Experimental Behavior of Laced Reinforced Concrete One Way Slab under Static Load

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ABSTRACT

Test results of eight reinforced concrete one way slab with lacing reinforcement are reported. The tests were designed to study the effect of the lacing reinforcement on the flexural behavior of one way slabs. The test parameters were the lacing steel ratio, flexural steel ratio and span to the effective depth ratio. One specimen had no lacing reinforcement and the remaining seven had various percentages of lacing and flexural steel ratios. All specimens were cast with normal density concrete of approximately 30 MPa compressive strength. The specimens were tested under two equal line loads applied statically at a thirds part (four point bending test) up to failure. Three percentage of lacing and flexural steel ratios were used: (0.0025, 0.0045 and 0.0065). Three values of span to effective depth ratio by (11, 13, and 16) were considered, the specimens showed an enhanced in ultimate load capacity ranged between (56.52% and 103.57%) as a result of increasing the lacing steel ratio to (0.0065) and decreasing the span to effective depth ratio by (31.25%) respectively with respect to the control specimen. Additionally the using of lacing steel reinforcement leads to significant improvements in ductility by about (91.34%) with increasing the lacing steel ratio to (0.0025) with respect to the specimen without lacing reinforcement.

Key words: one way slab**,** laced reinforced concrete, ductility, crack, static loading.

تصرف البلاطات الاحادية الاتجاه والحاوية على حديد متعرج تحت تأثير الاحمال الساكنة

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الخلاصة

في هذا البحث تم مناقشة النتائج العمليه لثمانية بلاطات خرسانيه احادية الاتجاه مسلحه وحاويةعلى تسليح متعرج. ان الغرض من هذا البحث هو دراسه تأثير استخدام التسليح المتعرج على سلوك البلاطات الاحادية الاتجاه. وكانت المتغيرات نسبة حديد التسليح المتعرج و هي(0, 0.0025, 0.0045, 0.0065)، نسبة الحديد الرئيسي وهي (0.0065, 0.0045,0.0025) ونسبة الطول الصافي الى العمق الفعال للبلاطةوهي (13,16 , 11) . احد العينات لاتحتوي على حديد متعرج اما العينات المتبقيه فكانت تحتوي على نسب مختلفة من حديد التسليح المتعرج والرئيسي. بينت النتائج العمليه بان التحمل الكلي للبلاطات تحسن بمقدار (56,52%) نتيجه لاستخدام الحديد المتعرج بنسبة (0.0065) و بمقدار (103,57%) كنتيجة لتقليل نسبة الطول الصافي الى العمق الفعال بمقدار (31,25%) للبلاطات الحاوية على حديد متعرج بنسب متساوية. من ناحيه اخرى فأن استخدام الحديد المتعرج حسن وبشكل ملحوظ معامل المطيلية للبلاطات حيث كانت نسبة الزيادة حوالي (91,34%) للبلاطة ذات نسبة تسليح متعرج (0.0025) مقارنة مع البلاطة بدون حديد تسليح متعرج.

الكلمات الرئيسية: البلاطة الاحادية الاتجاه، خرسانة الحديد المتعرج، المطيلية، التشقق، التحميل الساكن.

1. INTRODUCTION

Conventional reinforced concrete (RC) is known to have limited ductility and concrete confinement capabilities. The structural properties of RC can be improved by modifying the concrete matrix and by suitably detailing the reinforcements. A laced element is reinforced symmetrically, i.e., the compression reinforcement is the same as the tension reinforcement, The straight flexural reinforcing bars on each face of the element and the intervening concrete are tied together by the truss action of continuous bent diagonal bars as shown in **Fig. 1**. The dashed lacing bar indicates the configuration of the lacing bar associated with the next principal steel bar. In other words, the positions of the lacing bars alternated to encompass all temperature steel bars. LRC enhances the ductility and provides better concrete confinement, **UFC 3-340-02, 2008**.

The primary purpose of shear reinforcement is not to resist shear forces, but rather to improve performance in the large-deflection region by tying the two principal reinforcement mats together. In the design of conventional structures, the primary purpose of shear reinforcement is to prevent the formation and propagation of diagonal tension cracks, **Stanley C. Woodson, 1992**.

The lacing bar permits the element to attain large deflections and fully develop the reinforcement through its strain hardening region. The maximum deflection of a laced element corresponds to 12 degrees support rotation; the maximum deflection of an element with single leg stirrups is limited to 6 degrees support rotation under flexural action or 12 degrees under tension membrane action, thus the shear reinforcement is significantly effect in enhancing the ductility of flexural element, **UFC 3-340-02, 2008**.

Extensive experimental investigations were carried out by **Parameswaran et al., 1986**, showed that the end support rotations are varied between 6^o to 8^o. The results of the investigations suggested that a plastic hinge rotation of 4^o at end supports and 8^o at all other plastic hinge locations in continuous construction. The continuous lacings are normally inclined at 45º and 60º to horizontal. The significance of shear resistance in enhancing the ductility of a flexure element can be observed. A sudden shear failure is obvious in the event of inadequate capacity. A test programme to understand the behavior of laced reinforced concrete structural elements under blast loading was undertaken by **Keshava Rao et al., 1992**, to see whether the ductility realized in monotonic tests could be achieved under blast loading, whether an increase of 25% in strength as recommended can be used in design.

Anandavlli N. et al., 2012, A new approach for finite element modeling of RC/LRC structural elements that are primarily under flexure is proposed. The current approach considers RC/LRC as a homogenous material whose stress-strain characteristics are derived based on the moment curvature relationship of the structural component. The proposed model is extended for the application to the LRC slab, where the slab is simply supported on all four sides and subjected to uniform pressure loading.

Madheswaran C.K. et al., 2015, Describes the ductility behavior of Laced Reinforced Geopolymer concrete beam (LRGPC), for the beams with shear span-to-depth ratio is less than 2.5, for these beams the ductile failure of Reinforced Concrete (RC) with conventional stirrups is not possible. Therefor they improved ductile failure of these members by proper detailing of reinforcement with inclined bars in the case of normal concrete mix. Monotonic load testing on two specimens with 45° lacing are conducted.

2. RESEARCH SIGNIFICANCE

Knowledge of the effectiveness of the lacing reinforcement on the behavior of the one way slab. A better understanding of the contributions of the shear reinforcement will allow the designer to compare the benefits of using (or not using) shear reinforcement. The static behavior of laced reinforced concrete one way slab under four point loads was studied experimentally. The tests focused on the influences of lacing steel ratio, flexural steel ratio and clear span to effective depth ratio of slab.

