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STRUCTURAL RESPONSE OF REINFORCED CONCRETE BEAMS STRENGTHENED IN FLEXURE WITH NEAR SURFACE MOUNTED FIBRE REINFORCED POLYMER REINFORCEMENT EXPERIMENTAL SETUP

BY

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Abstract. This paper presents the organization of an experimental study on the efficiency of near surface mounted (NSM) carbon fibre reinforced polymer (CFRP) reinforcement for the flexural strengthening of reinforced concrete (RC) beams. Four series of three beams each, having the same cross section and longitudinal tensile steel reinforcement, are investigated. The shear reinforcement is designed so that flexural failure will prevail. First and second series are strengthened with CFRP bars. For the third and the fourth series CFRP strips are used for strengthening. One reference beam is realized without any strengthening. The experiment setup of the RC beams allows determining the overall stiffness and flexural capacity of the strengthened specimens in comparison to the reference one.

Key words: near surface mounted; carbon fibre reinforced polymer; reinforced concrete; composite strips.

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1. Introduction

The use of fibre reinforced polymer (FRP) composites for the strengthening of deficient RC structural elements has increased during previous years due to the fact that they offer significant advantages when compared to traditional materials, like steel and concrete. These benefits include high durability and tensile strength, low self weight and easy application.

The most common method used is represented by externally bonded reinforcement (EBR), in which the composites are applied directly on the face of the RC element to be strengthened, using epoxy adhesives. The research carried out until now has revealed that the full tensile strength of the FRP material is not used, mainly due to their premature debonding (Lorenzis, 2002; Cruz, 2004; Barros, 2005; Ţăranu, 2006; Hollaway, 2008).

Near Surface Monted (NSM) FRP reinforcement has attracted a significant amount of attention in both research and practical applications, as an attempt to overcome the disadvantages of the EBR technique. The principle of this method is to install FRP bars/strips into pre-cut grooves in the concrete cover of the elements to be strengthened. The bond between carbon fibre reinforced polymer (CFRP) and concrete is realized with epoxy adhesive. (Lorenzis, 2007)

The absence of relevant provisions, regarding NSM technique, from the existing codes on the FRP strengthening of RC structures (fib TG 9.3; ACI 440.2R-02), makes this method much limited when compared to EBR solutions.

However, the international engineering community has become aware of the practical advantages of this method among which: less risk to debonding from the concrete substrate; better protection to accidental impacts and unchanged aesthetic features. (Barros, 2006)

In the available scientific literature some studies can be found regarding the applicability of this technique to RC structures with good results in increasing the load carrying capacity and the overall stiffness.

2. Literature Review

Extensive research has been carried out by many research teams to assess the effectiveness of NSM technique for strengthening RC beams subjected to bending.

Barros and Fortes (2005) conducted a study on flexural strengthening of RC beams using CFRP laminates bonded into slits. The aim of the study was to increase the load carrying capacity of the test specimens subjected to bending. The results of the experiments indicated an average increase of 91% of the ultimate load for the strengthened RC beams in comparison with the benchmark. The maximum strains in the CFRP laminates ranged from 62% to 91% of its ultimate strain revealing that this technique can mobilize stress levels close to the tensile strength of the composite material.

Teng *et al.* (2006) analysed the influence of the embedment length of NSM CFRP strips on a group of five, 3.2 m long RC beams with rectangular cross section (150 × 300 mm), strengthened in flexure. The results of the tests showed that the debonding failure mode of NSM CFRP strips was interfacial at the FRP-epoxy adhesive interface. Flexural tests indicated that a significant increase in the ultimate load and post-cracking stiffness can be achieved using CFRP reinforcement.

Capozucca (2009) investigated the behaviour of RC beams damaged and strengthened with NSM CFRP rods. Results of static and dynamic tests showed an improved load deflection response and a high ultimate load capacity for the investigated beams. The failure mechanisms for all beams were characterized by the crushing of the concrete on the compressed side.

Al-Mahmoud *et al.* (2009) developed an experimental program regarding overall behaviour of RC beams strengthened by NSM and subjected to flexure. The NSM reinforcement was applied on the beams using epoxy adhesive and cement mortar. The results of the tests showed an increase of the flexural strength of RC beams for both filling material used for bonding. The concrete grade does not influence the load-carrying capacity of the strengthened beam when NSM system fails.

Kalayci *et al.* (2010) carried out a study to identify the effects of groove size tolerance on NSM FRP system. The main conclusion of the experiment showed that a groove size tolerance up to ±22% does not affect the overall performance of such systems.

