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Behavior of Laced Reinforced Concrete Beam under Static Load

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Abstract: Laced Reinforced Concrete T-beams which are used inclined continuous reinforcement of two layers on each side of the beam have been studied in this research. The inclination angles of lacing reinforcement with respect to the longitudinal reinforcement are 45^o and 60^o respectively. Laced Reinforced Concrete T-beams of cross sectional dimensions (300mm * 80mm) flange and (150mm * 220mm) web have been used. Results have shown that specimens with lacing reinforcement are more ductile than beams without lacing (conventional vertical stirrups) and the ductility factor of laced reinforced beams ranges from 1.94 to 9.44, while it is 1.46 for unlaced (stirrups) beams. Also, the support rotation of laced reinforced concrete beams are about six times higher than that of conventional reinforcement. It has been shown that the lacing reinforcement of 60^o inclination angle with respect to longitudinal reinforcement has more stiffness i.e. less deflection than lacing reinforcement of 45^o inclination angle with respect to longitudinal reinforcement, while the strength capacity of the first type above is about 14% more than that of 45^o inclination angle. The study of effect of diameter size of lacing reinforcement shows that lacing reinforcement of 8mm diameter has less deflection about 15% than that of 6mm diameter, also the ultimate load of first type above is more about 3% than other type. The results show that beams with lacing reinforcement are stiffer than beams with conventional stirrup reinforcement.

Keywords:*Lacing Reinforcement, Reinforced Concrete, Static Loading, T-beam*

السلوك الانشائي للعتبات الخرسانية ذات التسليح المتعرج تحت الاحمال الساكنة

الخلاصة:تم في هذا البحث دراسة سلوك العتباتالخرسانية ذات المقطع (T) ومسلح بتسليح متعرج والتي تحتوي على حديد التسليح المائل والمستمر والمكون من طبقتين لكل جانب من العتبة. ان زوابا الميلان لحديد التسليح المتعرج نسبة الى اتجاه حديد التسليح الطولي هي o45 و o60 على التوالي. تم استخدام عتبات خرسانية ذات المقطع (T) وبتسليح متعرج وبابعاد مقطع (300 ملم * 80 ملم) للجزء العلوي المستعرض و(150 ملم * 220 ملم) الجزء السفلي الوترة.تم قياس الهطول عند منتصف الفضاء وتحت كل حمل مسلط وكذلك قياس الانفعال المحوري في منتصف كلا من الحديد الطولي العلوي والسفلي اضافة الى الانفعال المحوري في كل من حديد التسليح المتعرج وحديد التسليح الحلقي وفي اماكن محددة مسبقا.تبين ان حديد التسليح المتعرج بزاوية ميلان^o 60 نسبة الى اتجاه الحديد الطولي تمتلك جساءة اكبر (هطول اقل) من حديد التسليح المتعرج بزاوية ميلان o45 نسبة الى اتجاه الحديد الطولي بينما مقاومة النوع الاول اعلاه هي حوالي 14% اكبر منها لحديد التسليح المتعرج بزاوية ميلان^o 45.دراسة تأثير قطر حديد التسليح المتعرج تبين ان حديد التسليح المتعرج بقطر 8 ملم له هطول اقل بحوالي 15% من حديد التسليح المتعرج بقطر 6 ملم. كذلك فأن الحمل الأقصى كان للنوع الاول اعلاه بحدود 3% من النوع الآخر. بينت النتائج انه العتبات ذات حديد التسليح المتعرج اكثر جساءة من العتبات ذات التسليح الاعتيادي الحلقي.

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1. Introduction

In the last two decades, considerable researches have been carried out to study how to increase the ductility levels of structural elements. The ductile structures should be designed to have an acceptable resistance with considerable inelastic deformation and no local failure of structural elements.

Ductility of reinforced constructions is a property where resistance to brittle failure during flexure is required to ensure structural integrity. Ductile behavior of a structure can be enhanced through the use of plastic hinges positioned at specific locations throughout the structural frame.

These frames are designed to provide reasonable ductility to resist structural collapse after the yield stress of the material has been achieved. The available ductility of plastic hinges in reinforced concrete member is determined based on the relationship of the moment-curvature relations. Ductility may be defined as the ability to undergo deformations without a substantial reduction in the flexural capacity of the member (Park & Ruitong 1988) [1]. Ductility of concrete members can be achieved by special detailing technique, one such detailing of reinforced concrete elements is laced reinforced concrete. Lacing provide reinforcement in the strut and tie directions leads to good enhancement in ductility (Anandavalli, N., 2012)[2]. Behavior of laced reinforced concrete LRC and its application for blast resistant design has been discussed in detail by Lakshmanan (2008) [3]. Response of laced reinforced concrete LRC beam under low shear span to depth ratio is also presented.

