. Deep Beam M-HC2%-S60x60

Plate 11. Deep Beam R-HC2%-S60x60

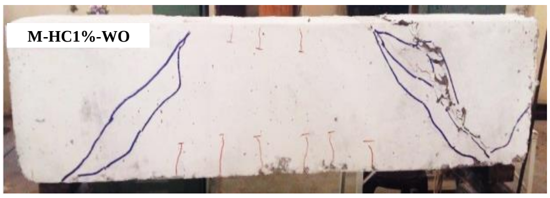

Plate 12. Deep Beam M-HC1%-WO

Plate 13. Deep Beam R-HC1%-WO

Plate 14. Deep Beam M-HC1%-S40x40

Plate 15. Deep Beam R-HC1%-S40x40

7.1 Effect of Loading type

Table (5) explain the effect of loading type, monotonic or repeated with load level of 55% of its control ultimate deep beams load.

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

Beam No.	Beam Designation	Beam Type	SF (%)	Type of Loading	No. of Cycles	Ultimate Load (kN)	% Percentage Decrease
1	M-CC-S60x60	Non-Hybrid (CC)	0	Monotonic (Control)	-	320	25
2	R-CC-S60x60	Non-Hybrid (CC)	0	Repeated (55% of Control Beam Load)	6	240	
3	M-FC-S60x60	Non-Hybrid (FC)	1	Monotonic (Control)	-	460	30.43
4	R-FC-S60x60	Non-Hybrid (FC)	1	Repeated (55% of Control Beam Load)	6	320	
5	M-HC1%-S60x60	Hybrid	1	Monotonic (Control)	-	440	31.82
6	R-HC1%-S60x60	Hybrid	1	Repeated (55% of Control Beam Load)	6	300	
7	M-HC2%-S60x60	Hybrid	2	Monotonic (Control)	-	540	35.19
8	R-HC2%-S60x60	Hybrid	2	Repeated (55% of Control Beam Load)	6	350	
9	M-HC1%-WO	Hybrid	1	Monotonic (Control)	-	590	35.59
10	R-HC1%-WO	Hybrid	1	Repeated (55% of Control Beam Load)	6	380	
11	M-HC1%-S40x40	Hybrid	1	Monotonic (Control)	-	530	35.85
12	R-HC1%-S40x40	Hybrid	1	Repeated (55% of Control Beam Load)	6	340	
							X'** = 32.31

*1.All beams have the same (a/h) ratio = 1.14

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

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

**X'= Mean

From the observation of Table (5), the following points can be noticed:

1. The percentages decrease in ultimate load according to repeated loading for non-hybrid deep beams of FC with square web openings of size 60mmx60mm (1.37% of beam size) is higher than CC with same web openings which are 30.43% and 25%, respectively.
2. The percentages decrease in ultimate load according to repeated loading of hybrid deep beams which have SF ratio 2% with square web openings of size 60mmx60mm (1.37% of beam size) is higher than hybrid deep beams which have SF ratio 1% with same opening which are 35.19% and 31.82%, respectively.
3. The percentages decrease in ultimate load according to repeated loading of hybrid deep beams without web openings is 35.59%.
4. The percentages decrease in ultimate load according to repeated loading of hybrid deep beams with square web openings of size 40mmx40mm (0.61% of beam size) is 35.85%.

7.2 Effect of Beam Type

7.2.1 Deep Beams under Monotonic Loading

Effects of the variable beam type on the ultimate load for deep beams with square web openings of size 60mmx60mm (1.37% of beam size) tested under monotonic loading in this study are shown in Figure (3) and Table (5). Beam M-CC-S60x60 was cast using CC, while beam M-HC1%-S60x60 was cast using CC at mid region and FC at shear region, finally beam M-FC-S60x60 was cast using FC.

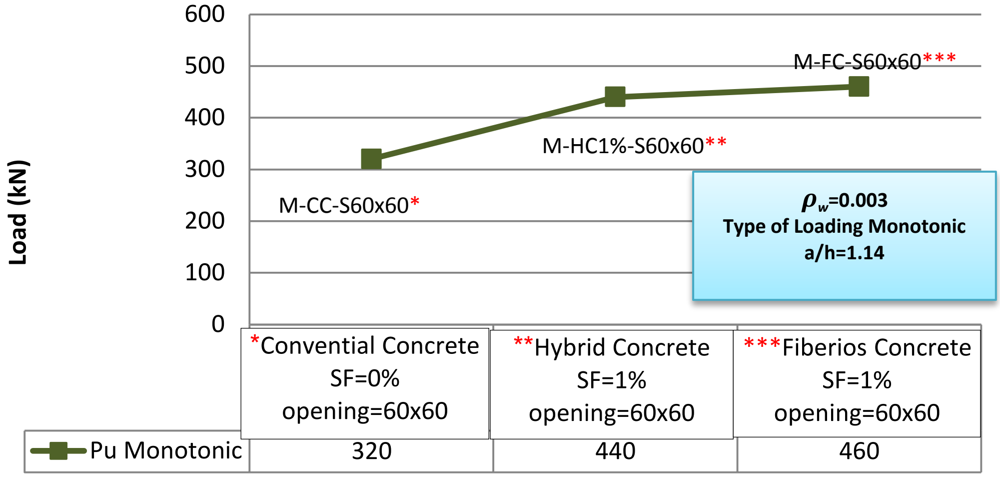

Figure 3. Effect of Beam Type on Ultimate Load under Monotonic Loading

Table 5. Effect of Beam Type on Ultimate Load under Monotonic Loading

Beam Designation	Beam Type	SF (%)	ρ_w	Ultimate Load (kN)	% Increase of Ultimate Load *
M-CC-S60x60	Non- Hybrid (CC)	0	0.003	320	-
M-HC1%-S60x60	Hybrid	1	0.003	440	37.5
M-FC-S60x60	Non- Hybrid (FC)	1	0.003	460	43.75**

*The percentage of increase is measured with respect to beam M-CC-S60x60.
** The percentage increasing of load of the beam M-FC-S60x60is 4.55% with respect to beam M-HC1%-S60x60.

From the detailed results in Table (5), it is noticed that the increase in the ultimate load for M-FC-S60x60 and M-HC1%-S60x60 are about 43.75% and 37.5% respectively, with respect to M-CC-S60x60. Through this results, it is observed that the addition of a moderate proportion of SF (1%) to beam shear spans M-HC1%-S60x60 lead to improve the amount of resistance by a significant ratio of 37.5%, while when the same proportion of SF was added through the entire length of the beam M-FC-S60x60, the percentage of increase is also significant 43.75% but slightly higher than the hybrid beam with SF only at shear spans 4.55%. It can be concluded that the presence of SF in the region of pure bending is insignificant in deep beams with web openings subjected to monotonic loading.

7.2.2 Deep Beams under Repeated Loading

Results shown in Figure (4) and listed in Table (6) show the effect of beam type on the ultimate load for deep beams with square web openings (1.37% of beam size) tested under repeated loading by 55% of ultimate monotonic loading of similar beams.