Costa and Barros (2010) analysed the influence, in terms of shear resistance, of cutting the steel stirrups to install CFRP strips for the flexural strengthening of RC beams. The obtained results showed that, for monotonous loading, cutting the bottom arm of the steel stirrups led to a decrease of the beam's load carrying capacity less than 10%.

3. Specimen Design

For the experimental program a total of four series of specimens, consisting in 3 m long RC beams with a rectangular cross section of 200 × 300 mm have been conceived. Concrete grade used is C25/30 and the compression strength is determined according to the standard procedures (SR EN 12390-2).

The tension and compression reinforcements used are steel bars with 8 mm diameter. The shear reinforcement, designed to induce the flexural failure, consists of steel stirrups of 8 mm nominal diameter spaced at 100/150 mm. In Fig. 1 the geometric characteristics of each series and the position of the composite bars and strips are presented. Mechanical characteristics of the steel reinforcement are presented in Table 1.

Table 1
Steel Reinforcement Mechanical Characteristics

	PC52	OB37
Yield strength, [N/mm^2]	360	255
Tensile strength, [N/mm^2]	510	360
Breaking elongation A_{10}, [%]	–	–
Breaking elongation A_5, [%]	20	25

The thickness of the concrete cover is 25 mm on the lateral and upper faces of the beam and 35 mm on the bottom one.

CFRP bars used have a nominal diameter of 8 mm, 3 m long and with a smooth exterior texture. CFRP strips have a thickness of 1.4 mm with a width of 12 and 18 mm. The values of the ultimate tensile strength and modulus of elasticity are equal to 2,068 MPa and 124/131 GPa, respectively (bars/strips) given in the product technical sheet of the manufacturer (MAPEI, 2010).

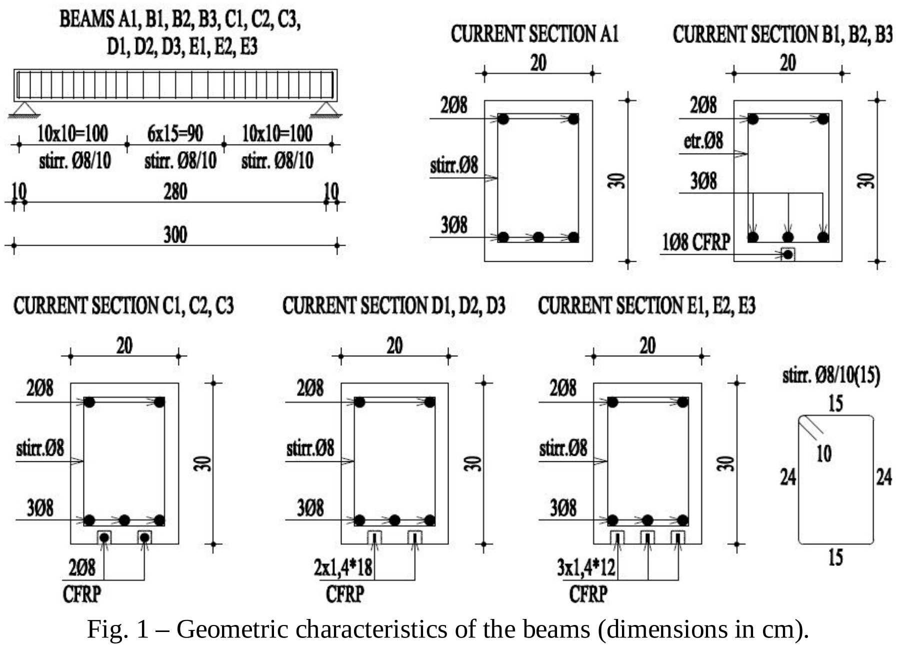

Fig. 1 – Geometric characteristics of the beams (dimensions in cm).

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 (Mapei, 2010).

Installation of the NSM reinforcement begins by cutting the grooves with a diamond blade cutter. Pressurised air is used to remove dust and debris, to ensure a better adherence between the concrete and the CFRP elements. Each groove is filled halfway with epoxy adhesive and then the bar/strip is inserted and lightly pressed so the paste is forced to flow around and fill completely the space between it and the sides of the groove. The surface is levelled and the excess material is removed.

One beam (A1) is tested without strengthening and serves as the control specimen. First (B1, B2, B3) and second (C1, C2, C3) series of girders are strengthened using one and respectively two CFRP bars with 8 mm diameter, installed into 15 mm rectangular grooves situated on the tension side of the beams.

