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EXPERIMENTAL STUDY ON TWO WAY REINFORCED CONCRETE SLABS WITH OR WITHOUT OPENINGS STRENGTHENED WITH COMPOSITE STRIPS
PART A: EXPERIMENTAL SETUP

BY

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Abstract. This paper presents the investigation on the feasibility of strengthening reinforced concrete (RC) slabs in flexure, with or without openings, using carbon fibres reinforced polymer (CFRP) strips bonded on the tensioned side of the slab. There are investigated two series of slabs. The first series represents four slabs without openings and the second series represents four slabs with a central openings. Each series has a control slab which is not strengthened with CFRP strips. The test setup and instrumentation of the RC slabs allow determining the overall stiffness and flexural capacity of the strengthened specimens in comparison with the control specimens.

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

1. Introduction

The strengthening of reinforced concrete structures has emerged as a necessity due to different causes that affect a building during the life span.

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Some of these causes refer to the damages that affected the structural integrity of the building, the need for upgrading the load-carrying capacity, changes in the structure or correcting the problems that occurred during the construction. Different techniques for strengthening or repairing the reinforced concrete (RC) structural elements have been used in the past in order to overcome these problems. For RC slabs the techniques used for strengthening include: section enlargement, ferrocement cover, external steel plate bonding, external post-tensioning, span shortening techniques and adding supplementary supports, each of them having advantages and disadvantages depending on the circumstances in which are applied (Emmons, 1993; Radomski, 2002).

The use of fibre reinforced polymer (FRP) composite as an alternative for the strengthening techniques presented above has been studied and used in order to try and overcome some of the disadvantages encountered in applying them. The experimental investigations on strengthening RC slabs with FRP materials have as main objective to present the advantages of this technique and the expected problems (disadvantages) that can occur. In the scientific literature available at this moment can be found studies on the applicability of this technique to one-way or two-way RC slabs with or without cut-outs that present good to very good results as regards the increase in load carrying capacity and overall stiffness.

2. Literature Review

Recent studies carried out by international researchers on the behaviour of two-way RC slabs strengthened with different FRP systems have shown the benefits of using these material systems.

Experimental studies on the strengthening of two-way RC slabs using bounded composite systems have been made by Mosallam *et al* .(2003) on 264 × 264 × 7.6 cm specimens strengthened with carbon/epoxy and *E*-glass/ epoxy composite systems. The results of the experiments indicated that the composite system restored not only the original capacity of the damaged slabs but also resulted in an appreciable increase of the strength of the repaired slabs to an average increase of more than 540% the original capacity .of the as-built slabs. The deformation of the tested specimens before failure was relative large, measuring more then 1/45 of the clear span length. Limam *et al.* (2005) investigated also the collapse mechanism and corresponding load capacity for strengthened RC two-way slabs with CFRP strips.

Kim *et al.* (2010) conducted a study on RC slabs retrofitted with prestressed or non-prestressed CFRP sheets. The results of the experiments presented an increase in the ultimate load-carrying capacity of the slabs strengthened with CFRP sheets from 4% to 18%, including a 25% increase in cracking loads, with respect to the control specimen. Similar study based on criteria for punching failure have been conducted by Michel *et al.* (2007) on reinforced concrete slabs strengthened with externally bonded CFRP.

Foret *et al.* (2008) realised a comparative study on the strengthening of two-way RC slabs with composites using two different systems. First system was based on the external bounding method and the second one used the near surface mounted (NSM) method for strengthening the RC slab. For the NSM strengthened slab an increase of 67% was observed for the flexural strength. The experiments concluded that a more ductile behaviour was observed compared to external bonding technique and an economical advantage of NSM technique relative to a lower carbon fibre quantity is observed too.

Agbossou *et al.* (2008) analysed the influence of the concrete cover on the strengthening of RC slabs with externally bonded composite strips. In their study the low mechanical quality of the concrete between the reinforcing steel and the CFRP strips was analysed to see how it influences the effectiveness of this strengthening technique, taking into account that upon failure debonding of the FRP strips can occur with the dislocation of the concrete cover.

