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Flexural Performance of Laced Reinforced Concrete Beams under Static and Fatigue Loads

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ABSTRACT

This paper introduces experimental results of eighteen simply supported reinforced concrete beams of cross sections ($160\ mm \times 300\ mm$) and length 3000 mm to study the effect of lacing reinforcement on the performance of such beams under static and fatigue loads. Twelve reinforced concrete beams (two of them are casted with vertical shear reinforcement used as control beams) are tested under four points bending loading with displacement control technique and six laced reinforced concrete beams were exposed to high frequency (10 Hz) by fixing the fatigue load in each cycle. Three parameters are used in the designed beams, which are: lacing bar diameter (4mm, 6mm, and 8mm), lacing bar inclination angle to horizontal ($30^\circ, 45^\circ$and 60°), and lacing steel ratio depending on number of lacing bar in each longitudinal face of beam and lacing bar diameter. The comparison results of experimental tests revealed that the ultimate loads of laced reinforced concrete beams are higher than the conventional reinforced concrete beams due to increasing lacing bar diameter, angle of inclination lacing bar, and lacing steel ratio, while the deflection is reduced. Also, the laced reinforced concrete beams can safely withstand the fatigue loading.

Key words: laced reinforcement, reinforced concrete beam, static and fatigue loading.

تصرف الانحناء للعتبات الخرسانية ذات التسليح المربط تحت تاثيرالاحمال الساكنة والاعياء

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الخلاصة

يقدم هذا البحث النتائج العملية لثمانية عشر عتبة خرسانية ذات الاسناد البسيط وبمقطع (160ملم ×300 ملم) وطول 3000 ملم لدراسة تأثير التسليح المربط على أداء هذه العتبات تحت تاثيرالأحمال الساكنة والكلل. تم اختبار اثنتي عشرة عتبا خرسانيا مسلحا (اثنان منها ذات تسليح قص العمودي واستخدمتا كعتبات مرجعية) تحت أربع

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نقاط تحميل باستخدام تقنية التحكم في الإزاحة ، كما تعرضت ست عتبات خرسانية مسلحة لحمل كلل ذو تردد عالي (10 هرتز) عن طريق تثبيت حمل الكلل في كل دورة.استخدمت ثلاث محددات في تصميم العتبات ، وهي: قطرالحديد المتعرج (4 مم ، 6 مم ، و 8 مم) ، وزاوية ميل االحديد المتعرج إلى الافق (30°,45°و 60°)، ونسبة الحديد المتعرج التي تعتمد على عدد الحديد المتعرج في كل وجه طولي (واحد أو اثنين) وقطر الحديد المتعرج. أوضحت نتائج المقارنة للفحوصات العملية أن الأحمال القصوى للعتبات الخرسانية المسلحة أعلى من العتبات الخرسانية المسلحة التقليدية بسبب زيادة قطر الحديد المتعرج ، وزاوية الحديد المتعرج ، ونسبة الحديد المتعرج ، في حين الهطول قل. كما ان العتبات الخرسانية ذات التسليح المربط تستطيع مقاومة حمل الكلل بأمان.

الكلمات الرئيسية: الحديد المربط, العتبات الخرسانية المسلحة, الاحمال الساكنة والاعياء.

1. INTRODICTION

Normal Reinforced Concrete RC beams are known to have vertical shear reinforcement, which enhances the ductility and shear strength. Through the experimental test on the RC beams that subjected to bending load, observed that beams suffered from diagonal and flexural shear cracks, **Anandavalli, et al., 2016**. Therefore an acceptable solution it is found to reduce such cracks in the construction elements by using the lacing reinforcement techniques. Laced Reinforced Concrete (LRC) elements are used in the building which exposed to explosions or chemical explosions. LRC elements consist of equal tension and compression longitudinal reinforcement connected by cross bar with continuous lacing reinforcement as shown in **Fig. 1**, **UFC 3-340-02, 2008**.

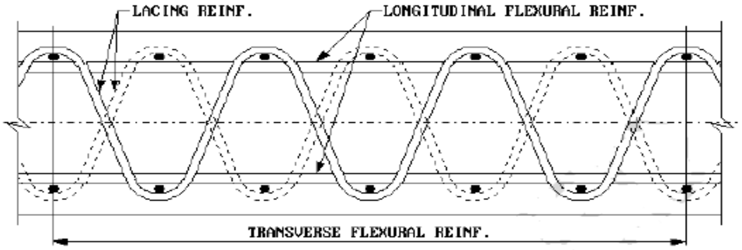


Figure 1. Configuration of lacing reinforcement, UFC 3-340-02, 2008.

Lakshmanan, et al., 2008 investigated the effect of lacing reinforcement in concrete beams with and without steel fibers subjected to reverenced cyclic shear loading. Their results showed that an improvement in the ultimate shear load and found that the ductility of such beam are lower than static ductility. The response of Laced Steel Concrete Composite (LSCC) beams with lacing inclined angle 45°, and 60°under monotonic and reversed cyclic loads was investigated by **Anandavlli, 2012**. Her results showed that the concrete spallation and fragmentation be prevented by using the LSCC technique. And she found that the first cyclic energy absorption was more than the energy absorption at second and third cycles. **Allawi, and Jabir, 2016a and 2016b**, presented a study on the behavior of 16 LRC one way slabs under the influence of static and repeated loads. The results revealed that the ultimate load of such slabs is increased with increasing lacing steel ratio and the slabs deflection was reduced. **Allawi, and**

Shubber, 2017 and 2018 studied the performance of T-LRC beams with lacing inclined angle 45°, and 60° under static and repeated loads. The results showed that the ultimate load capacity of T-LRC beam with inclined lacing angle 60° are more than the T-LRC beam with inclined lacing angle 45°. Degradation in deflection was noticed in those beams. **Al-Abboodi, et. al, 2017a and 2017b** studied the behavior of laced reinforced concrete beams under static and fatigue loads individually.

