Response of Laced Reinforced Concrete One Way Slab to Repeated Loading

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ABSTRACT

Test results of nine reinforced concrete one way slab with and without lacing reinforcement are reported. The tests were designed to study the effect of the lacing reinforcement on the flexural response of one way slabs. The test parameters were considered is the lacing steel ratios of (0, 0.0025, 0.0045, and 0.0065), flexural steel ratios of (0.0025, 0.0045, and 0.0065) and span to the effective depth ratios of (11, 13, and 16). Two specimens had no lacing reinforcement and the remaining seven specimens had the lacing reinforcement. Four point bending test were carried out, one of the specimens was tested under the static load applied gradually up to failure and the other specimens were tested under repeated load (5 cycles) loading-unloading to 80% of the ultimate load of the control specimen then loaded manually by the hydraulic jack up to failure. The specimens showed an improving in ultimate load capacity ranged between (54.54% - 100%) 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 reducing the residual deflection by about (57.24%) for the specimen with the largest lacing reinforcement compared with the control specimen (without lacing reinforcement).

Key words: laced one way slab**,** reinforced concrete, crack, residual deflection, repeated loading.

إستجابة البلاطات الخرسانية المسلحة الاحادية الاتجاه والحاوية على حديد متعرج للاحمال المتكررة

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الخلاصة

تم في هذا البحث مناقشة النتائج العمليه لتسعة بلاطات خرسانيه احادية الاتجاه مسلحه وحاويةعلى تسليح متعرج. ان الغرض من هذا البحث هو دراسه تأثير استخدام التسليح المتعرج على سلوك واستجابة البلاطات الاحادية الاتجاه. وكانت المتغيرات هي نسبة حديد التسليح المتعرج وهي(0,0.0025,0 ,0.0045 , 0.0065), نسبة الحديد الرئيسي وهي (0.0025, 0.0045 , 0.0065) ونسبة الطول الصافي الى العمق الفعال للبلاطة وهي (13,16 , 11). اثنان من العينات لاتحتوي على حديد متعرج اما السبعة المتبقيه فكانت جميعها تحتوي على حديد التسليح المتعرج. تم فحص احدى العينات الغير حاوية على حديد متعرج ستاتيكيا الى الفشل بينما تم فحص العينات المتبقية تحت تاثير الاحمال المتكررة بخمسة دورات تحميلية الى حد 80% من قيمة الحمل الاقصى للعينة المفحوصة ستاتيكياً ثم تحميل العينة الى حد الفشل .بينت النتائج العملية بان التحمل الكلي للبلاطات تحسن بمقدار (54,54%) نتيجه لاستخدام الحديد المتعرج بنسبة (0.0065) و بمقدار (100%) 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 قلل وبشكل ملحوظ مقدار الهطول الدائمي للبلاطات بنسبة (57,24%) للبلاطة ذات اعلى نسبة تسليح متعرج مقارنة مع البلاطة بدون حديد تسليح متعرج.

الكلمات الرئيسيه: البلاطة الاحادية الاتجاه ذات التسليح المتعرج , الخرسانة المسلحة, التشقق, الهطول الدائمي, التحميل المتكرر.

1. INTRODUCTION

Traditional 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. Laced reinforced concrete (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 Woodson, 1992**.

A repeated load is a force which is applied many times to a member, causing stress in the material that continually varies, usually through some defined range. If a stress is developed in a member and then released, the member is said to have been subjected to a cycle of stresses. Further, if a tensile stress has been developed, and released, and then a compressive stress is developed, and this stress then is released, the member is said to have been subjected to a reversed cycle of stresses or, briefly, to a reversal of stresses, the reversal of stresses is complete if the opposite stresses are of equal magnitudes.

Investigations were carried out by **Lakshmanan et al., 2008**, to study the behavior of laced reinforced concrete beams with and without steel fibers under shear loading. Reversed cyclic shear loading tests were also carried out on the LRC beams with and without steel fibers.

Behaviour of LRC and its application for blast resistant design has been discussed in details by **Lakshmanan, 2008**. Response of 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.

Behavior of the concrete one way slabs reinforced by the steel bars made of scrap metals and subjected to cyclic load with different cycles loads were conducted by **Adom-Asamoah and Kankam, 2009**, as a results of this study, the stiffness of slab, failure load, and the ultimate deflection were reduced when comparing the behavior of the specimen tested under monotonic load with that subjected to cyclic loading.

Sivagamasundari and Kumaran, 2011, investigated the behavior of the one-way slabs reinforced with Glass Fiber Reinforced Polymer GFRP bars and compared with those of traditionally reinforcement subjected to cyclic loading with variable and constant amplitude fatigue loads. A nonlinear finite element analysis is also performed by considering the material nonlinearity for the entire size of the specimens; a good agreement was evident on comparison the analytical model results with the experimental test results.

Anandavlli, 2012, applied reversed cyclic load on two Laced Steel Composite Concrete (LSCC) beams, one of them for 45° and another for 60° lacing angle. Reverse cyclic loading consists of loading and unloading the beam in both the directions alternatively.

2. RESEARCH SIGNIFICANCE

To know 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 repeated response of laced reinforced concrete one way slab under four point bending test 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 (135mm, 160mm, and 185mm). Two of these slabs were without lacing reinforcement (reference specimens), and seven specimens were having the lacing reinforcement with 45º lacing angle, 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 nine specimens (**SS45/0**, **RS45/0, RS45/25**, **RS45/45**, **RS45/65**, **RS25/45**, **RS65/45**, **RM45/25** and **RL45/25**) were tested. The specimen designation can be explained as follows. The first symbol indicates the type of load (S=static load and R=repeated 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 gauge 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 gauges 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 fixed 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 on the shorter opposite sides, where the specimen was placed inside the testing frame so that supports lines, points load, LVDT were fixed in their correct locations, as shown in **Fig. 3**. The specimens were loaded by two equal lines load at third parts of the tested slab (four point bending test). The static load was increased gradually by a step load of (3.63 kN) up to failure. Repeated load was applied by incremental loads gradually up to (80%) of the ultimate load level of the control specimen (**SS45/0**) and then release the load gradually to zero with (5 cycles) loading-unloading. Then the slabs were loaded manually up to failure 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 reinforcement (tension and lacing steel bars), and strain in compressive face of slab were recorded. 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

