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EXPERIMENTAL ANALYSIS OF REINFORCED CONCRETE SLABS STRENGTHENED WITH STEEL PLATES

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Abstract

The present research is concerned with the strengthening of reinforced concrete slabs with epoxy – bonded steel plates. The strengthening is intended to enhance the inherent resistance of existing slabs.

The strengthened slabs have been analyzed through the experimental program done. The parameters studied in the present study are the thickness, dimensions, and location of steel plates. The more effective parameter which enhances the overall behavior of R.C. slabs is the effect of steel plate dimensions more than the thickness effect The max increases in ultimate strength are found in slabs S3 and S5 as (135%) and (79.6%), respectively. From the analysis results, using steel plates for strengthening of R.C. slabs can enhance the overall resistance of these members significantly.

الخلاصــة:

يهتم البحث الحالي بتقوية البلاطات الخرسانية باستخدام صفائح فولاذية والتي تعمل على تحسين مقاومة هذه البلاطات. تم تحليل هذه البلاطات بفحصها مختبريا تحت احمال واقعية.

تم دراسة عدة عوامل من خلال هذه الدراسة وهي سمك و أبعاد، وموقع الصفائح الفولاذية. أكثر هذه العوامل فاعلية هو اختيار الطول المناسب لهذه الصفائح حيث حسّنت السلوك العام للبلاطات الخرسانية. اعظم زيادة في المقاومة وجدت للبلاطة S3وS5 وهي(135%) و(79.6%) على التوالي.

من خلال نتائج التحليل تبين أن وجود الصفائح الفولاذية الرابطة لجميع البلاطات الخرسانية المسلحة يحسن من اداؤها بشكل ملحوظ.

Key words: R.C slabs, Strengthening, Thin Plates

INTRODUCTION:

Reinforced concrete existing structures may need strengthening when an unexpected overloading might be applied. Among many strengthening techniques, the method of plate bonding has been an attractive one in recent years, due to its simplicity, speed of application and minimum increase in the self weight. Steel plates and fiber – reinforced polymer plates (FRP) have both been used in plate bonding, depending on the requirement of a particular situation.

Steel plates are used in this work with two different thicknesses and dimensions for strengthening reinforced concrete test slabs.

The main objective is to determine experimentally the load – deflection relationships of the test specimens, ultimate loads and the debonding stage of the strengthening plates.

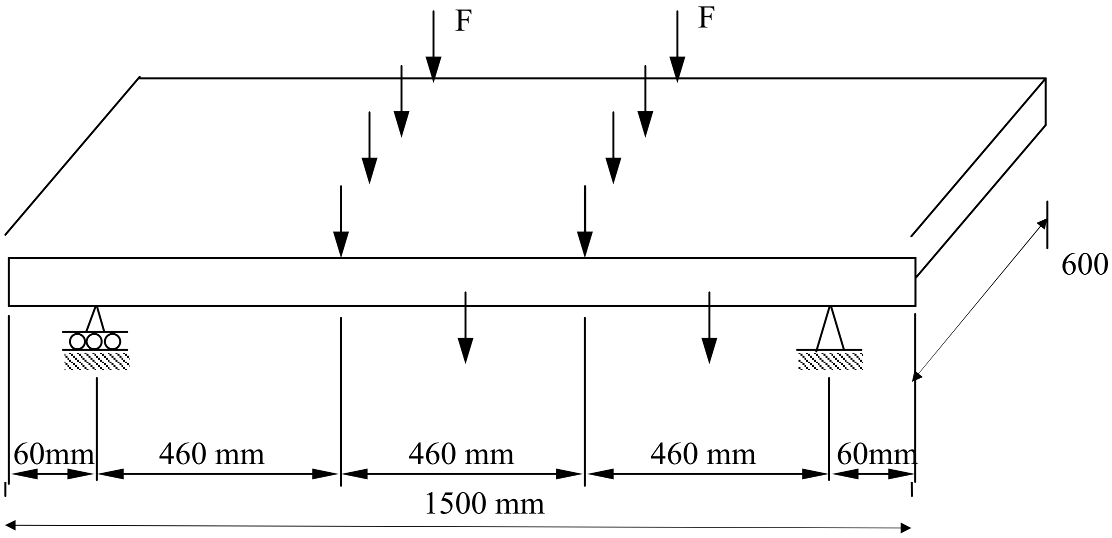
TEST SPECIMENS:

A total of 5 identical slabs were cast and cured under laboratory conditions. The tested slabs are of dimension (60mm×600mm×1500mm). The details of the tested specimens are shown in Table (1).

