Volume 3, Number 1 (March 2007) p. 93-120 ISSN 1809-1121
Revista IBRACON de Estruturas
IBRACON Structural Journal

Experimental Analysis of Precast Slabs with Lattice Trusses Strengthened by Concrete Overlay

Análise Experimental de Lajes Treliçadas Reforçadas pela Face Superior

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Abstract

This work discusses the results of an experimental study on the behavior of precast slabs strips, using lattice truss reinforcement, strengthened by concrete overlay, with the same mechanical properties of the substrate. Twelve precast slabs strips, divided in three series, were tested. Specimens were 215 cm long and 100 cm wide and the lattice truss was 8 cm deep for the slabs of the first and third series and 12 cm deep for the second series. The slabs, before receiving the new concrete layer, were tested until a pre-determined load. Results showed that this strengthening method was efficient, leading to an ultimate load increase ranging from 38% to 149%, because of the greater effective depth. Monolithic and reinforced slabs with the same properties failed with similar loads, and this revealed that pre-cracking in reinforced slabs did not alter their performance at the ultimate limit state.

Keywords: precast slab, reinforcement, structural analysis, lattice truss.

Resumo

Este trabalho apresenta os resultados de um estudo experimental para a verificação do comportamento de faixas de lajes treliçadas reforçadas à flexão pelo aumento da seção de concreto, de mesmas propriedades mecânicas do concreto do substrato, na face superior. Foram ensaiadas doze lajes de 100 cm x 215 cm, divididas em três séries de ensaio, sendo as 1ª e 3ª séries compostas por peças com vigotas treliçadas de 8 cm de altura e a segunda com vigotas de 12 cm. As lajes reforçadas, antes da execução do reforço, foram pré-carregadas. Os resultados mostraram que este método de reforço foi eficiente, aumentando a capacidade de carga das peças reforçadas, de 38% a 149%, em relação às lajes de referência de cada série, em função do acréscimo do braço de alavanca e, conseqüentemente, do momento resistente da peça. Lajes monolíticas e reforçadas de mesmas características romperam com carregamentos semelhantes, mostrando que a pré-fissuração das lajes reforçadas não alterou seu desempenho no estado limite último.

Palavras-chave: pré-moldados, reforço, análise estrutural, laje treliçada.

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1 Introduction

A modern trend in Structural Engineering is the use of slabs with wide spans. A solution that has been widely adopted is the use of pre-fabricated lattice truss slabs which are capable of overcoming wide spans with reduced structure weight. In such slabs, part of the concrete is replaced by a filling material, whereas in cast-in-place concrete slabs overcoming large spans involves a considerable increase in thickness and, therefore, in weight. On the other hand, easiness in execution allows for several small industries to enter the market, many of which are informal and lack the adequate technical knowledge required. Consequently, many problems often arise regarding the safety of such slabs, due especially to the insufficient reinforcement ratio, use of inadequate concrete, inadequate cross sectional effective depth, and incorrect assembly. As a result, the following pathologies may occur: excessive deflection and cracking, reinforcement corrosion, among others.
Thus, the study of structure repair, recovery, and strengthening has become extremely important in construction engineering. Several strengthening techniques can be found in the literature and it is up to the engineer in charge of intervention to analyze the causes of pathologies and choose the best technical and economical option.
The general objective of this study is to verify the efficiency of flexural strengthening of unidirectional pre-fabricated lattice truss slab strips. The slab strengthening was done by the addition of a concrete overlay on the slabs upper surface.
In an attempt to reduce construction costs and time of execution, the appearance of pathologies has greatly increased. These are especially connected with the use of low-quality materials and problems in execution, design and serviceability, which demand intervention in the structure. Therefore, nowadays, studies on strengthening and recovery of structures have acquired a considerable importance in technical and scientific fields because these researches offer adequate guidance for each case.

Figure 1 – Concrete compressive strength curve

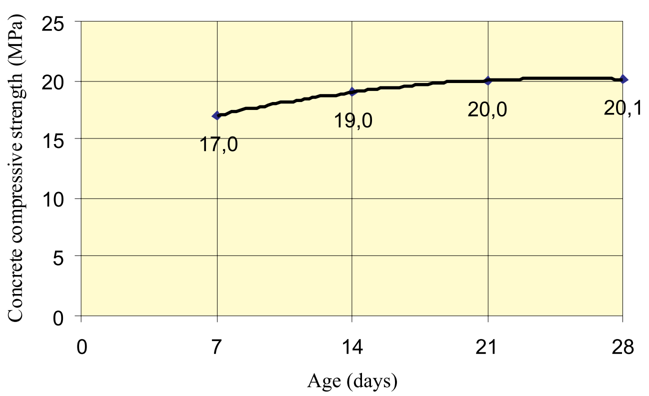


Table 1 – Mechanical properties of concrete at testing day

Series	Slab	Age (days)	f_c (MPa)
1st	L1-80	37	20,1
	L2-80	40	20,1
	L3-80	43	20,1
	L4-80	19	18,0
	L5-80	21	18,1
	L2/L2R-80*	26	19,2
	L3/L3R-80*	28	19,7
2nd	L1-120	39	20,1
	L2-120	42	20,1
	L3-120	44	20,1
	L4-120	20	18,0
	L5-120	23	18,6
	L2/L2R-120*	27	19,5
	L3/L3R-120*	29	19,7
3rd	L6-80	14	17,0
	L7-80	16	17,3
	L7/L7R-80*	14	19,0

*Value of concrete strength refers only the concrete overlay.

A questionnaire was distributed out among lattice truss slab users in the state of Goiás which included the stages of design, production, and slab execution. Results show that 63,6% of structural designers consider excessive deflection as the main problem affecting pre-fabricated lattice truss slabs [6]. In some cases such deflection may require slab strengthening.
When strengthening of lattice truss slabs using concrete overlay occurs, there is a time gain and execution is easier because all that is necessary is the correct treatment of the old concrete surface and substrate cleaning and saturation before the subsequent placing of the new concrete layer.

2 Materials and Experimental Program

2.1 Materials

To place slab concrete, including the strengthening overlay, the present study used ready mixed concrete with a 28-day compressive strength of 20 MPa [1]. Two cylindrical test specimens measuring 150mm x 300mm were cast from this concrete at various ages to determine the compressive strength vs. time curve, as is shown in Figure 1. At testing day, this curve was used to obtain values of concrete compressive strength shown in Table 1.
The values of the secant modulus of elasticity at 0,40 of compressive strength [2] and tensile strength of concrete [3] were only obtained at 28 days. Average values of ten-

Table 2 – Mechanical properties of steel

ϕ (mm)	Nº of specimens	f_y (MPa)	ε_y (%)	f_u (MPa)	E_s (GPa)
4,2	2	605,0	0,51	720,0	193,8
5,0	2	646,9	0,50	722,8	215,6
6,0	2	600,0	0,44	547,0	247,9
8,0	2	599,5	0,30	707,2	199,8

f_y – steel yield strength ε_y – strain at yielding f_u – rupture strength E_s – elastic modulus of elasticity

sile strength and secant modulus of elasticity of concrete were 2,4 MPa and 21,5 GPa, respectively.

