FACTA UNIVERSITATIS
Series: **Architecture and Civil Engineering** Vol. 8, N° 2, 2010, pp. 177 - 185
DOI: 10.2298/FUACE1002177R

EFFECTS OF RC BEAMS REINFOCEMENT USING NEAR SURFACE MOUNTED REINFORCED FRP COMPOSITES

UDC 624.072.22:691.32(045)=111

Slobodan Ranković[1], Radomir Folić[2], Marina Mijalković[1]

[1]The Faculty of Civil Engineering and Architecture of Niš, Serbia
[2]Department of Civil Engineering of the Faculty of Technical Sciences, Novi Sad, Serbia

Abstract. *This paper analyzes application of modern reinforcement methods for reinforced concrete (RC) beams using fiber-reinforced polymer (FRP) materials. Basic characteristics of FRP materials and the method of mounting the FRP bars within concrete, that is, near the surface of the beams (NSM method) are presented. The properties of this method and its advantages in comparison to externally bonded reinforcement laminate method (EBR) have been analyzed. The results of measured deflections and width of the cracks of the beams reinforced by FRP bars, depending on the load are presented and discussed, in comparison to the results obtained from the non-reinforced beams. The experimental research was published at the Faculty of Civil Engineering and Architecture of Niš in 2009.*

Key words: *Strengthening, FRP composite, NSM method, GFRP reinforcement, testing*

1. INTRODUCTION

Application of composite materials has become very prominent lately, especially for remedying and reinforcing the reinforced concrete (RC), pre-stressed concrete (PC), masonry, timber and even various steel structures. Usage of fiber reinforce polymer (FRP) composites as additional reinforcement, is a very attractive technique due to numerous advantages, in respect to the conventional methods (addition of new concrete and steel reinforcement, pre-stressing, addition of new steel elements), particularly for RC structures reinforcement. The most important advantage of these composite materials is their high strength and lightness, resistance to corrosion and simplicity in installation [7]. In combination with pre-stressing they give especially good results, and they are particularly suitable for applications in seismic areas. The progressively increasing usage of FRP is illustrated by the fact that numerous global manufacturers of material, e.g. from Switzerland (*Sika*), Italy (*Mapei, Sinit, Sireg*), USA (*Hughes Brothers*), Canada (*Pultral*), Japan..., produce some of the varieties of these products [1]. Even though the initial investment is

Received February, 2010

higher, due to a higher price of the material, the speed and ease of installment, and resistance to the aggressive environment, retained dimensions of the structures and esthetic appearance, they can be advantageous in respect to the other ways of strengthening [9].

The non-metal reinforced used, most often produced by pultrusion process, whose basic component (polymer fibres) can be made of carbon (CFRP), glass (GFRP) or aramid (AFRP). The other component is the matrix, most frequently made of epoxy resin, with the filler and additives for enhancement of some of the properties of the final product, FRP reinforcement. [6]. Then the reinforcement is shaped into laminates, sheets, bars or strips. (figure 1).

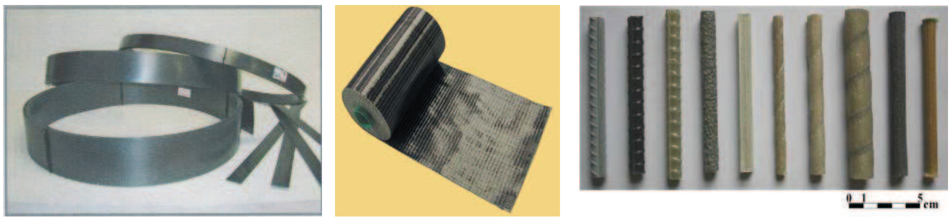

Fig. 1 Shapes of FRP elements: Laminates, sheets, bars

They are used in reinforcing the structures of concrete, bricks, metal and timber against buckling, shearing or compression. Various structural elements can be reinforced: beams, slabs, walls or columns (figure 2).

Fig. 2 Examples of application of NSM FRP bars (Nanni 2000)

When reinforcing the RC structures exposed to buckling, two primary methods of application of FRP stand out: EBR - external bonded laminate reinforcement and NSM – near surface mounted bars. As opposed to the EBR method of using the FRP elements, which has been developing for more than two decades, the NSM method of FRP bars application emerged only in the last decade and has not been sufficiently dealt with in literature, and is lacking appropriate recommendations and designing guidelines. Internationally, the fundamentals for design and application of these structural reinforcement systems were laid out in the papers by Nanni, Rizkalla, Teng, De Lorenzis, Park, Jung, Barros, Derby-a, Thiagarajan, Ashour, Wang, Belarbi, Galati and others, and in Serbia by R. Folić and S. Ranković [7,8,9,10,11].

2. FRP Material Characteristics

The FRP composite materials used here have 70% of glass, aramid or carbon fibers, 5 to 25 µm in diameters, bound by a polyester resin (matrix) (*figure 3*) and accordingly are called GFRP, AFRP or CFRP. Their mechanical characteristics depend on the matrix and fibers (*figure 4*), and the tensile strength in the fiber direction is far higher than that of steel (*figure 5*). Behavior of FRP material at tensioning is linearly elastic until failure.

