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EXPERIMENTAL STUDY OF TWO WAY RC SLABS WITH OR WITHOUT OPENINGS STRENGTHENED WITH COMPOSITE STRIPS

B. EXPERIMENTAL RESULTS

BY

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Abstract. In this paper are presented the results obtained from testing eight two-way reinforced concrete (RC) slabs with or without openings that were strengthened using composite strips bonded on the tensioned face of the elements. For the strengthened slabs without openings an increase in the load-carrying capacity of 29% and a reduction of the deflection of up to 57% is achieved in comparison to the unstregthened slab. The strengthened slabs with openings had an increase in load-carrying capacity of 115% and a reduction of the deflection of up to 74% in comparison to the control specimen. The strengthened slabs have presented a progressive failure, which was controlled by the flexural failure.

Key words: reinforced concrete slab; strengthening; composites; experiments.

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1. Introduction

The experimental investigation is a very important tool in order to establish the effectiveness of a strengthening technique for the existing damaged structures. Using laboratory conditions researchers have tried to simulate the actual situations that occur in practice, situations that make necessary the strengthening of the RC elements. The most commune causes that are simulated for the RC slabs are the followings:

a) corrosion of the steel reinforcement (simulated by using a low percentage of steel reinforcement) (Mosallam, 2003);

b) under sizing of the RC slabs (design error) (Agbossou, 2008);

c) increase of the service loads (change in use of the building) (Kim, 2010);

d) cracking of the RC slabs due to excessive loading (Floruţ, 2010);

e) weakening of the RC slabs by creating new openings in existing slabs (post-installation of stairs, elevators, air conditioning, heating system, etc.) (Enochsson, 2007).

In this study the strengthening of two-way slabs with or without openings is evaluated. The slabs are strengthened using the exterior bonded technique. Many studies that analysed the strengthening of two-way slabs have proven that this technique is efficient, ensuring at least the same carrying capacity of the undamaged element or a considerable increase. Also the deflections of the strengthened specimens are reduced, the stiffness of the strengthened elements being increased.

2. Experimental Program

The experimental program consisted in testing two series of RC slabs. The first series, denoted SW, represents four homogeneous slabs, from which three have been strengthened with carbon fibre reinforced polymer (CFRP) strips bonded with epoxy adhesives. The second series, denoted SO, represents the slabs with openings, from which three have been strengthened (Banu, 2012). For the openings no supplementary reinforcement was used, simulating the sawn-up situation.

The dimensions of the RC slabs were 110 × 110.5 cm and for the opening, 20 × 20 cm. The dimensions have been chosen to enable the evaluation of the two way slabs structural response, and correlated with the testing facilities of the laboratory. The materials used to execute the slabs were concrete grade C20/25 and steel wire mesh reinforcement SPPB 10 × 100 × 100 with the yield strength equal to 460 N/mm^2 (SR 438-3, 1998).

The strengthening of the slabs was made using CFRP strips with the modulus of elasticity equal to 200 GPa and the tension strength of 3,300 MPa (MAPEI, 2010). The strips were bonded to the RC slabs using epoxy adhesives. The configuration of the strengthening systems used for the two series is presented in Fig. 1.

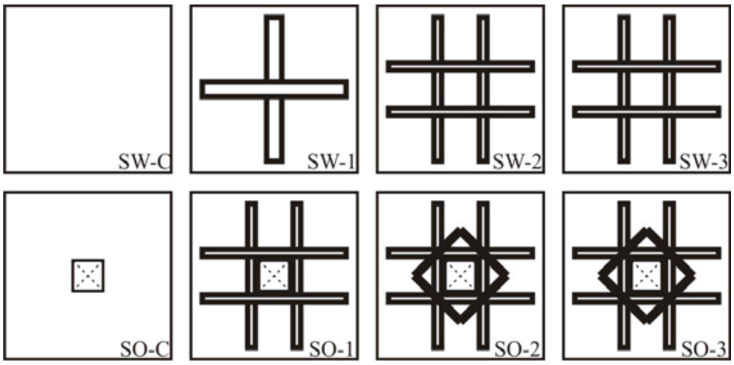

Fig. 1 – Strengthening scheme for series SW and SO.

During the testing the slabs were considered to be simply supported on all four edges, with the distance between supports equal to 100 cm. The support conditions were chosen in order to facilitate the flexural failure of the slabs. If the corners of the slabs had been blocked, probably the failure had been dominated by shear punching (Casadei, 2004).