It was also observed that cyclic ductility is significantly lower than static ductility for these beams. Inclusion of fibers was found to increase the performance substantially under reversed shear cyclic loading. The versatility of laced reinforced concrete LRC under blast loading was demonstrated by full scale testing. Anandaralli, et al (2012)[4] proposed a new system of laced steel -concrete composite (LSCC). The LSCC system is consisted of a steel cover plates provided with perforations, in which reinforcements in the form of lacing are fixed in position with the presence of transverse bars, then concrete is filled in between the two cover plates. The maximum support rotation of conventional reinforced concrete (CRC), laced reinforced concrete (LRC) and laced steel-concrete composite (LSCC) beam elements had been estimated to be 3.5o, 7o, and 15o respectively. The comparison between laced steel-concrete composite (LSCC) and steel-concrete composite (SCC) in terms of support rotation indicates that LSCC beams have relatively high support rotations. Recently, Allawi, A. A. and Jabir, H. A. (2016a, 2016b)[5,6] studied the behavior of reinforced concrete one way slab with lacing reinforcement under both static and repeated loading.

They tested eight one way slabs under static loading and nine one way slabs under repeated loading. All the tested slabs were designed to investigate the effect of the lacing reinforcement on the flexural behavior of one way slabs. The parameters were the lacing steel ratio, flexural steel ratio and span to the effective depth ratio. All specimens were tested under four point loading up to failure.

2. Test Program

Two point loads at the third span length from each end of simply supported type beams have been adopted for testing reinforced T-beams. Five reinforced concrete T-beams were tested under static loadings. Lacing reinforcement of 6 mm and 8 mm diameter with 45°and 60°inclination angle with longitudinal main reinforcement have been used for beams. Also, conventional shear reinforcement (vertical stirrups) have been used for the remaining beam.

The detailed explanation has been shown in Table (1).

Table 1. T-beams used in experimental work.

Beam symbol	Type of shear reinforcement	Diameter (mm)	Inclination angle (degree)	Type of loading
Conv.-S	stirrup	8	-	static
L-6-45-S	lacing	6	45	static
L-6-60-S	lacing	6	60	static
L-8-45-S	lacing	8	45	static
L-8-60-S	lacing	8	60	static

The following abbreviations have been adopted in this research:

S: static;
L: laced reinforcement;
Conv.: conventional shear reinforcement (stirrup).

3. Details of Beam Specimen

3.1 Dimensions of T-Beam

The dimensions of T-beams used as testing specimens are as follows:
Length of the T-beam is 2450 mm, effective span length of T-beam is 2250 mm, flange width is 300 mm, flange thickness is 80 mm, depth of web is 220 mm and width of web is 150 mm as shown in Fig. (1).

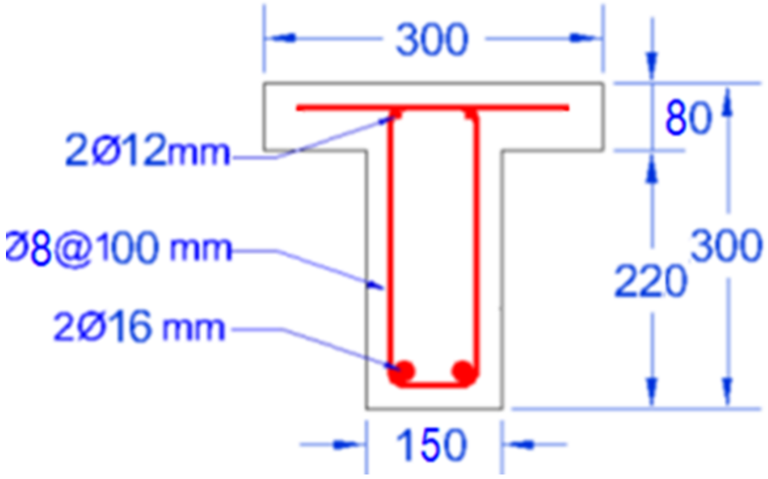

Figure 1. Dimensions of testing T-beam specimens.

3.2. Details of Lacing Reinforcement

Lacing reinforced concrete beams consists of continuous bent reinforcement over laps each other and located on each side of the beam in the direction of flexural (longitudinal) reinforcement.