For a simply supported one-way slab subjected to equal line loads at the third points, the middle third of the span is subjected to pure bending (such that it is under zero shear and maximum bending moment); whilst the remaining sections experience maximum shear force and varying bending moment. The middle third experiences the largest strains and therefore the concrete beneath undergoes cracking first. Then, the first crack 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. 4** shows the crack pattern of the static tested specimen at failure. It is clear from this figure that the generated flexural cracks are approximately parallel and did not show any cracking on either side of the specimen near the support regions. Also, the crack patterns of the specimens tested under repeated load **Fig. 5-a to 5-h** are approximately same that for the specimen under static load. Further development of cracks occurs and width of cracks, on increasing the number of loading cycles for the specimen under repeated load. Generally it is noticed 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 occurred 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 listed in **Table 5**. The first cracks (flexural) occurred at a load range of about (18.18% to 24.07%) of the ultimate load capacity of these specimens.

Also, from the experimental testing results, it is demonstrated that the ultimate load increased as the lacing steel ratio for the specimens **RS45/25**, **RS45/45** and **RS45/65** increased by about (22.73%, 45.45%, and 54.54%) respectively with respect to the specimen **RS45/0** (without lacing reinforcement). For the specimens of the different flexural steel reinforcement ratio and the same lacing steel ratio, it is observed that a slightly increase in the ultimate load capacity of the specimen **RS25/45** on that recorded for the specimens **RS45/45** and **RS65/45**. This is because of using the lacing reinforcement caused by decreasing the effect of the flexural reinforcement and this may be explained as the de-bonding between the concrete and the steel reinforcement for the specimen **RS25/45** occurs at the load level higher than that for the other two specimens. As expected, the ultimate load capacity increased by increasing the slab thickness, where the load increase by about (51.85% and 100%) for the specimens **RM45/25** and **RL45/25** respectively with respect to the specimen **RS45/25**.

6.3 Load-Deflection Response

The vertical deflection is measured at the middle of the slab and beneath the points load at each load step; the behavior of the specimens is compared with the behavior of control specimen for each group at the failure load stage. Generally, when a specimen is subjected to a gradually load increase, the deflection increases linearly with the load in an elastic range. 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. Load-displacement response of the slab tested under static load is shown that the failure load is found to be (83.49 kN). Therefore, the amplitude of the repeated load is taken as 80% of this load as shown in **Fig. 7**.

It is demonstrated that as the lacing steel ratio increase, the deflection for the specimens **RS45/25**, **RS45/45**, and **RS45/65** decrease by about (27.83%, 47.94%, and 50.22%) respectively compare with that of the specimen **RS45/0** at the failure load, as illustrated in **Fig. 8**. For the specimens with the same ratio of the lacing steel reinforcement **RS25/45**, **RS45/45**, and **RS65/45** and the different flexural steel ratios, it is noticed that the load-deflection behavior is approximately identical, and there is a clear interaction between the curves as shown in **Fig. 9**. Then, the deflections were reduced by about (74.42% and 79.93%) for the specimens **RM45/25** and **RL45/25** respectively compared with the deflection at the failure load of the specimen **RS45/25**, this is due to the significant effect of increasing the slab thickness to increase the stiffness of the specimens, as shown in **Fig. 10**.

6.4 Residual Deflection Response

The experimental test results showed that there is an increase in deflection at the same point and the same increment of the load with an increase a number of cycles of loading for all the specimens. That causes slab not to return to the original position when the load decreased to zero level at the end of each cycle of loading. The lacing reinforced slab exhibited the lowest residual deflection and greatest stiffness. Among the five load cycles at a level of (80%) of the control specimen **SS45/0**, it is always the first cycle that is found to absorb more energy of the slab. Energy absorbed in the other cycles is found to be lower than that absorbed in the first cycle for the specimens.

It is noted that the increasing of the lacing steel ratio reduced the residual deflection for the specimens **RS45/25**, **RS45/45**, and **RS45/65** by about (9.6%, 45.55%, and 57.24%) respectively with respect to the specimen **RS45/0** as shown in **Fig. 11**. It’s observed that the increasing of flexural steel reinforcement ratio for the specimens, **RS45/45** and **RS65/45** causes increasing in the residual deflection by about (52.94% and 73.53%) respectively with respect to the specimen **RS25/45**. This is due to increase the stiffness of the specimens, and the reinforcement in the slabs were not able to return to dissipate energy without permanent deformation, as illustrated in **Fig. 12**. Also, as the depth of the slab increases, the stiffness will be increased. As a result, the deflection at the peak load of the first cycle will be decreased, then the residual deflection for the specimens **RM45/25** and **RL45/25** are reduced by about (59.46 % and 77.22%) respectively with respect to the specimen **RS45/25** as shown in **Fig. 13**.

6.5 Load-Strain Relations

The load-strain relations of steel reinforcement and the compression concrete surface were measured to get a better understanding for the response and behavior of the laced one way reinforced concrete slab. Strain gauges of (60 mm) length were installed on the top concrete surface to measure the compressive strain of concrete. 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 compared with the specimen without lacing reinforcement **SS45/0**.

Figs. 14-a to 14-c illustrate that the flexural steel reinforcement is yielded with recorded the tensile strain by about (3121-4089) microstrains and the maximum compressive strain of the concrete was (2055) microstrain, while the lacing bars within the elastic range by the tensile strain of (806-994) microstrains at the service load stage of the specimens **RS45/0**, **RS45/25**, **RS45/45**, and **RS45/65B**. Then the compressive strain of the concrete reached to (3835-5340) microstrains and increasing the tensile microstrain of the lacing reinforcement to (2709-3157) at the ultimate load of specimens, while the flexural steel reinforcement were re-strained.

The effect of increasing the flexural steel ratio of the specimens **RS25/45**, **RS45/45** and **RS65/45** on the load-strain curves were illustrated in **Figs. 15-a to 15-c**. It can be seen that there is significant record in tensile strain of the flexural steel reinforcement by about (4014-5380) microstrains, the compressive strain of concrete was ranged by (1587-2173) microstrain and the lacing steel reinforcement was recorded (705-1126) microstrains at service load. Then compressive strain of the concrete reached to (4114-5621) microstrains, and the lacing steel reinforcement recorded the tensile strain by about (2113-3895) microstrains at the ultimate load of specimens, the similar re-strained behavior was previously explained for the flexural steel reinforcement is observed.