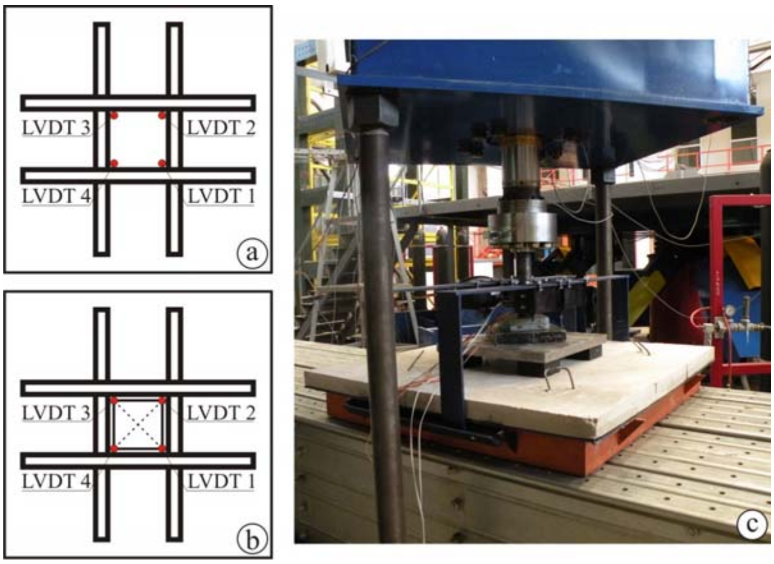

Fig. 2 – Experimental stand and LVDTs position.

The slabs were loaded in four points, using displacement control of the actuator in order to create a monotone loading of the slabs, which was monitored using a load cell. The displacement rate used was of 1 mm/6 s and 1 mm/10 s for slab SO-3. During the testing of the slabs the transversal displacement was measured in four points using linear variable differential transducers (LVDT). In Fig. 2 the experimental stand and the position of the LVDTs is represented.

3. Experimental Results

During the testing of the slabs the following parameters have been monitored: the value of the applied load and the transversal displacement which was measured in the four points previously established.

3.1. RC Slabs without Openings

During the testing of the RC slabs without openings was used a displacement control of the actuator of 1 mm/6 s. The maximum displacement imposed for the actuator varied from one slab to another in order to analyse the influence on the failure mode. For slabs SW-C and SW-3 was used a maximum displacement of 30 mm and for slabs SW-1 and SW-2, of 40 mm.

Fig. 3 – Bond failure of the strengthening system.

The dominant failure mode for the unstrengthened slab was flexural failure. The strengthened slabs had also failed due to flexural loading, but it has been observed a punching shear failure component due to the inclined cracks that formed after reaching the carrying capacity of the specimens. The failure of the strengthened elements was initiated by the premature debonding of the strengthening systems. Bond failure had occurred in the concrete near the surface at the ends of the CFRP strips, and along the line of the embedded steel reinforcement in the aria were the strips intersect and the inclined cracks from punching shear formed. In Fig. 3 are shown the bond failure situations that occurred for the homogeneous slabs.

The number of cracks that formed on the tensioned side for the strengthened slabs is much smaller than that of the unstrengthened one. Their dimensions are also smaller as it can be seen in Fig. 4.