Another issue is mentioned here, which is the behavior of RC elements under fatigue loads. The fatigue strength of RC elements is influence by many factors for instance range of loading, loading rate, loading history and properties of material as explained in **ACI Committee 215, 1974**. Fatigue is occurred in concrete when strains of concrete record larger values and micro-cracks appear more than concrete element under static load. Fatigue of reinforcing steel bar known as the spread of fatigue crack at the long side especially at the link area with the transverse lugs of stirrups, **ACI Committee 215, 1974**. Many studies reported that the RC beams were failing under fatigue loading was not similar as the failure technique of such beams subjected to static loading **Barnes, and Mays, 1999**. **Graf, 1934 and Brenner, 1936** investigated the influence of frequency on the fatigue life, their results revealed that the fatigue life is minor influenced by frequency of loading change between (4.5Hz-7.5Hz). And also mentioned that the fatigue life, reduced when the loading frequency be less than 0.16Hz. Other researchers **ACI Committee 215, 1974** and **Murdock, 1965** indicated that the fatigue life was less affected by frequency of loading change between (1Hz-15Hz) and subjected to stress level less than 75% of the static compressive strength (f_c'). In this paper, static and fatigue performance of LRC beams is presented.

2. RESEARCH SIGNIFICANCE

To find out the effectiveness and usefulness of using lacing reinforcement in the behavior of RC beams under static and fatigue loads, the experimental tests of LRC beams under the influence of four points loads have been carried out and presented as shown in **Fig. 2.**

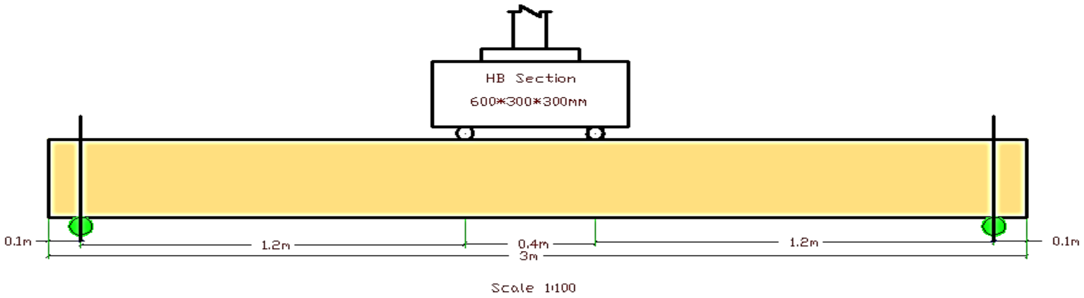


Figure 2. Beam dimensions and Loading scheme.

3. TEST BEAMS

The LRC beams are designed according to **ACI 318M-14, 2014**, and matched with **UFC 3-340-02, 2008**, requirements for the LRC elements. Material properties are listed in **Table 1**. The dimensions of the concrete section are (160mm × 300mm) with length of 3000mm. Eighteen beams are used to investigate the effect of changing diameter of lacing bar, inclination angle of lacing bar and lacing steel ratio as illustrated in **Figs. 3 to 6**. The beam parameters are scheduled in **Table 2**. The beam designation symbols are explained as follows. First symbol refers to diameter of stirrup or lacing bar, second one refers to shear reinforcement type (stirrups or lacing (single/double)), the third symbol refer to reinforced concrete, fourth symbol after slash refer to loading type (static/fatigue loads), and the last symbol refers to inclination angle of lacing bar to horizontal.

Table 1. Materials properties of LRC beams.

Cylinder Compressive strength of concrete at 28 days (MPa)	**Tensile strength of concrete at 28 days (MPa)**	**Nominal Bar diameter (mm)**	**Yielding stress of steel reinforcement (MPa)**
33	3.6	16	564
		10	562
		8	492
		6	456
		4	545

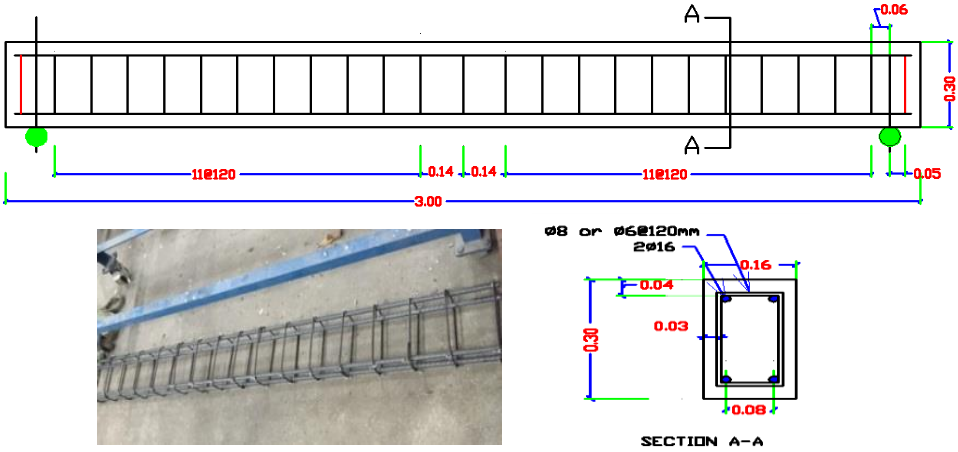


Figure 3. Conventional beams.