It is demonstrated that from **Figs. 16-a to 16-c** the flexural steel reinforcement is yielded with the tensile strain range of (3348-4514) microstrains, and recorded the compressive strain at the top surface of concrete by about (1318-1838) microstrains, while the lacing reinforcement recorded the tensile strain by about (504-1389) microstrains at the service load stage of the specimens **RS45/25**, **RM45/25**, and **RL45/25**. These values increase to (4208-4721) microstrains at the top of concrete and (2709-4856) microstrains for the lacing steel reinforcement at the ultimate load stage of specimens, while the flexural steel reinforcement is re-strained at the plastic region because the effective of using the lacing steel bars.

7. SUMMARY AND CONCLUSIONS

The main conclusions can be summarized as follows:-

1. The crack pattern and mode of failure for the specimen tested under repeated load were similar to that described in the similar specimen tested under static load.

2. The ultimate load for specimen tested under repeated load was smaller than that of similar specimen subjected to static load.
3. The first cracking load increased by about (40%) for the specimen with highest lacing steel ratio, and by about (116.67%) for the specimen with lowest L/d ratio with respect to the control specimen for each group.
4. The ultimate load showed increase with increasing the lacing steel ratio, where the ultimate load for the specimen with the highest lacing steel ratio was (54.54%) greater than the control specimen.
5. The ultimate load capacity enhanced by (100%) as a result of decreasing the (L/d) ratio to (31.25%) with respect of the control specimen.
6. The ultimate deflection for specimen subjected to repeated load was smaller than of similar specimen tested under static load.
7. It is observed that with the increase in the number of load cycles, the corresponding deflection and number of cracks increased.
8. Residual deflection reduced by about (57.24%) for the specimen with the largest lacing reinforcement compared with the control specimen (without lacing bars).
9. Repeated loading produces a residual deflection which increases with the increased the flexural steel ratio, and the (L/d) ratio.
10. The flexural steel reinforcement is not able to return to dissipate energy without permanent deformation.

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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 steel details	Flexural steel details
1	SS45/0	135	16	0.0045	0	Without lacing	$\emptyset 8\ mm\ at\ 100\ mm$
2	RS45/0	135	16	0.0045	0	Without lacing	$\emptyset 8\ mm\ at\ 100\ mm$
3	RS45/25	135	16	0.0045	0.002	$\emptyset 6\ mm\ at\ 100\ mm$	$\emptyset 8\ mm\ at\ 100\ mm$
4	RS45/45	135	16	0.0045	0.004	$\emptyset 6\ mm\ at\ 60\ mm$	$\emptyset 8\ mm\ at\ 100\ mm$
5	RS45/65	135	16	0.0045	0.006	$\emptyset 8\ mm\ at\ 70\ mm$	$\emptyset 8\ mm\ at\ 100\ mm$
6	RS25/45	135	16	0.0025	0.004	$\emptyset 6\ mm\ at\ 60\ mm$	$\emptyset 6\ mm\ at\ 100\ mm$
7	RS65/45	135	16	0.0065	0.004	$\emptyset 6\ mm\ at\ 60\ mm$	$\emptyset 8\ mm\ at\ 70\ mm$
8	RM45/25	160	13	0.0045	0.002	$\emptyset 6\ mm\ at\ 80\ mm$	$\emptyset 8\ mm\ at\ 80\ mm$
9	RL45/25	185	11	0.0045	0.002	$\emptyset 6\ mm\ at\ 70\ mm$	$\emptyset 8\ mm\ at\ 70\ mm$

Table 2. Details of slab groups.

Group	Description	Specimens
I	$\frac{L}{d} = 16$ $\rho t = 0.0045$ $\rho s\ Variable$ (Lacing)	*SS45/0 (ρs=0)* *1. RS45/0 (ρs=0)* *2. RS45/25 (ρs=0.0025)* *3. RS45/45 (ρs=0.0045)* *4. RS45/65 (ρs=0.0065)*
II	$\frac{L}{d} = 16$ $\rho s = 0.0045$ $\rho t\ Variable$	*1. RS25/45 (ρt=0.0025)* *2. RS45/45 (ρt=0.0045)* *3. RS65/45 (ρt=0.0065)*
III	$\rho t = 0.0045,$ $\rho s = 0.0025$ $\frac{L}{d} = Variable$	*1. RS45/25 (d=112.5mm, L/ d=16)* *2. RM45/25 (d=137.5mm, L/ d=13)* *3. RL45/25 (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
RS45/0	47.90	36.14	3.7	3.58	29.32
RS45/25	45.57	37.15	3.78	3.74	25.32
RS45/45	41.15	33.43	3.7	3.39	22.18
RS45/65	42.28	34.58	4.2	3.22	24.01
RS25/45	44.44	37.57	3.72	3.82	28.09
RS65/45	45.08	34.77	3.52	3.15	25.83
RM45/25	43.62	36.81	3.74	3.68	25.82
RL45/25	45.51	34.23	3.56	3.12	25.23

Table 5. Cracking and ultimate loads of test specimens.

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
	SS45/0	18.15	83.49	21.74	Ref.	Ref.
Group I	RS45/0	18.15	79.86	22.73	Control	Control
	RS45/25	21.78	98.01	22.22	20	22.73
	RS45/45	25.41	116.16	21.87	40	45.45
	RS45/65	25.41	123.42	20.64	40	54.54
Group II	RS25/45	21.78	119.79	18.18	Control	Control
	RS45/45	25.41	116.16	21.87	16.67	-3.03
	RS65/45	25.41	112.53	22.58	16.67	-6.06
Group III	RS45/25	21.78	98.01	22.22	Control	Control
	RM45/25	32.67	148.83	21.95	50	51.85
	RL45/25	47.19	196.02	24.07	116.67	100