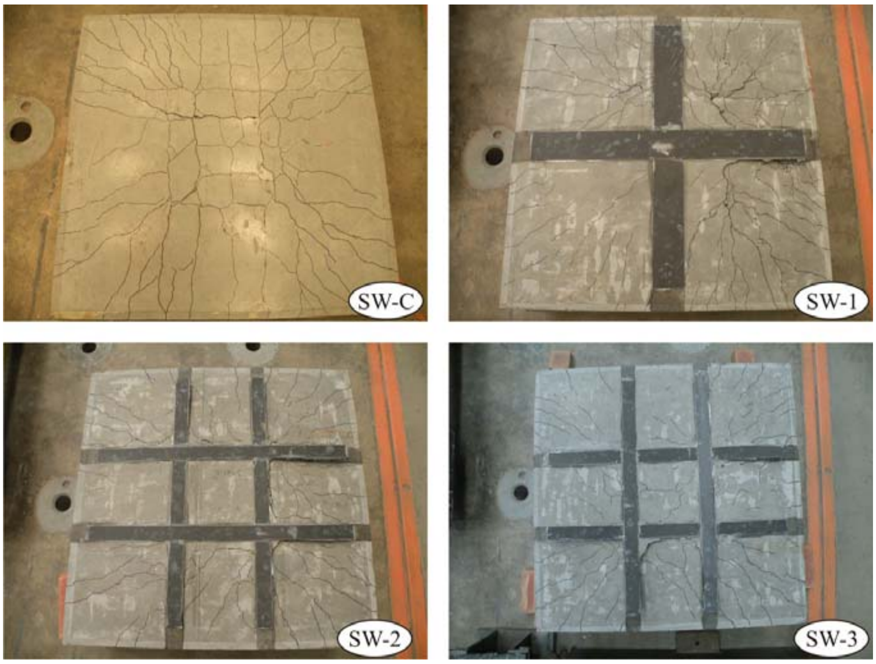

Fig. 4 – Crack patterns for the slabs in series SW.

At the compressed side of the RC slabs the crushing of the concrete manifested trough a circular pattern that was formed around the loading aria.

The experimental results for series SW are given in Table 1.

Table 1
Experimental Results for Series SW

Slab	Maximum force kN	Displacement LVDT 1, [mm]	Displacement LVDT 2, [mm]	Displacement LVDT 3, [mm]	Displacement LVDT 4, [mm]
SW-C	46.96	17.07	18.12	17.97	17.60
SW-1	46.62	9.14	12.05	11.65	8.70
SW-2	55.71	7.73	7.83	7.73	7.32
SW-3	60.71	7.83	8.43	8.58	7.58

The force *vs*. displacement diagrams for series SW are given in Fig. 5. The diagrams correspond to the four points in which the transversal displacements were measured.

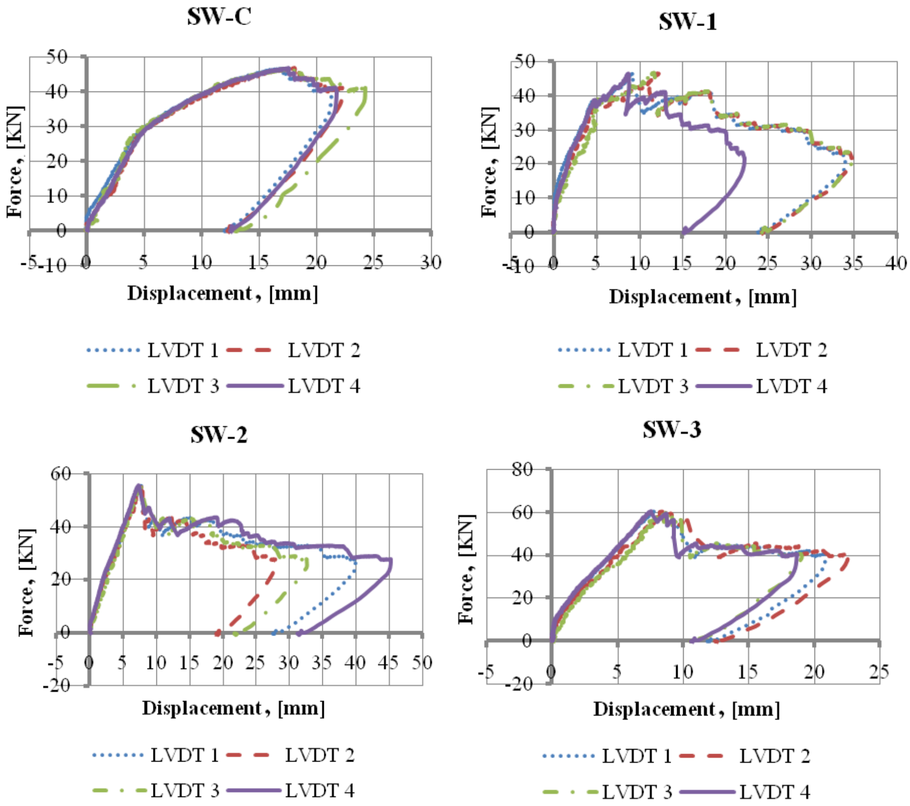

Fig. 5 – Load *vs.* displacement diagrams for SW series.