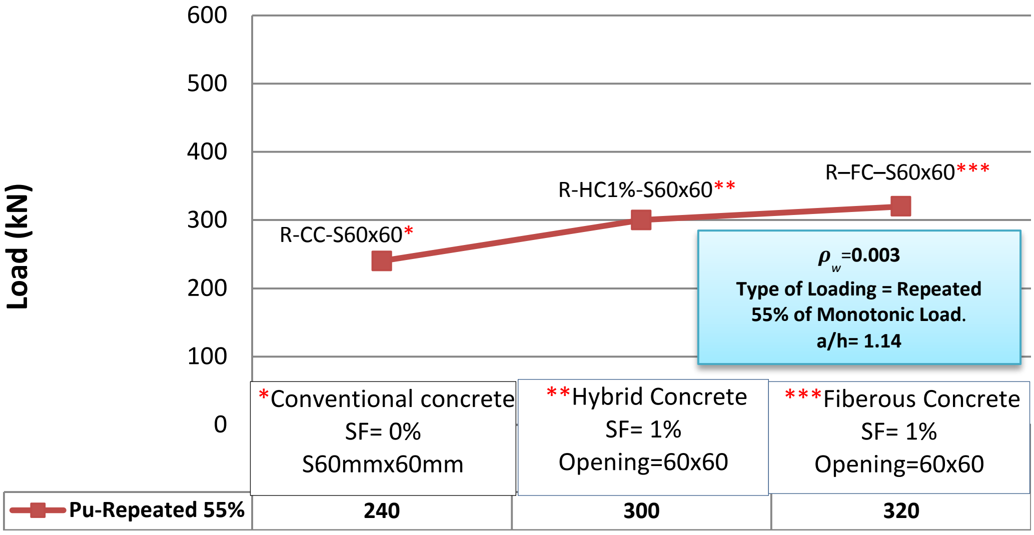

Figure 4. Effect of Beam Type on Ultimate Load under Repeated Loading

Table 6. Effect of Beam Type on Ultimate Load under Repeated Loading

Beam Designation	Beam Type	SF (%)	ρ_w	Ultimate Load (kN)	% Increase Ultimate Load *
R-CC-S60x60	Non- Hybrid (CC)	0	0.003	240	-
R-HC1%-S60x60	Hybrid	1	0.003	300	25
R-FC-S60x60	Non- Hybrid (FC)	1	0.003	320	33.33**

*The percentage increase is measured with respect to beam R-CC-S60x60.
**The percentage increase of load of beam R-FC-S60x60 is 6.67% with respect to beam R-HC1%-S60x60.

From observation of results of Table (6), it can be seen that the hybrid deep beam R-HC1%-S60x60 fails in load higher than non-hybrid deep beam cast from CC by 25%, while deep beam R-FC-S60x60 which was cast from FC with SF ratio of 1% fails in load significantly higher than R-CC-S60x60 by 33.33%.

The percentage of increasing in ultimate load of beam R-FC-S60x60 is 6.67% with respect to beam R-HC1%-S60x60.

Figure (5) shows the effect of beam type under monotonic and repeated loading. It can be concluded that the ultimate load values of deep beams with web openings of size 60mmx60mm (1.37% of beam size) subjected to repeated loadings are lower than those subjected to monotonic loading of level 55% of its control values.

Also, the presence of SF in the region of pure bending in beams subjected to monotonic and repeated loading level of 55% of monotonic ultimate load of similar beams are insignificant.

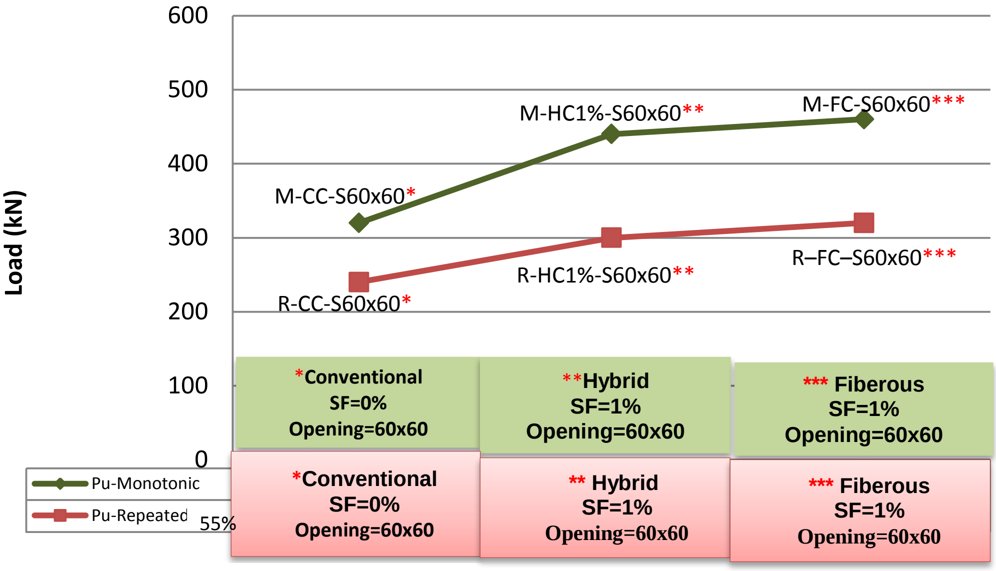

Figure 5. Effect of Beams Type on Ultimate Load under Monotonic and Repeated Loading.

7.3 Effect of SF Ratio

Three of volumetric ratios of SF (0%, 1% and 2%) were used in this experimental work to investigate the behavior of shear strength for hybrid deep beams with square web openings of size 60mmx60mm (1.37% of beam size) under monotonic and repeated loading. These amounts of SF were added to shear span regions of hybrid deep beams.

7.3.1 Deep Beams under Monotonic Loading

Figure (6) and results in Table (7) show the effect of SF ratio on the ultimate loads for deep beams with square web openings of size 60mmx60mm (1.37% of beam size) that tested under monotonic loading.

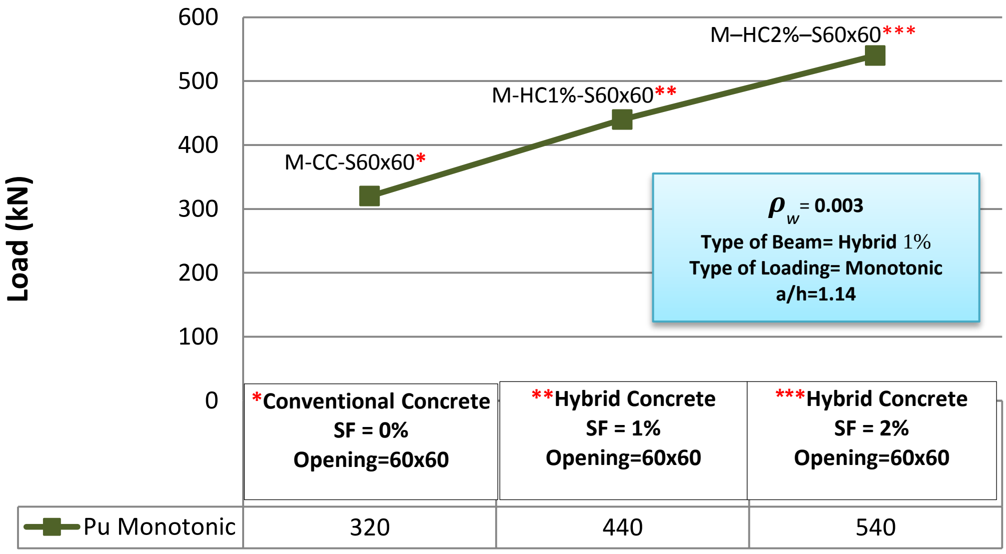

Figure 6. Effect of SF Ratio on Ultimate Load of Beams under Monotonic Loading

Table 7. Effect of SF Ratio on Ultimate Load of Beams under Monotonic Loading

Beam Designation	Beam Type	SF (%)	ρ_w	Ultimate Load (kN)	%Increase Ultimate Load *
M-CC-S60x60	Non-Hybrid** (CC)	0	0.003	320	-
HC1%-S60x60	Hybrid	1	0.003	440	37.5
M-HC2%-S60x60	Hybrid	2	0.003	540	68.75***

*The percentage increase is measured with respect to beam M-CC-S60x60
**Hybrid beam with SF ratio = 0%
***The percentage increase of load of beam M-HC2%-S60x60is 22.73% with respect to beam M-HC1%-S60x60

The ultimate load for hybrid beam with SF ratio of (2%) M-HC2%-S60x60 and SF ratio of (1%) M-HC1%-S60x60 was increased by 68.75% and 37.5%, respectively with respect to M-CC-S60x60 which was cast without SF.