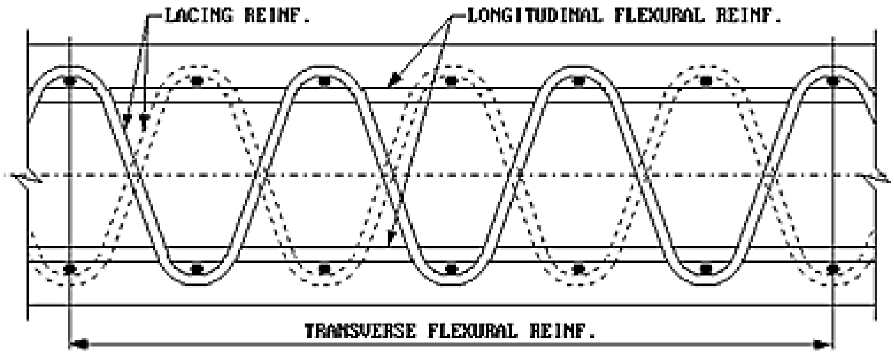
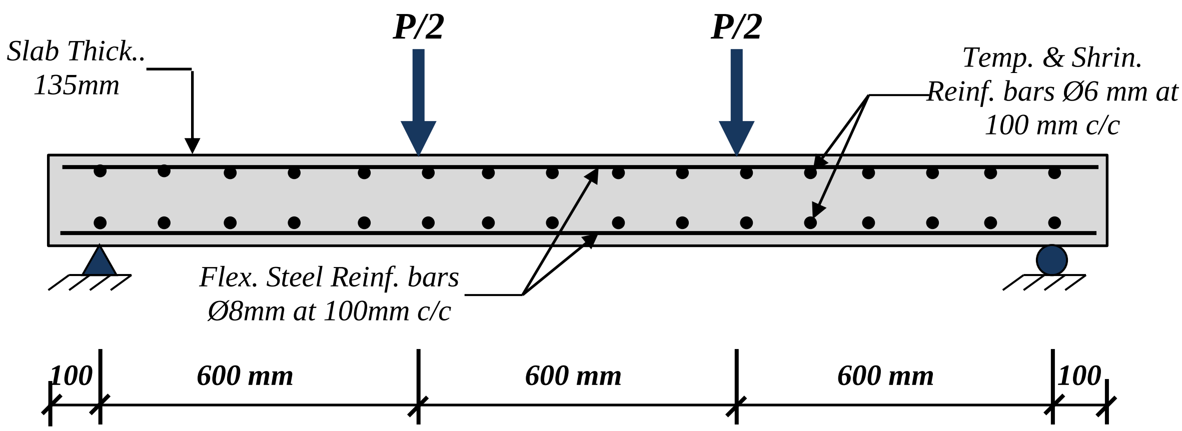
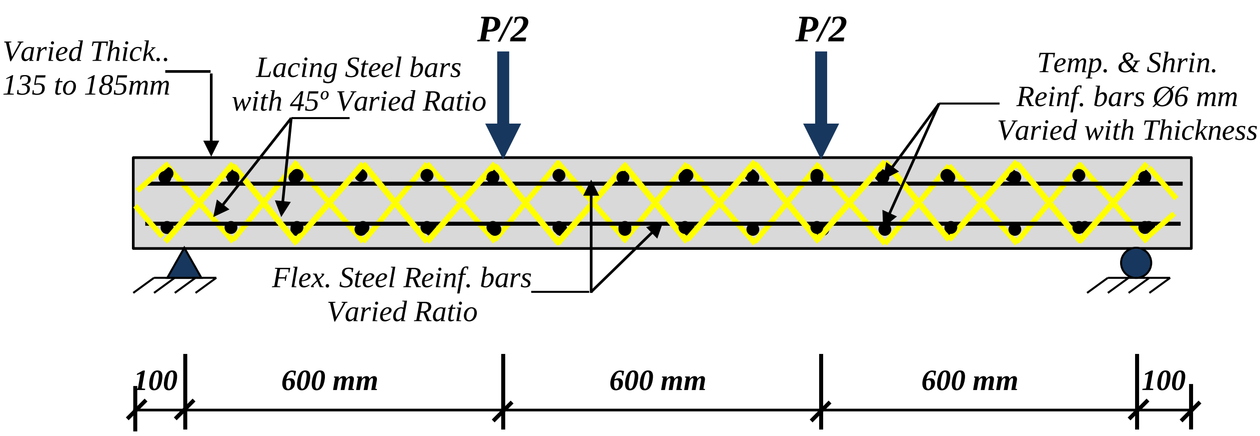


Figure 1. Typical laced reinforced concrete structural element.



a. Longitudinal section in slab without lacing reinforcement.



b. Longitudinal section in slab with lacing reinforcement.

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

a. Testing Machine.

b. Data Logger.

c. LVDTs Arrangement.

Figure 3. Photographs of specimen and instruments setup.

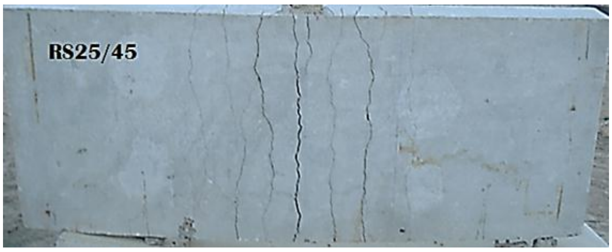
Figure 4. Cracks pattern at the tension face of the specimen SS45/0 after failure.

a. specimen RS45/0.

b. specimen RS45/25.

c. specimen RS45/45.

d. specimen RS45/65.



e. specimen RS25/45.

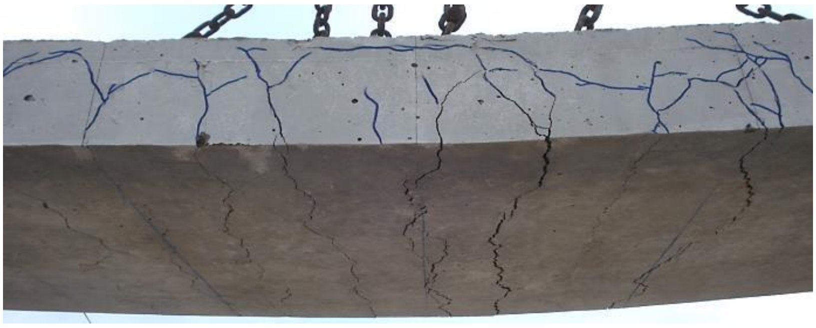
f. specimen RS65/45.

g. specimen RM45/25.

h. specimen RL45/25.