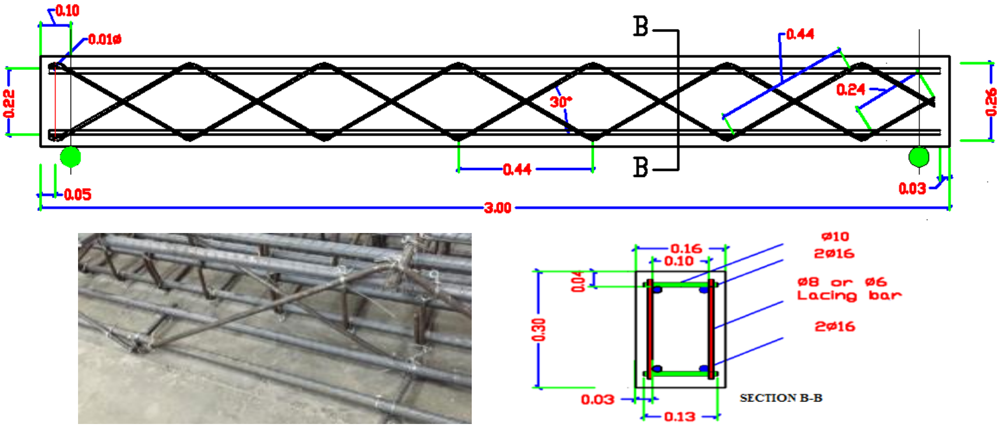


Figure 4. LRC Beams with angle 30° lacing inclination to horizontal.

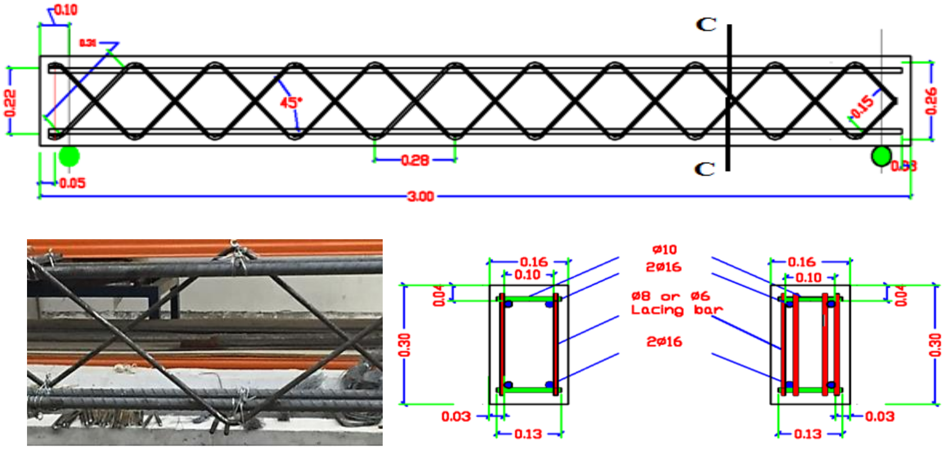


Figure 5. LRC Beams with angle 45° lacing inclination to horizontal.

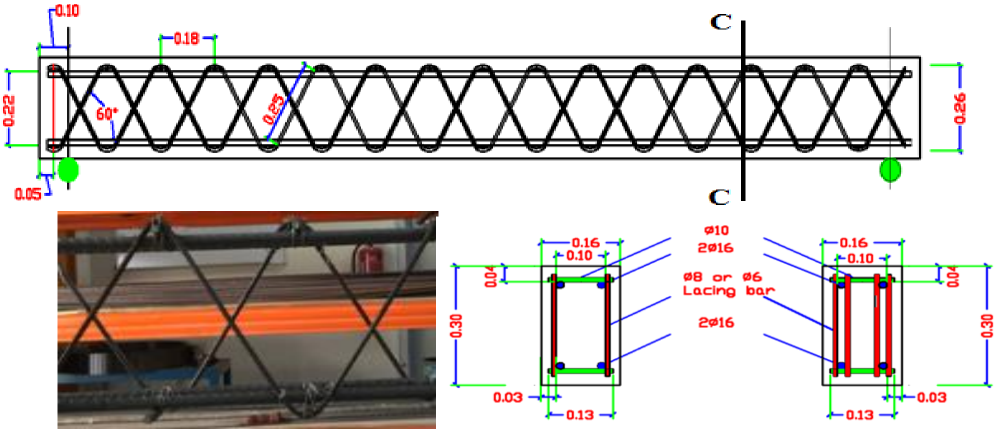


Figure 6. LRC Beams with angle 60° lacing inclination to horizontal.

Table 2. Parameters of reinforced concrete beams under static and fatigue Loads.

Beam designation symbols	Type of loading	lacing ratio			Diameter of stirrup and Lacing Bar (mm)
		Angle of inclined lacing bar to horizontal			
		30°	45°	60°	
6SRC	Static (S)	0	0	0	6
6SLRC-S/F-30	Static (S) and Fatigue (F)	0.0012	0	0	6
6SLRC-S/F-45	Static (S) and Fatigue (F)	0	0.0019	0	6
6SLRC-S/F-60	Static (S) and Fatigue (F)	0	0	0.00297	6
6DLRC-S-60	Static (S)	0	0	0.0059	6
8SRC	Static (S)	0	0	0	8
8SLRC-S/F-30	Static (S) and Fatigue (F)	0.0021	0	0	8
8SLRC-S/F-45	Static (S) and Fatigue (F)	0	0.0033	0	8
8SLRC-S/F-60	Static (S) and Fatigue (F)	0	0	0.0052	8
8DLRC-S-45	Static (S)	0	0.00665	0	8
8DLRC-S-60	Static (S)	0	0	0.01	8
4SLRC-S-45	Static (S)	0	0	0.00134	4

4. MEASURING INSTRUMENTS

The instrumentations are used to record strains and deflections of testing beams, and also to observe their behavior. Strain gauges of 120Ω resistance (TML/ Japan), are involved to measurement the steel strain at mid span. For deflection measurement at mid span, LVDT (Linear variable deferential transformer) have been used and located at bottom of mid-span of beam.