Mechanical properties of the steel were obtained by testing a sample of two specimens for each bar diameter used in slabs [4]. Test specimens were extracted from the original steel roll at the lattice truss factory. Bar diameters used were 8,0 mm (additional reinforcement), 6,0 mm (top chord wire), 5,0 mm (bottom chord wires of the second series), and 4,2 mm (bottom chord wires of slabs in the first and third series, and sinusoid). Results are shown in Table 2.

2.2 Experimental Program

For the experimental analysis of the strengthening of prefabricated lattice truss slabs with concrete overlay, three series of 1,0 m wide and 2,15 m long slab strips were tested and their cross section is shown in Figure 2. The variables under analysis were: truss height, thickness of slab flange and overlay, reinforcement ratio, and application of preloading.

The first series consisted of five slabs with 80 mm high trusses, the second series had five slabs with trusses of 120 mm, and the third series had two slabs with 80 mm high trusses, the same height as in the first series. However, the last series' bottom longitudinal steel ratio was considerably smaller than that of the slabs in the first series because no additional reinforcement was placed on the concrete base of the lattice trusses. There were three monolithic concrete slabs and two strengthened slabs in each of the first two series, and one reference slab and one strengthened slab in the third series.

Slab nomenclature was based on the height of the electro welded steel truss (h_t). Therefore, monolithic slabs were referred to, in the first series, as Ln-80 (n varying from 1 to 5) and the two strengthened slabs were referred to as L2/L2R-80 and L3/L3R-80. These two slabs resulted from the strengthening of L2-80 and L3-80 slabs which received a new concrete overlay of 3 cm and 6 cm, respectively. In the second series, monolithic slabs were known as Ln-120 (n varying from 1 to 5) because trusses had 120 mm in height, whereas strengthened slabs were called L2/L2R-120 and L3/L3R-120; these slabs were L2-120 and L3-120 with a concrete overlay of 3 cm and 6 cm, respectively. The third series, whose trusses had 80 mm in height, consisted of slabs L6-80 and L7-80; the latter became known as L7/L7R-80 after receiving a 3 cm strengthening overlay. The main properties of the tested slabs are shown in Table 3.

Post-strengthened slabs – initially known as original reinforced slabs – were loaded up to a pre-defined load based

Figure 2 – Strengthened slab cross section – units: cm

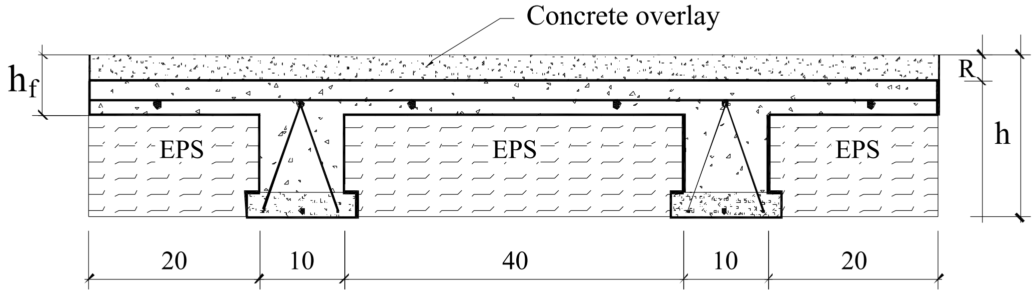


Table 3 – Main properties of tested slabs

Series	Slab	h_t (mm)	h_f (mm)	h (mm)	R (mm)	ρ(%)	Slab type
1st	L1-80	80	40	120	-	0,519	Reference
	L2-80		40	120	-	0,519	Original
	L3-80		40	120	-	0,519	Original
	L4-80		70	150	-	0,338	Strengthened Monolithic
	L5-80		100	180	-	0,251	Strengthened Monolithic
	L2/L2R-80		70	150	30	0,338	Strengthened
	L3/L3R-80		100	180	60	0,251	Strengthened
2nd	L1-120	120	40	160	-	0,489	Reference
	L2-120		40	160	-	0,489	Original
	L3-120		40	160	-	0,489	Original
	L4-120		70	190	-	0,333	Strengthened Monolithic
	L5-120		100	220	-	0,252	Strengthened Monolithic
	L2/L2R-120		70	190	30	0,333	Strengthened
	L3/L3R-120		100	220	60	0,252	Strengthened
3rd	L6-80	80	40	120	-	0,341	Reference
	L7-80		40	120	-	0,341	Original
	L7/L7R-80		70	150	30	0,222	Strengthened

h_t – truss height h_f – depth of concrete slab flange h – total slab depth R – depth of concrete overlay * These are nominal dimensions

on the strain of the main reinforcement (start of yielding) or on midspan deflection (equal to $\ell_0/250$ in which ℓ_0 is span length), and were then unloaded and strengthened for a subsequent test until failure.
The strengthening material used consisted of concrete of mechanical properties (tensile strength, compression resistance and modulus of elasticity) similar to those of the concrete of original slabs. The preparation of the substrate was done by removing the superficial layer of slab concrete with hammer and chisel with consequent substrate cleaning and saturation before the subsequent placing of the new concrete layer.
Tests were carried out through the application of third-point concentrated loads so the analyzed region (central section) would be under pure flexure. The test setup used is shown in Figure 3.
Reinforcement used in the slabs was made up of the electro welded trusses, additional reinforcement and distribution reinforcement. In slabs of the first and third series, trusses of 80 mm in height were used, whereas trusses of 120 mm in height were used for slabs in the second series. An additional reinforcement (1Φ8,0 mm per lattice truss) was placed on the slabs of the first two series in the same position as the bottom chord wires of electro welded trusses. Distribution reinforcements were placed on slabs in both directions and in the same position (distance of the slab lower surface) as the top chord wires of trusses. Larger distribution reinforcement (3 Φ 5,0 mm) was placed in the area of load application in order to avoid localized failure due to concrete crushing in that region and to provide a more effective load distribution along the slab's width. Slab reinforcement details are shown in Figure 4.
Deflections were measured by digital deflectometers with a precision of 0,01 mm and a 12,7 mm stroke. Eleven deflectometers were placed on each slab, two of which measured horizontal displacement and the remaining nine measured vertical deflections. Deflectometer position is shown in Figure 5.
Electric strain gauges were attached to slab reinforcement in both of the specimen's joists. Both truss reinforcement (top and bottom chord wires and sinusoid) and additional reinforcement were monitored at the central section and at the section of load application.