Chen *et al.* (2008) conducted an experimental investigation on the strengthening of two-way RC slabs using different type of composite materials. In their study they analysed strengthening with carbon (CFRP), glass (GFRP) and basalt (BFRP) composites. The failure of the tested specimens strengthened with GFRP and BFRP was by FRP-rupture and for those strengthened with CFRP was by FRP-debonding. This was mainly due to the difference in the modulus of elasticity of different materials. Thus it is important to choose appropriate FRP material system in order to achieve good strengthening effect.

Studies on the strengthening of two-way RC slabs with openings have been made by Casadei *et al.* (2004) and by Enochsson *et al.* (2007). The first study analysed the increase in flexural capacity and overall stiffness using external bounding of FRP materials and the anchorage of the FRP laminates at their ends in order to prevent premature failure by debonding. It was concluded that anchoring the CFRP resulted in higher capacity then the situation without anchoring. The second study was based on a comparison between strengthened homogeneous slabs and slabs with made openings. The load carrying capacity for the CFRP strengthened slabs was increased with 24%...125% in comparison to respective weakened slab, and with 22%...110% in comparison to the homogeneous slab.

A different approach to the strengthening of two-way RC slabs with or without cut-outs was studied by Elsayed *et al.* (2009). They used a strengthening technique that does not involve the use of adhesives to bond the composite strips to the tensioned side of the RC slabs. The mechanically fastened FRP-strengthening system presented by them had very good results and some advantages in comparison to the externally bonded system. For slabs without cut-outs, increase in the yield and ultimate load of about 30% and 66%, were observed in comparison to the control specimen. For slabs with cut-outs, the strengthened specimens showed increases up to 17%, 10% and 33% in the crack, yield, and ultimate loads over the corresponding control specimen.

3. Specimen preparation

For the experimental program there were prepared two series of RC slabs. The first series represents the slabs without openings (SW) and the second series refer to the slabs with openings (SO). Each series has 4 slabs from which three of them are strengthened using CFRP strips in different layouts and one unstrengthened which will represent the control slab.

The slab dimensions (110 × 110 × 5 cm) were chosen based on the laboratory possibilities of testing them. In Fig. 1 there are presented the geometric characteristics of each series and the positioning of the composite strips.

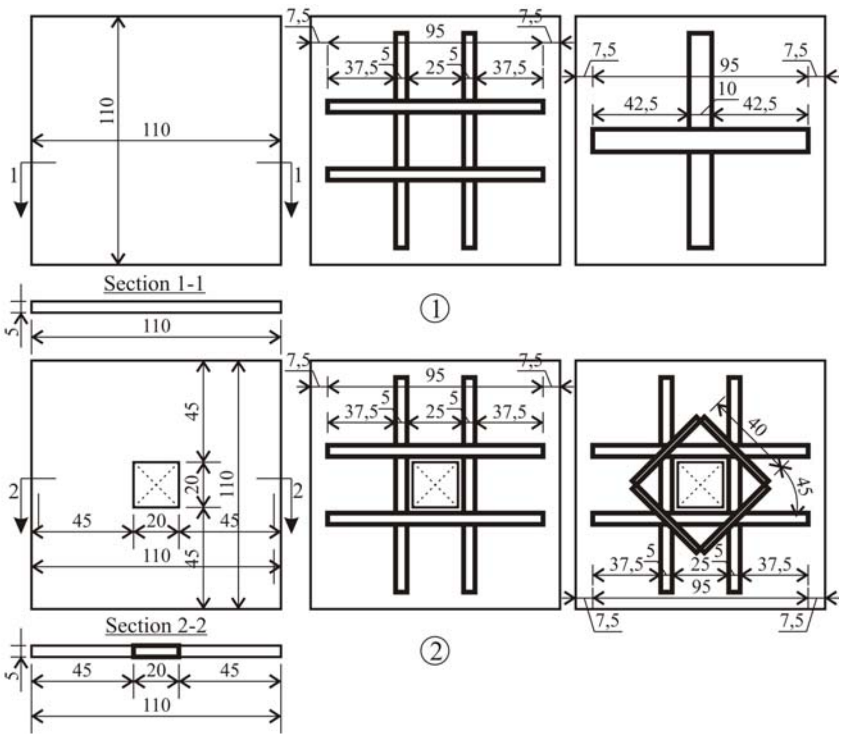

Fig. 1 – Geometry and strip positioning: 1 – SW series; 2 – SO series (dimensions in cm).

