Effect of externally bonded steel plates on the bearing capacity of composite slabs

C.P.C. Bruwer
University of Johannesburg, Johannesburg, South Africa

ABSTRACT: Reinforced concrete structures can be strengthened by externally bonding steel plates to the concrete surface in tension creating a composite structural element. This paper compare the increase in the load bearing resistance of un-strengthened reinforced concrete slabs (control slabs) to composite slabs strengthened by means of externally epoxy bonded steel plates.

Test results of full scale experimental control and composite slabs are presented which are loaded by either a point load at mid span or point loads at third spans mimicking a uniformly distributed load. The following variations in the composite slaps are considered: (1) number of bonded steel plates (2) width of the bonded steel plates (3) thickness of the bonded steel plates.

1 INTRODUCTION

Reinforced concrete structural elements can be strengthened due to construction errors whereby too little reinforcement bars were placed in the concrete, corrosion of the reinforcing bars or due to an increase of the designed load. A method for strengthening a reinforced concrete flexural member is to bond steel plates, as external reinforcement, to the tension face by means of epoxy. The advantages of this bonding technique are the relative simplicity of the application, the speed of construction and the small change in structural weight and size. This paper compare the increase in the load bearing resistance of un-strengthened reinforced concrete slabs (control slabs) to composite slabs strengthened by means of externally epoxy bonded steel plates.

The test results of full scale experimental control and composite slabs are presented which are loaded by either a point load at mid span or point loads at third spans mimicking a uniformly distributed load. The following variations in the composite slaps are considered: (1) number of bonded steel plates (2) width of the bonded steel plates (3) thickness of the bonded steel plates.

2 EXPERIMENTAL PROGRAMME

One way spanning reinforced concrete slabs were constructed for this research study. The size of these slabs are 4 800 mm long, 1000 mm wide and 125 mm thick.

The reinforcement consist of five longitudinal 12 mm diameter high yield reinforcement bars spaced at 200 mm intervals with a total cross sectional area of 565 mm^2, and 12 mm diameter high yield transverse reinforcement bars spaced at 100 mm intervals. The cover to the longitudinal reinforcement bars is 25 mm.

The concrete used for this research study is ready mixed, ordered with a compressive strength (f_{cu}) of 25 MPa. The cement laitance on the concrete surface is removed by means of scabbling to expose the well-bonded large aggregate.

The bonded plates are mild steel, grade 350W, and 4000 mm long. The steel plate surface are dry grit blasted to a white metal finish to obtain a 100–140 µm blast profile.

Pro-Struct 618LV primer and Pro-Struct 617NS non-sag epoxy is used to bond the steel plates to the concrete surface.

The slabs are simply supported at a 4500 mm spacing. The loading onto the slabs are either a third-span line load (TSLL) indicated in figure 1, to mimic a uniformly distributed load, or a mid-span line load (MSLL) indicated in figure 2. Table 1 indicate the number of research specimens constructed, the type of load configuration, the number and size of bolted steel plates and the concrete strength of the individual specimens.

Figure 1. TSLL applied to specimen

Figure 2. MSLL applied to specimen

Table 1. Research specimens constructed

Slab Name	Type of Line Load	Number and Size of Steel Plate/s (mm)	Concrete Cube Strength (f_{cu}) (MPa)
Contr 1-T	TSLL		31.74
Contr 2-T	TSLL		31.74
Contr 3-T	TSLL		31.74
Comp 1-T	TSLL	1, 110 x 6	24.70
Comp 2-T	TSLL	1, 110 x6	24.70
Comp 3-T	TSLL	1, 110 x 6	24.70
Comp 4-T	TSLL	2, 110 x 6	23.10
Comp 5-T	TSLL	2, 110 x 6	23.10
Comp 6-T	TSLL	2, 110 x 6	23.10
Comp 7-T	TSLL	1, 150 x 8	24.70
Comp 8-T	TSLL	1, 150 x 8	24.70
Comp 9-T	TSLL	2, 150 x 8	23.10
Comp 10-T	TSLL	2, 150 x 8	23.10
Contr 1-M	MSLL		31.74
Comp 2-M	MSLL		31.74
Comp 1-M	MSLL	1, 110 x 6	24.70
Comp 2-M	MSLL	1, 110 x 6	23.10
Comp 3-M	MSLL	1, 110 x 6	30.60
Comp 4-M	MSLL	2, 110 x 6	24.70
Comp 5-M	MSLL	2, 110 x 6	23.10
Comp 6-M	MSLL	1, 150 x 8	24.70
Comp 7-M	MSLL	1, 150 x 8	30.60
Comp 8-M	MSLL	2, 150 x 8	24.70
Comp 9-M	MSLL	2, 150 x 8	24.70

3 RESULTS OBTAINED

Figures 3, 4, 5 and 6 indicate the load-deflection graphs for control slabs and composite slabs strengthened with externally bonded steel plate/s. Tables 2, 3, 4 and 5 indicate the maximum applied loads and the strength increase..