Figure 5. Cracks patterns at the tension face of the specimens tested under repeated load after failure.

a. specimen without lacing reinforcement.



b. specimen with lacing reinforcement.

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

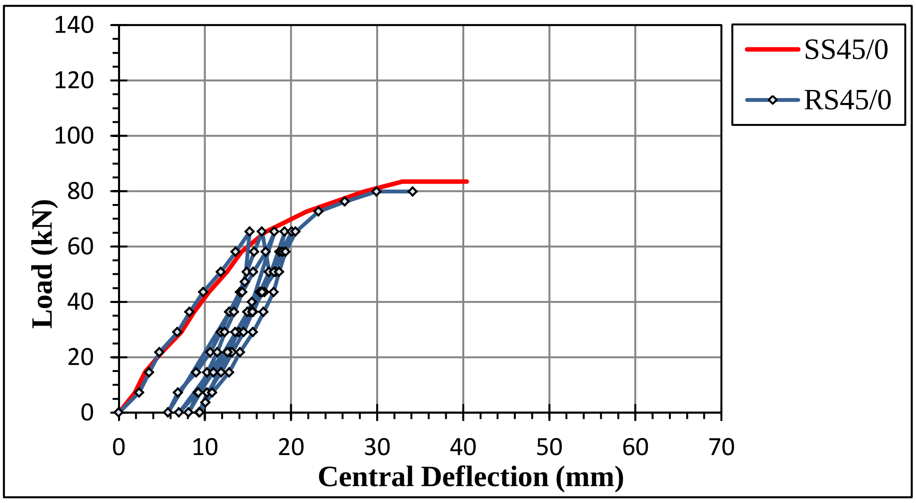


Figure 7. Load-central deflection behavior for the specimens without lacing reinforcement.

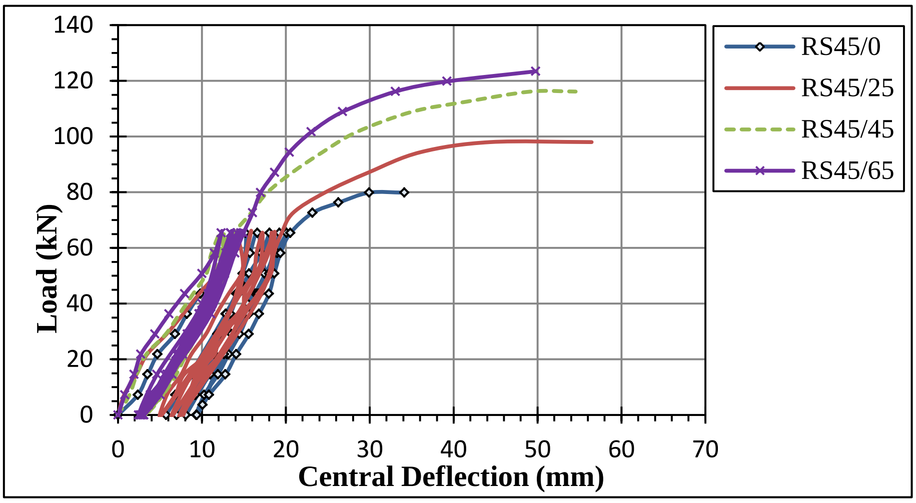


Figure 8. Influence of the lacing steel ratio on load-central deflection behavior for group (I).

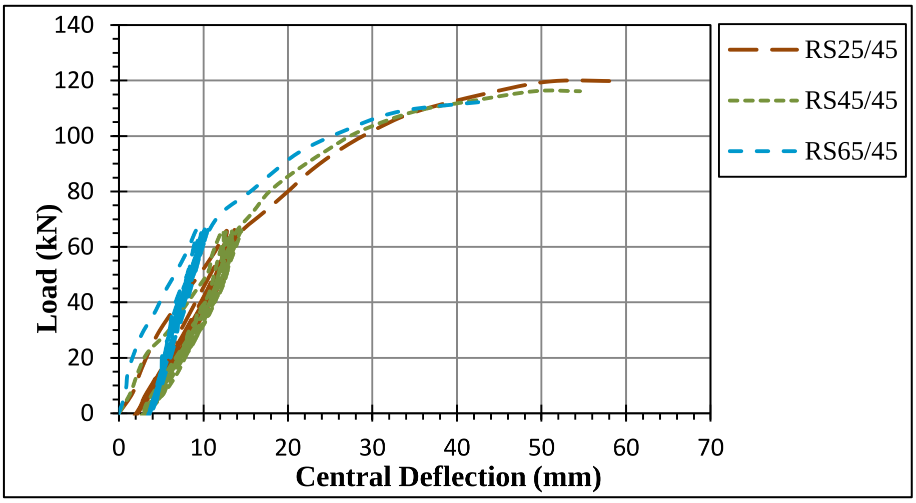


Figure 9. Influence of the flexural steel ratio on load-central deflection behavior for group (II).

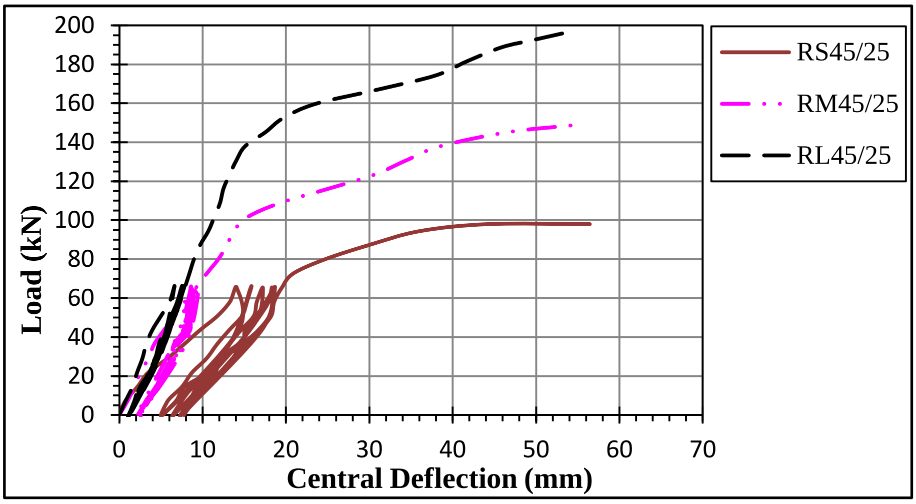


Figure 10. Influence of the L/d ratio on load-central deflection behavior for group (III).