Figure 3 – Test setup Lateral view – units: cm

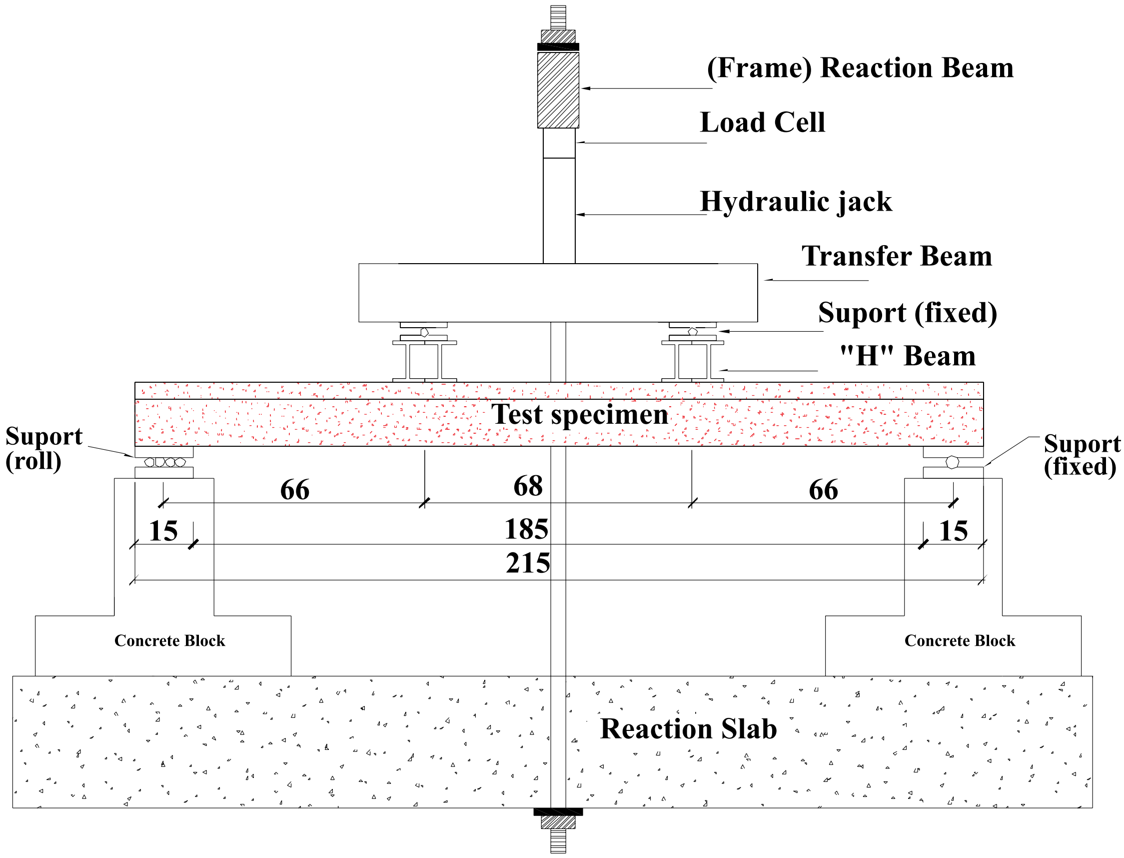
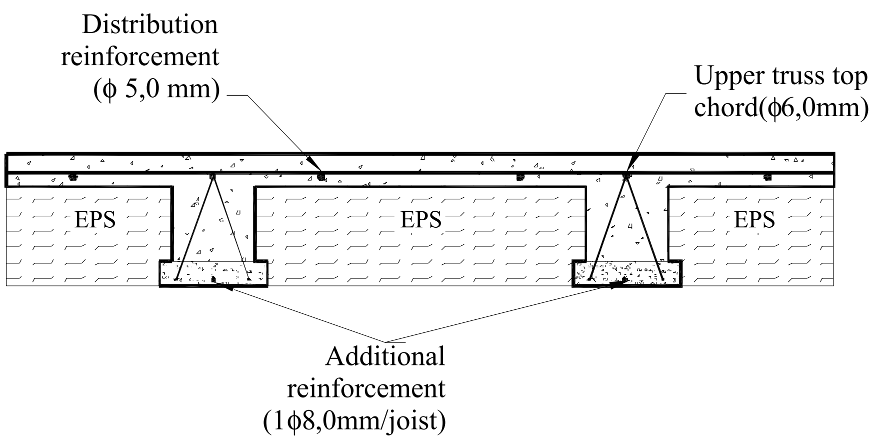


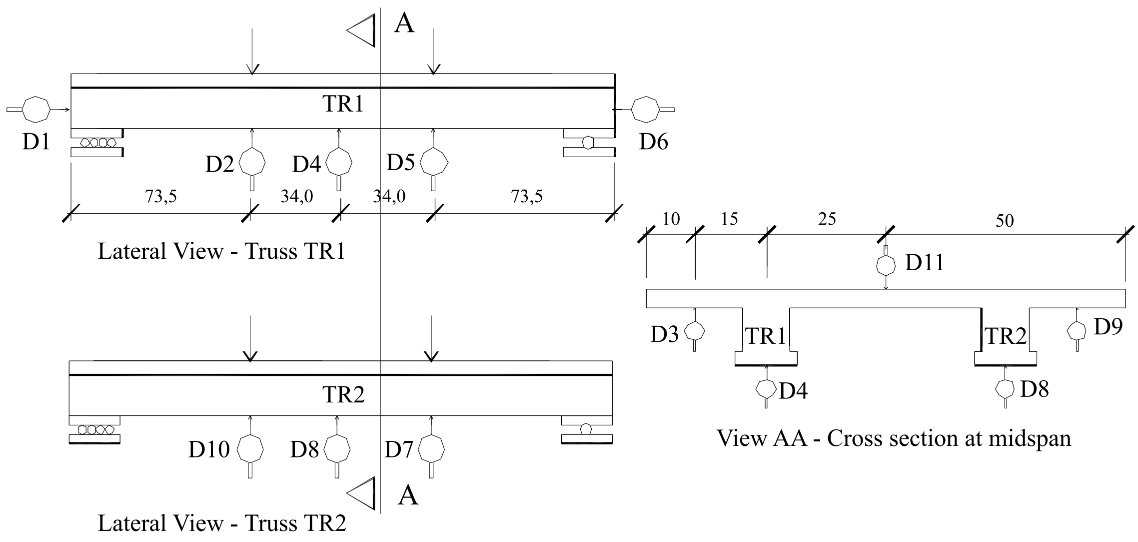
Figure 4 – Reinforcement details



Concrete strains were measured by electric strain gauges that were attached to the upper surface at slabs' central section, in the direction of the axis of the two lattice trusses (see Figure 7).

Four procedures of slab preparation were adopted with the aim of assuring perfect bond between old concrete (substrate) and strengthening material (concrete overlay): removing the superficial layer of old slab concrete with hammer and chisel, cleaning, saturation of substrate, and application of new concrete. Such procedures were chosen so that the strengthened elements would act like monolithic slabs and thus there would be a complete force transfer from one material to the other in the horizontal joint region.