3. TEST SPECIMENS

The slabs were designed to reflect the interaction of the lacing reinforcement with the other primary parameters. All slabs were designed to be simply supported conditions, the dimensions, and steel reinforcement ratios were selected according to **ACI 318M-2014** code, and to satisfy and meeting with **UFC 3-340-02, 2008**, requirements for the laced reinforced concrete structures. Details of the test specimens, both with and without laced reinforced steel are discussed hereafter. The dimensions of the tested slabs are (2000mm × 700mm) and different thickness of (H=135mm, 160mm and 185mm). One of these slabs were without lacing reinforcement (Reference specimen), and seven specimens were have the lacing reinforcement with various tension steel ratio (ρt=0.0025, 0.0045, and 0.0065) lacing steel ratio (ρs=0.0025, 0.0045, and 0.0065), and clear span to effective depth ratio (L/d=11, 13, 16), as shown in **Fig. 2**. A total of eight specimens (**SS45/0**, **SS45/25**, **SS45/45**, **SS45/65**, **SS25/45**, **SS65/45**, **SM45/25** and **SL45/25**) were tested. The specimen designation can be explained as follows. The first symbol indicates the type of load (S=static load) the second symbol indicates the thickness of slab (S=small thickness=135mm, M=medium thickness=160mm, and L=large thickness=185mm), the third symbol before slash indicates the flexural steel ratio (25=0.0025, 45=0.0045, and 65=0.0065), and the last symbol denotes to the lacing steel ratio (0=no lacing reinforcement, 25=0.0025, 45=0.0045, and 65=0.0065). The entire characteristics and details of the tested specimens are listed in **Table 1**, and **Table 2** shows the details of each group.
The properties of the steel used in the reinforcing mats of the slabs are listed in **Table 3**. The specimens were constructed using a normal density concrete with a compressive strength of approximately 30 MPa. A mechanical mixer was used to produce the concrete using normal portland cement, fine aggregate, and crushed coarse aggregate of 19 mm maximum nominal size. The mixing processes were performed according to the procedure of **ASTM C192-2002**. **Table 4** lists the final strengths based on the average values from the tests performed on at least three 150 x 300mm cylinders for each test specimen. The tensile strength of the concrete was determined by performing the split cylinder tests.

4. INSTRUMENTATION

The instrumentation of the slab specimens was designed to register the maximum quantity and most reliable data of local strains, deflections and crack widths, to achieve the behavior of the laced reinforced concrete one way slab. Uniaxial electrical resistance (foil) strain gage was the adopted method to measure the strain in both concrete and steel. Two different sizes of pre-wired strain gages of (120Ω) resistance, made in Japan for TML, were used in the test, All the used types of strain gages were normally installed by the recommended adhesive (CN-E and CN-Y) before which the contact surface was suitably prepared. In order to measure the vertical deflection of the tested slabs LVDT (Linear variable deferential transformer) was adopted tool to measure the deflection at mid span and at the two thirds part of the tested slab, were attached to lower steel beams of the testing machine under the tension face of the specimens.

5. TEST PROCEDURE

All specimens were tested using the hydraulic testing frame. The specimens were a simply supported condition where supported on the shorter opposite sides as shown in **Fig. 3** the specimens placed inside the testing frame so that supports lines, points load, LVDT were fixed in their correct locations, as shown in **Fig. 4**. Four point bending test were carried out by load increment of (3.5 kN) applied statically by using a hydraulic jack of (500 kN) capacity.
At each loading stage, the test measurements included the magnitude of the applied load, deflection of the slab at three locations, cracks width, strain in steel reinforcements (flexural and lacing), and strain in compressive face of slab were recorded also. At the end of each test, the cracks propagated were marked and the crack pattern and mode of failure for each specimen were carefully examined.

6. TEST RESULTS AND DISCUSSION

6.1 General Behavior and Crack Patterns

The first crack (flexural) occurred at the tension face for the middle third of slab, and then growths slowly across the width of the slab (i.e. parallel to the supports). Development and formed of flexural cracks occurred parallel to that crack and slowly propagated throughout the thickness of the slab, on increasing the application of static load. **Fig. 5-a to 5-h** shows the crack pattern of the tested specimens. It is clear from these figures that the generated of flexural cracks are approximately parallel and did not show any cracking on either side of the specimen near the support regions. Generally it is notice that the cracks develops and growths throughout the slab thickness on increasing the applied load are parallel and vertically up to failure for the specimen without lacing reinforcement. While the cracks are curved and connected together through the slab thickness for the specimens with lacing reinforcement, and this overlap increase as the lacing steel ratio increased, as illustrated in **Fig. 6-a and 6-b** respectively. Finally, the modes of failure for specimens were occurs by excessive yielding of tension steel reinforcement and followed by concrete crushing at the top surface of the slab at failure.

6.2 Cracking and Failure Loads

The experimental results for cracking and ultimate loads of all specimens are given in **Table 5**. The test results show that, the initial crack, there was compatibility between all the tested specimens. The first cracks (flexural) occurred at a load range of about (18.6% to 22.58%) of the ultimate load capacity of these specimens. Also, it is clear that from the experimental test results, the ultimate load capacity enhanced by about (56.52%) for the specimen with the highest lacing steel ratio with respect to the specimen **SS45/0**. And the ultimate load was decreased by about (3.13%) for the specimens with highest flexural steel ratio with respect to the specimens **SS45/25**. As a result of increasing the stiffness and the moment of inertia of the specimen due to increase the slab thickness, the load capacity were improved by about (103.57%) for the specimen **SL45/25** that have the largest thickness compared with the specimen **SS45/25**.

6.3 Load-Deflection Response

The behavior of the specimens is compared to the behavior of control specimen for each group at two load stages: a service load stage and the failure load stage. The serviceability limit is about (70-75%) of the peak load **Tan and Zhao, 2004**. In the presented discussion of deflections, the service loads are considered to 70% of the peak load of control specimens. The failure loads of the control specimens are equal to the recorded load, in **Table 5**.

Generally when a specimen is subjected to a gradually load increase, the deflection increases linearly with the load in an elastic manner. After the cracks start developing, deflection of the slab increases at a faster rate. After cracks have developed in the slab, the load-deflection curve is approximately linear up to the yielding of flexural reinforcement after which the deflection continues to increase without an appreciable increment in load.

Fig. 7 illustrated that the effect of increasing the lacing steel ratio and compared with the control specimen without lacing reinforcement. The experimental test results show that, the influence of the lacing ratio on the recorded deflections at service stage is relatively small, where the deflection reduced by about (4.15%, 12.89% and 19.82%) for the specimens **SS45/25**, **SS45/45** and **SS45/65** at service load with the respect to the control specimen **SS45/0**. At failure, these percentages increases to (10.64%, 45.54% and 55.94%) compared with the control specimen.

From **Fig. 8** it can be observed that, there is a maximum decrease in the recorded deflection at service load was (23.53%) for the specimen with the highest flexural steel ratio. At failure load, there is no significant decrease in the recorded deflection just by a bout (2.11%) for the specimen **SS45/45** compared with the specimen **SS25/45**. As expected, the deflection will be decrease as the slab thickness increase, where it is reduced by about (68.72%) for the specimen **SL45/25** at the service load, and by about (86.20%) at the failure load of the control specimen, as shown in **Fig. 9**. All percentages of central deflection of tested specimens at service and ultimate loads are listed in **Table 6**.