The presence of SF in shear span regions for hybrid deep beams with square web openings of size 60mmx60mm (1.37% of beam size) contributes in enhancing resistance of hybrid deep beams.

Also, the increase in SF ratio from 1% to 2% in shear spans are of considerable importance since the percentage of increase is 22.73% between the two beams (M-HC1%-S60x60 and M-HC2%-S60x60) under monotonic loading.

7.3.2 Deep Beams under Repeated Loading

Figure (7) and Table (8) show the effect of SF ratio on the ultimate load of hybrid deep beams tested under repeated loading level of 55% of their corresponding control monotonic loading.

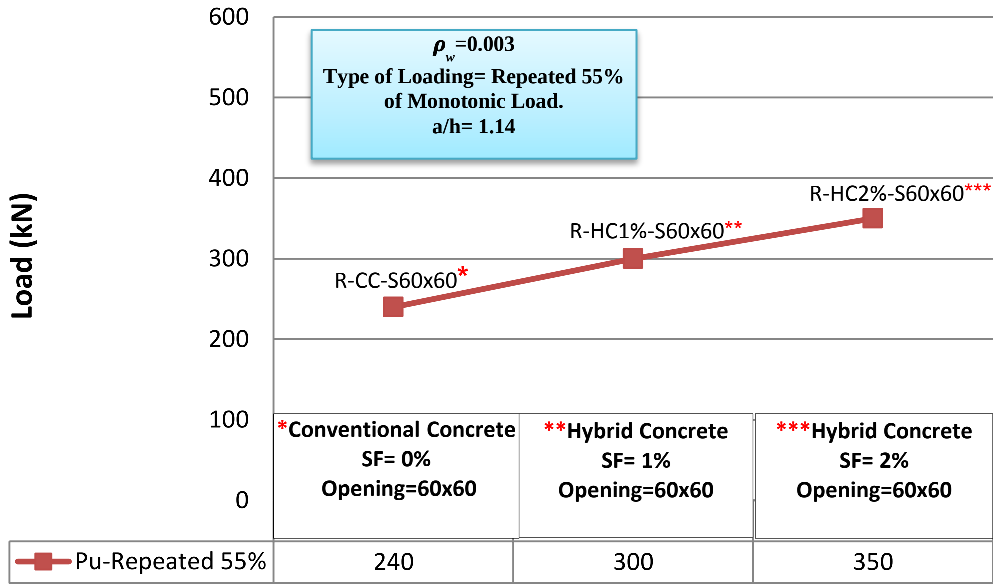

Figure 7. Effect of SF Ratio on Ultimate Load of Beams under Repeated Loading

Table 8. Effect of SF Ratio on Ultimate Load of Beams under Repeated Loading

Beam Designation	Beam Type	SF (%)	ρ_w	Ultimate Load (kN)	% Increase Ultimate Load*
R-CC-S60x60	Non-Hybrid** (CC)	0	0.003	240	-
R-HC1%-S60x60	Hybrid	1	0.003	300	25
R-HC2%-S60x60	Hybrid	2	0.003	350	45.83***

*The percentage of increase is measured with respect to beam R-CC-S60x60.
**Hybrid beam with SF ratio = 0%.
***The percentage of increase of load of beam R-HC2%-S60x60 is 16.67% with respect to beam R-HC1%-S60x60.

From the observation of results in Table 8, it was found that the addition of SF in hybrid beams under repeated loading is significant.

The capacity of hybrid deep beams with SF ratio of 2% and 1% are increased by 45.83% and 25%, respectively with respect to R-CC-S60x60.

Also, the increase in SF ratio from 1% to 2% in shear spans region of considerable importance since the percentage of increase is 16.67% between the two beams (R-HC1%-S60x60 and R-HC2%-S60x60) under repeated loading.

Figure (8) show the effect of SF ratio on ultimate load of hybrid deep beams with square web openings of size 60mmx60mm (1.37% of beam size) under monotonic and repeated loading of 55% of their control beam failure monotonic loadings.

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.

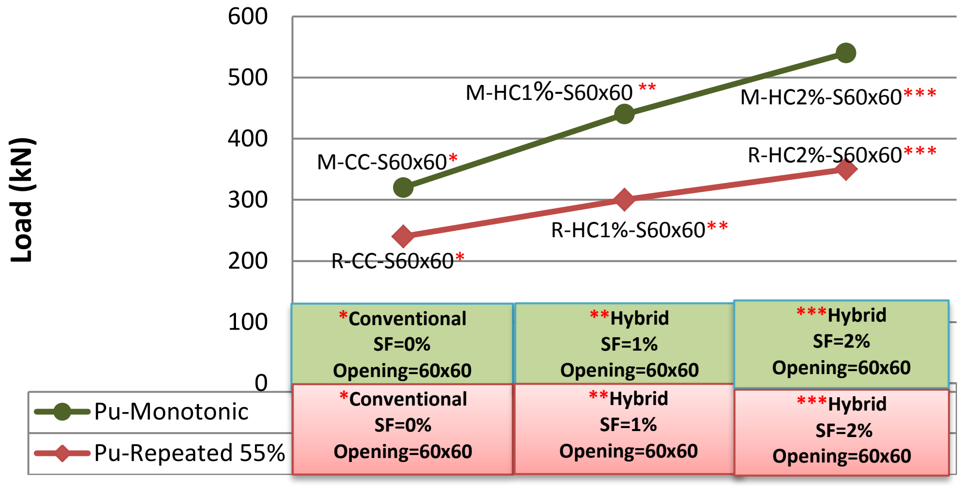

Figure 8. Effect of SF Ratio on Ultimate Load of Beams under Monotonic and Repeated Loading.

7.4 Effect of Size of Web Openings

7.4.1 Deep Beams under Monotonic Loading

The effect of size of web openings is studied under constant ratio of SF on ultimate load. The results are drawn in Figure (9) and also listed in Table (9).

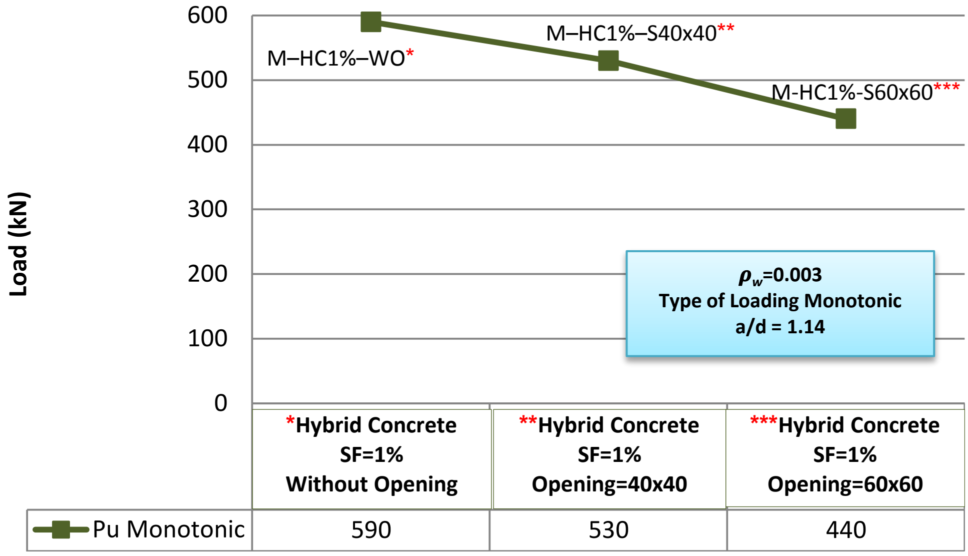

Figure 9. Effect of size of web openings on Ultimate Load of Beams under Monotonic Loading

Table 9. Effect of size of Web Openings on Ultimate Load of Beams under Monotonic Loading

Beam Designation	Beam Type	SF (%)	ρ_w	Ultimate Load (kN)	% Increase Ultimate Load *
M-HC1%-WO	Hybrid	1	0.003	590	-
M-HC1%-S40x40	Hybrid	1	0.003	530	-10.17
M-HC1%-S60x60	Hybrid	1	0.003	440	-25.42**

*The percentage of increase is measured with respect to beam M–HC1%–WO.
**The percentage increase of load of beam M-HC1%-S60x60 is -16.98% with respect to beam M-HC1%-S40x40.