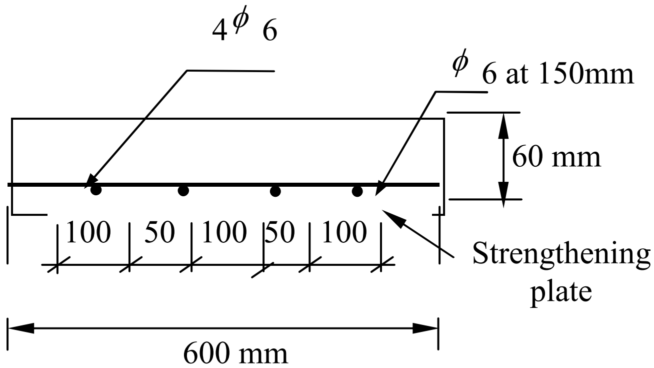
Table (1): Test Specimens and Strengthening Plate Dimensions

Specimens type	Symbols	Slab dimensions (mm)	Steel plate dimensions (mm)
Slabs	S1 (control)	60×600×1500	No plate
	S2	60×600×1500	3(1.5×100×600)*
	S3	60×600×1500	3(1.5×100×1200)*
	S4	60×600×1500	3(1.0×100×600)*
	S5	60×600×1500	3(1.0×100×1200)*

*see Fig. (1)



Le = 1.38 m (distance between supports for load test)



All dimension in mm

Fig.(1): Test Layout and Specimen Geometry of Slabs

MATERIALS:

CONCRETE:

All the specimens were cast from the same batch of material. The concrete is of 12 mm maximum size of crushed aggregate. The material proportions are summarized in Table (2):

Table (2): Mix Properties of Concrete

Material	Proportions (kg/m^3) of concrete
Type (V) (Kuwait) Portland Cement	400
Water	154
Sand	600
Crushed Aggregate	1177

The compressive strength of concrete was obtained using (150×300mm) cylinders tested at 28 days after curing. The tests were conducted in accordance with ASTM C39 – 01, using a 2000 kN capacity hydraulic Universal testing machine (ELE – Digital Elect 2000). The average strength of the cylinder tested was 30 MPa.

A splitting tensile test was conducted on three samples that have been carried out on standard (100×200mm) cylinders at an age of 28 days after curing. Test procedure was according to ASTM C496 – 96. A 2000 kN capacity hydraulic Universal testing machine (ELE–Digital Elect 2000) was used, an average splitting tensile strength equals to 3.27 MPa was obtained.

STEEL REINFORCEMENT:

One grade of steel reinforcement was used, according to ASTM A 615M. Grade 60 steel. Slabs were reinforced with four $\phi 6$ at long direction and with $\phi 6$ at a spacing of 150 mm. Two bar samples were tested. The test results are summarized in Table (3).

Test specimens were cut randomly from the bars and the tensile tests showed a consistent strength for all samples.

Table (3): Properties of Steel Reinforcement

Reinforcing Bar size No. (mm)	Yield strength (MPa)	Elongation %	Tensile strength (MPa)
6 (deformed)	736	5.0	850

STEEL PLATES:

Two thicknesses of steel plates (1.0 mm and 1.5 mm) are used to strengthen slab specimens.

The effects of thickness and steel plate length bonded to concrete members (600 mm and 1200 mm) are considered in the present study. Fig. (1) shows the steel plates arrangement for slab specimens.

The distribution of steel plate strengthening on the specimens are shown in Table (1). Two samples of each size were tested. Both plate sizes were tested on a hydraulic testing machine under stroke control, and the test results are summarized in Table (4).

Table (4): Steel Plate Properties

Steel plate thickness (mm)	Yield strength (MPa)	Elongation %	Tensile strength (MPa)
1.0	279.4	15	353.7
2.0	279.4	15	365.6

ADHESIVE BETWEEN CONCRETE AND STRENGTHENING PLATES:

Epoxy resin is widely used as the bond product for most materials used in construction, such as concrete, masonry units, wood, glass, and metals.

In the present work, the epoxy – resin based bond agent is of a trademark of concresive® 2200 supplied by MBT's Dubai, UAE facility. It was selected to bond steel plate to hardened reinforced concrete beams and slabs. This resin is composed of two components (A and B) and available in packages of 3 kg. Properties of the concresive® 2200 are shown in Table (5). These properties of epoxy are in accordance with ASTM C881M–02: type 1, grade 3 and classes B and C.