6.4 Load-Strain Relations

The load-strain relations of steel reinforcements and the compression concrete surface were measured to get a better understanding for the response and behavior of the laced reinforced concrete one way slab. Generally, it is so clear that the effect of lacing reinforcement to restrain the flexural reinforcement through its plastic region for all specimens with lacing reinforcement compare with the specimen without lacing reinforcement **SS45/0**. It is notice that from **Fig. 10-a to 10-c** the flexural steel reinforcement are yielded and the maximum compressive strain at the top of concrete surface is (2245) microstrain, while the lacing reinforcement within the elastic limit, at service load stage. At ultimate load, the concrete is crushed and the lacing reinforcements are yielded. **Fig. 11-a to 11-c** showing that the flexural steel reinforcement are yielded, the concrete uncrushed with recorded microstrain by a bout (2558.4), and the lacing reinforcement within the elastic limit, at the service load of the specimens. At failure, the concrete reached to crushing with the range of microstrain by about (4873 - 5637), and the lacing reinforcement were yielded. As expected, as the slab thickness increase the strain will be decrease compared with the specimen with the smallest thickness, this is illustrated in **Fig. 12-a to 12-c** where the maximum compressive microstrains in concrete reached to (1913), and the lacing reinforcement still within the elastic limit, at the service load of the specimens, whereas the flexural steel reinforcement are yielded. Thereafter, the concrete excess the crushing strain and the lacing reinforcement are yielded at the failure load of the specimens.

6.5 Ductility Factor

The ductility factor defined as the ratio of deflection at failure (ultimate deflection) to the deflection at steel yielding for the tested specimens. Thus, it is notice that from **Fig. 13** the ductility factor for all specimens with lacing reinforcement was found to be the higher compared with the specimen without lacing reinforcement, and it is recorded the maximum enhancement in ductility factor by about (91.34%) for the specimen with the lower lacing steel ratio.
As demonstrated in **Fig. 14** the ductility factor decreased by about (29.42%) for the specimen with the highest flexural steel ratio with respect to the specimen **SS25/45**, this is due to increasing the stiffness of the slab as the flexural steel ratio increased.
Fig. 15 show the clear dropping in the ductility factor of the tested slabs as the slab thickness increase, where the ductility factor decrease by about (29.95% and 34.94%) respectively for the specimens **SM45/25** and **SL45/25** with respect to the specimen **SS45/25**, this is due to increasing the flexural stiffness of the slabs. The ductility factor is calculated and tabulated, as shown in **Table 7**.

7. CONCLUSIONS

A series of experimental tests were performed on eight one-way simply-supported slabs reinforced with alternative lacing bars. As predicted that all specimens were failed in flexural mode by yielding of tension steel reinforcement, the first flexural crack always initiated at the bottom face of the slabs at the middle third of slab (constant moment) and propagated across the width and depth of the slab in the direction Parallel to the supports axis, and it was observed that the cracks were curved and connected together for the specimens with lacing reinforcement, and also notice that for all slabs with lacing steel reinforcement the crack width smaller than what observed in the control slab (specimen without lacing reinforcement) during the same loading stage.

Increasing the lacing steel reinforcement causes an increasing in the cracking load by (20%) and improving the ultimate load capacity by about (56.52%) with respect to the control specimen, and there is no significantly affected on enhanced the ultimate load capacity of the specimens when increasing the flexural steel reinforcement, whereas the ultimate load capacity increased by about (103.57%) as a result of decreasing the (L/d) ratio by (31.25%) with respect to the control specimen. While the deflection at the service load was decreased by about (19.82%) for the slab with the highest lacing steel ratio, and reduced by about (23.53%) and (68.72%) for the specimens with the highest flexural steel ratio and with the smallest (L/d) ratio respectively.

The load strain response for the flexural steel reinforcement of all the specimens with lacing reinforcement was similar, and it is so clear that the effect of lacing reinforcement to re-strain it through the plastic region, while the concrete strain at the extreme compressive fiber behaved non-linearly with load until failure of the specimen.

The ductility factor of all the laced slabs were observed more than that the slab without lacing reinforcement, where it is enhanced by about (91.34%) for the specimen with the lower lacing ratio, however the ductility factor decrease with increasing the lacing steel ratio. Also, the ductility factor of the slabs increased with decrease the flexural steel ratio, and with increasing the (L/d) ratio.

REFERENCES

- ACI Committee 318, 2014, *Building Code Requirements for Structural Concrete ACI 318M-14 and commentary*, American Concrete Institute, Farmington Hills,503pp.

- Anandavalli, N., Lakshmanan, N., G.M. Samuel Knight, 2012, *Simlified Approach for Finite Element Analysis of Laced Reinforced Concrete Beams*, ACI Structural Journal, Vol. 109, No.1, pp. 91-100, February.

- ASTM Designation C192/C192M-02, 2002, *Making and Curing Concrete Test Specimens in Laboratory*, Annual Book of ASTM Standards, American Society for Testing and Materials, Philadelphia, Pennsylvania, Vol. 4, 02.

- Keshava Rao, M.N., Lakshmanan, N., Srinivasulu, P. and Dharaneepathy, M. V., 1992, *Application of Laced Reinforced Concrete Construction Techniques to Blast Resistant Structures - Phase II*, Report No. S-015, CSIR-SERC.

- Madheswaran C.K., Gnanasundar G. and Gopalakrishnan N., 2015, *Performance of Laced Reinforced Geopolymer Concrete (LRGPC) Beams under Monotonic Loading*, Advances in Structural Engineering, mechanics, Vol. 1, pp 355-367.

- Parameswaran, V.S., Lakshmanan, N., Srinivasulu, P, Krishnamoorthy, T.S., Balasubramanian, K., Thandavamoorthy, T.S. and Arumugam, M.,1986, *Application of Laced Reinforced Concrete Construction Techniques to Blast Resistant Structures*, Report No. RCC-SR-86-1, CSIR-SERC.

- Stanley C. Woodson, 1992, *Lacing Versus Stirrups an Experimental Study of Shear Reinforcement in Blast Resistant Structures*, U.S. Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, March.

- Tan, K. G. And Zhao, H. , 2004, *Strengthening of Openings in One-Way Reinforced-Concrete Slabs Using Carbon Fiber-Reinforced Polymer Systems*, Journal of Composites for construction ,ASCE, Vol. 8, No. 5, pp. 393-402.

- Unified Facilities Criteria UFC 3-340-02, 2008, *Structures to Resist the Effects of Accidental Explosions*, Department of Army, Navy and the Air Force, U.S.A., Washington, 05 December.

Table 1. Characteristics of the tested slabs.