5. STATIC AND FATIGUE TESTS PROCEDURE

Hydraulic actuators of 300 kN capacity was used to test all beams under static and fatigue loading as shown in **Plate 1**. The supports were made as rollers types to distribute loads equally of both sides during test, **Papakonstantinou, 2000**. Displacement control technique with velocity of 0.05mm/sec was used during testing of the twelve beams to draw the curve after reached the ultimate load. Load, strain in steel reinforcement and deflection at mid span were detected and recorded for each loading stage. Fatigue test of the six beams was made by imposing constant amplitude. Fatigue loading process was made in two phases. In the first phase, the beams were loaded statically upward to maximum cycle load (P_{Max}). After that the fatigue load with sinusoidal wave with high frequency (10 Hz) and low stress level was applied as shown in **Fig. 7**. This process makes the material behave within the elastic range and reduces the time of the test. So the maximum load has to be less than the yielding load and it will be within the elastic range. The important parameters that used in fatigue test were: the limit of fatigue life N_f, maximum fatigue load (P_{Max}), minimum fatigue load (P_{Min}), the mean of fatigue load(P_m), amplitude fatigue load (P_a), the range of fatigue load (P_r), the ratio of fatigue load (R), maximum fatigue stress(σ_{max}), minimum fatigue stress (σ_{min}) and the range of fatigue stress (σ_r). **Table 3** shows the fatigue parameters used in this study. Also in each cycle, load, strain in steel reinforcement and deflection in mid span were detected and recorded.

Plate 1. The hydraulic actuators used to test the LRC beams.

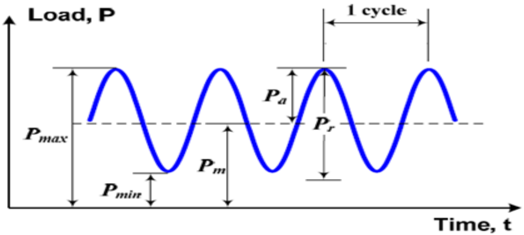


Figure 7. The Parameters of fatigue loading used in this study.

Table 3. Parameters used at fatigue test according to ACI Committee 215, 1974 and machine limitation.

Parameter	**Value**	**Parameter**	**Value**	**Parameter**	**Value**	**Parameter**	**Value**
N_f	2×10^6 Cycles	P_m	19kN	R	0.8	σ_r	1.53 MPa
P_{Max}	21 kN	P_a	2 kN	σ_{max}	8.07 MPa		
P_{Min}	17 kN	P_r	4 kN	σ_{min}	6.54 MPa		

6. TEST RESULTS AND DISCUSSION

6.1 Crack Patterns

The crack pattern of static test was flexural tension micro- cracks growth gradually from mid span to the regions near the supports. Before failure of the beams, the horizontal cracks were observed under loading area in compression zone declaring of failure propagation. The failure mode for statically tested beams was flexural failure. First cracking load for twelve reinforced beams are listed in **Table 4**. From the results, it is noticed that the first cracking load is increased with increasing of lacing bar diameter, the inclined angle of lacing shear bar and lacing steel ratio. The shape of cracking at failure is shown as vertical and parallel along the cross section of the beam. In fatigue test, a few cracks were observed at mid span especially in the tension area. The tested beam not reach the failure stage, due to the used of low stress range in every cycle which did not exceed the strength of tensile limit of concrete, **Robbat, et al., 1978**. **Plates 2 and 3** shows the crack patterns for the tested beams under static and fatigue load.

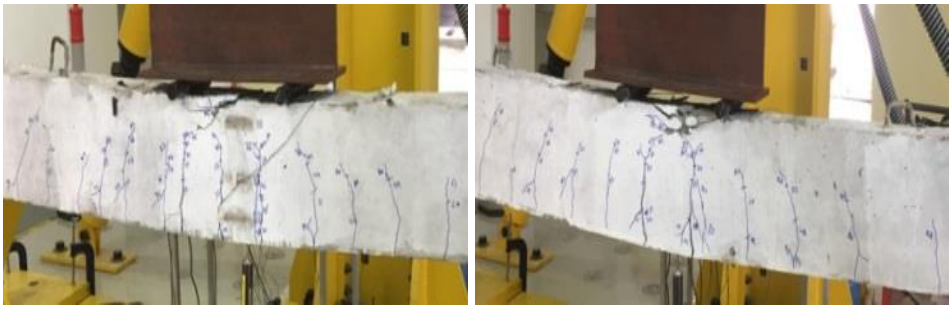
Table 4. Comparisons for laced reinforced concrete beams with respect to reinforced concrete beams under static loading.

Beam Symbol	**Cracking load (P_{cr}) kN**	**Ultimate load (P_u) kN**	**% increasing in first cracking load respect to Ref. beam**	**% increasing in ultimate load respect to Ref. beam**	**Deflection at Ultimate Load (mm)**	**Deflection at Same Load Level of Ref**	**%Decrease in Deflection at Same Load**
6SRC	13	85.14	Ref.	Ref.	38.56	Ref.	Ref.
6SLRC-S-30	16	90.25	23.07	6.002	28.5	22.03	42.87
6SLRC-S-45	16	88.97	23.07	4.5	40.17	25.56	33.71
6SLRC-S-60	17	85.25	30.77	0.13	32.41	31.9	17.3
6DLRC-S-60	19	93.1	46.15	9.35	34.9	21.09	45.3
8SRC	13	86.72	Ref.	Ref.	35.86	Ref.	Ref.
8SLRC-S-30	17	92.17	30.77	6.28	26.11	16.67	53.5

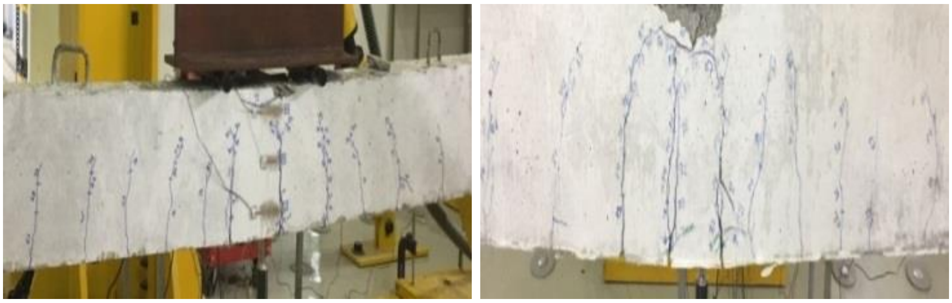
8SLRC-S-45	20	100.61	53.85	16.02	36.22	16.5	53.99
8SLRC-S-60	20	88.14	53.85	1.64	31.12	27.52	23.26
8DLRC-S-45	14	101.7	7.7	17.3	37.93	15.86	55.77
8DLRC-S-60	17	93.6	30.77	7.93	31.2	19.69	45.09
4SLRC-S-60	18	91.12	-	without ref.	32.58	-	-

a. Beam 8SRC **b.** Beam 6SRC

Plate 2. Observation of cracks after static test of beams.