The materials used for the RC slab preparation are concrete grade C20/25 and steel wire mesh reinforcement SPPB 4 × 100 × 100. In Fig. 2 are illustrated the formwork used for the specimen preparation and the positioning of the steel reinforcement. For this experiment it was considered to use only tension reinforcement. Due to the thickness of the RC slab the concrete cover is considered to be of 1 cm. The maximum dimension of the aggregate used to realize the concrete mix is of 7 mm. The mechanical characteristics of the steel reinforcement are presented in Table 1.

Table 1
Steel Reinforcement Mechanical Characteristics

	SPPB 4 × 100 × 100
Yield strength, [N/mm^2]	460
Tensile strength, [N/mm^2]	510
Breaking elongation A_{10}	8
Breaking elongation A_5	10

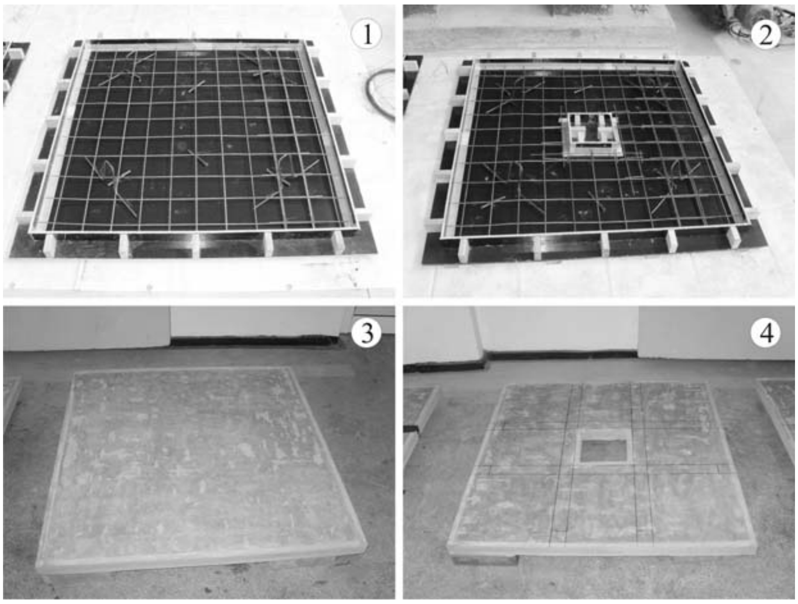

Fig. 2 – Reinforced concrete slabs preparation: 1, 2 – steel reinforcement positioning; 3, 4 – final specimens.

For the strengthening of the RC slabs there were used carbon fibre composite strips from MAPEI which were bonded to the lower face (tensioned face) of the RC slabs as supplementary tension reinforcement. The adhesive is a two component product based on epoxy resin, selected fine-grain aggregates and special additives according to a formula developed by the producing company.

Prior to adhesive application the surface of the reinforced concrete slab was prepared. The concrete substrate was prepared by removing all traces of cement laitance and form-release oil and vacuumed in order to remove all the dust particles. Primer was applied on the RC slab in order to increase the bonding between the adhesive and concrete substrate (Fig. 3).

Fig. 3 – Substrate preparation: 1 – removing cement laitance and traces of form-release oil; 2 – vacuum dust removing; 3 – marking and applying the primer.

In the Tables 2,..., 4 the mechanical and technical characteristics of the materials used for strengthening the RC slabs are given.

Table 2
CFRP Strips Mechanical Characteristics (MAPEI, 2010)

Characteristic	MAPEI Carboplate type		
Thickness x width × length, [mm]	1.4 × 950 × 50	1.4 × 400 × 50	1.4 × 950 × 100
Density, [g/cm^3]	1.56	1.56	1.56
Modulus of elasticity, [GPa]	200	200	200
Tension strength, [MPA]	3,300	3,300	3,300
Ultimate elongation, [%]	1.4	1.4	1.4

Table 3
Adhesive Mechanical Characteristics (MAPEI, 2010)