From the results it can be seen that the ultimate load for the hybrid deep beam with square web openings of size 40mmx40mm (0.61% of beams size) M-HC1%-S40x40 is decreases by 10.17% as compare with the hybrid deep beam without web openings M-HC1%-WO.

Also the hybrid deep beam with square web openings of size 60mmx60mm (1.37% of beam size) M-HC1%-S60x60 decreases by 25.42% as compared with beam M-HC1%-WO.

Also, it can be seen that the ultimate load of deep beams with square openings of size 60mmx60mm (1.37% of beams size) M-HC1%-S60x60 is lower than the ultimate load of deep beam with square web openings of size 40mmx40mm (0.61% of beams size) M-HC1%-S40x40 by 16.98%.

It is an expected results that when the opening size has increase the ultimate load was decreased.

7.4.2 Deep Beams under Repeated Loading

The effect of size of web openings on the ultimate load for hybrid deep beams under repeated loading of level 55% of their corresponding control monotonic loading is shown in Figure (10) and listed in Table (10).

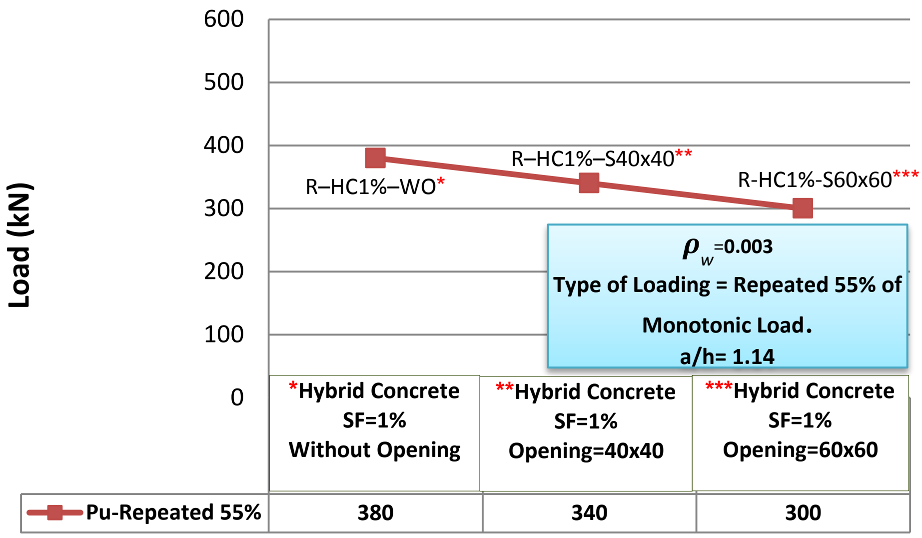

Figure 10. Effect of size of web openings on Ultimate Load of Beams under Repeated Loading.

Table 10. Effect of size of web openings on Ultimate Load of Beams under Repeated Loading.

Beam Designation	Beam Type	SF (%)	ρ_w	Ultimate Load (kN)	% Increase Ultimate Load *
R-HC1%-WO	Hybrid	1	0.003	380	-
R-HC1%-S40x40	Hybrid	1	0.003	340	-10.53
R-HC1%-S60x60	Hybrid	1	0.003	300	-21.05**

*The percentage of increase is measured with respect to beam R–HC1%–WO.
**The percentage increase of load of beam R-HC1%-S60x60 is -11.76% with respect to beam R-HC1%-S40x40.

From observation of Figure (10) and Table (10), it can be seen that the ultimate load for the hybrid deep beam with square web openings of size 40mmx40mm (0.61% of beams size) R-HC1%-S40x40 was decreased by 10.52% lower than that of the hybrid deep beam without web openings M-HC1%-WO.

The ultimate loads of hybrid deep beam with square web openings of size 60mmx60mm (1.37% of beam size) R-HC1%-S60x60 decreases by 21.05% compare with R-HC1%-WO which is without web openings.

Also, it can be seen that deep beams have square openings of size 60mmx60mm (1.37% of beams size) R-HC1%-S60x60 has the lowest ultimate loads as compared with deep beams with square web openings of size 40mmx40mm (0.61% of beams size) R-HC1%-S40x40 which are 11.76%.

Also, it is an expected results that when the opening size has increase the ultimate load decrease.

Figure (11) show the effect of size of web openings with different size on ultimate load of hybrid deep beams as they subjected to monotonic loading and repeated loading of level 55% of their control beams monotonic ultimate load.

It can be seen the deep beam suffer convergent behavior as this subjected to monotonic or repeated loading.

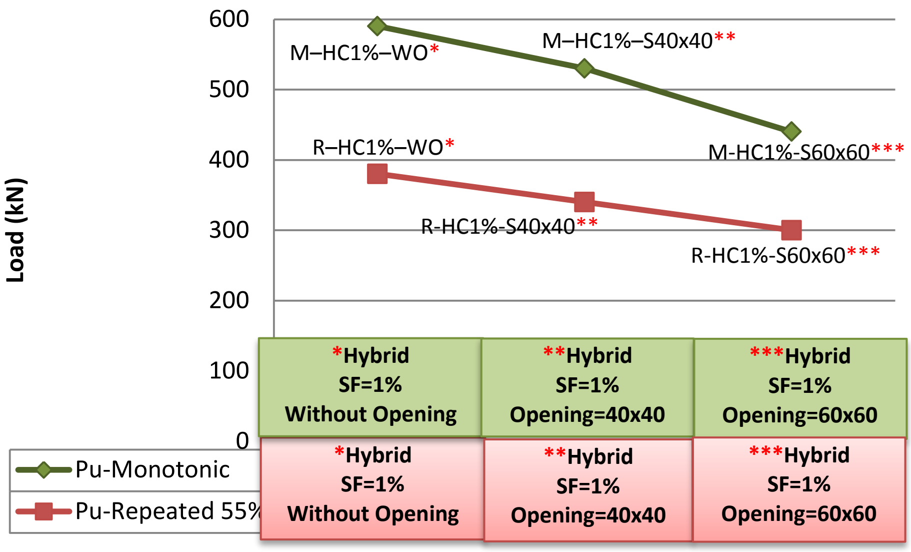

Figure 11. Effect of size of web openings on Ultimate Load of Beams under Monotonic and Repeated Loading.

8. Load-Deflection Response

The load versus mid-span deflection curves are shown in Figure (12) through (23) for the tested deep beams in the present work as they subjected to monotonic and repeated loading.

The load mid-span deflection varies from linear of initial stages of loading to nonlinear with different slopes after initiating of cracking.

The load versus mid-span deflection curves appeared to be dependent on type of loading, presence of web openings, size of web openings, type of beam and different ratio of SF.