c. Beam 6SLRC-S-30 **d.** Beam 8SLRC-S-30



e. Beam 6SLRC-S-60 **f.** Beam 6DLRC-S-60

g. Beam 8SLRC-S-60 **h.** Beam 8DLRC-S-60

i. Beam 4SLRC-S-60 **j.** Beam 6SLRC-S-45

Plate 2. Continued.

k. Beam 8SLRC-S-45 **l.** Beam 8DLRC-S-45

Plate 2. Continued.

a. Beam 6SLRC-F-30 **b.** Beam 8SLRC-S-30

c. Beam 6SLRC-F-45 **d.** Beam 8SLRC-S-45

e. Beam 6SLRC-F-60 **f.** Beam 8SLRC-F-60

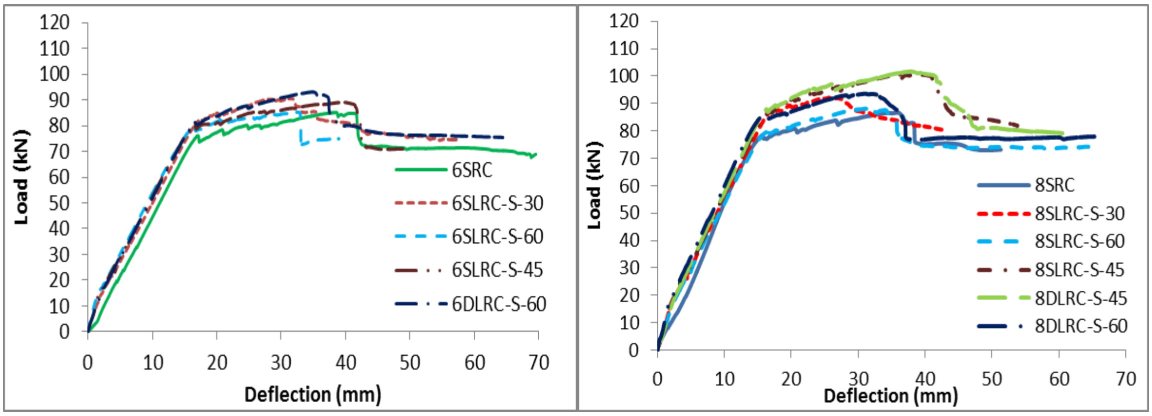
Plate 3. Observation of cracks after fatigue test of the beams.

6.2 Load-Deflection Behavior

6.2.1 Load-deflection behavior of beams under static loading

The load-deflection responses of the tested reinforced concrete beams can be described by two paths, first one has a linear path before reaching the yielding of steel reinforcement, and the second path becomes non-linear until failure of beam due to crushing of concrete. The test continues after crushing the top surface of concrete, and it was noticed that the load was stabilized with increasing deflection therefore the test is stopped. From the results, it is indicated that the ultimate load is increased in laced reinforced concrete beams (LRC) by about 6.0%, 0.13%, 4.5%, 6.28%, 1.64%, 16.02%, 9.35% 7.93% and 17.3% for beams 6SLRC-S-30, 6SLRC-S-60, 6SLRC-S-45, 8SLRC-S-30, 8SLRC-S-60, 8SLRC-S-45, 6DLRC-S-60, 8DLRC-S-60 and 8DLRC-S-45 respectively, when compared to beams 6SRC and 8SRC as listed in **Table 4**. On the other hand, at the same load level of reference beams the deflection of LRC beams is reduced by about 42.86%, 17.27%, 33.7%, 53.5%, 23.25% and 53.98% for beams 6SLRC-S-30, 6SLRC-S-60, 6SLRC-S-45, 8SLRC-S-30, 8SLRC-S-60 and 8SLRC-S-45 respectively, with respect to reference beams 6SRC and 8SRC due to increasing the confinement of concrete. In addition, it is noticed that LRC beams with lacing steel ratio of (0.0059, 0.01 and 0.00665) results in deflection drop by about 45.3%, 45.09%, and 55.77% for beams 6DLRC-S-60, 8DLRC-S-60 and 8DLRC-S-45 respectively, as compared to reference beams 6SRC and 8SRC due to increasing the flexural stiffness of beams, as shown in **Fig. 8**. The mode of failure for all the tested beams is characterized as flexural failure mode.

Other comparisons have been made for the laced reinforced concrete beams (LRC) between themselves to investigate the effect of main parameters of the study such as diameter of lacing bar, inclination angle of lacing bar and the ratio of lacing steel bar on the load-deflection behavior as shown in **Table 5**. It can be noticed that the ultimate load is increased when the diameter of lacing bar is increased from 6mm to 8mm, increasing lacing steel ratio due to increasing the contribution of lacing reinforcing bars with the flexural reinforcement, and also it is increased in beams with lacing bar inclined with 30 and 45 degrees rather than 60 degree due to increasing the resistance of LRC beam to diagonal shear cracks and due to enhance the flexural ductility of LRC beams and also due to the behavior of beams with lacing reinforcement inclined with 60 degree which have similar effect to beams with stirrups shear reinforcement.