No.	Specimen designation	Slab thickness (mm)	$\frac{L}{d}$ ratio	Tension steel ratio (ρt)	Lacing steel ratio (ρs)	Lacing angle (θ)	Lacing steel details
1	SS45/0	135	16	0.0045	0	-	Without lacing
2	SS45/25	135	16	0.0045	0.0025	45°	$\emptyset 6\ mm\ at\ 100\ mm\ c/c$
3	SS45/45	135	16	0.0045	0.0045	45°	$\emptyset 6\ mm\ at\ 60\ mm\ c/c$
4	SS45/65	135	16	0.0045	0.0065	45°	$\emptyset 8\ mm\ at\ 70\ mm\ c/c$
5	SS25/45	135	16	0.0025	0.0045	45°	$\emptyset 6\ mm\ at\ 60\ mm\ c/c$
6	SS65/45	135	16	0.0065	0.0045	45°	$\emptyset 6\ mm\ at\ 60\ mm\ c/c$
7	SM45/25	160	13	0.0045	0.0025	45°	$\emptyset 6\ mm\ at\ 80\ mm\ c/c$
8	SL45/25	185	11	0.0045	0.0025	45°	$\emptyset 6\ mm\ at\ 70\ mm\ c/c$

Table 2. Details of slabs groups.

Group	Description	Specimens
I	$\frac{L}{d} = 16$ $\rho t = 0.0045$ $\rho s\ Variable$ (Lacing)	1. *SS45/0* *(ρs=0)* 2. *SS45/25* *(ρs=0.0025)* 3. *SS45/45* *(ρs=0.0045)* 4. *SS45/65* *(ρs=0.0065)*
II	$\frac{L}{d} = 16$ $\rho s = 0.0045$ $\rho t\ Variable$	1. *SS25/45* *(ρt=0.0025)* 2. *SS45/45* *(ρt=0.0045)* 3. *SS65/45* *(ρt=0.0065)*
III	$\rho t = 0.0045,$ $\rho s = 0.0025$ $\frac{L}{d} = \ Variable$	1. *SS45/25* *(d=112.5mm, L/ d=16)* 2. *SM45/25* *(d=137.5mm, L/ d=13)* 3. *SL45/25* *(d=162.5mm, L/ d=11)*

Table 3. Properties of steel reinforcement.

Nominal diameter (mm)	Measured diameter (mm)	Yield stress fy MPa	Ultimate strength fu MPa
6	5.83	724.4	777.4
8	7.87	626.24	775.34

Table 4. Mechanical properties of concrete.

Specimen ID	Compressive strength at time of specimen testing (MPa)		Modulus of rupture f_r at time of specimen testing (MPa)	Splitting tensile strength f_t at time of specimen testing (MPa)	Modulus of elasticity at time of specimen testing (GPa)
	f_{cu}	f'_c			
SS45/0	42.92	35.28	3.87	3.57	24.43
SS45/25	43.96	34.85	3.82	3.29	22.32
SS45/45	43.35	33.92	3.7	3.42	22.79
SS45/65	45.22	34.36	3.91	3.15	27.35
SS25/45	45.19	35.31	3.41	3.2	24.18
SS65/45	47.07	36.27	3.63	3.35	24.72
SM45/25	44.89	37.12	3.51	3.6	24.71
SL45/25	46.87	35.81	3.9	3.25	25.67

Table 5. Cracking and ultimate loads of the tested slabs.

Specimens		Crack load (Pcr) (kN)	Ultimate load (Pu) (kN)	% Pcr/Pu	%Increase in first cracking load with respect to control	%Increase in ultimate load with respect to control
Group I	SS45/0	18.15	83.49	21.74	Ref.	Ref.
	SS45/25	21.78	101.64	21.43	20	21.74
	SS45/45	21.78	116.16	18.75	20	39.13
	SS45/65	21.78	130.68	16.67	20	56.52
Group II	SS25/45	18.15	116.16	15.63	Control	Control
	SS45/45	21.78	116.16	18.75	20	0.00
	SS65/45	25.41	112.53	22.58	40	-3.13
Group III	SS45/25	21.78	101.64	21.43	Control	Control
	SM45/25	29.04	156.09	18.6	33.33	53.57
	SL45/25	43.56	206.91	21.05	100	103.57

Table 6. Central deflections of the tested slabs at service and ultimate loads.

Specimens		Deflection at service load of control specimen (mm)	% Decrease in deflection at service load	Deflection at ultimate load of control specimen (mm)	% Decrease in deflection at ultimate load
Group I	SS45/0	14.23	Ref.	40.40	Ref.
	SS45/25	13.64	4.15	36.10	10.64
	SS45/45	12.40	12.86	22.00	45.54
	SS45/65	11.41	19.82	17.80	55.94
Group II	SS25/45	22.10	Control	64.22	Control
	SS45/45	20.80	5.88	62.86	2.11
	SS65/45	16.90	23.53	*	*
Group III	SS45/25	23.40	Control	77.4	Control
	SM45/25	9.82	58.03	15.54	79.92
	SL45/25	7.32	68.72	10.68	86.20

*Ultimate load of control specimen is beyond the failure load of specimen SS65/45.

Table 7. Ductility factor of the tested slabs.

Specimens		Ultimate load (kN)	Yield deflection (mm)	Ultimate deflection (mm)	Ductility factor
Group I	SS45/0	83.49	12.05	40.40	3.35
	SS45/25	101.64	12.08	77.40	6.41
	SS45/45	116.16	12.26	62.85	5.13
	SS45/65	130.68	13.53	61.54	4.55
Group II	SS25/45	116.16	11.25	64.22	5.71
	SS45/45	116.16	12.26	62.85	5.13
	SS65/45	112.53	12.37	49.86	4.03
Group III	SS45/25	101.64	12.08	77.40	6.41
	SM45/25	156.09	13.14	59.09	4.49
	SL45/25	206.91	13.64	56.99	4.17