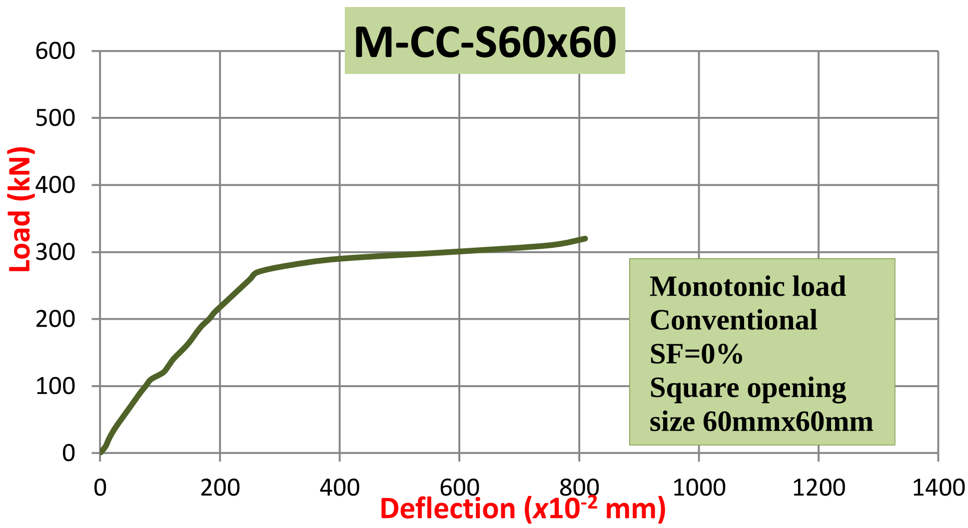

Figure 12. Load Versus mid-span Deflection Response for Beam M-CC-S60x60

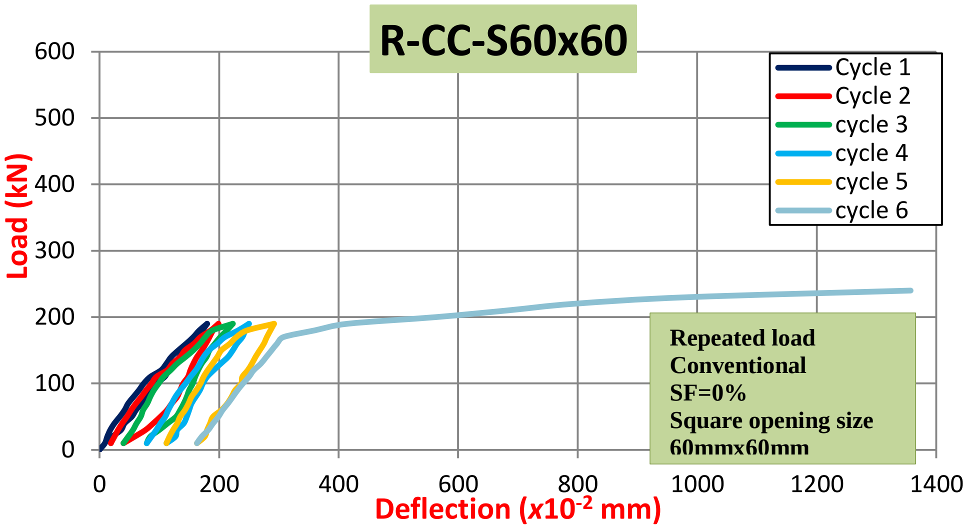

Figure 13. Load Versus mid-span Deflection Response for Beam R-CC-S60x60

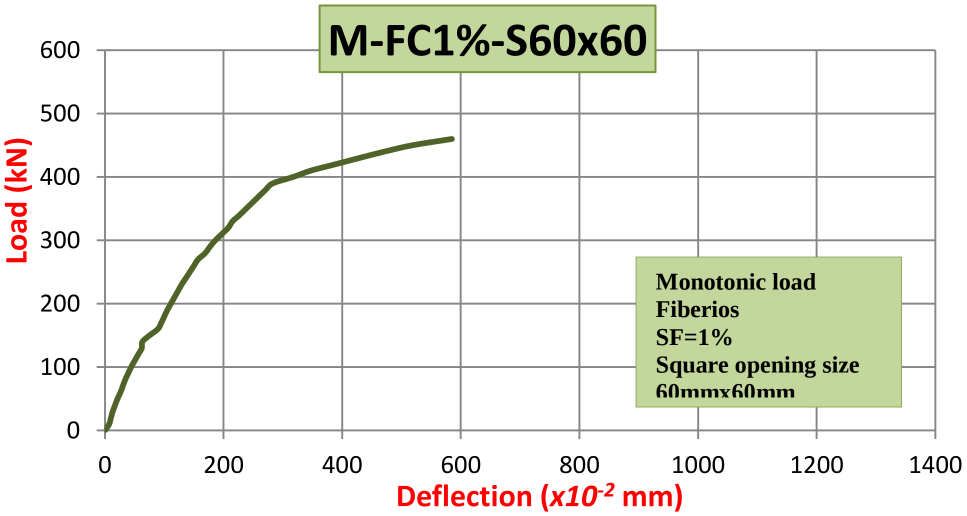

Figure 14. Load Versus mid-span Deflection Response for Beam M-FC-S60x60

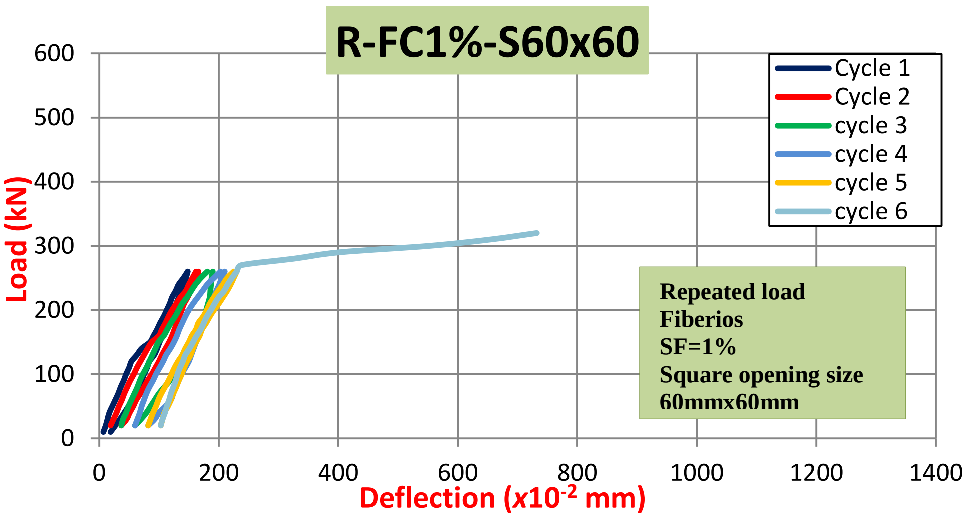

Figure 15. Load Versus mid-span Deflection Response for Beam R-FC-S60x60

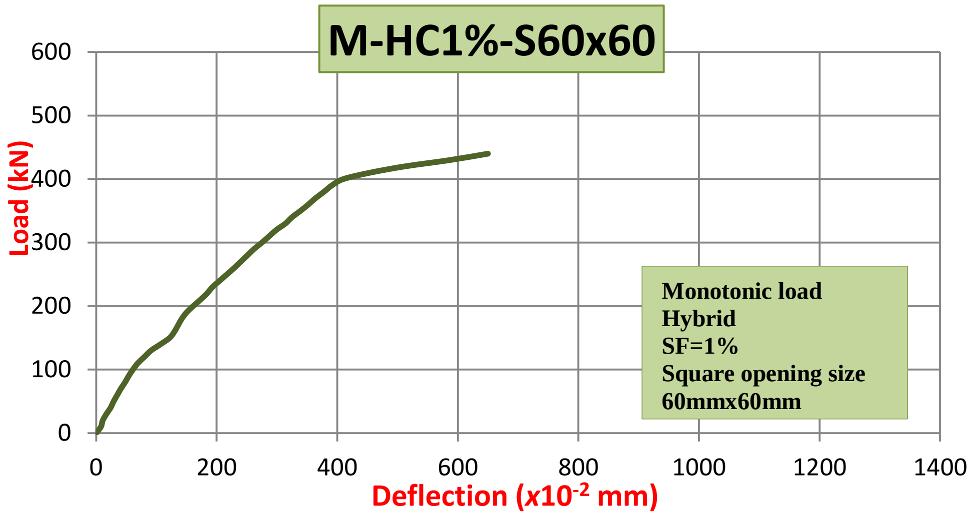

Figure 16. Load Versus mid-span Deflection Response for Beam M-HC1%-S60x60

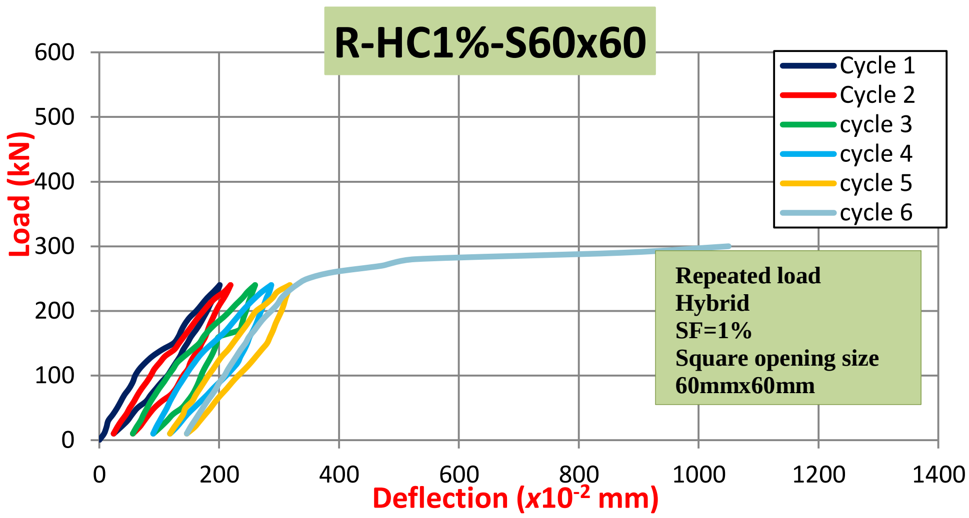

Figure 17. Load Versus mid-span Deflection Response for Beam R-HC1%-S60x60

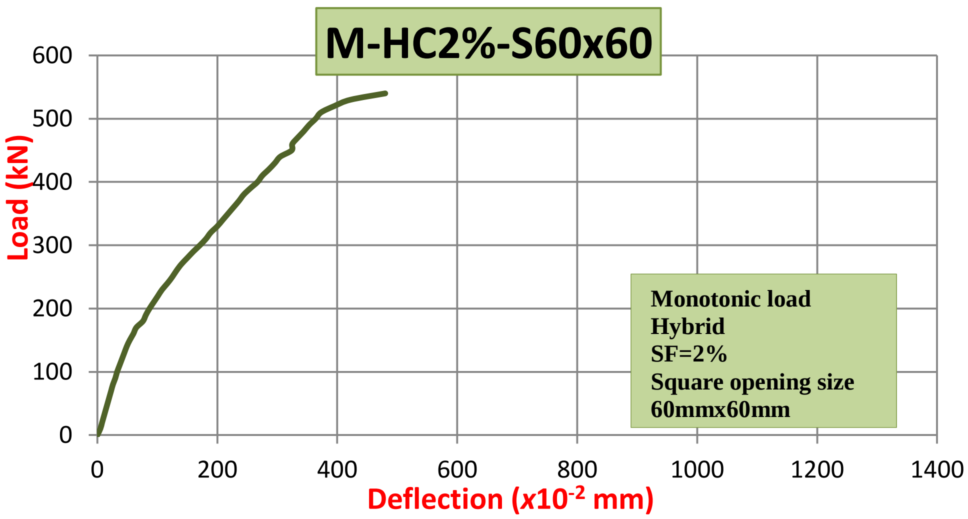