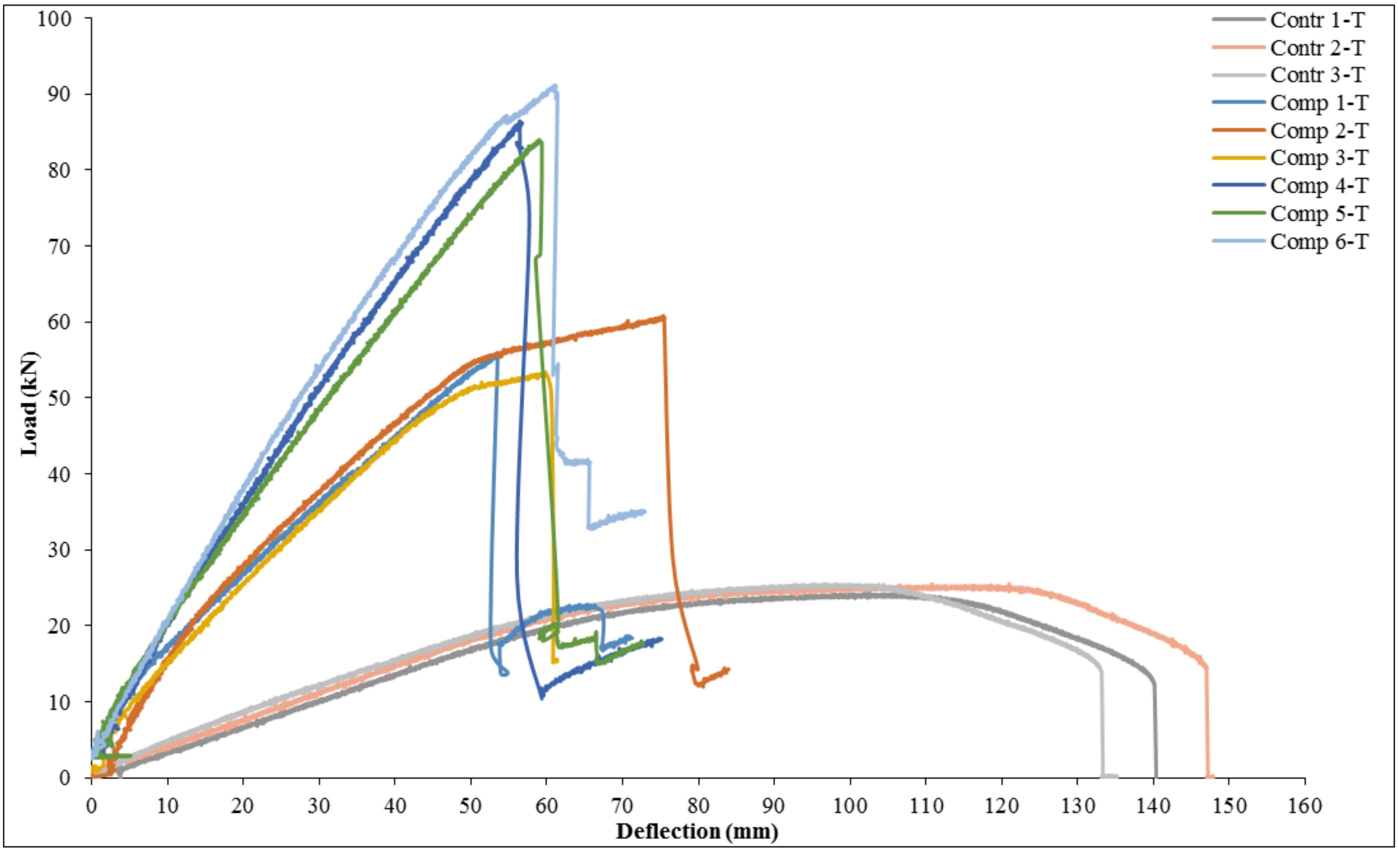

Figure 3. Load-deflection graphs, control and composite slabs strengthened with 110 mm x 6 mm steel plate/s TSLL