Characteristics	ADESILEX PG1
Mixing ratio	Component A : Component B = 3 : 1
Complete hardening time, [days]	7
Concrete-Carboplate bond strength	> 3 (failure of concrete)
Compressive modulus of elasticity, [N/mm^2]	6,000
Compressive strength, [N/mm^2]	> 70
Shear strength, [N/mm^2]	> 25

Table 4

Primer Mechanical Characteristics (MAPEI, 2010)

Characteristics	MapeWrap Primer 1
Mixing ratio	Component A : Component B = 3 : 1
Density, [g/cm^3]	1.1
Application temperature range, [^{o}C]	+10…+30
Concrete-Carboplate bond strength, [N/mm^2]	> 3 (after 8 days at +23^{o}C)
Complete hardening time, [days]	7

In Fig. 4 are presented the steps in applying the CFRP reinforcement on concrete slabs.

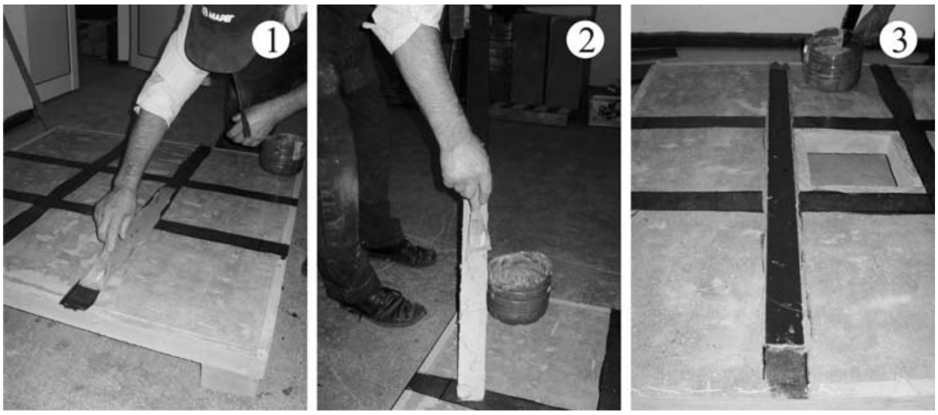

Fig. 4 – Applying the CFRP reinforcement strips: 1 – applying the adhesive on the RC slab; 2 – applying adhesive on the CFRP strip; 3 – applying the CFRP strip on the RC slab.

4. Experiment Setup

For the experiment the RC slab is considered to be simply supported on all sides and the loading to be transmitted through four points using rubber elements as presented in the Fig. 5.

The applied force will be monitored using a force cell which is connected directly to the loading device. During the experiment the displacement in different points is measured using linear variable differential transformers (LVDT). The strains in CFRP reinforcing strips will be measured using strain gauges (SG) with two measuring grids (T-rosette). The application of the strain gauges is realized in laboratory conditions respecting the indications given by norms and producing company (Bejan *et al.*, 2006; ASTM D-3039). The positioning of the LVDTs and SGs for the data acquisition is presented in Fig. 6.