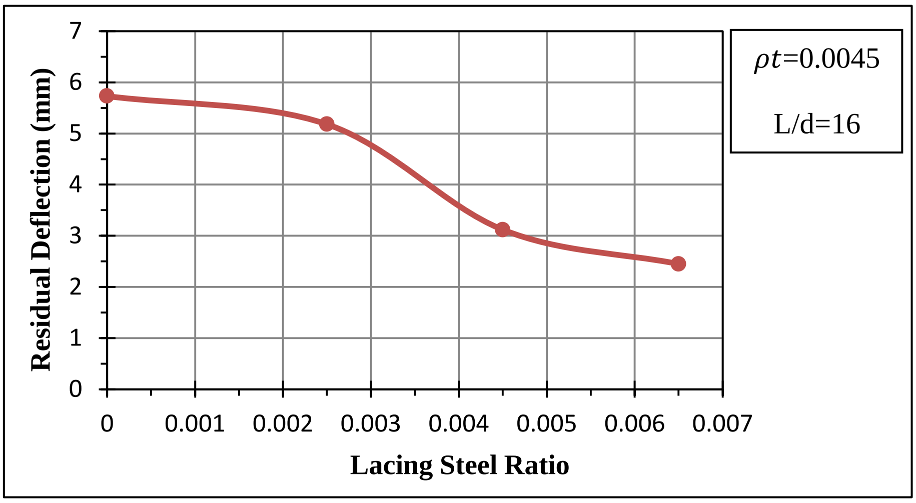


Figure 11. Influence of the lacing steel ratio on the central Residual deflection of group (I).

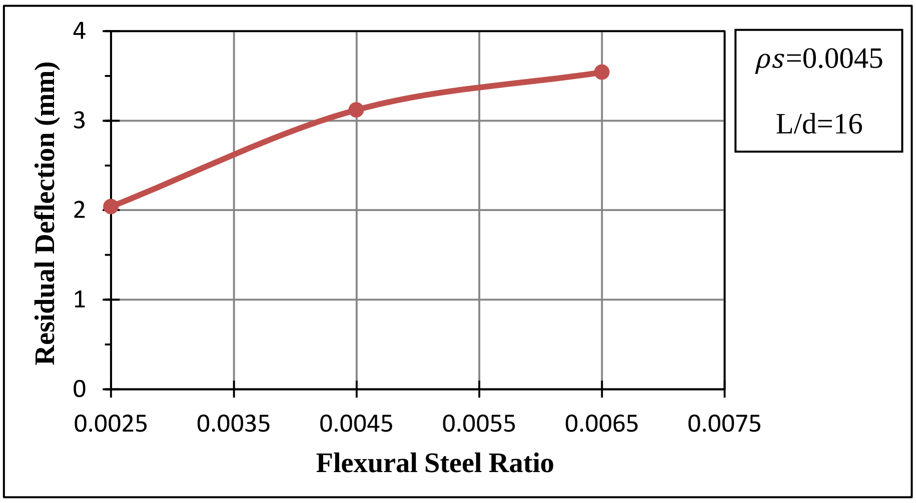


Figure 12. Influence of the Flexural steel ratio on the central Residual deflection of group (II).

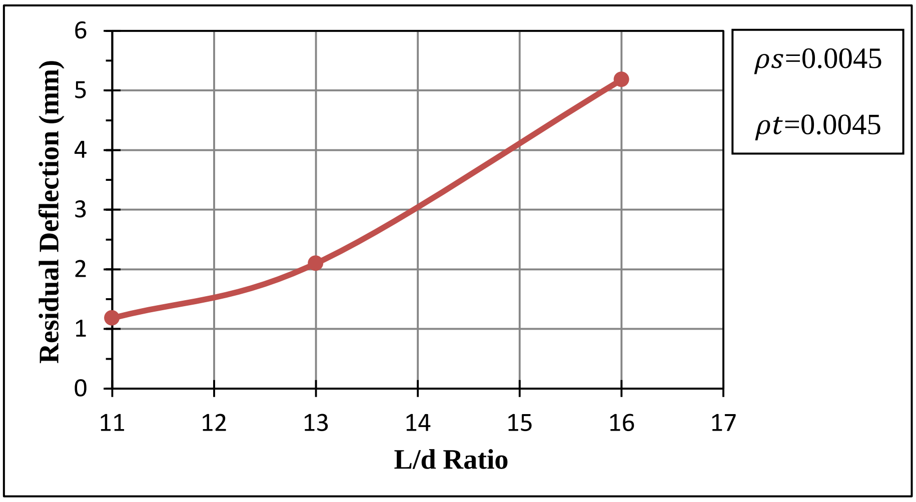
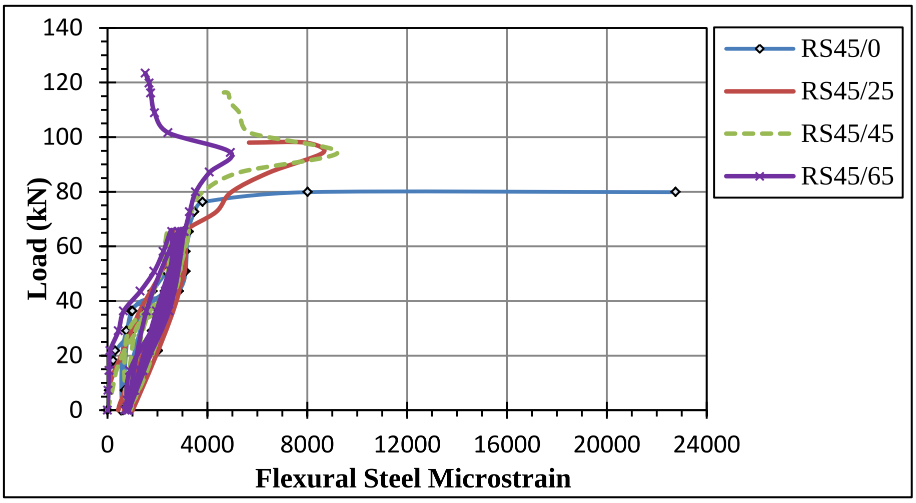
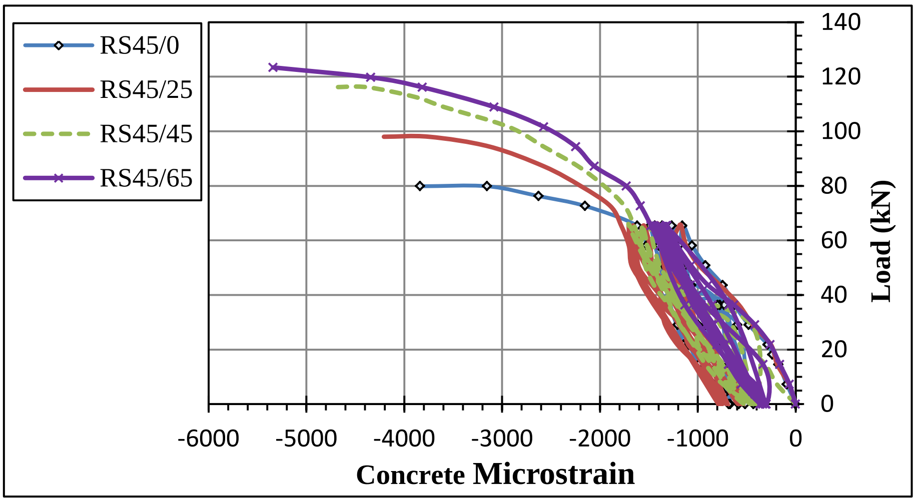