The steel reinforcement which is used for lacing reinforcement are of two diameter sizes, namely, 6 mm diameter and 8 mm diameter. Each one of them has been inclined at 45^{o} and 60^{o} with flexural (longitudinal) reinforcement.

The schematic details as shown in Fig.(2).

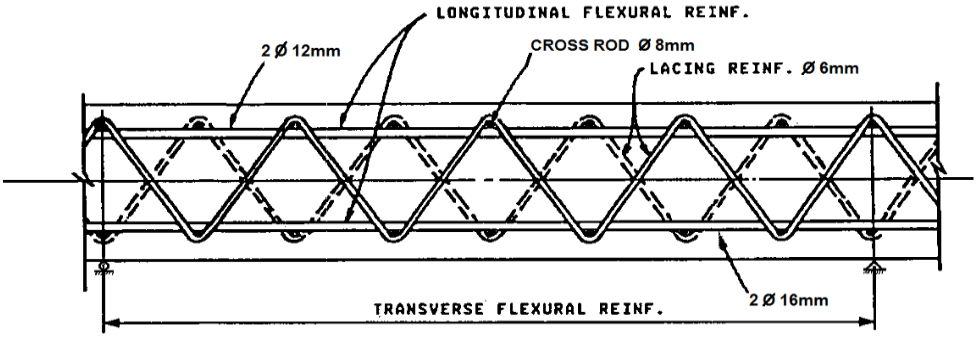

Figure 2. Laced reinforced element.

3.3 Fabrication of Lacing Reinforcement

Deformed steel bar of diameter 6 and 8 mm were used in fabricated of lacing reinforcement.The fabrication and construction of laced reinforcement to the required shape and dimension have been done by universal press machine in industrial zone in Shaikh Omar in Baghdad, as shown in Fig. (3).

Figure 3. Lacing reinforcement fabrication.

4. Material

4.1 Steel Reinforcement

For longitudinal reinforcement in both tension and compression zones, deformed steel bars of diameter 16 mm and 12 mm respectively have been used. While for conventional shear reinforcement (stirrups), we used deformed steel bars of 8 mm in diameter. Deformed steal bar of 8 mm diameter was also used as a cross rod to tie both sides of laced reinforcement over the longitudinal reinforcement.

Three specimens of 500 mm length for each deformed bar have been tested in the Consulting Engineering Bureau/ Collage of Engineering/ University of Baghdad.

The results of these tests are shown in Table (2).

Table 2. Mechanical properties of steel reinforcement.

Nominal diameterdeformed mm	Measured diameter mm	Yield stress f_y MPa	Tensile strength f_u MPa	Elongation %
6	6.0	415	574	5
8	8.0	425	605	4
12	12.0	600	730	8.5
16	16.0	620	755	12.5

4.2 Cement

For all test specimens, Ordinary Portland Cement (Type-I) (TASLUJA-BAZIAN) which is product of the United Cement Company for Cement Production (UCC) was used.

The chemical analysis and physical test results of the cement are given in Tables (3) and (4), respectively. They conform to the Iraqi Standard Specification (IQS) No. 5/1984.

Table 3. Chemical composition of cement.

Compound composition	Chemical composition	% Weight	IQS No.5/1984 limits
Lime	CaO	61.19	-
Silica	SiO2	21.44	-
Alumina	Al2O3	4.51	-
Iron oxide	Fe2O3	3.68	-
Magnesia	MgO	2.31	5*
Sulfate	SO3	2.70	2.8*
Loss on ignition	L.O.I	2.39	4.0*
Insoluble residue	I.R	1.18	1.5*
Lime saturated factor	L.S.F	0.87	0.66-1.02
	Bogue’s Potential Compound		
Tricalcium aluminates	C3A	6.06	-
Tricalcium silicate	C3S	Not available	-
Dicalcium silicate	C2S	Not available	-
Tricalcium aluminate ferrite	C4AF	Not available	-

Table 4. Physical composition of cement

Physical properties	Test Results	IQS No.5/1984
Fineness using Blain air permeability apparatus(m^2/kg)	405	230**
Soundness using autoclave method	Not available	0.8%*
Setting time using Vicat's instruments		
Initial(min.)	135	45**
Final(hr)	3:25	10*
Compressive strength for cement Paste Cube(70.7mm) at:		
3days(MPa)	24.4	
7days(MPa)	32.3	15**
28days(MPa)	47.2	23**

*Maximum limit
**Minimum limit

4.3 Fineaggregate

AL-Ukhaidher natural sand of (4.75mm) maximum size was used throughout this work. Grading of the sand conforms to the Iraqi Standard Specification (IQS) No. 45/1984, as shown in Table (5).