Figure 5 – Deflectometer position – units: cm



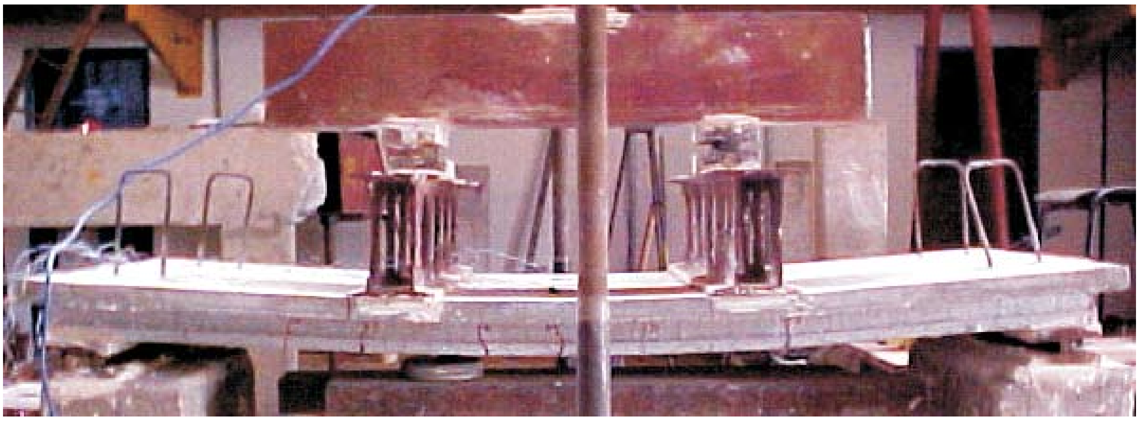
3 Results and Discussion

3.1 Failure Load and Mode of Failure

All slabs failed by flexure with yielding and ductile failure of the lower tensile reinforcement (Figure 6), without the appearance of horizontal cracks in the joint between the substrate and the strengthening material of the strengthened slabs. For slabs L1-80 and L4-80 (first series), L1-120 and L4-120 slabs (second series), and L6-80 slab (third series), in addition to reinforcement failure, high values of strain obtained from strain gauges attached to the concrete were also observed, as shown in Figure 7.

Table 4 shows the slab experimental failure loads compared to load values of the reference slab of each series. The strengthened slabs in the three test series (L2/L2R-80, L3/L3R-80, L2/L2R-120, L3/L3R-120, and L7/L7R-80) had an increase in the average effective depth of 36% to 97%, which generated an increase of flexural capacity, and consequently of load capacity, of 38% to 149%, despite a reduction in the reinforcement ratio of up to 54%.
Comparing strengthened slabs with their monolithic equivalents, failure loads were quite similar, and the maximum difference between them was 7,8%, probably due to construction imperfections. This indicates that the fact that strengthened slabs that were cracked due to pre-loading

Figure 6 – Typical slab at failure



[1]S_r – *radial spacing*
[2]A_{sv}*/cam – area of shear reinforcement per layer*

Figure 7 – Load x concrete strain

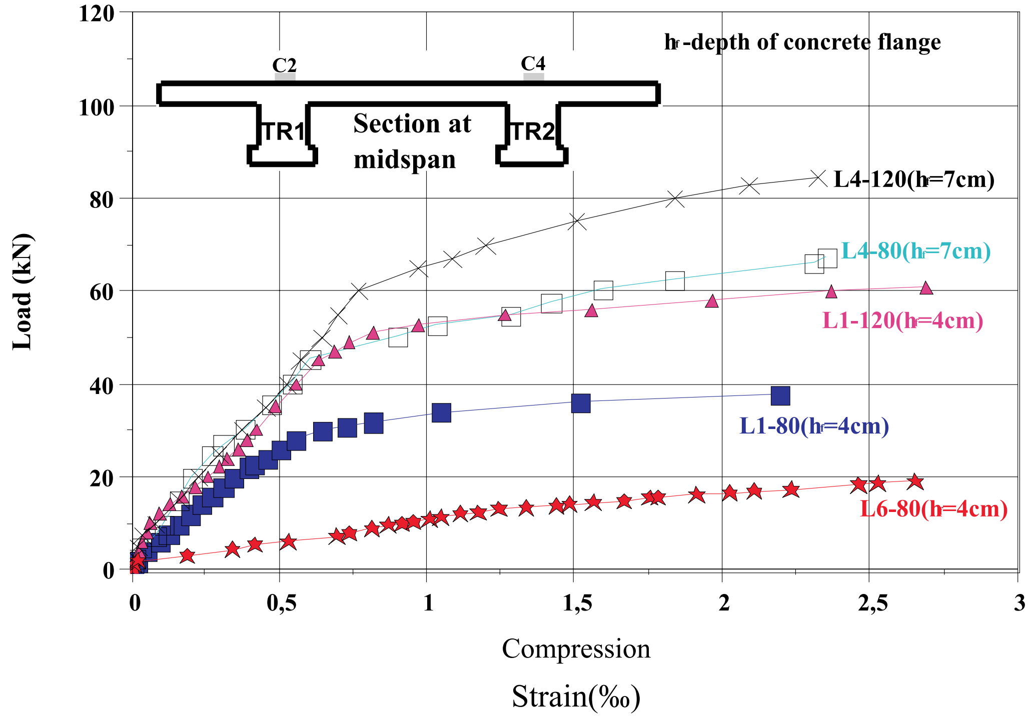


Table 4 – Comparisons of slab properties and slab failure loads

Slab	$d_{ave.}$ (cm)	$\rho_{adot.}$ (%)	$d_{ave.Li}$ / $d_{ave.L1}$ (col. 1)	$\rho_{adot.Li}$ / $\rho_{adot.L1}$	$P_{u.Exp}$ (kN)	$P_{u.Exp.Li}$ / $P_{u.Exp.L1}$ (col. 2)	Col.(2) / Col.(1)
L1-80	6,9	0,510	1,00	1,00	39,0	1,00	1,00
L4-80	10,4	0,316	1,51	0,62	70,0	1,79	1,18
L5-80	13,3	0,240	1,93	0,47	90,0	2,31	1,20
L2/L2R-80	10,8	0,303	1,57	0,59	74,0	1,90	1,21
L3/L3R-80	13,6	0,235	1,97	0,46	97,0	2,49	1,26
L1-120	9,4	0,481	1,00	1,00	63,0	1,00	1,00
L4-120	12,8	0,317	1,36	0,66	87,0	1,38	1,01
L5-120	16,0	0,250	1,70	0,52	110,0	1,74	1,02
L2/L2R-120	13,3	0,298	1,41	0,62	87,0	1,38	0,98
L3/L3R-120	16,5	0,241	1,75	0,50	113,0	1,79	1,02
L6-80	4,8	0,341	1,00	1,00	19,0	1,00	1,00
L7/L7R-80	7,8	0,222	1,62	0,65	36,0	1,89	1,17

$d_{ave.}$ – average effective depth $P_{u.Exp.}$ – Ultimate load recorded during testing
ρ_{adot} – reinforcement ratio calculated at midspan