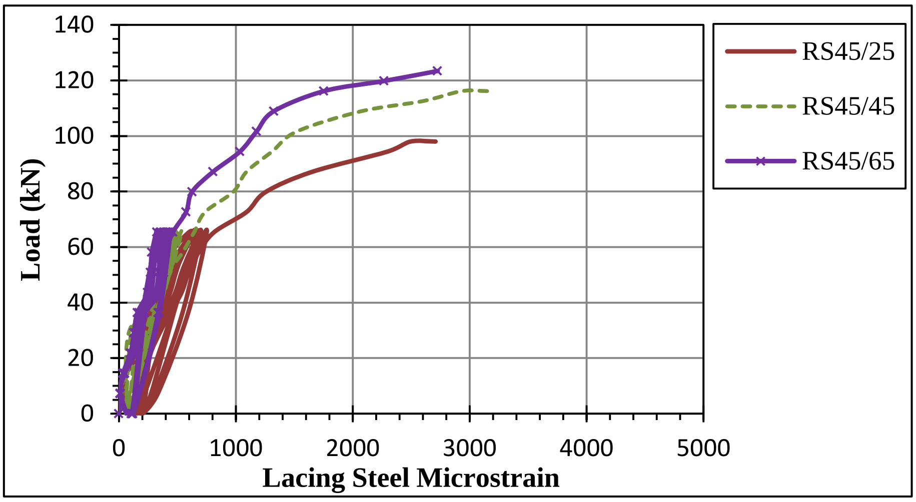
Figure 13. Influence of the L/d ratio on the central Residual deflection of group (III).



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

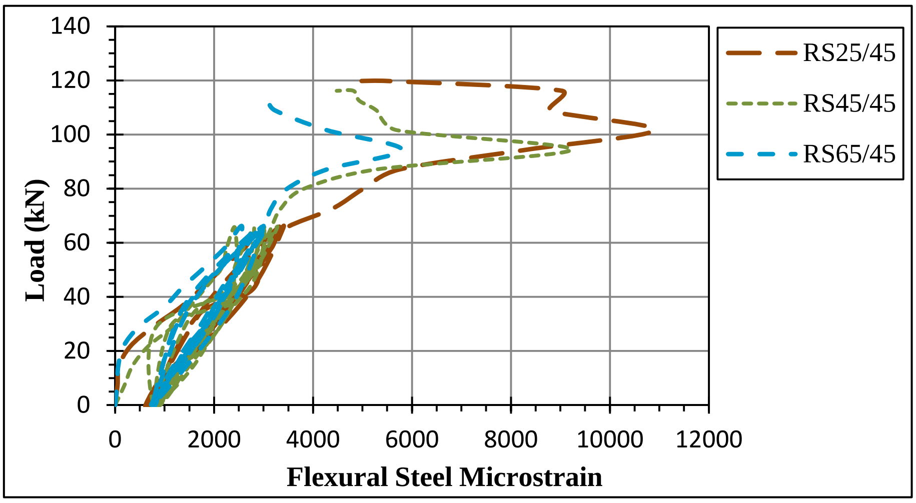


b. Load–strain curves at the top surface of concrete.

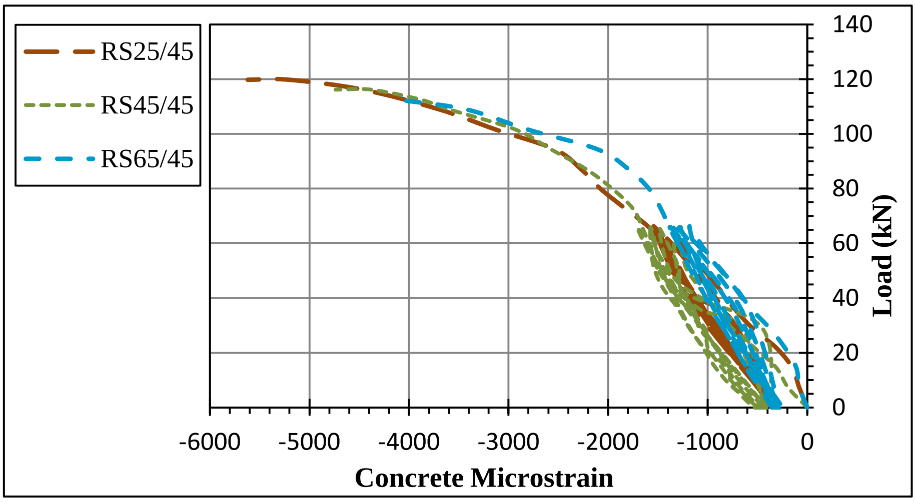


c. Load–strain curves at the lacing steel reinforcement.