3.2. RC Slabs with Openings

The maximum displacement imposed to the actuator was of 20 mm for slab SO-C, 30 mm for slabs SO-1 and SO-3, and 40 mm for slab SO-2. The displacement rate used to control the loading was of 1 mm/6 s for slabs SO-C, SO-1 and SO-2. The displacement rate for slab SO-3 was increased to 1 mm/10 s in order to see if it will influence the carrying capacity and the failure mode of the specimen.

The controlling mode of failure for the RC slabs with openings was flexural failure. Post-failure inspection of the slabs showed that cracks on the sides of the opening had formed. Some of this cracks sliced through the plane of the slab. This can be interpreted as a form of punching shear behaviour. The failure of the strengthened RC slabs with openings was initiated by the debonding of the composite strips. At the end of the strips the bond failure occurred in the concrete near the surface. Around the openings the bond failure occurred in the plane of the embedded steel reinforcement.

In Fig. 6 are shown the bond failure situations that occurred for the RC slabs with openings.

Fig. 6 – Bond failure of the strengthening system.

The crack patterns that formed on the tensioned side of the RC slabs with openings are similar for all the specimens (Fig. 7). The major cracks for the unstrengthened specimen had the starting point the corners of the openings, and developed towards the corners of the slab. The cracks for the strengthened

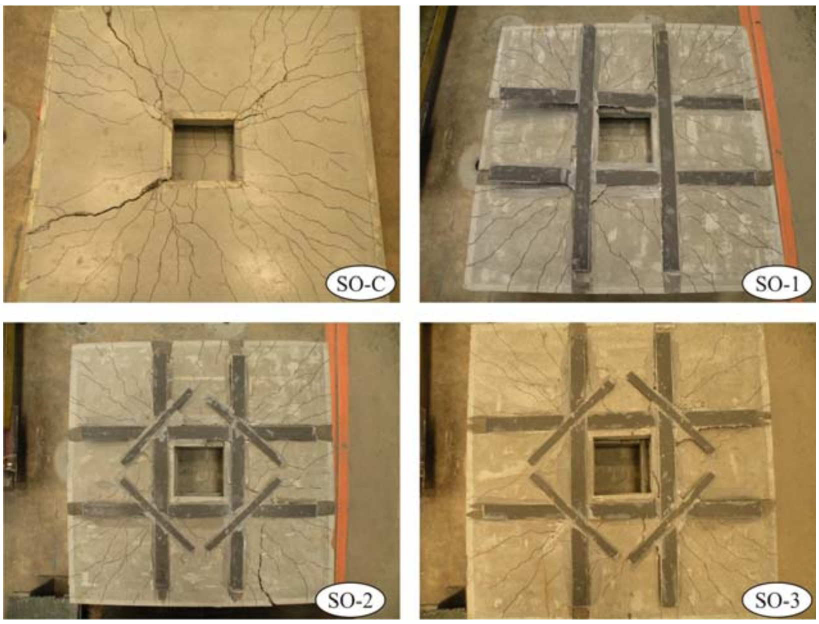

Fig. 7 – Crack patterns for the slabs in series SO.

slabs formed from the intersection of the CFRP strips and developed towards the corners of the slab. On the sides of the openings, of the strengthened slabs, flexural cracks formed that induced the bond failure of the composite strips, creating the failure in the plane of the steel reinforcement resulting and the entire concrete cover being pulled off. The number and dimensions of cracks that formed for the strengthened specimens were much smaller in comparison with the unstrengthened slab. On the top surface of the slabs, crushing of the concrete was observed, circular patterns around the loading aria being formed.

The experimental results for series SO, consisting in the maximum force and the afferent transversal displacement, are given in Table 2.

Table 2

Experimental Results for Series SO

Slab	Maximum force kN	Displacement LVDT 1, [mm]	Displacement LVDT 2, [mm]	Displacement LVDT 3, [mm]	Displacement LVDT 4, [mm]
SW-C	35.29	22.34	24.38	25.10	24.82
SW-1	54.75	6.10	6.48	6.48	5.80
SW-2	75.97	7.53	7.48	7.53	7.43
SW-3	71.56	6.02	6.63	6.98	5.39

The force *vs*. displacement diagrams for series SO are given in Fig. 8. The diagrams correspond to the four points in which the transversal displacements were measured.