Table 5 – Experimental and theoretical slab loads

Slab	$d_{ave.}$ (cm)	$d_{ave.Li}/d_{ave.L1}$	$P_{u.Exp.}$ (kN)	$P_{u.Theo.}$ (kN)	$P_{y.Theo.}$ (kN)	$P_{y,nom}$ (kN)	$P_{u.Exp}/P_{u.Theo.}$
L1-80	6,9	1,00	39,0	37,6	31,2	26,8	1,03
L4-80	10,4	1,51	70,0	58,7	49,8	41,6	1,19
L5-80	13,3	1,93	90,0	76,9	65,3	54,6	1,17
L2/L2R-80	10,8	1,57	74,0	61,2	51,9	42,2	1,20
L3/L3R-80	13,6	1,97	97,0	78,6	66,9	55,4	1,23
L1-120	9,4	1,00	63,0	57,6	49,8	42,8	1,09
L4-120	12,8	1,36	87,0	78,4	68,0	58,3	1,11
L5-120	16,0	1,70	110,0	95,4	82,9	70,9	1,15
L2/L2R-120	13,3	1,41	87,0	80,4	69,7	59,8	1,08
L3/L3R-120	16,5	1,75	113,0	97,4	84,6	72,4	1,16
L6-80	4,8	1,00	19,0	14,8	12,3	10,3	1,28
L7/L7R-80	7,8	1,62	36,0	26,5	22,5	18,9	1,35

d_{ave} = average effective depth (weighted average)
$P_{u.Exp.}$ = Ultimate load recorded during testing
$P_{u.Theo.}$ = Theoretical ultimate load, calculated using experimental rupture stresses in steel and concrete
$P_{y.Theo.}$ = Theoretical yield load, calculated using experimental steel yield stress
$P_{y,nom}$ = Nominal yield load, considering material safety reduction factors (1,15 for steel and 1,4 for concrete).

Figure 8 – Load x slab vertical deflection

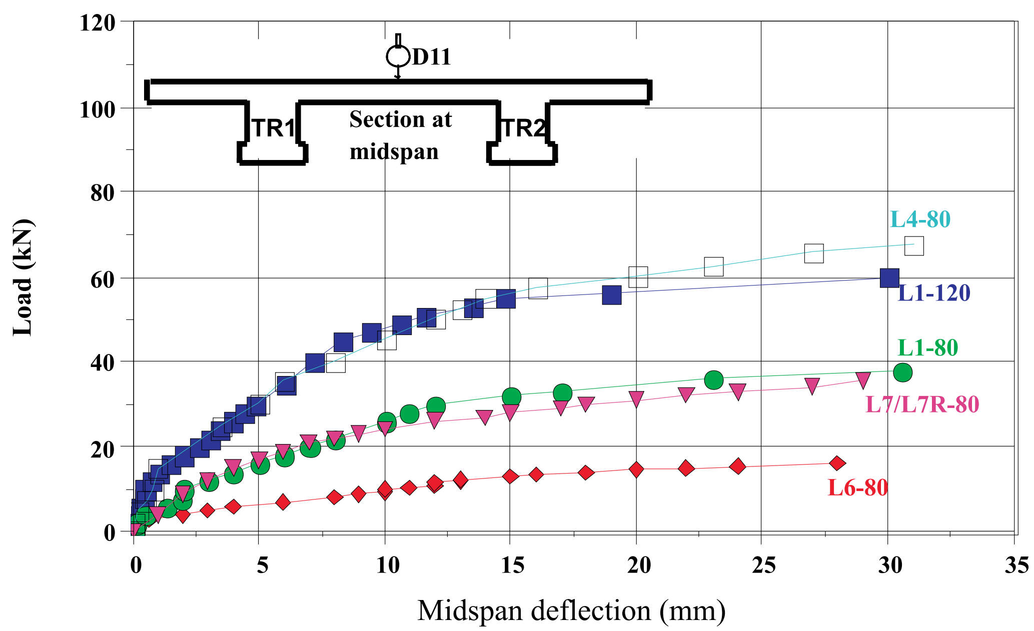
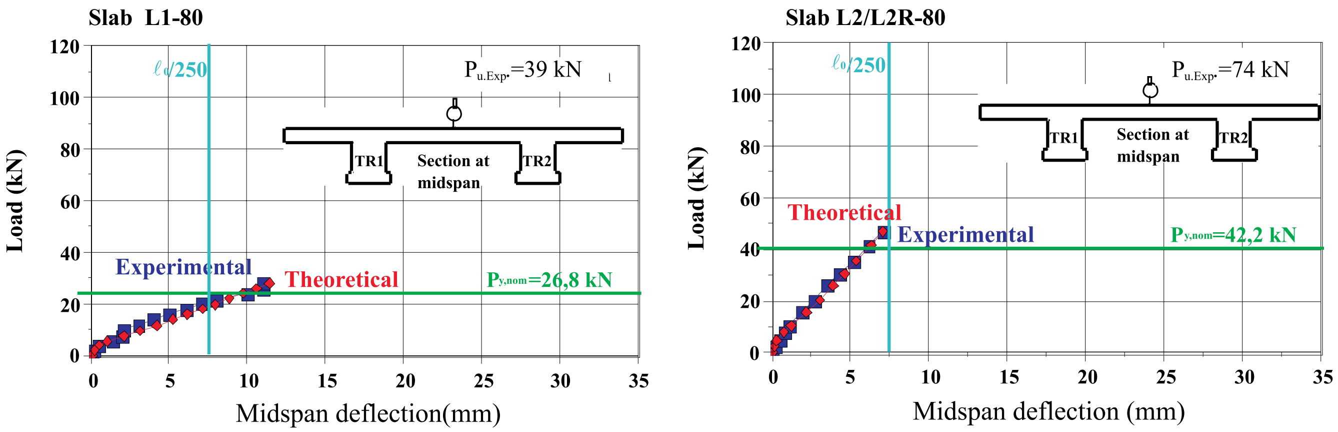


Figure 9 – Load x theoretical and experimental vertical deflection for slabs of the first series



did not alter their behavior at ultimate limit state because there was no loss in the load carrying capacity of slabs.
Table 5 compares experimental loads with those obtained in accordance with calculation criteria of the Brazilian code [5]. Results show that the values of failure load of strengthened slabs obtained experimentally ($P_{u.Exp}$) were from 8% to 35% higher than theoretical values ($P_{u.Teo}$).
The values of failure load of L1-80 and L7/L7R-80 slabs were quite similar, 39 kN and 36 kN, respectively. Results show that the reduction in the reinforcement ratio ($\rho_{adot.}$) of 56% (Table 4: 0,222 and 0,510) was compensated by an increase of 13% in the average effective depth (Tables 4 or 5: 7,8 and 6,9). Such evidence reveals that, in this type of strengthening, an increase in effective depth is more decisive for the gain in load carrying capacity than the variation in the reinforcement ratio.