Figure 18. Load Versus mid-span Deflection Response for Beam M-HC2%-S60x60

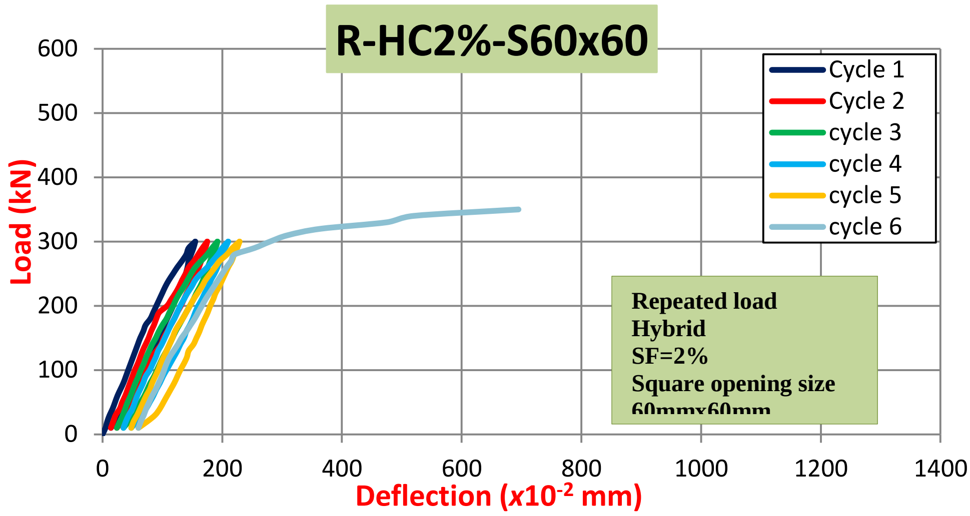

Figure 19. Load Versus mid-span Deflection Response for Beam R-HC2%-S60x60

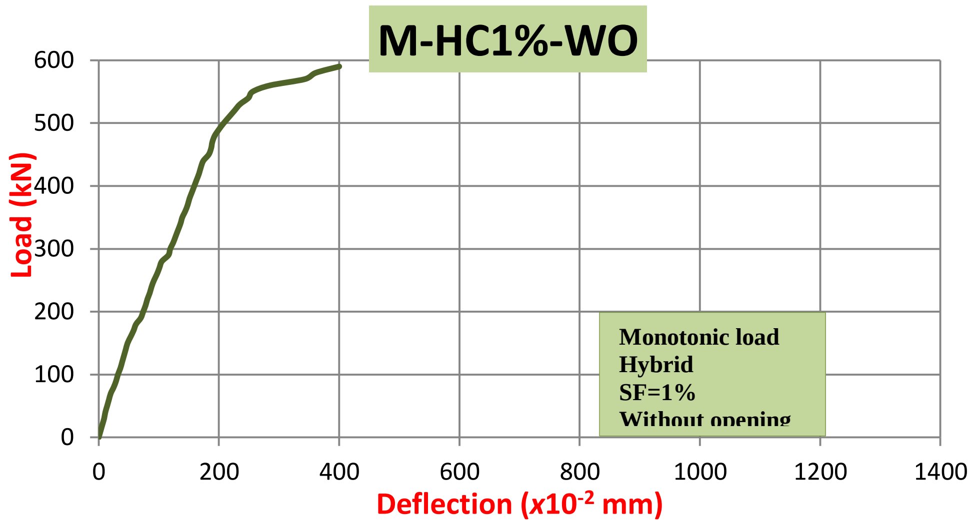

Figure 20. Load Versus mid-span Deflection Response for Beam M-HC1%-WO

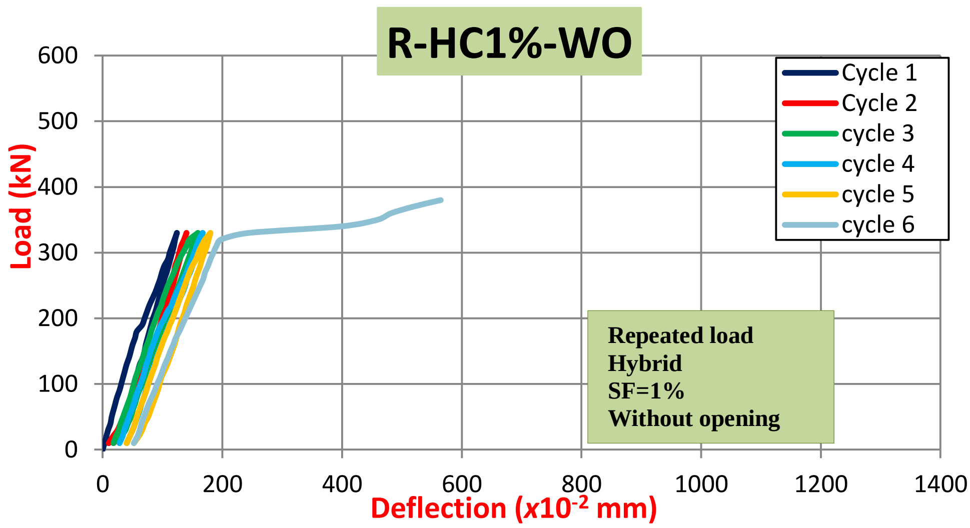

Figure 21. Load Versus mid-span Deflection Response for Beam R-HC1%-WO

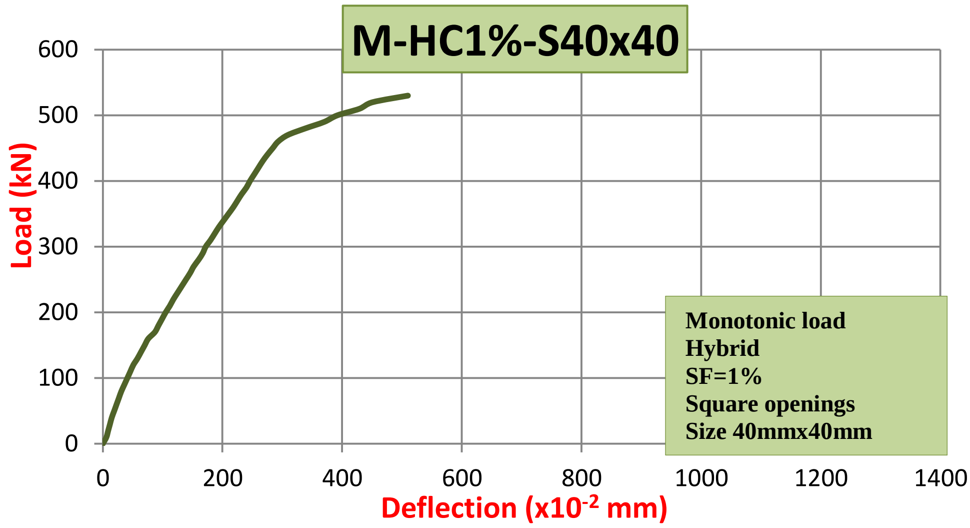

Figure 22. Load Versus mid-span Deflection Response for Beam M-HC1%-S40x40

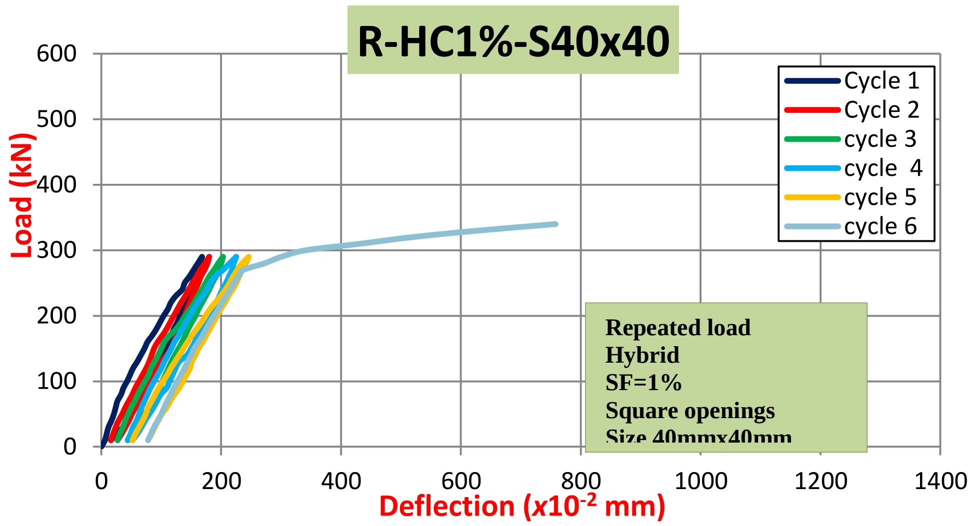

Figure 23. Load Versus mid-span Deflection Response for Beam R-HC1%-S40x40

8.1 Effect of Beam Type