a b

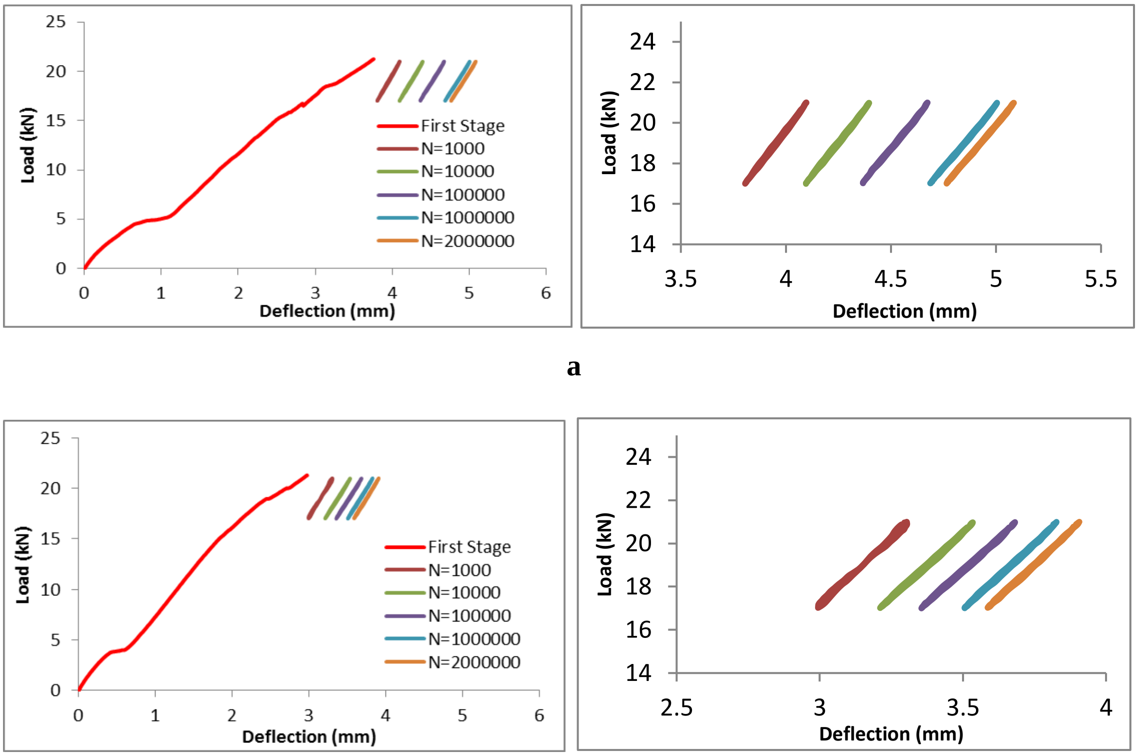
Figure 8. Load-mid span deflection curves for beams with: (a) 6mm and (b) 8mm shear reinforcing bars.

Table 5. Laced reinforced concrete beams comparison under static loading.

Beam designation	% increase in the ultimate load	% decreased in the deflection	Beam designation	% increase in the ultimate load	% decreased in the deflection
6SLRC-S-30	**8SLRC-S-30**		**8SLRC-S-45**	**8DLRC-S-45**	
	2.13	21.63		1.08	3.53
6SLRC-S-45	**8SLRC-S-45**		**6SLRC-S-60**	**6SLRC-S-30**	
	13.08	54.5		5.87	31.72
6SLRC-S-60	**8SLRC-S-60**			**6SLRC-S-45**	
	3.39	21.75		4.36	20.55
6SLRC-S-60	**6DLRC-S-60**		**8SLRC-S-60**	**8SLRC-S-30**	
	9.2	34.65		4.6	39.36
8SLRC-S-60	**8DLRC-S-60**			**8SLRC-S-45**	
	6.19	31.75		14.15	42.99

6.2.2 Load-deflection behavior of beams under fatigue loading

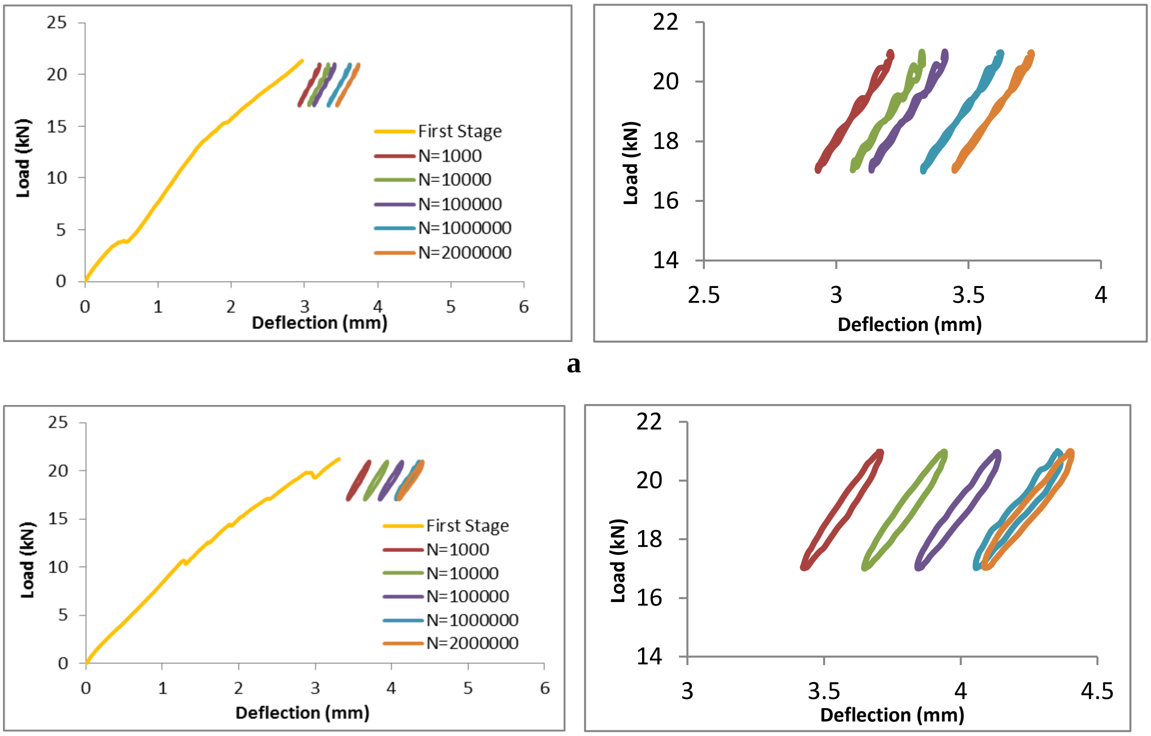
The load-deflection responses for six LRC beams tested under fatigue loading scheme at specified cycles (N= 10^3,10^4,10^5,10^6 and 2×10^6) are presented as shown in **Figs. 9 to 11**. Firstly, these beams have been preloaded with maximum fatigue load and the slope of the load-deflection curves was ascending line. Then the fatigue sine waves applied to the LRC beams forming a straight line of load-deflection response with minimum slope as compared to first line despite the increasing number of cycles. Failure has not occurred at these beams due to the amplitude of stress is not sufficient to shatter each of concrete and steel reinforcement, **Balaguru, 1981**. The comparison of the LRC beams deflections under fatigue loading are listed in **Table 6**. The comparison results show that the deflections for LRC beams are decreased with increased diameter of lacing bar, the ratio of lacing steel reinforcement and inclination angle of lacing bar except for special cases due to confinement of concrete and due to the contribution of lacing bar with flexural reinforcement to resisting the applied load as shown in **Table 6**.