3.2 Load x Vertical Deflection

The relationship *load x vertical deflection* at midspan is illustrated by curves in Figure 8. This figure shows *load x vertical deflection* curves present the same format for all the slabs and basically had three segments: the first occurs when the concrete of the tensioned side has not yet cracked, characterizing stage I (this did not occur on strengthened slabs because they were already cracked); afterwards there is a change in curve inclination which reveals a loss of rigidity resulting from the start of the cracking process (stage II); and lastly there is the plastic phase (stage III) which reveals a greater increase in the deflection without considerable increments of the imposed load until reaching failure load.
It can be observed that as flexural rigidity of a slab is increased due to the increase of the depth of concrete slab flange, the change in curve inclination is smaller, especially in stage II, and generates smaller displacements for the same load values.
Figures 9 and 10 show that, using the Brazilian code [5], the estimated slab deflection in the first two series was reasonable because the obtained values were very close to experimental values of all the slabs until the nominal yield load ($P_{y,nom.}$). As for

Figure 10 – Load x theoretical and experimental vertical deflection for slabs of the second series

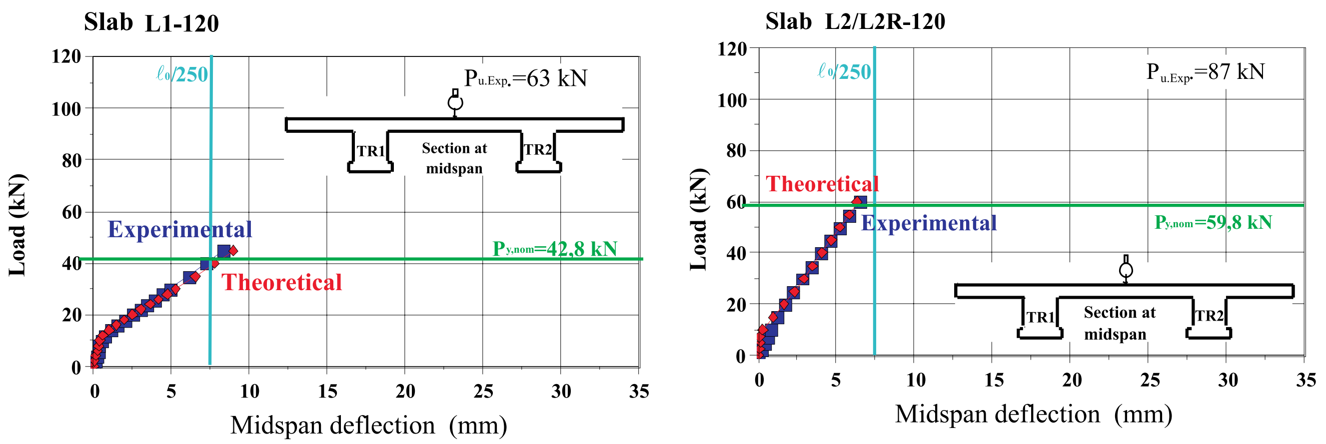
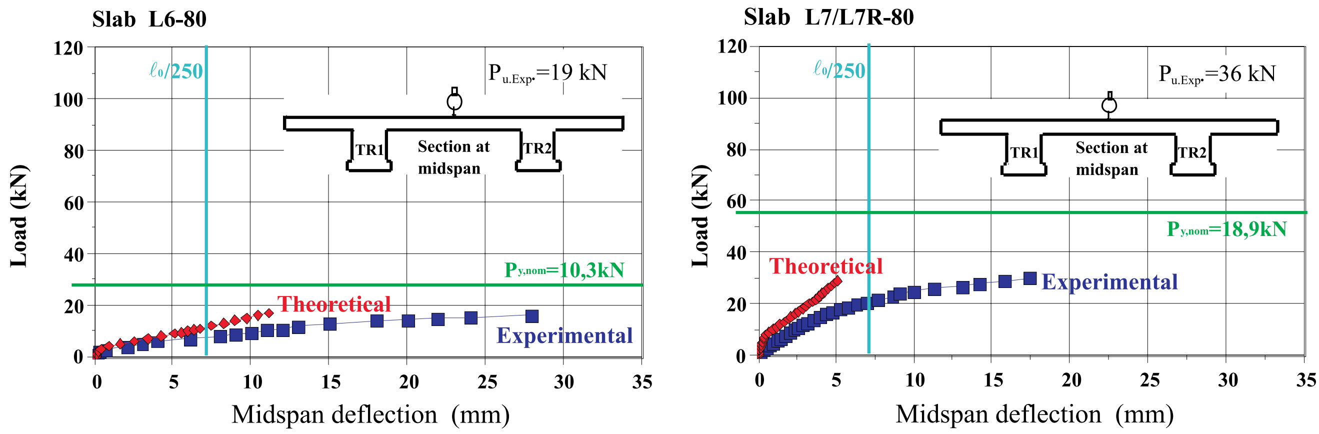


Figure 11 – Load x theoretical and experimental vertical deflection for slabs of the third series



the third-series slabs (see Figure 11), theoretical values were not so close to experimental values and this was unexpected.

3.3 Load x Reinforcement Strain

Figure 12 shows that the lower tensile reinforcement of slabs (additional reinforcement and bottom chord wires of trusses) came close to the excessive plastic deformation of 10‰. The increase of slab rigidity, which was obtained due to the addition of the concrete overlay, caused less reinforcement strain for the same load values.

Figure 13 shows *load x reinforcement strain* curves for the top chord wires of trusses. This figure shows that such reinforcements yielded.

Figure 12 – Load x lower chord truss steel strain (average of E1, E2, E9 e E10)

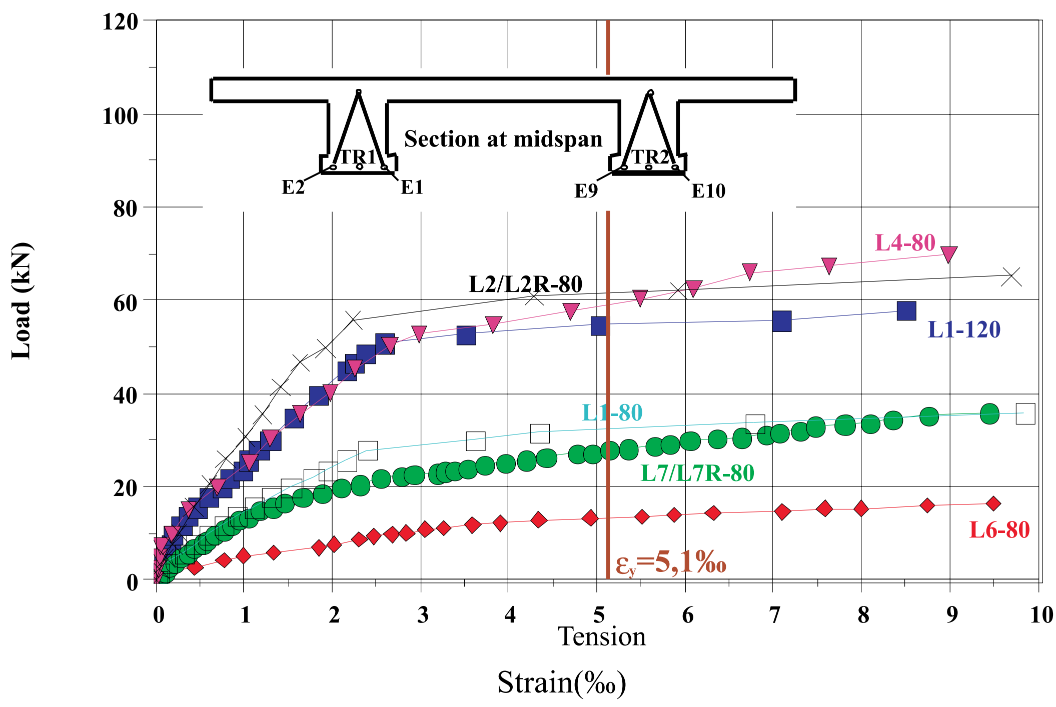


Figure 13 – Load x upper chord truss steel strain in slabs of the first series (average of E4 e E12)