Table 5. Grading of fine aggregate

No.	Sieve (mm)	%Passing	
		Fine aggregate	IQS No.45/1984Zone(2)
1	5	100	90-100
2	2.36	83.75	75-100
3	1.18	63.84	55-90
4	0.6	35.84	35-59
5	0.3	8.84	8-30
6	0.15	0.64	0-10

4.4 Coarse aggregate

Graded Crushed gravel of a maximum size of 10mm brought from AL-Niba'ee fields was used throughout this work. Table (6) shows the grading of the aggregate which conforms to the limits specified by the Iraqi Standard Specification (IQS) No. 45/1984. Sieve analysis for fine and coarse aggregate was performed in the Material Laboratory at the College of Engineering, Al-Mustansiriya University.

Table 6. Grading of coarse aggregate.

Sieve size (mm)	% Passing	
	Coarse aggregate	IQS No.45/1984 limits
14	100	100
10	89	85-100
5	5	0-25
2.36	1	0-5

4.5 Water

Tap water was used for both curing and mixing procedures. For concrete mixing, the water cementitious material ratio (w/c) was (0.5).

5. Concrete Mixing

The mixing proportion [cement: sand: coarse aggregate] was (1: 1.5: 3) by weight and the water cementitious material ratio was (0.5) in order to produce concrete with average cylindrical compressive strength of 27 MPa. It is evident that the w/cm is relatively high since the mixing was done in June (when temperature at the laboratory was about 45°C and the evaporation of water was in a high ranges). The mix contents for (1 m^3) of concrete are given in Table (7).

Table 7. Mix proportions for (1 m^3) of concrete.

Cement (kg/m^3)	Sand (kg/m^3)	Gravel (kg/m^3)	w/cm ratio	Water (lit/m^3)
400	600	1200	0.5	200

7. Test Results

7.1 Load Deflection Relationship

The deflections have been measured at mid-span (designated as mid) and under left and right applied loads (designated as L and R respectively).

The load-deflection curves have been plotted for each tested beam, as shown in Figs. (4).

The maximum vertical deflection obtained is 10.8 cm corresponding to ultimate load (165 kN) for specimen L-8-60.

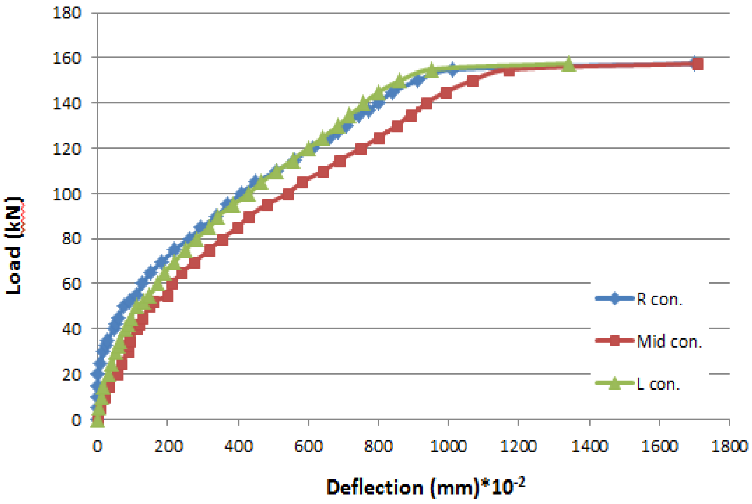

Figure 4(a). Load-deflection relationship for beam with conventional stirrup.

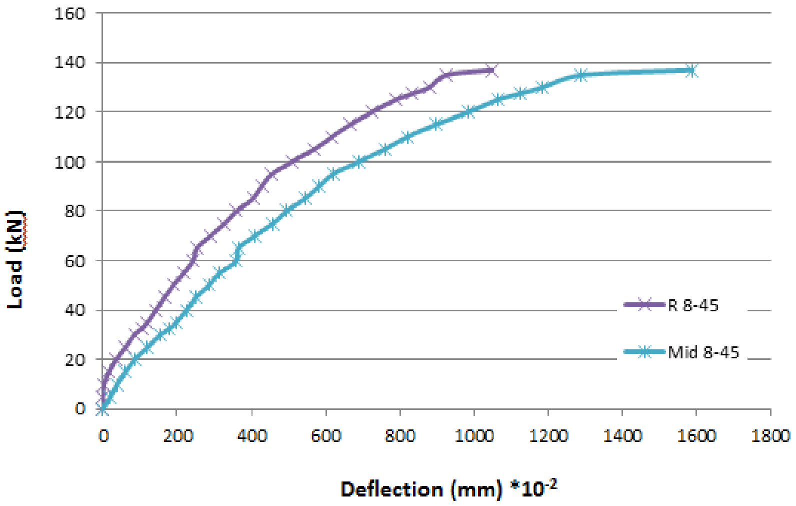

Figure 4(b). Load-deflection relationship for beam L-8-45.