Figure (24) shows the difference between load versus mid-span deflection responses of non-hybrid (CC) beam M-CC-S60x60, beam M-HC1%-S60x60 (hybrid beam with SF ratio 1% in shear spans) and non-hybrid (FC) beam M-FC-S60x60 with SF ratio of 1% under monotonic loading.

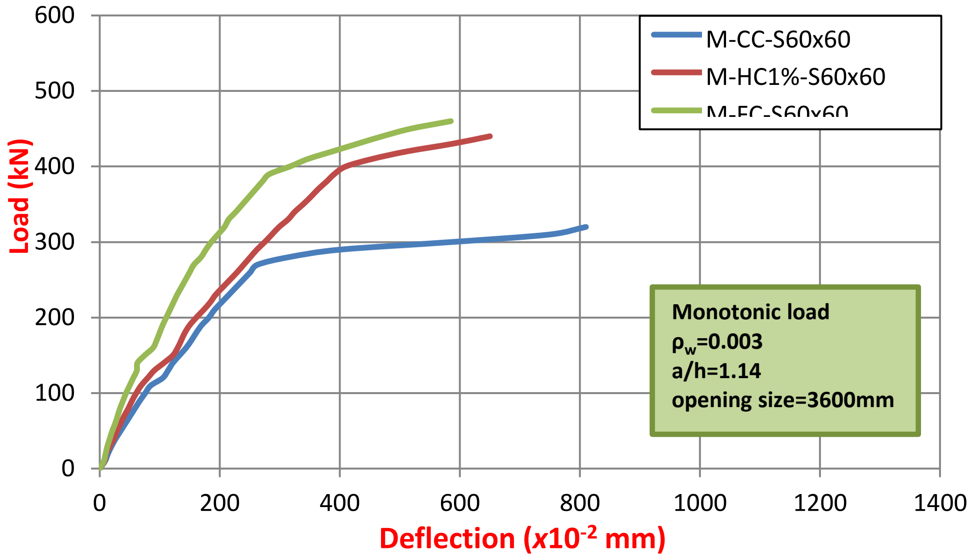

Figure 24. Load Versus mid-span Deflection Response for Different Beam Types under Monotonic Loading

8.2 Effect of SF Ratios

Figure (25) shows the effect of the addition of SF for hybrid deep beams on load versus mid-span deflection response under monotonic loading. Three volumetric ratios of SF were used. Hybrid beam with SF ratio of 2% (M-HC2%-S60x60) have the smaller deflection values at each stage of loading as compared to other beams that have SF ratios of 1% (M-HC1%-S60x60) and 0% (M-CC-S60x60).