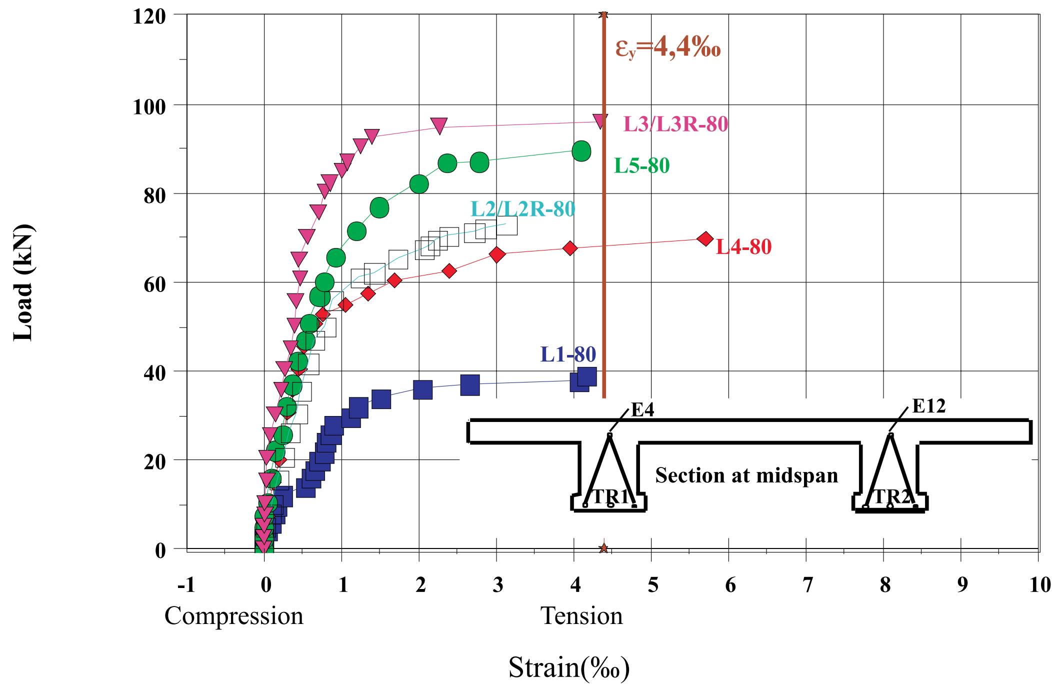


Figure 14 – Typical strain diagram for the slabs

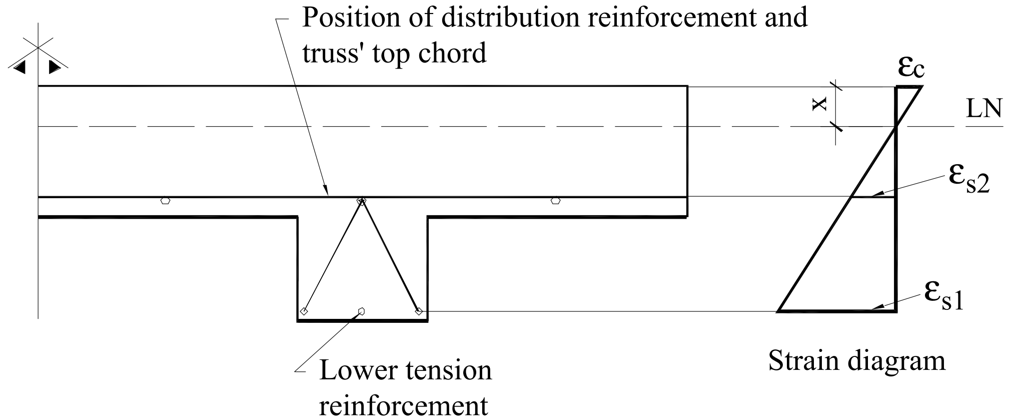


Table 6 shows the position of the reinforcement of the truss' top chord and of the slab's neutral axis for the first and last loading stages in which strain was measured. These values were obtained using the hypothesis that plain sections remain plain after bending, as is shown in Figure 14. Results show that at first loading, prior to concrete cracking (except for strengthened slabs which were already cracked), the neutral axis of eight slabs was already above the truss' top chord reinforcement, so this reinforcement was under tension. This did not occur in slabs L1-80, L1-120, L4-120, and L6-80. In the last loading stage, the neutral axis was positioned closer to the slabs' upper surface.
Results shown in Table 6 confirm that distribution reinforcement and the truss' top chord reinforcement contrib-

uted to the flexure strength of the tested slabs, for such reinforcements were tensioned close to failure and considerably below the position of the neutral axis (x), as shown in Figure 14.
As strengthened slabs were cracked at the start of the second test, the position of the neutral axis (x) showed a smaller deflection from the first to the last loading in contrast with its respective monolithic strengthened slabs, whose neutral axis changed positions considerably. Such a change in the position of the neutral axis can be seen in Figure 15.

3.4 Load x Concrete Strain

Figure 7 shows load-concrete strain relationships (average strain in gauges in C2 and C4 positions) and indicates that as the flange of the concrete slab increases, there is a smaller change in curve inclination after concrete cracks in the tensioned zone. This leads to less concrete compressive strain the same load levels, which is what occurred with *load x vertical deflection* curves. This is due to an increase in slabs' flexural rigidity due to an addition of the concrete overlay.