Table 2. Increase in load bearing capacity, control to composite slab strengthened with 110 mm x 6 mm steel plate/s TSLL

Slab Name	Type of Line Load	Number and Size of Steel Plate/s (mm)	Applied load to Control Slab (kN)	Applied Load to Composite Slab (kN)	Percentage Increase in Load Bearing Capacity	Average Percentage Increase in Load Bearing Capacity
Contr 1-T	TSLL		24.32			
Contr 2-T	TSLL		25.54			
Contr 3-T	TSLL		25.51			
Comp 1-T	TSLL	1, 110 x 6		52.72	109.87%	
Comp 2-T	TSLL	1, 110 x6		60.79	141.99%	119.97%
Comp 3-T	TSLL	1, 110 x 6		52.26	108.04%	
Comp 4-T	TSLL	2, 110 x 6		83.42	232.09%	
Comp 5-T	TSLL	2, 110 x 6		80.99	222.41%	235.13%
Comp 6-T	TSLL	2, 110 x 6		88.14	250.88%	

All composite slabs show a brittle failure mode which occur due to debonding of the steel plate. The failure mechanisms of epoxy bonded plate is instantaneous without any warning signs visible on the flexural structural element. Composite slabs 2-T and 3-T show yielding of the reinforcement and bonded steel plates at approximately 50 mm deflection.