Third (D1, D2, D3) and fourth (E1, E2, E3) series of beams are strengthened with two and respectively three CFRP strips having the dimensions 1.4 × 18 mm and respectively 1.4 × 12 mm. The composite laminates are installed into 5 × 30 mm rectangular grooves situated also on the tension side of the beams.

The positions of the grooves was established after consulting similar performed studies (Lorenzis, 2002; Cruz, 2004; Barros, 2005; Barros, 2006, 2007) and are represented in the Fig. 2.

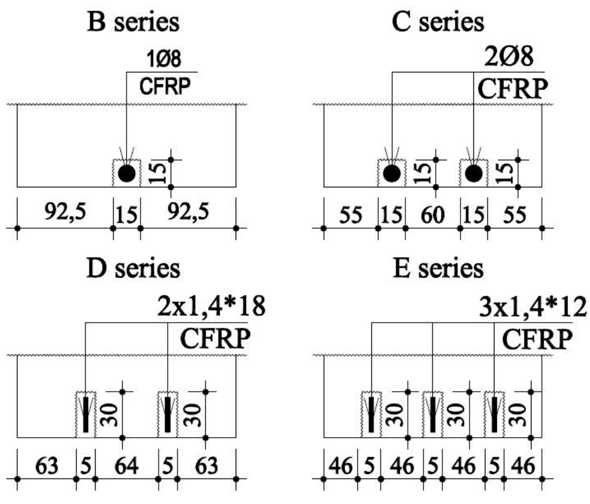

Fig. 2 – Positions of the grooves (dimensions in mm).

4. Experimental Setup

For the experiment the RC beams are simply supported and tested under four-point bending. The applied load is monotonically increased approximately by 2 kN steps and monitored using a load cell which is connected directly to the loading device (Fig. 3).

Fig. 3 – Support and loading system.

The deflections are measured during the experiment using five linear variable differential transducers (LVDT), which are mounted at midspan and at 40 cm and 80 cm from midspan on each side as presented on Fig. 4.

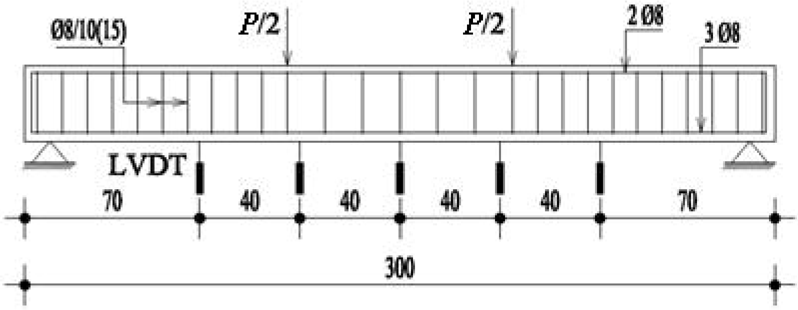

Fig. 4 – Positions of LVDT's (dimensions in cm).

The strains in CFRP reinforcement are measured using strain gauges (SG) installed in characteristic points for each NSM bar/strip, chosen based on similar studies and provisions given by norms (Bejan *et al.*, 2006; ASTM D-3039).

4. Conclusions

NSM CFRP method offers some significant advantages, when compared with EBR solutions, including a reduced risk of debonding, a more efficient use of the FRP material and a better protection from the external sources of damage.

A good preparation of the experimental testing and an analytical model to reflect the reality is needed in order to understand the effects of the strengthening parameters on the structural performance of the RC members.

An experimental program has been conceived at the Faculty of Civil Engineering and Building Services from Iaşi, to evaluate the response of RC beams strengthened in flexure with NSM FRP reinforcement. It is anticipated that the results will clarify some uncertain aspects of the technique and its advantages compared to EBR.

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 until failure.

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RĂSPUNSUL STRUCTURAL AL GRINZILOR DIN BETON ARMAT CONSOLIDATE CU FÂŞII COMPOZITE APLICATE LÂNGĂ FEŢELE EXTERIOARE
Organizarea experimentului

(Rezumat)

Se prezintă organizarea unui studiu experimental privind consolidarea la încovoiere a grinzilor din beton armat cu ajutorul fâşiilor compozite armate cu fibre, montate lângă fețele exterioare (NSM). În cadrul experimentului urmează să fie testate patru serii de grinzi având aceeaşi secțiune transversală. O grindă de control neconsolidată este realizată, față de care se vor raporta rezultatele. Testarea acestora permite compararea rigidității generale şi a rezistenței la încovoiere a grinzilor consolidate în comparație cu grinda de control neconsolidată.