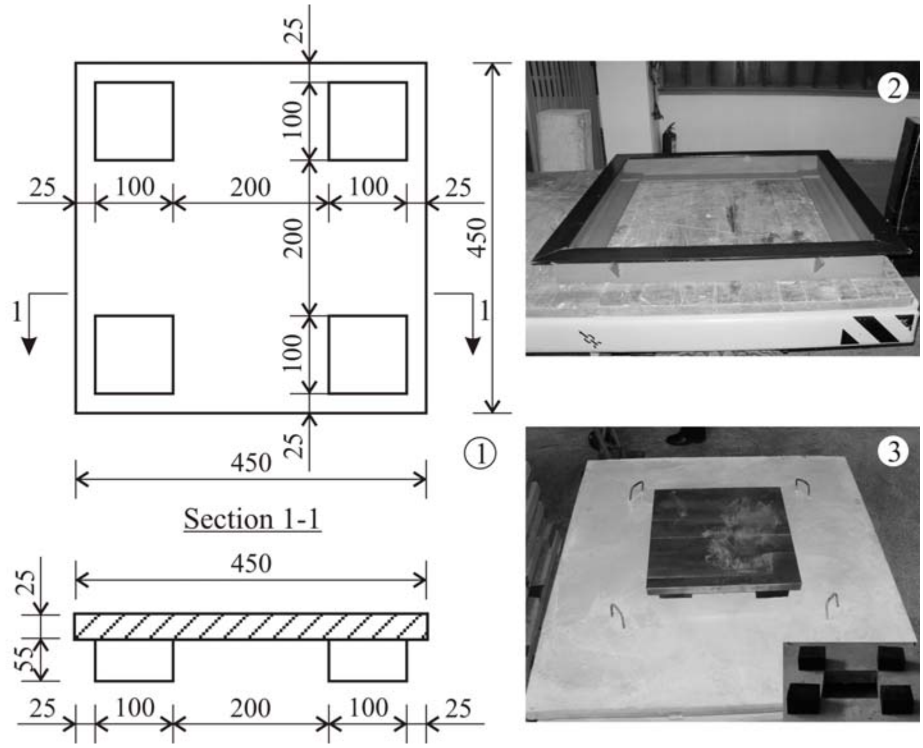

Fig. 5 – Support and loading system: 1 – load transmitting system;
2 – Support system; 3 – load transmitting system position.

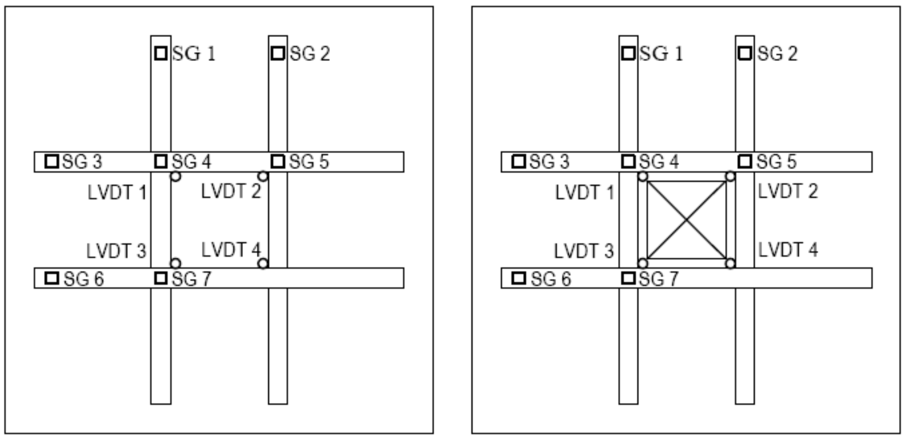

Fig. 6 – SG and LVDT positioning for the strengthened RC slabs
with and without openings.

5. Conclusions

The use of fibre reinforced polymer composites for the strengthening of the reinforced concrete slabs comes with important advantages in comparison with the “traditional” solutions that were used in the past and even in the present.

Some of these advantages are: the permanent loads don’t increase considerable by using FRP materials; these materials are not affected by corrosion; the possibility of designing the orientation of the fibres from the FRP reinforcement in order to conduct their properties in the needed direction of strengthening.

A good preparation for the experimental testing is needed in order to obtain accurate results which reflect the efficiency of the strengthening system analysed. The acquisition of as many data as possible is important in order to analyse and observe the way the strengthened element acts under loading and before failure.

The study of these strengthening techniques is essential for overcoming the disadvantages and problems that appear during installation and service life.

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STUDIU EXPERIMENTAL AL PLĂCILOR DIN BETON ARMATE PE DOUĂ DIRECŢII CU SAU FĂRĂ GOLURI CONSOLIDATE CU PLATBANDE COMPOZITE
A: Organizarea experimentului

(Rezumat)

Se analizează fezabilitatea consolidării plăcilor din beton armat solicitate la încovoiere folosind platbande compozite polimerice armate cu fibre din carbon lipite pe faţa tensionată a plăcii. În cadrul experimentului sunt analizate două serii de plăci. Prima serie reprezintă plăcile fără goluri iar cea de a doua serie reprezintă plăci cu goluri în zona centrală. În cadrul fiecărei serii de epruvete există o placă de control neconsolidată faţă de care se vor raporta rezultatele. Organizarea modului de încercare şi instrumentare al plăcilor din beton armat permite determinarea rigidităţii generale şi a rezistenţei la încovoiere a plăcilor consolidate în comparaţie cu plăcile de control neconsolidate.