a

b

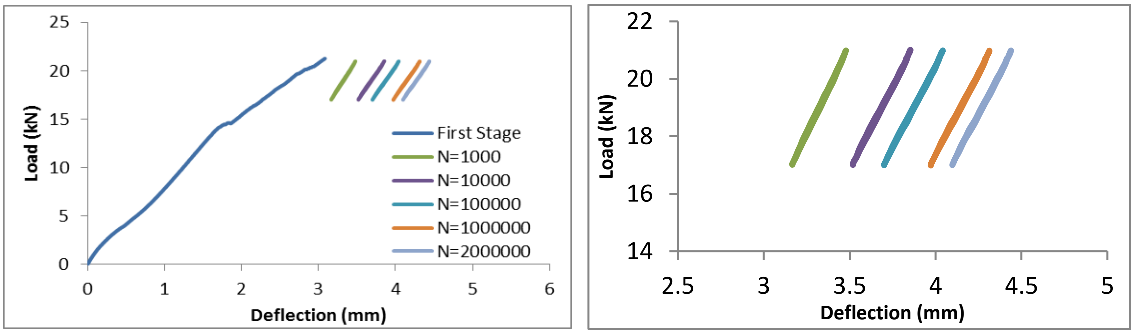
Figure 9. Load-deflection response for laced reinforced concrete beams: (a) 6SLRC-F-30 and (b) 8SLRC-F-30 under fatigue loading.



a

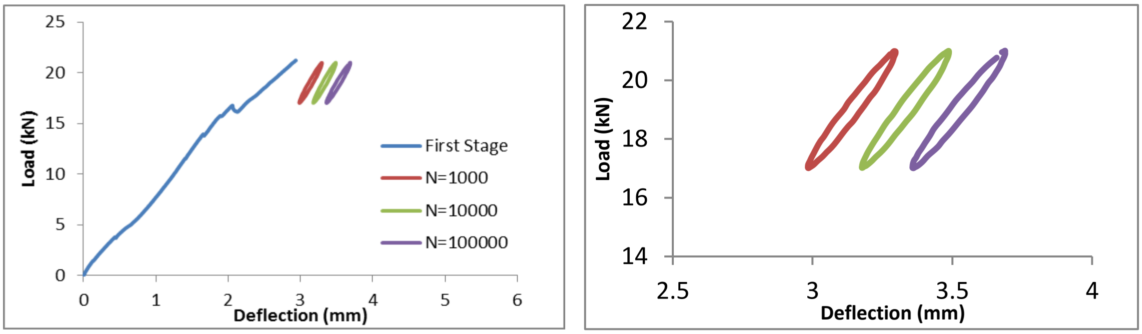
b

Figure 10. Load-deflection response for laced reinforced concrete beams: (a) 6SLRC-F-45 and (b) 8SLRC-F-45 under fatigue loading.



a

Figure 11. Load-deflection response for laced reinforced concrete beams: (a) 6SLRC-F-60 and (b) 8SLRC-F-60 under fatigue loading.



b

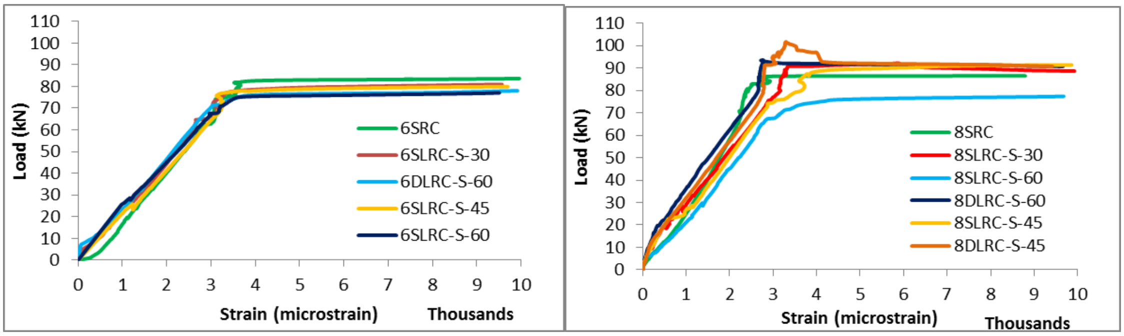
Figure 11. Continued.