Table 6 – Neutral axis position and upper chord truss wires position

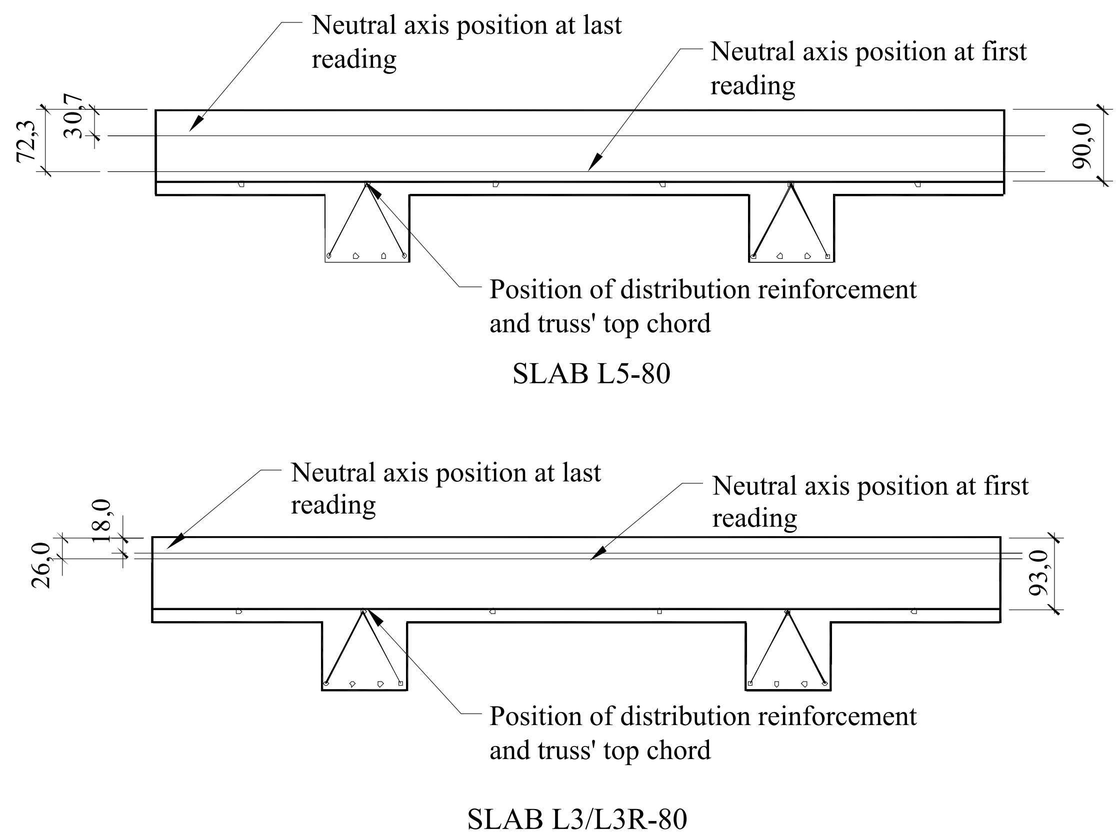
Slab	Upper chord position (cm)	Load (kN)	ε_c (mm/m)	ε_{s1} (mm/m)	x (cm)
L1-80	2,6	2,0	0,02	0,033	4,01
		37,0	1,52	8,233	1,65
L4-80	6,1	2,0	0,01	0,024	4,11
		68,0	2,32	8,989	2,89
L5-80	9,0	2,0	0,01	0,014	7,23
		90,0	1,99	9,044	3,07
L2/L2R-80	6,5	2,0	0,02	0,065	3,42
		70,0	1,72	5,848	3,30
L3/L3R-80	9,3	2,0	0,01	0,057	2,59
		85,0	1,14	9,817	1,80
L1-120	2,6	2,5	0,010	0,030	3,62
		55,0	1,265	8,209	1,93
L4-120	6,0	2,5	0,008	0,011	7,14
		75,0	1,845	8,415	3,14
L5-120	8,5	2,5	0,005	0,008	7,88
		100,0	1,460	8,518	2,99
L2/L2R-120	6,5	2,5	0,020	0,068	3,99
		70,0	1,010	7,020	2,20
L3/L3R-120	9,0	2,5	0,018	0,044	5,83
		105,0	1,490	8,019	3,21
L6-80	2,5	1,0	0,010	0,016	3,97
		16,0	2,030	10,440	1,72
L7/L7R-80	5,5	1,0	0,017	0,053	3,53
		36,0	1,447	9,433	1,93

ε_c – compressed concrete strain (upper surface)
ε_{s1} – strain in highest stress steel (lower chord truss steel)
x – Neutral axis position with respect to upper slab surface
U pper chord position – Position of the truss' upper chord with respect to upper slab surface

4 Conclusions

After analysis of all experimental results, the following conclusions were obtained:
1) Ductile failure was observed in all slabs, without the appearance of horizontal cracks in the joint between the substrate and the concrete overlay. Slabs revealed considerable deflection and strain.
2) Based on the slabs failure mode, in order to obtain effective bond between the substrate and concrete overlay for a good performance of the strengthened slabs, it is enough to remove the superficial layer of the old concrete with hammer and chisel, followed by substrate cleaning and, moments before the new concrete placing, to saturate the old concrete in order to prevent loss of water of the strengthening material.
3) In first-series of slabs, the application of strengthened overlay 3 cm and 6 cm deep increased the ultimate failure load by 90% and 149%, respectively, with respect to the reference slab. In second-series of slabs the increase was 38% and 79% for the same overlay depth, whereas the increase for the third-series slab reinforced a 3 cm overlay totaled 89%.
4) Comparing the experimentally obtained loads with those calculated using with Brazilian codes [5], it was concluded that the effective depth of the total section may be used in the calculation of ultimate loads of strengthened slabs, considering the overlay working monolithically (perfect bond) with of the original slab concrete. This conclusion was possible because experimentally obtained loads were basically identical to those of their respective monolithic slabs and were always higher than calculated loads, even if the rehabilitated slabs were in fact pre-cracked due to pre-loading.
5) When simply supported pre-fabricated lattice truss slabs are calculated, one considers as flexure reinforcement only the reinforcement positioned at the concrete base of the lattice truss (truss' bottom chord wires, additional reinforcement, and longitudinal complementary reinforcement). However, the present study made it possible to verify that the top chord wires of lattice trusses and the distribution reinforcement also contributed to the flexure resistance of slabs.
6) The relationship load x vertical deflection at midspan of the slabs was relatively well estimated using the Brazilian code criteria [5] up to the nominal yield load ($P_{y,nom.}$) in slabs of the first and second series. Some slabs had a deflection higher than $\ell_0/250$ at yield load.

Figure 15 – Neutral axis position at the start and near the final loading stages – units: mm



7) The addition of the concrete overlay caused a considerable reduction of vertical deflections as compared to the reference slab of each series for the load at first yielding or at the deflection of $\ell_o/250$: 76% and 88% in strengthened slabs of the first series, 45% and 61% in slabs of the second series, and 77% in the slab of the third series. This fact proves the efficiency of the strengthening in the reduction of vertical deflections in stage II.
8) In this type of strengthening, the increase of slab effective depth was more important for the gain in load carrying capacity than the variation of the reinforcement ratio, since slabs L1-80 and L7/L7R-80 – which had different average effective depths and reinforcement ratios – behaved similarly both in the ultimate limit state and in the serviceability limit state. In such slabs, a reduction of 56% in the reinforcement ratio was compensated by the increase of only 13% in average effective depth.

5 Acknowledgements

To Capes (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) and to Procad (Programa Nacional de Cooperação Acadêmica) for the financial support.
To the following companies: Carlos Campos Consultoria Limitada; Lajes Santa Inês, Isoeste, Companhia Siderúrgica Belgo-Mineira; Furnas Centrais Elétricas S. A.; IMPERCIA – Produtos Químicos para Construção; Perfinasa – Perfilados, and Ferros Nossa Senhora Aparecida Ltda; Realmix – Concreto e Argamassa, for the supply and testing of various materials.

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