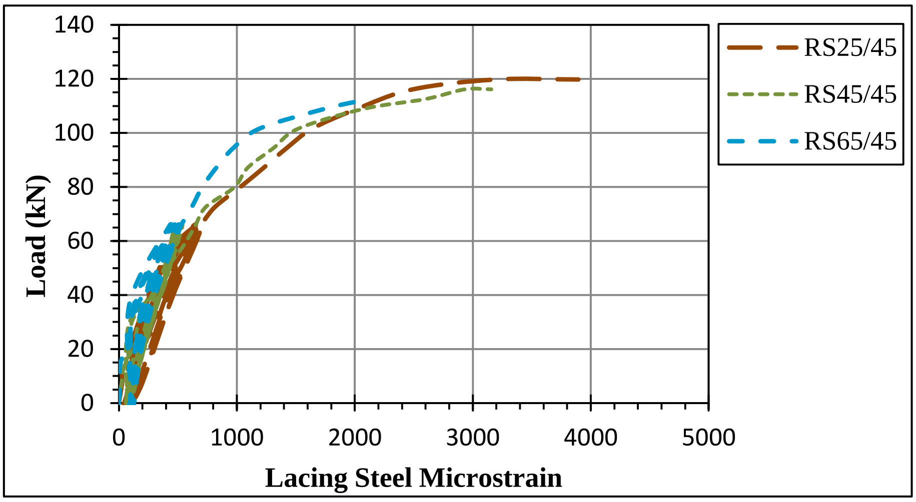
Figure 14. Influence of the lacing steel ratio on load–strain curves at mid-span for group (I).



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

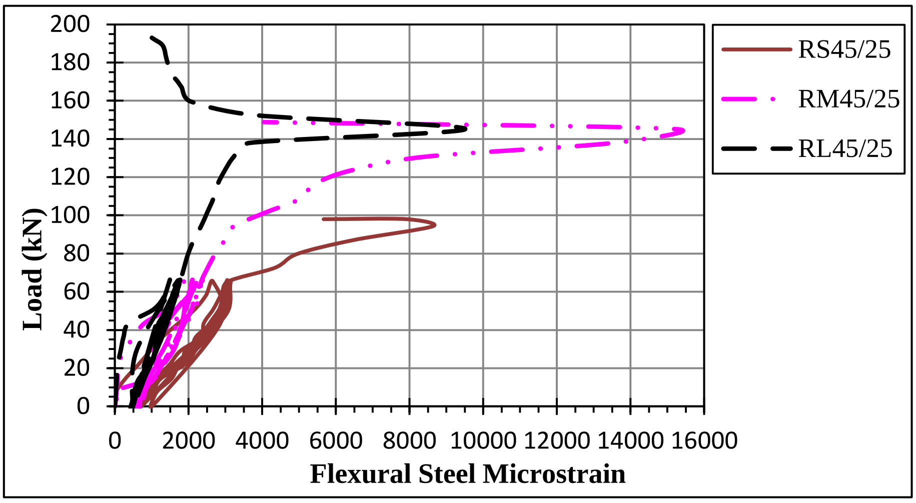


b. Load–strain curves at the top surface of concrete.

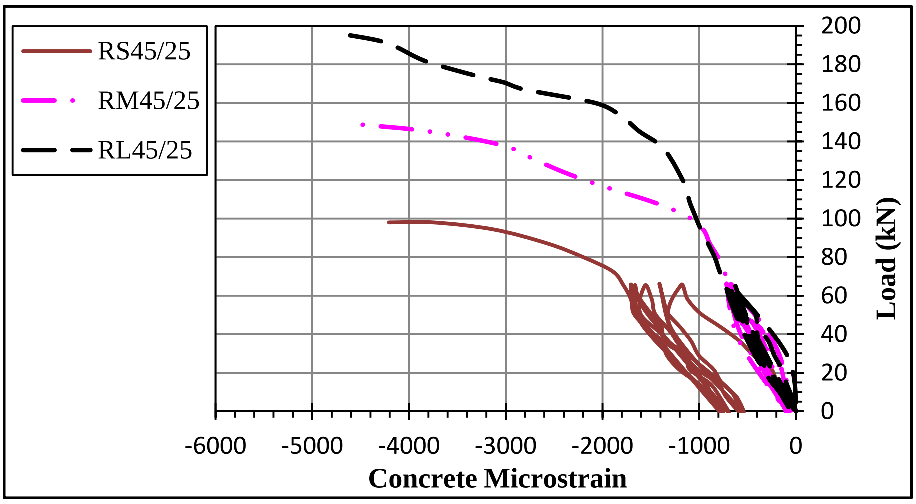


c. Load–strain curves at the lacing steel reinforcement.

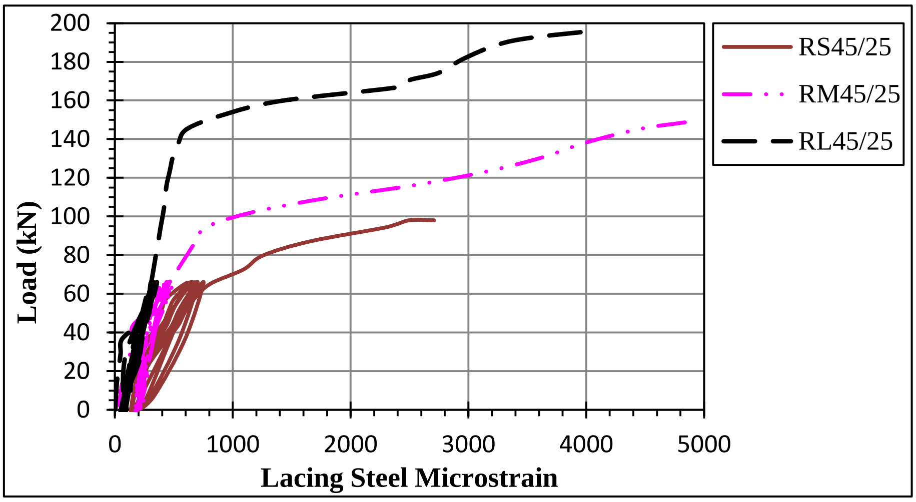
Figure 15. Influence of the flexural steel ratio on load–strain curves at mid-span for group (II).



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