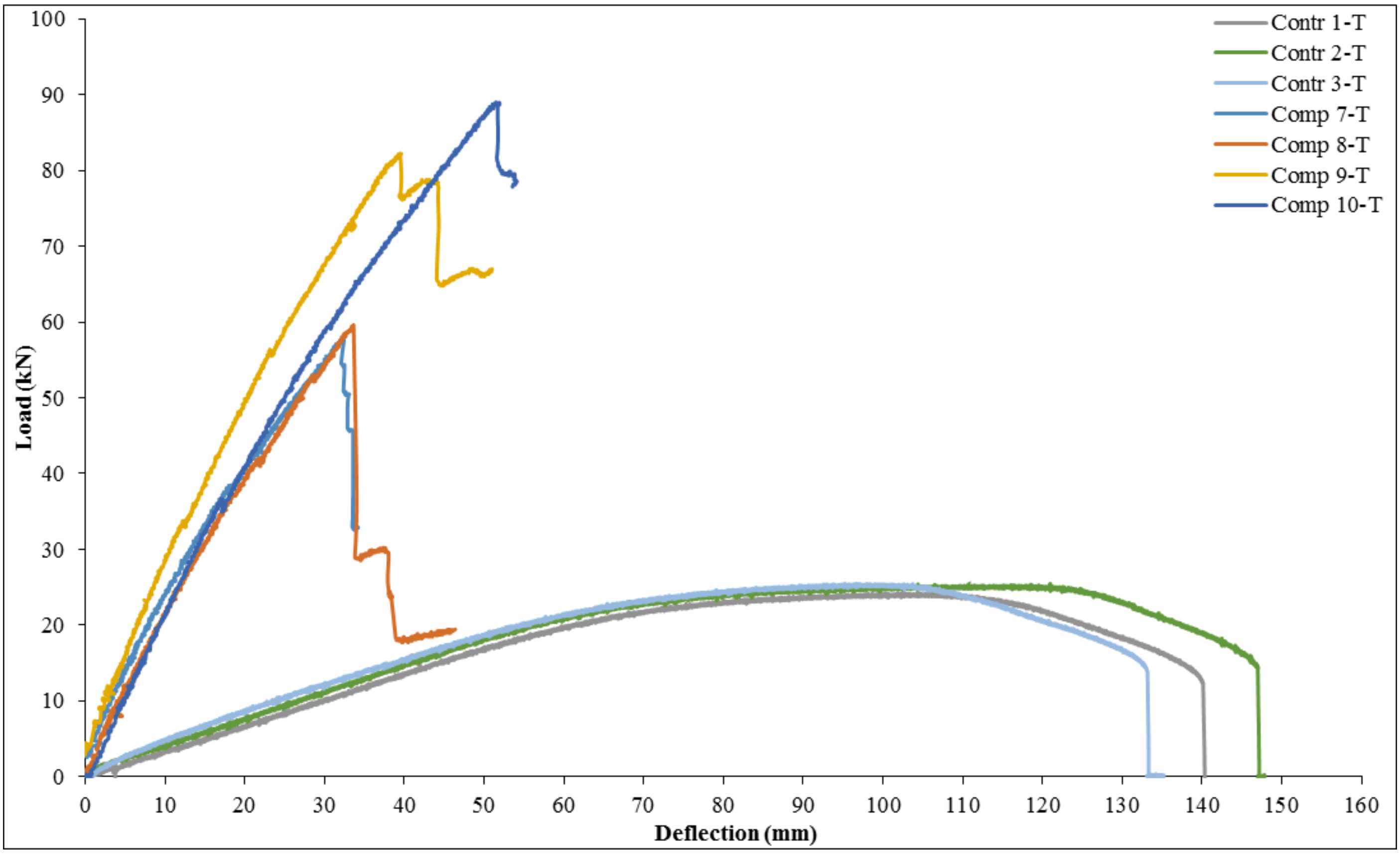

Figure 4. Load-deflection graphs, control and composite slabs strengthened with150 mm x 8 mm steel plate/s TSLL

Table 3. Increase in load bearing capacity, control slab to composite slab strengthened with 150 mm x 8 mm steel plate/s TSLL

Slab Name	Type of Line Load	Number and Size of Steel Plate/s (mm)	Applied load to Control Slab (kN)	Applied Load to Composite Slab (kN)	Percentage Increase in Load Bearing Capacity	Average Percentage Increase in Load Bearing Capacity
Contr 1-T	TSLL		24.32			
Contr 2-T	TSLL		25.54			
Contr 3-T	TSLL		25.51			
Comp 7-T	TSLL	1, 150 x 8		54.72	117.83%	
Comp 8-T	TSLL	1, 150 x 8		59.61	137.30%	127.57%
Comp 9-T	TSLL	1, 150 x 8		79.25	215.49%	
Comp 10-T	TSLL	2, 150 x 8		89.00	254.30%	234.90%

As indicated before on composite slabs strengthened with 6 mm x 110 mm steel plate, composite slabs strengthened with 8 mm x 150 mm steel plates with TSLL also have a brittle failure mode due to debonding of the steel plate. The increase in the load bearing capacity of composite slabs is evident compared to control slabs.