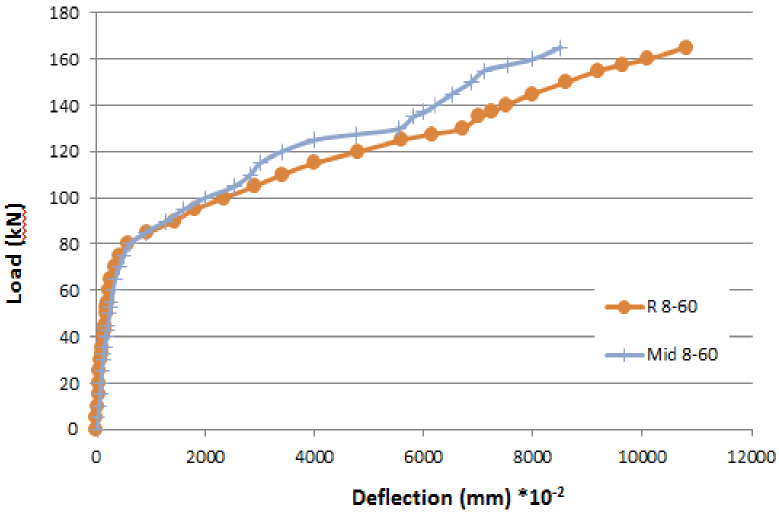

Figure 4(c). Load-deflection relationship for beam L-8-60.

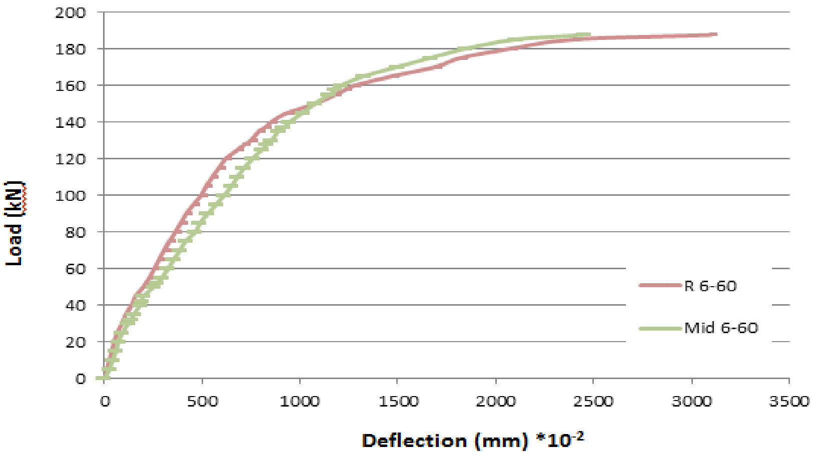

Figure 4(d). Load-deflection relationship for beam L-6-60.

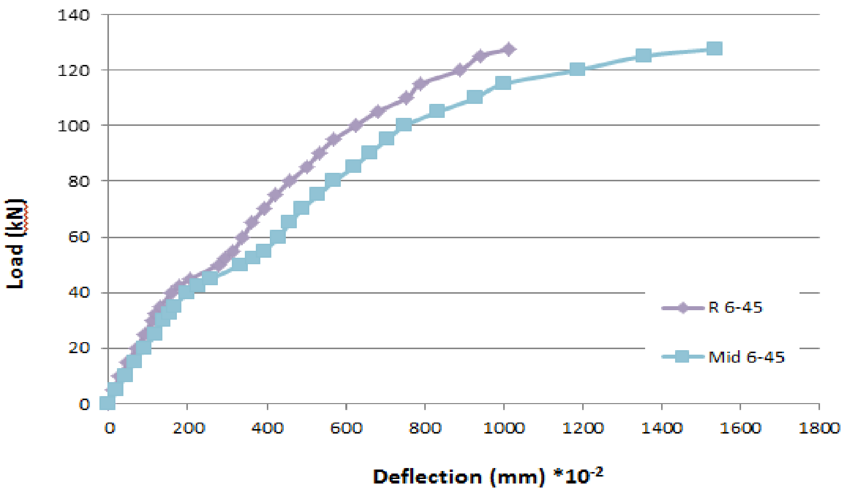

Figure 4(e). Load-deflection relationship for beam L-6-45.