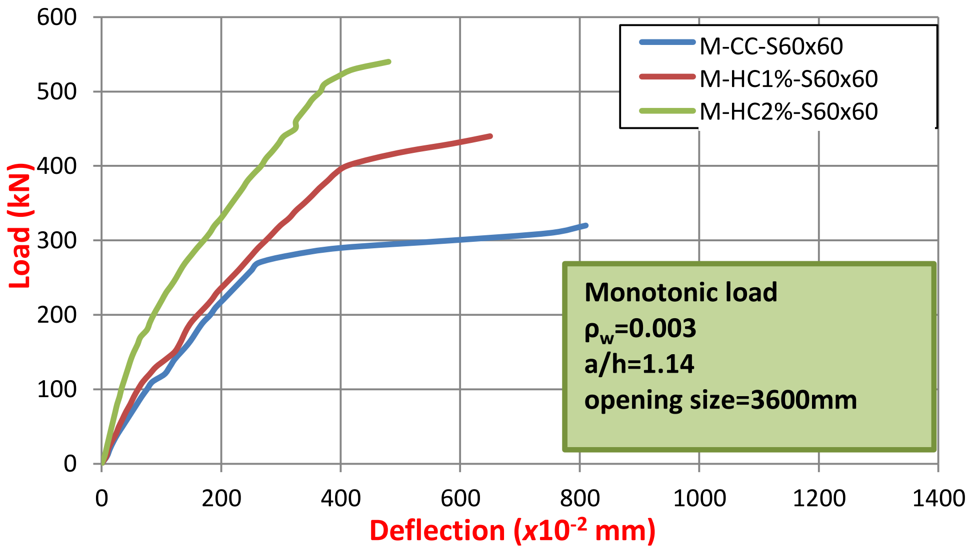

Figure (25) Load Versus mid-span Deflection Response for Hybrid Beams with square web openings of size 60mmx60mm 1.37% of beam size with Different SF Ratios under Monotonic Loading

8.3 Effect of Size of web openings

Figure (26) shows effect of size of web openings on load versus mid-span deflection for deep beams (controls) which are tested under monotonic loading. The size of openings are 0, 40mmx40mm and 60mmx60mm (0%, 0.61% and 1.37% from beam size), respectively. It can be seen that an expected result which is as the opening size decreases as the deflection decrease at the same stages of loading.

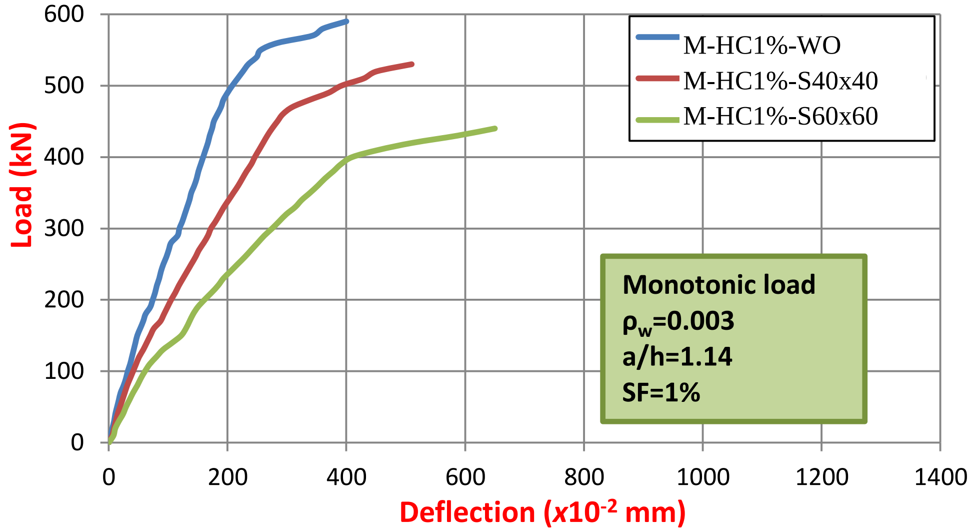

Figure 26. Load Versus mid-span Deflection for Hybrid Deep Beams with Different size web openings under Monotonic Loading

9. 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 and without 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 for non-hybrid deep beams of FC with square web openings of size 60mmx60mm (1.37% of beam size) is higher than CC which are 30.43% and 25%, respectively.
   ii. The percentages decrease in ultimate load according to repeated loading of hybrid deep beams which have SF ratio 2% with square web openings of size 60mmx60mm (1.37% of beam size) is higher than hybrid deep beams which have SF ratio 1% with same opening which are 35.19% and 31.82%, respectively.
   iii. The percentages decrease in ultimate load according to repeated loading of hybrid deep beams without web openings is 35.59%.
   iv. The percentages decrease in ultimate load according to repeated loading of hybrid deep beams with square web openings of size 40mmx40mm (0.69% of beam size) is 35.85%.
   v. The mean value of the percentages decrease of beams subjected to monotonic and 55% repeated loading is 31.927.

2. It can be concluded that the presence of SF in the region of pure bending is insignificant in deep beams with web openings of size 60mmx60mm (1.37% of beam size) subjected to monotonic loading. It is observed that the addition of a moderate proportion of SF (1%) to beam shear spans M-HC1%-S6x6 lead to improve the amount of resistance by a significant ratio of 37.5%, while when the same proportion of SF was added through the entire length of the beam M–FC–S6x6, the percent of increase is also significant 43.75% but slightly higher than the hybrid beam with SF only at shear spans 4.55%.
3. the presence of SF in the region of pure bending in beams subjected to monotonic and repeated loading level of 55% of monotonic ultimate load of similar beams are insignificant. It can be found that the hybrid deep beam with web openings (1.37% of beam size) fails in load higher than non-hybrid deep beam cast from CC by 25%, while deep beam which was cast from FC with SF ratio of 1% fails in load significantly higher than deep beam casting with CC by 33.33%. The percentage increase in ultimate load of deep beam cast with FC is 6.67% with respect to hybrid deep beam with SF=1% only in shear zone.
4. The ultimate load for hybrid beam with web opening (1.37 of beam size) with SF ratio of (2%) and SF ratio of (1%) under monotonic load is increased by 68.75% and 37.5%, respectively with respect to beam with web opening (1.37% of beam size) which is cast without SF. The presence of SF in shear span regions for hybrid deep beams with square web openings (1.37% of beam size) contributes in enhancing resistance of hybrid deep beams. Also, the increase in SF ratio from 1% to 2% in shear spans are of considerable importance since the percentage of increase is 22.73%.
5. It was found that the addition of SF in hybrid beams under repeated loading is significant. The capacity of hybrid deep beams with SF ratio of 2% and 1% are increased by 45.83% and 25%, respectively with respect to deep beam cast with CC. Also, the increase in SF ratio from 1% to 2% in shear spans are of considerable importance since the percentage of increase is 16.67%.
6. For size parameters, It is an expected results that when the opening size has increase the ultimate load decrease, from the results it can be seen that the ultimate load for the hybrid deep beam with square web openings of size 40mmx40mm (0.61% of beams size) and web openings of size 60mmx60mm (1.37% of beams size) is decreases by 10.17% and 25.42%, respectively as compare with the hybrid deep beam without web openings, Also, it can be seen that the ultimate load of deep beams with square openings of size 60mmx60mm (1.37% of beams size) is lower than the ultimate load of deep beam with square web openings of size 40mmx40mm (0.61% of beams size) by16.98%.
7. For size parameters of openings, it found that under monotonic loading when changing the web openings' area from 40mmx40mm (0.69 of beam size) to 60mmx60mm (1.37% of beam size), the ultimate load decreases from 10.17% to 25.42%, as compared with hybrid deep beams without openings. Also, under repeated loading for different hybrid deep beams with web openings' area

40mmx40mm (0.69 of beam size) to 60mmx60mm (1.37% of beam size) decrease from 10.52% to 21.05%, as compared with hybrid deep beams without openings.

8. For size parameters of openings, which tested under repeated loading, it can be seen that that the ultimate load for the hybrid deep beam with square web openings of size 40mmx40mm (0.61% of beams size) and 60mmx60mm (1.37% of beam size) is lower than that of the hybrid deep beam without web openings which decreases by 10.52% and 21.05% ,respectively. Also, it can be seen that deep beams haves square openings of size 60mmx60mm (1.37% of beams size) has the lowest ultimate loads as compared to deep beams with square web openings of size 40mmx40mm (0.61% of beams size) which are 11.76%.

10. 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