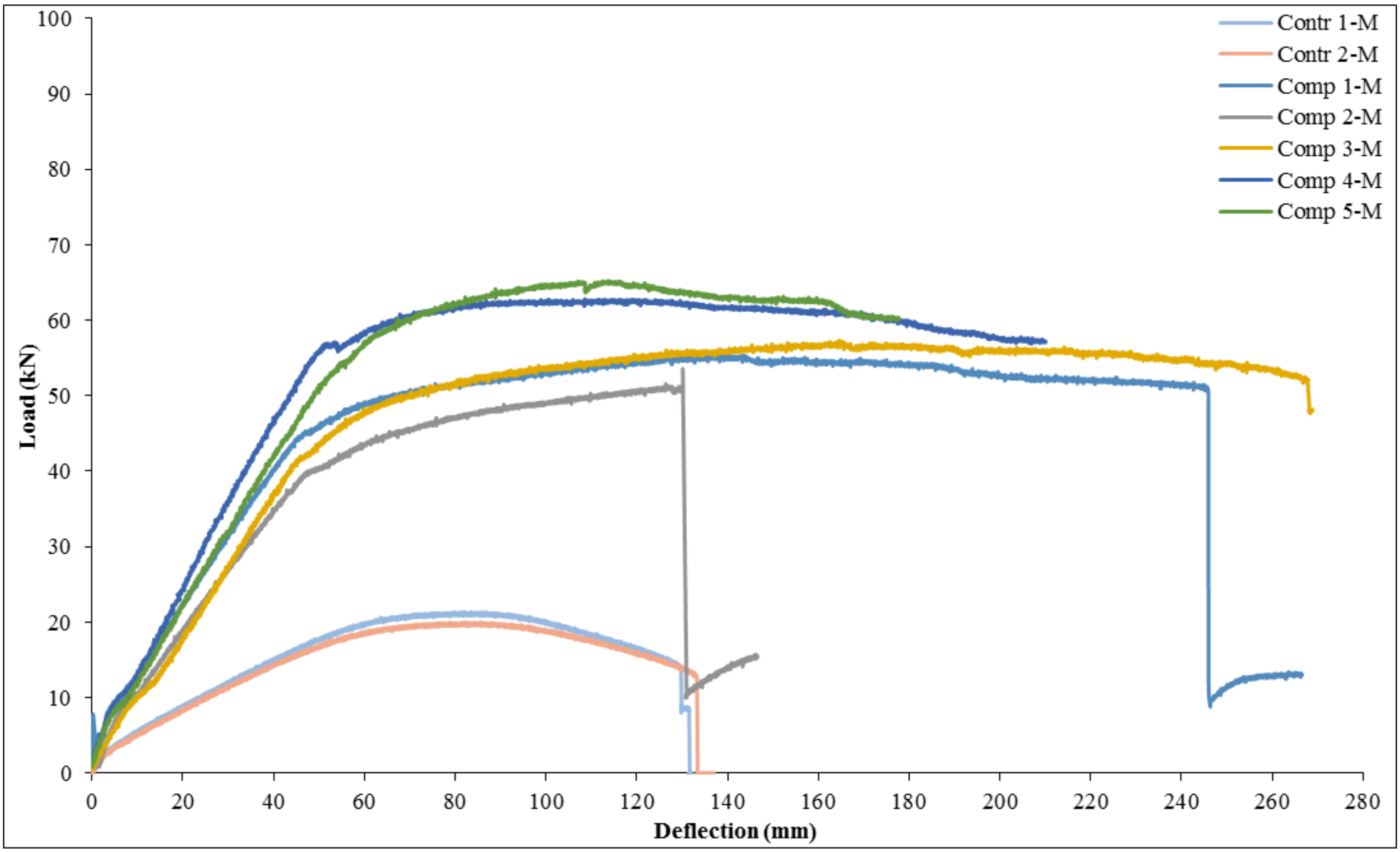

Figure 5. Load-deflection graph, control and composite slabs strengthened with 110 mm x 6 mm steel plate/s MSLL

Table 4. Increase in load bearing capacity, control slab to composite slab strengthened with 110 mm x 6 mm steel plate/s MSLL

Slab Name	Type of Line Load	Number and Size of Steel Plate/s (mm)	Applied load to Control Slab (kN)	Applied Load to Composite Slab (kN)	Percentage Increase in Load Bearing Capacity	Average Percentage Increase in Load Bearing Capacity
Contr 1-M	MSLL		21.39			
Contr 2-M	MSLL		20.05			
Comp 1-M	MSLL	1, 110 x 6		54.36	162.36%	
Comp 2-M	MSLL	1, 110 x 6		52.24	152.12%	161.95%
Comp 3-M	MSLL	1, 110 x 6		56.23	171.38%	
Comp 4-M	MSLL	2, 110 x 6		61.69	197.73%	
Comp 5-M	MSLL	2, 110 x 6		64.09	209.31%	203.52%

Composite slabs strengthened with 6 mm x 110 mm steel plates with MSLL show yielding of the reinforcement and bonded steel plates. This failure mode is ideal as the flexural structural member have a large deflection prior to failure.