Table (5): Epoxy Resin Properties

Properties	Results
Color mixed density	Cement grey 1758 kg/m³ at 25ºC
Compressive strength	60 MPa at 7 days
Bond strength	7.0 MPa
Compressive modulus	1000 MPa
Tensile strength	35 MPa at 7 days
Pot life*	at 25ºC : 1 hour 45 minutes at 40ºC : 45 minutes
Open time**	at 25ºC : 7 hour at 40ºC : 2 hour 15 minutes
Full cure	at 25ºC : 5 days 40ºC : 3 days

* Maximum time between final mixing and application during which a resin remains usable(3). Also known working life or used life.

** Open time starts when the adhesive has been applied to the parts to be jointed, it represents the time limit during which the joint has to be closed.

Slab Strength:

The nominal moment capacity M_n of a one way slab is calculated according to:

$$M_n = \rho f_y b d^2 \left(1 - 0.59\rho \frac{f_y}{f'_c}\right) \qquad \ldots(1)$$

For the one way slabs strengthened with steel plate, the depth of the equivalent compressive stress block (a) is obtained as follows:

$$A_s . f_s + A_p f_{sp} = 0.85 f'_c . a . b \qquad \ldots(2)$$

The nominal moment capacity M_n of one way slab strengthened with steel plate is calculated by using Eq. (3). $M_n = A_s . f_s \left(d - \frac{a}{2}\right) + A_p f_{sp} . \left(h - \frac{a}{2}\right)$ …(3)

Where:

A_p : cross – sectional area of steel plate

f_{sp} : steel plate stress (MPa)

As : cross – sectional area of steel reinforcement

f_{sp} : steel reinforcement stress (MPa)

a : equivalent compressive depth

h : total depth of slab

d : effective depth of slab.

Where the maximum applied load F for the case of loading shown in Fig. (1) is obtained using Eq. (4).

$$F = \frac{M_n}{L_e/3} \quad \dots(4)$$

Table (6) shows the slab design properties and the material properties.

Table (6): Slab Section Properties

Specimens Symbole	f'_c (MPa)	f_y (MPa)	M_n (kN-m)	Predicated maximum total load (kN)
S1	30	736	3.52	15.3
S2	30	736	5.9	26.0
S3	30	736	9.0	39.49
S4	30	736	5.11	22.23
S5	30	736	7.31	31.78

Test of Specimens:

Slabs specimens with the strengthening plate dimensions are shown in Fig. (1). One dial gage was placed at the middle point under the beams to record the deflection as the load was increased. The load was applied at the one – third points for all specimens, Fig. (2).

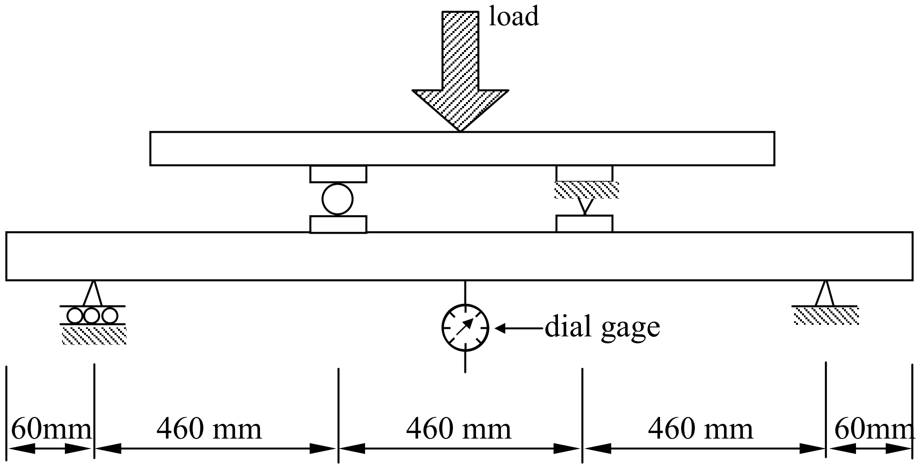


Fig. (2): Arrangement of Flexural Test

TEST RESULTS AND DISCUSSION OF SLAB SPECIMENS:

The test results of the slab specimens are given in Table (6) and Figs. (3) to (6). It's obvious from the test results that the overall properties of R.C. slabs are enhanced when strengthened with steel plate i.e., increase their first crack loads ultimate loads, and stiffness after cracking due to the large axial stiffness of plate.