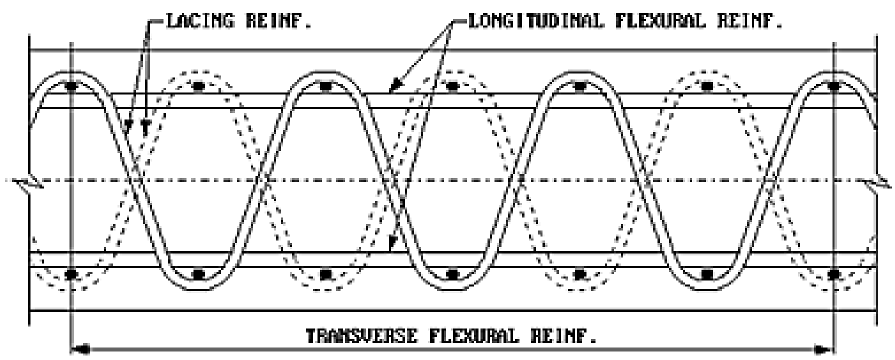
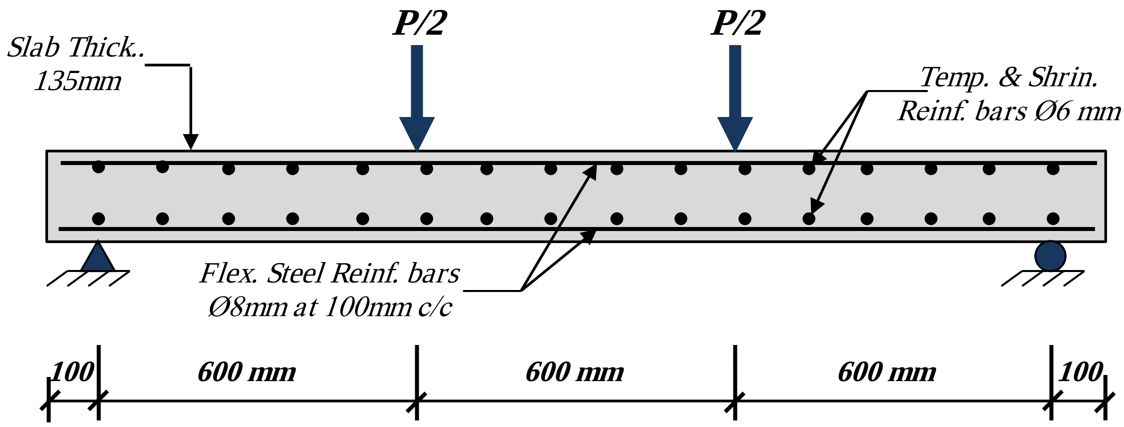
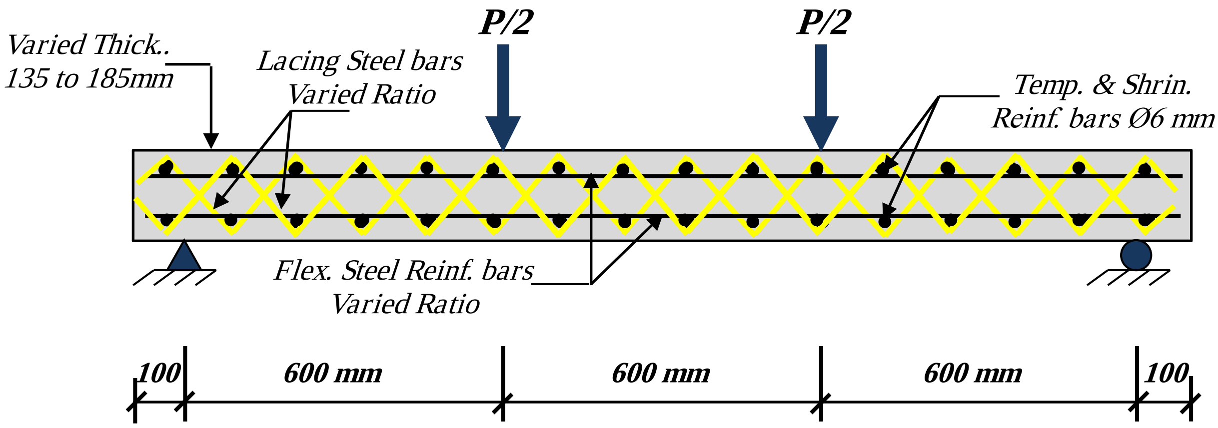


Figure 1. Typical laced reinforced concrete structural element.



a. Longitudinal section in slab without lacing reinforcement.



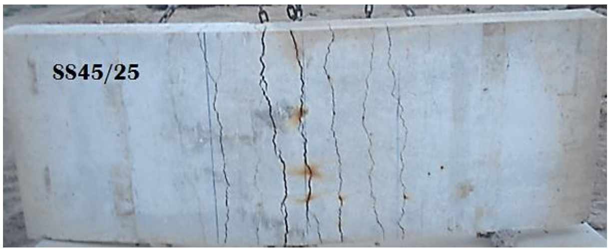
b. Longitudinal section in slab with lacing reinforcement.

Figure 2. Details and dimensions of the test slab specimens.

Figure 3. Photograph of specimen setup.

Figure 4. Photograph of instruments setup.

a. specimen SS45/0



b. specimen SS45/25

c. specimen SS45/45

d. specimen SS45/65

e. specimen SS25/45

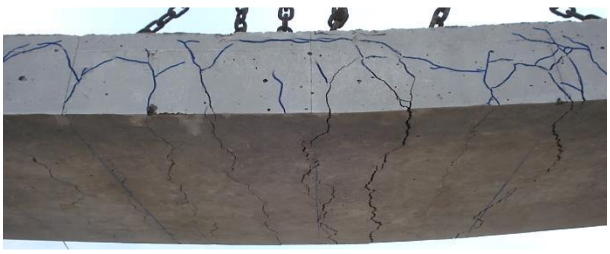
f. specimen SS65/45

g. specimen SM45/25

h. specimen SL45/25

Figure 5. Cracks pattern for the tension face of specimens tested after failure.

a. specimen without lacing reinforcement.



b. specimen with lacing reinforcement.

Figure 6. Typical cracks pattern for the side face of specimens tested after failure.

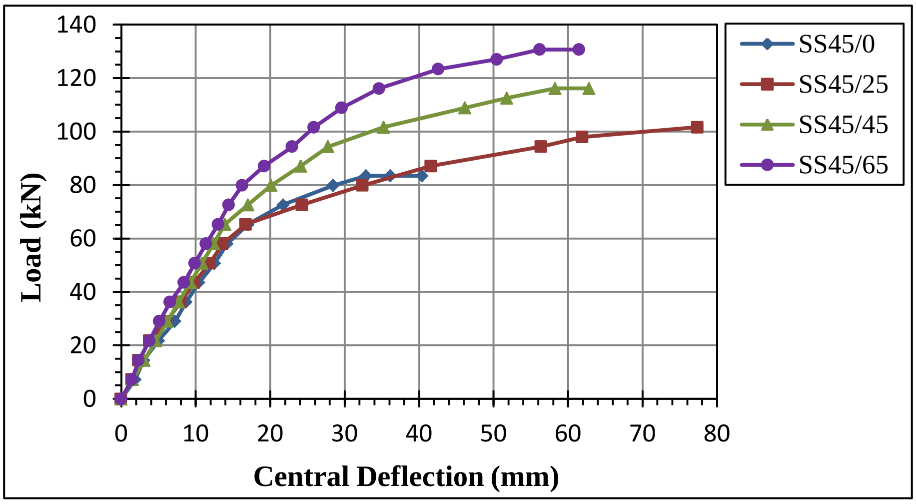


Figure 7. Influence of the lacing steel ratio on load-central deflection behavior for group (I).

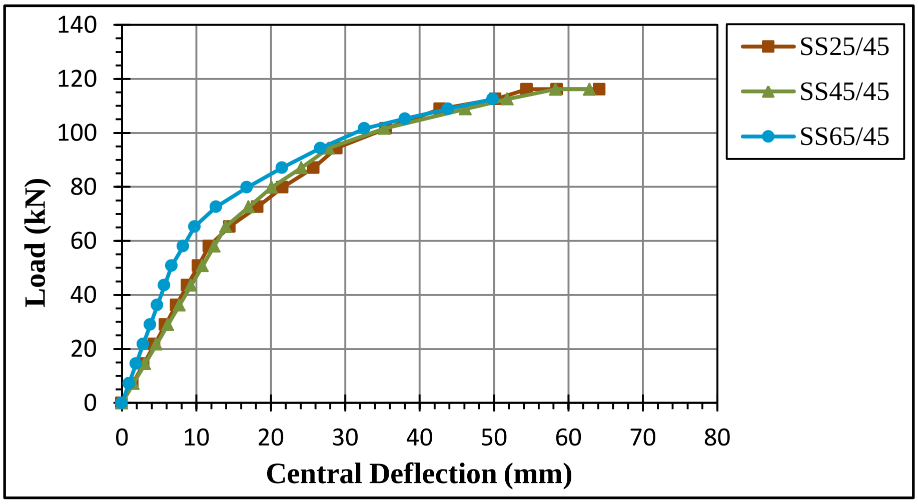


Figure 8. Influence of the flexural steel ratio on load-central deflection behavior for group (II).