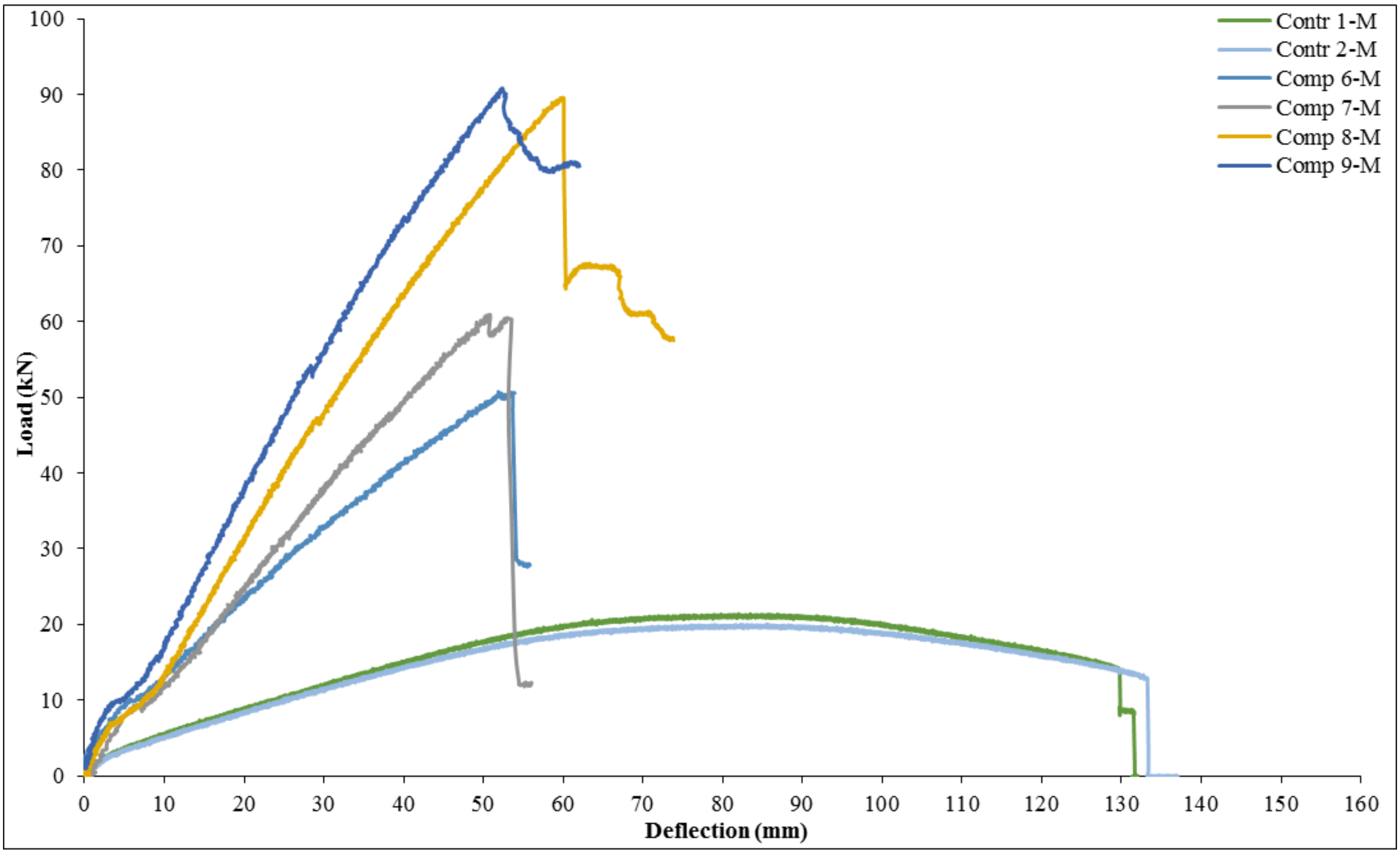

Figure 6. Load-deflection graph, control and composite slabs strengthened with 150 mm x 8 mm steel plate/s under a MSLL

Table 5. Increase in load bearing capacity, control slab to composite slab strengthened with 150 mm x 8 mm steel plate/s under MSLL

Slab Name	Type of Line Load	Number and Size of Steel Plate/s (mm)	Applied load to Control Slab (kN)	Applied Load to Composite Slab (kN)	Percentage Increase in Load Bearing Capacity	Average Percentage Increase in Load Bearing Capacity
Contr 1-M	MSLL		21.39			
Contr 2-M	MSLL		20.05			
Comp 6-M	MSLL	1, 150 x 8		49.60	139.38%	
Comp 7-M	MSLL	1, 150 x 8		52.24	194.06%	166.72%
Comp 8-M	MSLL	1, 150 x 8		56.23	332.34%	
Comp 9-M	MSLL	2, 150 x 8		61.69	332.92%	332.63%

Composite slabs strengthened by means of 8 mm x 150 mm steel plates with MSLL also have a brittle failure mode due to debonding of the steel plate as indicated before.

4 CONCLUSION

It is evident that the flexural strength of reinforced concrete structural elements increases significantly when steel plates are bonded to the concrete surface by means of epoxy as external reinforcement. The average increases are determined by comparing the experimentally measured point load acting on the unplated reinforced concrete structural element to a plated structural element and are as follow:

TSLL with 1, 110 x 6 mm steel plate is 119.97%.
TSLL with 2, 110 x 6 mm is 235.13%.
TSLL with 1, 150 x 8 mm steel plate is 127.57%.
TSLL with 2, 150 x 8 mm steel plates is 234.90%.
MSLL with 1, 110 x 6 mm steel plates is 161.95%.
MSLL with 2, 110 x 6 mm steel plates is 203.52%.
MSLL with 1, 150 x 8 mm steel plate is 166.72%.
MSLL with 2, 150 x 8 mm steel plates is 332.63%.

Consideration should be given to the design of the bonded plate/s as the plate end debonding mechanism is a sudden and brittle failure mode, yielding of the steel plates should be attained if possible.