It's marked that the first crack began at the zone out of steel plate, and also the failure crack are found at the same zone. As for the beams the effect of steel plate dimensions is more effective than the thickness effect. It had been seen clearly that for the R.C. slab strengthened with steel plates, detachment initiates at a zone between the plate end and the load application point at high load level. The increases in ultimate strength are found in slabs S3 and S5 as (135%) and (79.6%), respectively greater than that of the reference slab S1.

With reference to the tests results, it is possible to observe that the specimen failure is never due to concrete crushing or plate failure. Failure is always driven by a sudden loss of the composite action between the R.C. member and the strengthening plate.

The difference between the experimental and predicated ultimate loads is in the range of (3.5% – 30.3%) as obtained from Tables (6) and (7).

Table (7): Test Results of R.C. Slabs

Slab specimen	$\rho = \frac{V.plate}{V.beam}$	Initial crack load (kN)	Debonding load (kN)	Experimental ultimate load (kN)	$\frac{\text{Ult. Load for Si}}{\text{Ult. Load for S1}}$
S1	-----	6.2	-------	16.2	1.0
S2	0.005	9.9	**	18.1	1.11
S3	0.01	26.9	37.9	38.1	2.35
S4	0.002	9.9	**	16.5	1.01
S5	0.004	16.2	29.1	29.1	1.79

****No debonding was noticed at ultimate load.**

CONCLUSIONS:

1. The use of steel plates as a strengthening mean for R.C. slabs enhances the overall properties of these members i.e., increasing their first crack load by (59.6% – 333%) and ultimate load by (1.85% – 135%).
2. It's noticed that the first cracks began at zone out of steel plate then continue to propagate in that zone.
3. All slabs are failed without debonding of the steel plate except for the slab (S3) for which the steel plate debonded at 99% of failure load.
4. The effects of dimensions of the strengthening steel plate are more effective than the plate thickness for all specimens.

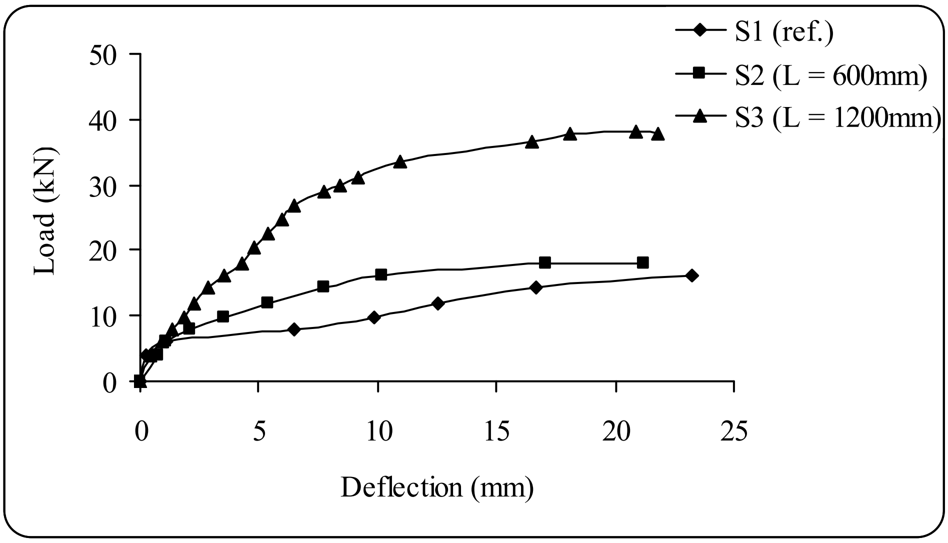


Fig. (3): Load – Deflection Relation of Simply Supported Slabs Strengthened with 1.5 mm Steel Plates