The load versus mid-span deflection for all the five tested beams have been plotted as shown in Fig.(5).

From Fig.(5), beam L-8-60 has more mid deflection range than other beams and the ductility of the beam can be distinguished clearly. The deflection range of beam L-6-60 is a little more than beams L-8-45, L-6-45, and conventional reinforcement (stirrup) beam.

For a constant diameter of lacing reinforcement with different inclined angles (group I and group II), the sixty degree inclination angle imposes more deflection range before failure (i.e. more ductile) than beams with lacing reinforcement of forty five degree inclination angle, as shown in Figs.(6) and (7) respectively.

While for a constant inclination angle with different diameter of lacing reinforcement (group III and group IV), the eight millimeters diameter lacing reinforcement beams have ultimate load capacity more than six millimeters diameters, as shown in Figs.(8) and (9) respectively.

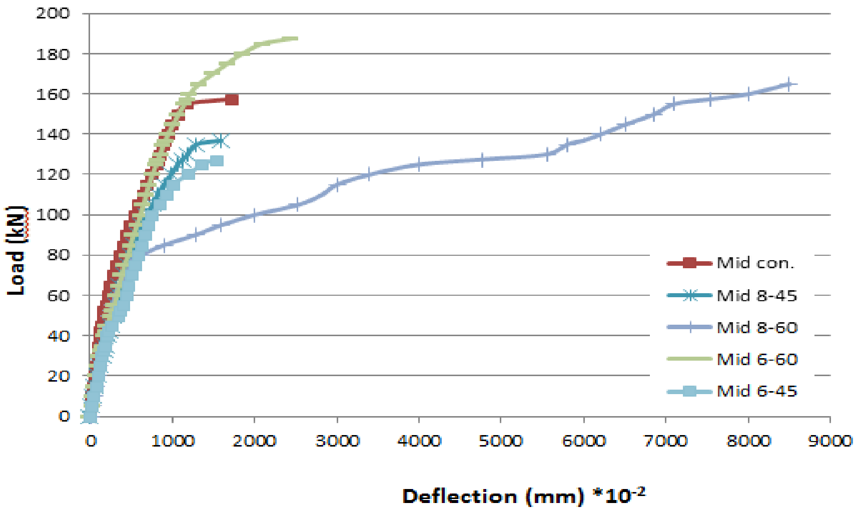

Figure 5. Load- mid span deflection relationship.

In order to study the effect of size of lacing and the inclination angle of lacing reinforcement, the following groups have been adopted:

Group I: diameter of lacing reinforcement is 6mm, with different inclination angle (45^o, 60^o).

Group II: diameter of lacing reinforcement is 8mm, with different inclination angle (45^o, 60^o).

Group III: inclination angle of lacing reinforcement is 45^o, with different diameter size of lacing (6mm, 8mm).

Group IV: inclination angle of lacing reinforcement is 60^o, with different diameter size of lacing (6mm, 8mm).

Load versus mid, left and right deflections have been plotted for each group as shown in Fig.(6), Fig.(7), Fig.(8) and Fig.(9) respectively.

The influence of inclination angle of lacing reinforcement on the load-deflection behavior is illustrated in Fig.(6) and Fig.(7).

The experimental results for group I show that 60^o inclination angle of laced reinforced specimens have more deflection about 60% more than specimen of 45^o inclination angle for the same size of lacing 6mm as shown in Fig.(6). While for group II (lacing reinforcement diameter 8 mm), the deflection increased by about 400% as shown in Fig.(7).

In group III, where inclination angle of lacing reinforcement is 45^o, the vertical deflection of 8 mm size of lacing reinforcement is approximately 3.5% more than specimens of 6 mm size of lacing reinforcement, as shown in Fig.(8).

For 60^o inclination angle in group IV, the specimens with lacing reinforcement of size 8 mm has vertical deflection about 240% greater than lacing of 8 mm diameter, as shown in Fig.(9).