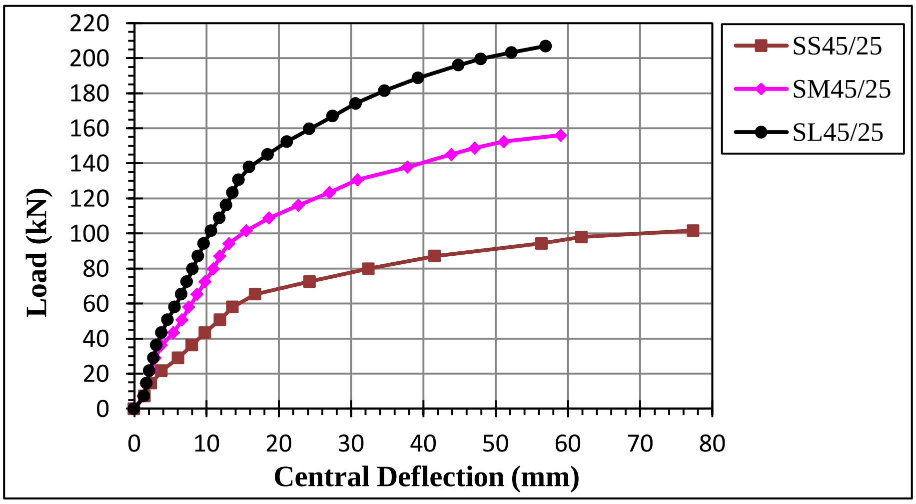
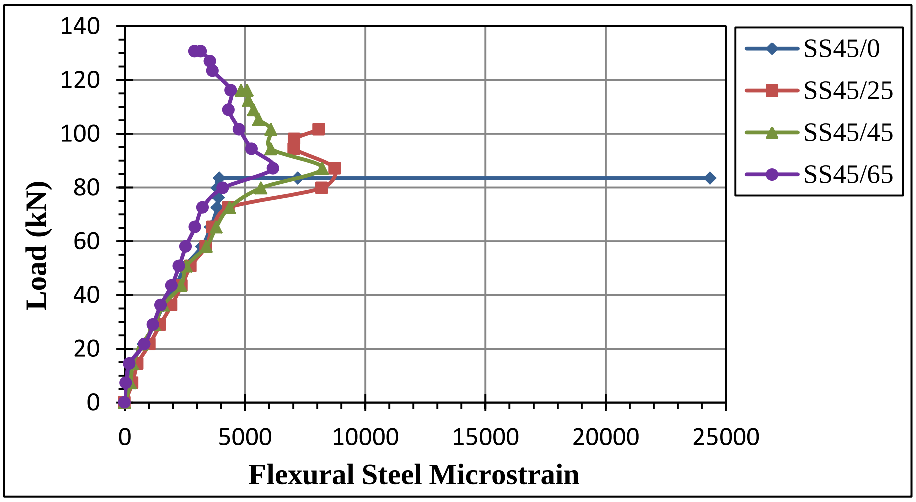
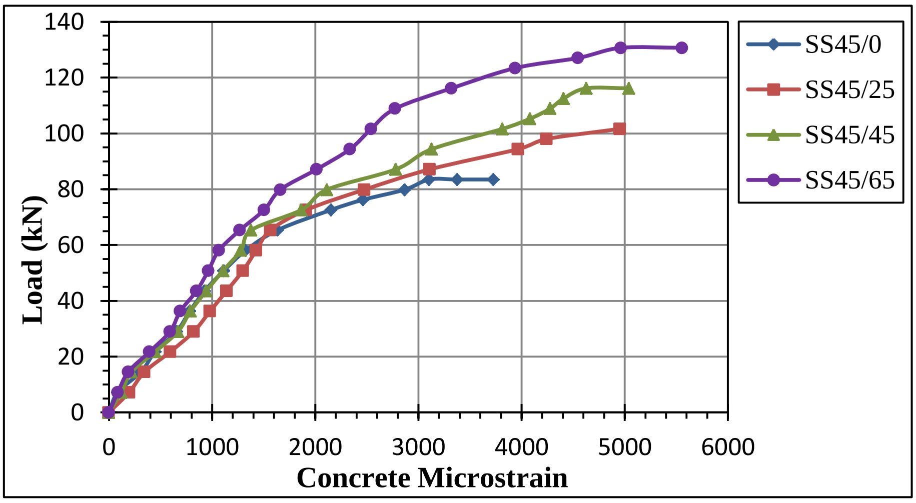


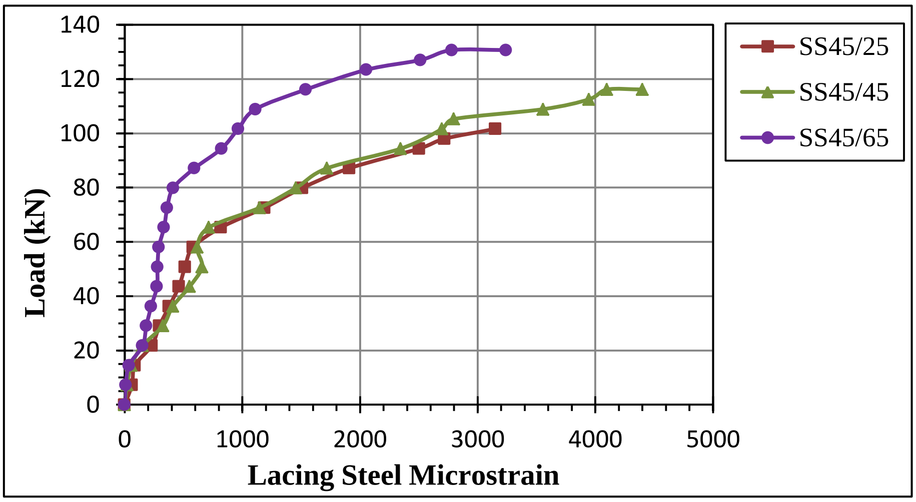
Figure 9. Influence of the L/d ratio on load-central deflection behavior for group (III).



a. Load–strain curves at the flexural steel reinforcement.