Table 6. Laced reinforced concrete beams comparison under fatigue loading

<table>
<tr><th>Reference beam</th><th>% increase in in the deflection</th><th>% decreased in the deflection</th><th>Reference beam</th><th>% increase in in the deflection</th><th>% decreased in the deflection</th></tr>
<tr><td rowspan="2">6SLRC-S-30</td><td colspan="2">8SLRC-S-30</td><td rowspan="4">6SLRC-F-30</td><td colspan="2">6SLRC-S-60</td></tr>
<tr><td>-</td><td>18.45</td><td>-</td><td>7.34</td></tr>
<tr><td rowspan="2">6SLRC-S-45</td><td colspan="2">8SLRC-S-45</td><td colspan="2">6SLRC-S-45</td></tr>
<tr><td>17.65</td><td>-</td><td>-</td><td>21.95</td></tr>
<tr><td rowspan="2">6SLRC-S-60</td><td colspan="2">8SLRC-S-60</td><td rowspan="4">8SLRC-S-30</td><td colspan="2">8SLRC-S-60</td></tr>
<tr><td>-</td><td>17.45</td><td>-</td><td>6.17</td></tr>
<tr><td rowspan="2" colspan="3"></td><td colspan="2">8SLRC-S-45</td></tr>
<tr><td>12.6</td><td>-</td></tr>
</table>

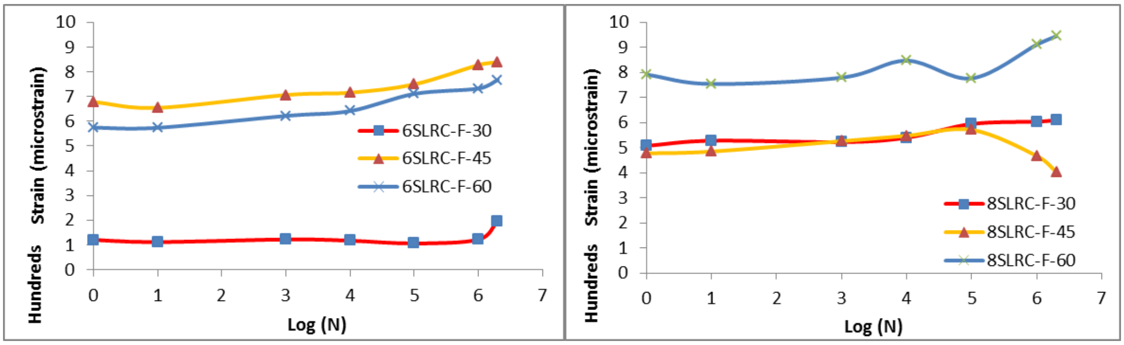
6.3 Steel Reinforcement Response under Static and Fatigue Loading Regimes

Strain values of steel reinforcement bars (flexural and lacing bars) were recorded and exhibited in this section to realize the performance of reinforcing steel in RC beams tested under static and fatigue loading. In static tests, it was noticed that the lacing bars was still within the elastic range before and after yielding of flexural steel reinforcement at loading failure. **Fig. 12** shows the response of load-strain response at flexural reinforcement in reinforced concrete beams. The recorded strain data at flexural steel reinforcement when failure occurred was (7283 με, 9959 με). Also it was observed that as a result of the provision of lacing bars in laced concrete beams, especially when increasing the diameter of lacing bar and lacing steel ratio leads to increase the resistance of flexural reinforcement to yielding. In fatigue test, it was noticed that the flexural steel reinforcement and lacing bars were still within the elastic range although the number of cyclic has been increased to the limit of fatigue life 2×10^6 cycles and recording (197.19 $\mu\varepsilon$, 944.634 $\mu\varepsilon$) and it was illustrated in **Fig. 13**. Also it was observed that although the use of insufficient lacing steel ratio, fatigue has not occurred in the flexural and lacing steel bars and still within the elastic limits as in beam 6SLRC-F-30. The strains of lacing steel bars under fatigue loading were listed in **Table 7**.



a **b**

Figure 12. Response of load with tensile strain to flexural steel reinforcing bars in LRC and RC beams having bar diameters: (a) 6mm and (b) 8mm at mid-span under static loading.



a **b**

Figure 13. Response of tensile strain to cycles of flexural steel reinforcement in LRC beams of lacing diameters: (a) 6mm and (b) 8mm at mid-span under fatigue loading

Table 7. Strain values at 2×10^6 cycles in lacing steel bars at mid-span under fatigue loading.

Beam Designation	Strain Gauges at Lacing Renf. ($\mu\varepsilon$)	Beam Designation	Strain Gauges at Lacing Renf. ($\mu\varepsilon$)
6SLRC-F-30	384	**8SLRC-F-45**	Damage
8SLRC-F-30	145	**6SLRC-F-60**	177
6SLRC-F-45	122	**8SLRC-F-60**	Damage

7. CONCLUSIONS

The conclusions obtained from the experimental results of the tested laced reinforced concrete beams tested under static and fatigue loads were briefed hereafter:

- The provision of lacing reinforcement in reinforced concrete beams leads to increase the ultimate loads rather than the conventional reinforced concrete beams due to confinement of concrete between the reinforcement contributions systems.
- Enhance the lacing percentage leads to increasing the ultimate loads otherwise the deflection decreases due to confinement of concrete between the steel reinforcement contribution systems.
- The ultimate load of LRC beams with inclined angle 45 degree is increased rather than LRC beams with inclined angle 60 degree due to increasing the shear capacity of LRC beams and due to increasing it resistance to diagonal shear cracks. On other hand the deflection reduced.
- The LRC beams withstand safely the fatigue loading ($2x10^6$cycles) of 10 Hz and minimum stress level.
- Despite the increase in the diameter lacing bar, inclination angle of lacing bar, and the ratio of lacing steel bar in laced reinforced concrete beams exposed to fatigue loading, the deflection values continued to decline due to confinement of concrete between the reinforcement cage (lacing and flexural reinforcement) .
- The lacing reinforcement bar in LRC beams under static loading characterized by its resistance to yielding rather than stirrup reinforcement bar.
- The flexural and lacing steel reinforcement responses in LRC beams exposed to fatigue loading with 10 Hz and minimum stress level are still within the elastic range.

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