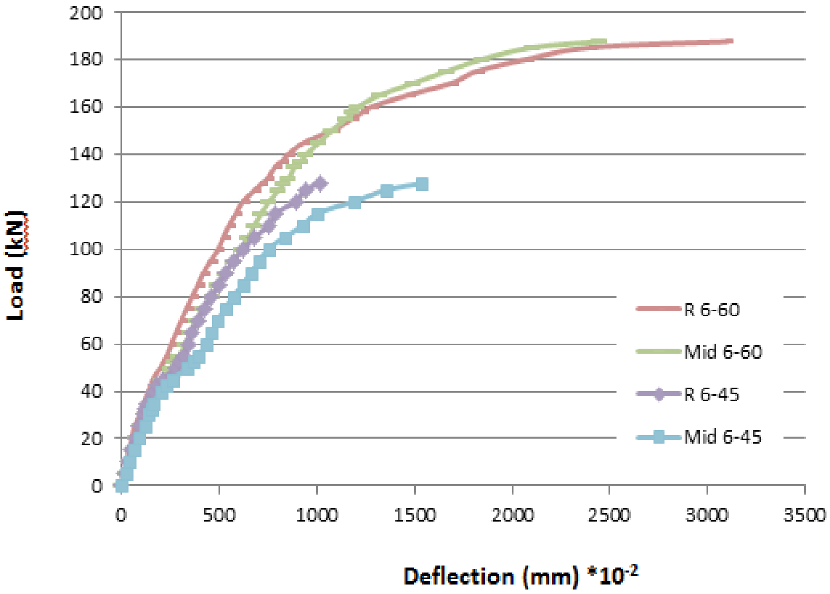

Figure 6. Load- deflection relationship of beam of group I.

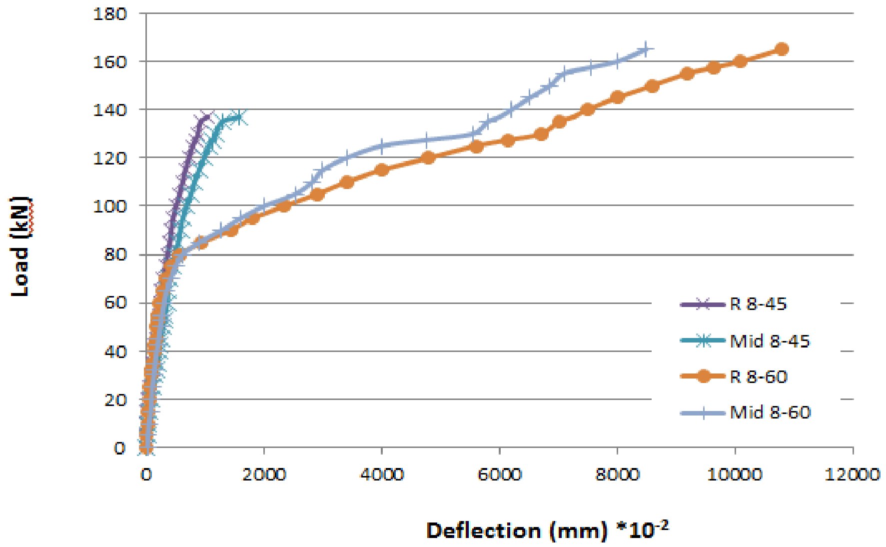

Figure 7. Load- deflection relationship of beam of group II.

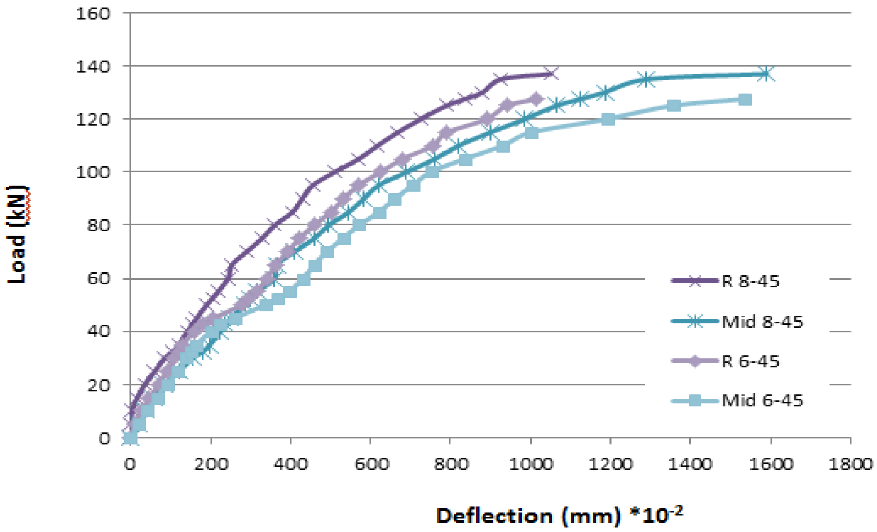

Figure 8. Load- deflection relationship of beam of group III.