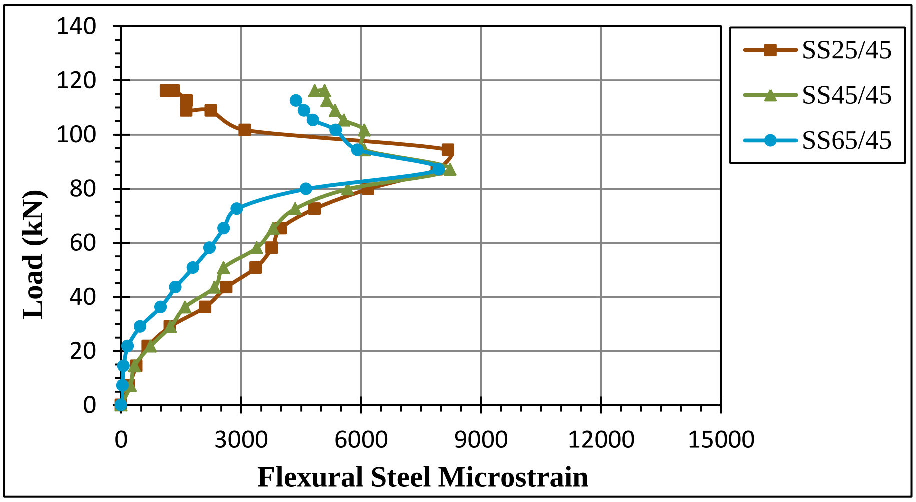


b. Load–strain curves at the top surface of concrete.

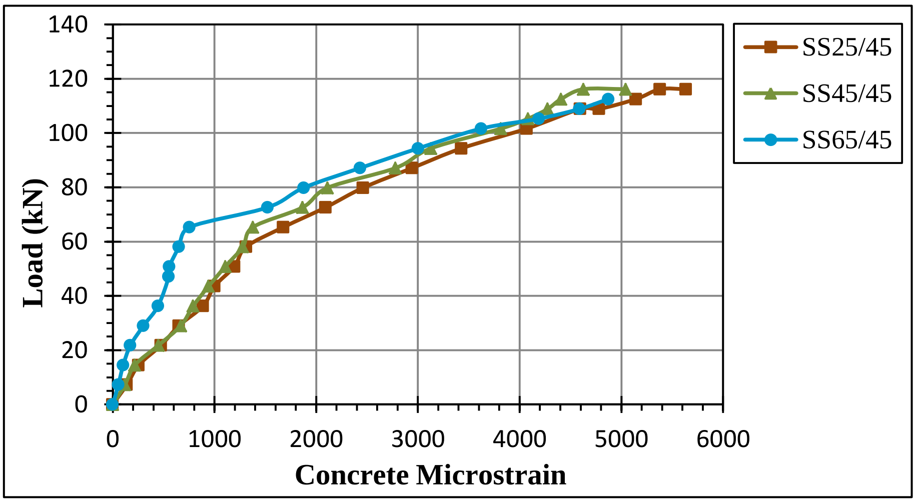


c. Load–strain curves at the lacing steel reinforcement.

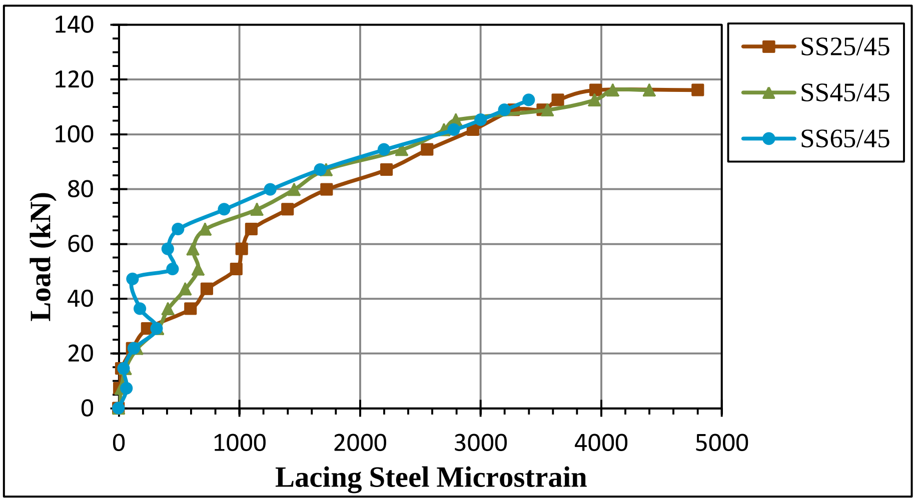
Figure 10. Influence of the lacing steel ratio on load–strain curves at mid-span for group (I).



a. Load–strain curves at the flexural steel reinforcement.

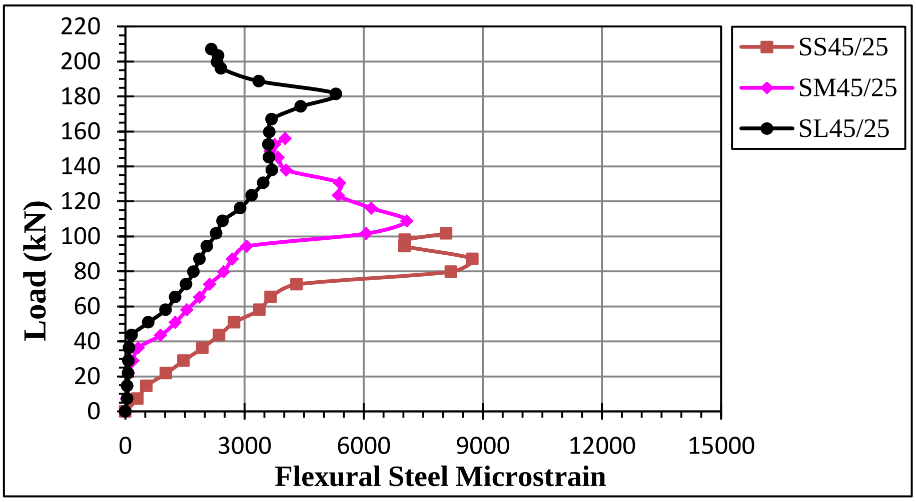


b. Load–strain curves at the top surface of concrete.

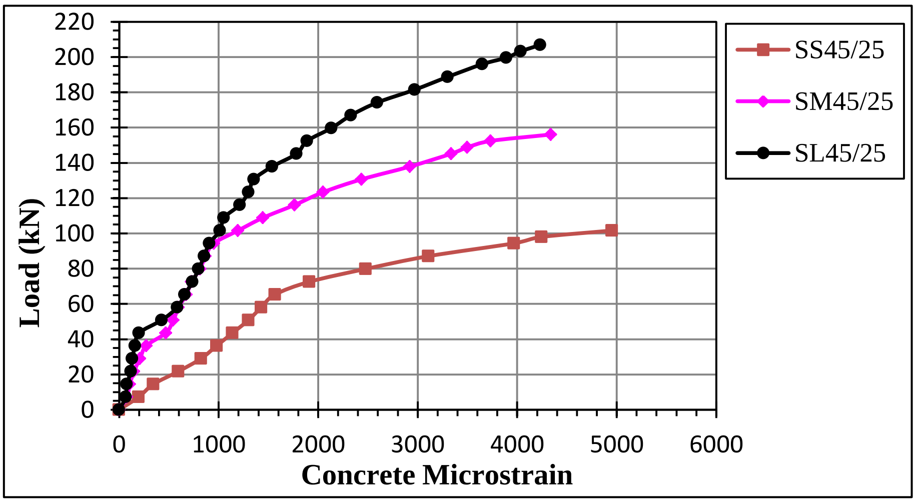


c. Load–strain curves at the lacing steel reinforcement.