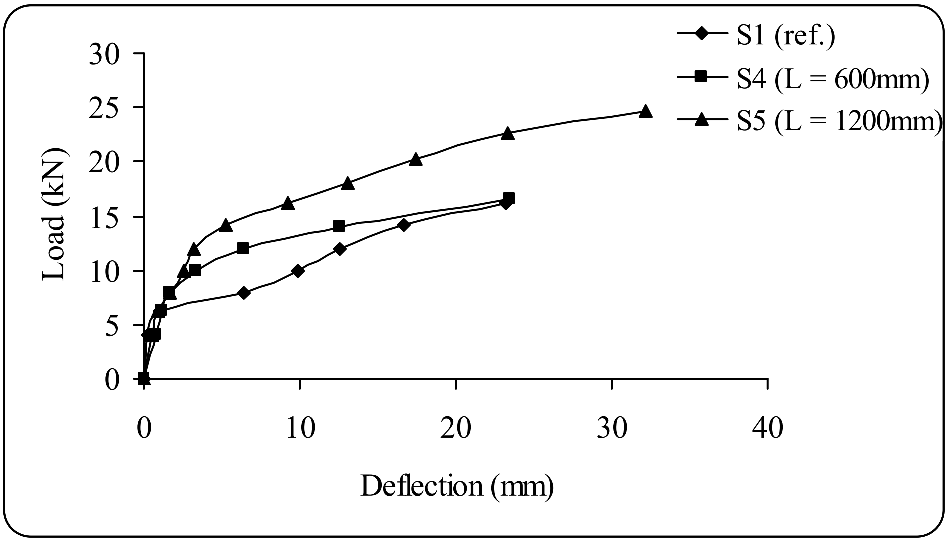


Fig. (4): Load – Deflection Relation of Simply Supported Slabs Strengthened with 1 mm Steel Plates

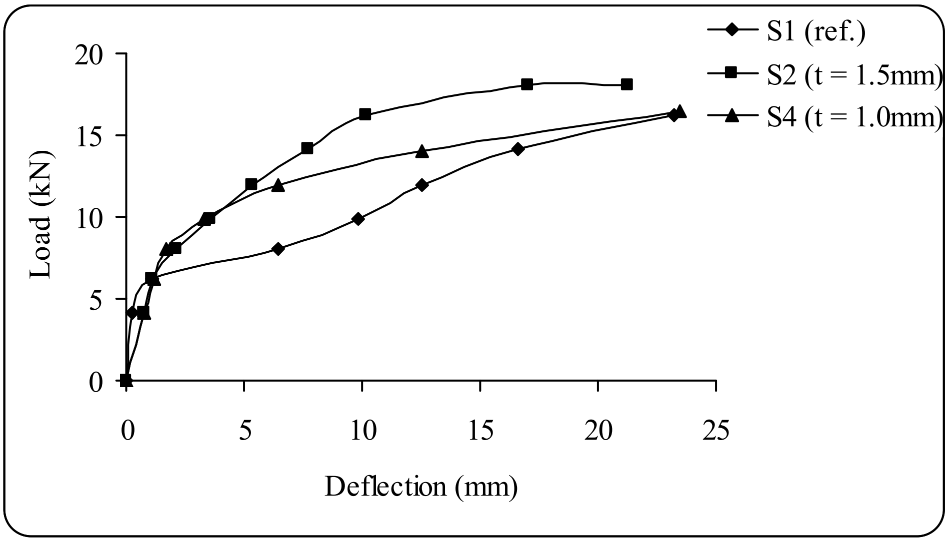


Fig. (5): Load – Deflection Relation of Simply Supported Slabs Strengthened with Steel Plates of Length 600 mm

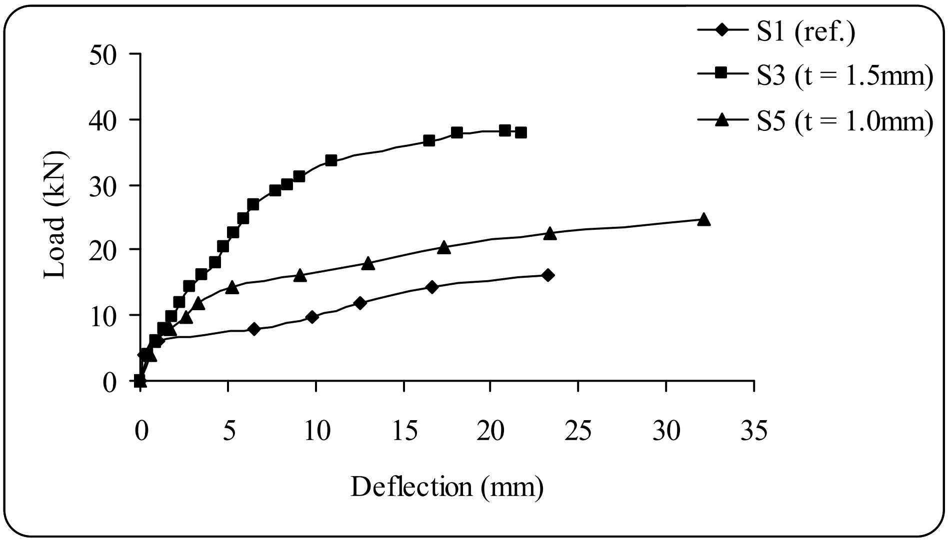


Fig. (6): Load – Deflection Relation of Simply Supported Slabs Strengthened with Steel Plates of Length 1200 mm

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