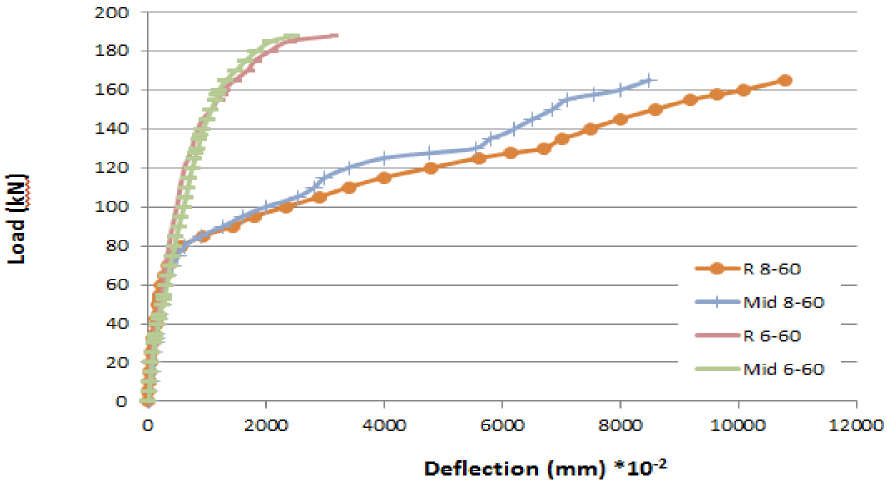

Figure 9. Load- deflection relationship of beam of group IV.

7.2 Calculations of Support Rotation

For a simply supported beam, two points loaded at each third length of the beam, the support rotation angle has been calculated according to the following equation:

$$\theta = \tan^{-1} (\Delta / L_1) \qquad (1)$$

Fig.(10) shows a typical diagram for deflected shape of the beam.

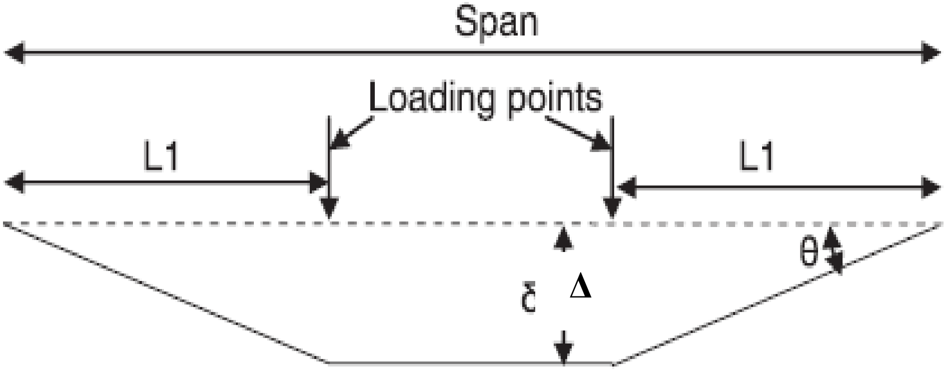

Figure 10. Calculation of support rotation.

Table (8) Summary of the calculated support rotation for each type of beam.

Beam symbol	P_u (kN)	Δ (mm)	Θ (deg.)
Ref.	157.5	17.00	1.3
L-6-45	127.5	10.15	0.78
L-6-60	187.5	31.00	2.37
L-8-45	137	10.50	0.81
L-8-60	165	108.00	8.19

The maximum support rotation of 8.19^o is obtained for specimen of 8 mm size and 60^o inclination angle of lacing reinforcement.

8. Conclusions

1. Lacing reinforcement with 60^o inclination angle specimens have more deflection about 60% more than specimen of 45^o inclination angle for the same size of lacing.
2. For 45^o inclination angle the vertical deflection of 8 mm size of lacing reinforcement is approximately 3.5% more than specimens of 6 mm size of lacing reinforcement.
3. For 60^o inclination angle in group IV, the specimens with lacing reinforcement of size 8 mm has vertical deflection about 240% greater than lacing of 6 mm diameter.
4. Support rotation of specimens with lacing is higher than that of specimens without lacing reinforcement.

5. The strength capacity of 60^o inclination angel LRC T-beam is 15% more than that of 45^o inclination angle LRC T-beam.
6. The re-straining effect has been occurred for beams with laced reinforced concrete.

9. References

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