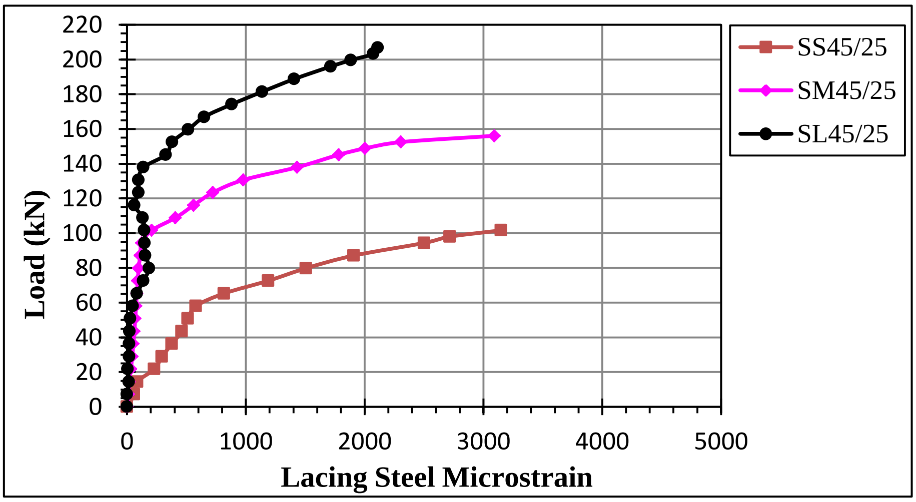
Figure 11. Influence of the flexural steel ratio on load–strain curves at mid-span for group (II).



a. Load–strain curves at the flexural steel reinforcement.



b. Load–strain curves at the top surface of concrete.



c. Load–strain curves at the lacing steel reinforcement.

Figure 12. Influence of the L/d ratio on load–strain curves at mid-span for group (III).

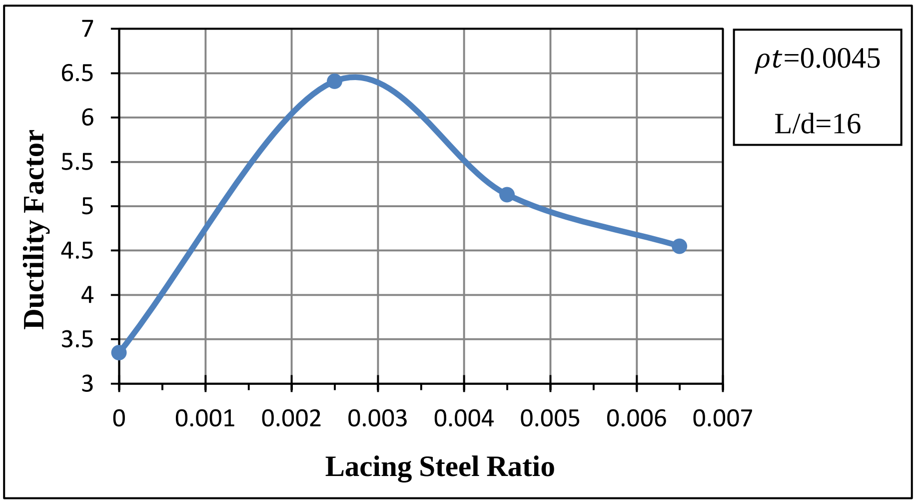


Figure 13*.* Ductility factor versus lacing steel ratio.

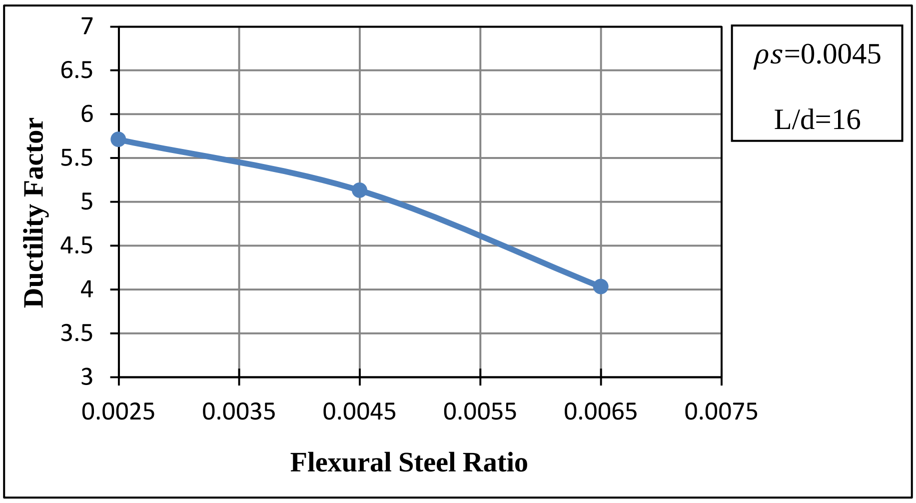


Figure 14. Ductility factor versus flexural steel ratio.

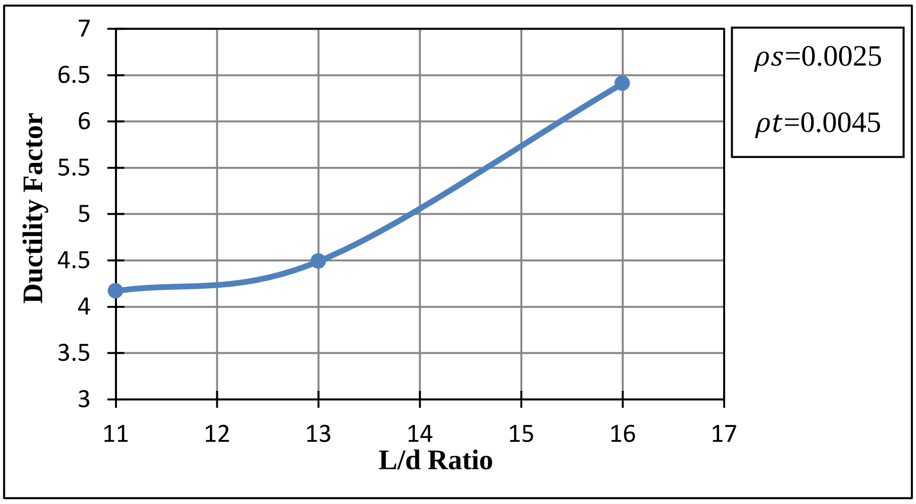


Figure 15. Ductility factor versus L/d ratio.