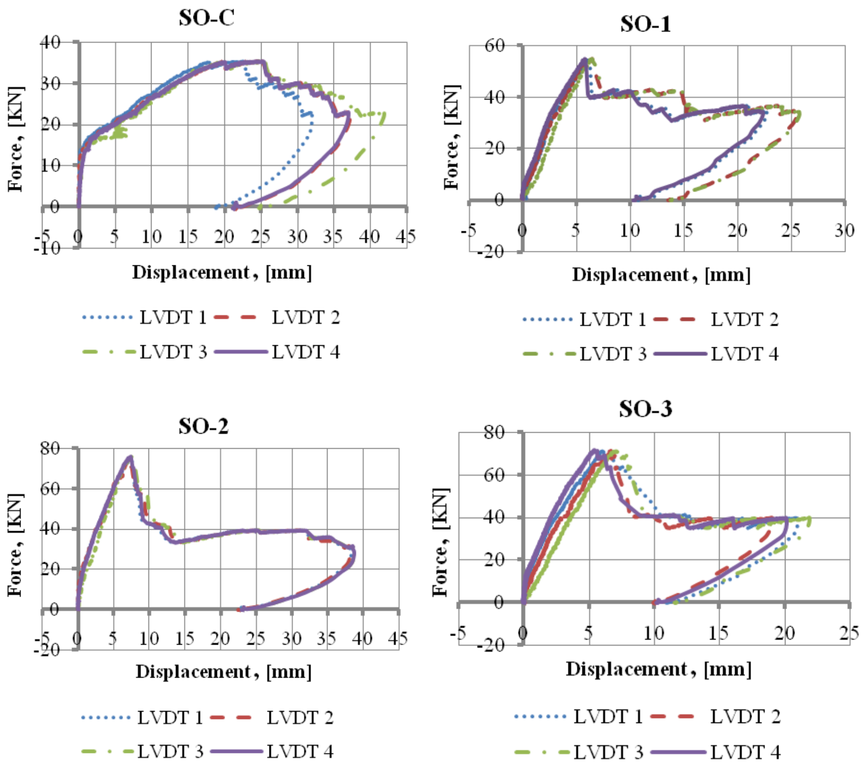

Fig. 8 – Load *vs*. displacement diagrams for SO series.

4. Conclusions

The results obtained after testing the RC slabs with and without openings, that were strengthened using the exterior bonded technique, demonstrate the effectiveness of the composite system. For all the slabs, from both series, the load carrying capacity of the strengthened elements has been increased and the corresponding maximum transversal displacement has been reduced. This reduction of the measured displacements can be interpreted as an increase in stiffness for the strengthened elements. The controlling failure method for all the slabs was the flexural failure with a component of punching shear.

In the SW series the load carrying capacity of the strengthened slabs increased with 18% for SW-2 and 30% for SW-3, and the maximum corresponding displacement was reduced with 41%...57%, in comparison with the control specimen SW-C. For the SO series, the load carrying capacity of the strengthened slabs was increased with 63% for SO-1 and 115% and 102% for slabs SO-2 and SO-3. The corresponding maximum displacements were reduced with 74%, 70% and 74%, respectively, as compared to the unstrengthened slab SO-C.

A special attention must be given to the bond failure of the strengthening system, for which special actions can be taken in order to prevent or delay it. One of these actions consists in anchoring the ends of the CFRP strips using different steel or composite fasteners.

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STUDIU EXPERIMENTAL AL PLĂCILOR DIN BETON ARMATE PE DOUĂ DIRECȚII CU SAU FĂRĂ GOLURI CONSOLIDATE CU PLATBANDE COMPOZITE

B. Rezultatele experimentului

(Rezumat)

Sunt prezentate rezultatele obținute în urma încercărilor experimentale efectuate pe opt plăci din beton armat pe două direcții, ce au fost consolidate folosind platbande compozite lipite la fața tensionată a plăcilor. Pentru plăcile fără gol, consolidate, a fost obținută o creştere a capacității portante de până la 29% şi o reducere a deplasărilor transversale de până la 57%, comparativ cu placa neconsolidată. În cazul plăcilor cu gol, consolidate, a fost înregistrată o creştere a capacității portante de până la 115%, iar deplasările transversale au fost reduse cu până la 74%, comparativ cu placa de control. Modul de cedare al plăcilor consolidate a fost unul progresiv şi a fost dominat de cedarea la încovoiere.