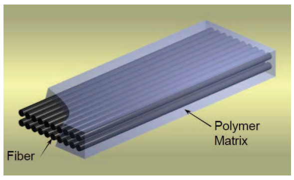

Fig. 3 Composition of FRP

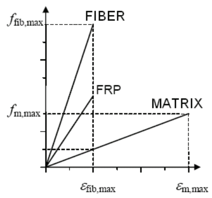

Fig. 4 Component ratio

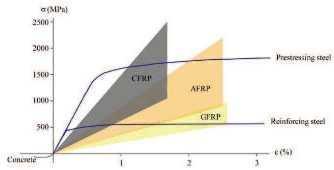

Fig. 5 Tensile strength

The FRP bars can be manufactured in an almost unlimited number of subvariants, that is, shapes. Thus, NSM FRP reinforcement can have square, rectangular or oval cross-section of the bar. The term "bars" is adopted as universal for all kinds of cross-section forms, while the term "strips" remains reserved for thin and narrow bands, strips [2]. Various forms of cross-section provide a variety of advantages and offer various possibilities for practical application. For instance, the square bars increase the specific reinforcement area of the bar, whereas the circular bar cross sections are easier to anchor during pre-stressing. Narrow thin strips increase the surface coefficient and thus reduce the risk of adhesion loss, but require a thicker concrete coating for a given surface area of the cross section. The FRP bars are produced with a variety of surface textures, which have a considerable effect on the increase of adhesiveness of the NSM reinforcement. Their surface can be smooth or rough, with spiral grooves or ribbed. In practical application, the choice depends more on the actual conditions, such as the available thickness of concrete cover, availability of cost of certain types of FRP reinforcement.

Adhesives constitute a very important part of the FRP reinforcement systems which are most frequently on the basis of an epoxy resin or rarely cement, and they are used as a binder with concrete. The total bearing capacity of the reinforcement system considerably depends on their performance.

On the basis of opinions on application of FRP elements available in the literature, the following conclusions of their characteristics are drawn: 1) under a short-term load, they behave linearly-elastic until failure, 2) they are not ductile and thus limit the ductility to the reinforced elements 3) the value of the adhesion should be determined experimentally (by a "pull-off" test), 4) the service life of the material should be taken into consideration [7].

3. NSM FRP Method

The NSM method is based on the technique, whereby the bar-shaped or strip-shaped FRP elements are placed as additional reinforcement in the groove made in concrete cover, and they are embedded in epoxy or cement resins (adhesives), which creates adhesion with the concrete, and provides anchoring [2,12] (figure 6).

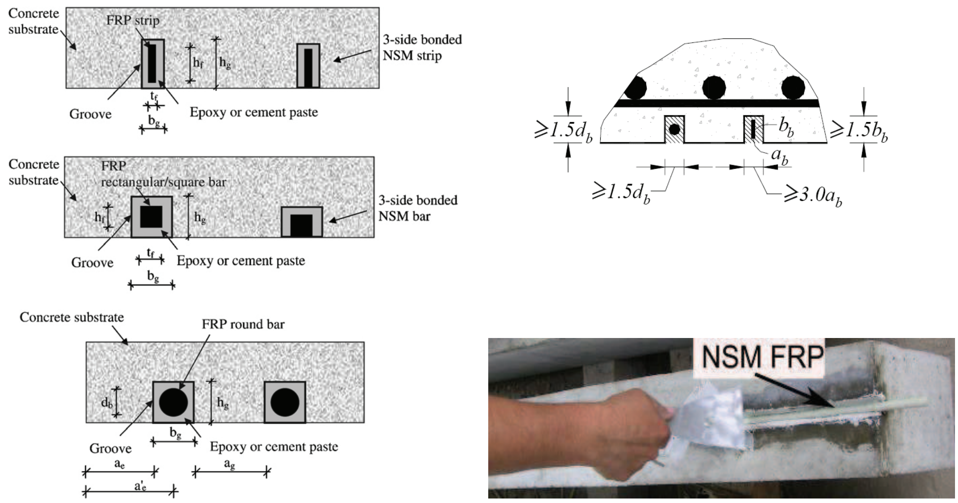

Fig. 6 Application of NSM FRP "bar" elements

Usage of the NSM reinforcement method via the FRP elements is justified in the following cases: 1) if the reinforced surface is susceptible to damage; 2) if the reinforced surface is rough; 3) if the concrete surface has insufficient tensile strength, while the remaining part of the cross section does have the sufficient strength and 4) if the space available to install other types of reinforcement is insufficient. These are, in fact, the most common cases occurring in practice. The limitation in application are related to provision of sufficient thickness of the of concrete cover, which should be 1.5 times larger than the diameter of the used reinforcement bars (∅6÷∅16 mm). Available experience also suggests that the form of the FRP element, size and form of the, size and shape of the groove, types of fiber, types of adhesive, concrete tensile strength and concrete surface preparation methods should be taken into account. [3,4]. According to the up-to-date experience in application of the NSM systems, three kinds of failure are possible: 1) separation from the adhesive; 2) separation of the concrete; and 3) under tensile forces, failure of the FRP elements is possible.

By analyzing the behavior of various kinds of reinforcements reveal that the NSM method has a number of advantages in comparison to EBR FRP method because it is safer and exhibits higher durability in respect to the EBR [6]. Namely, this system of reinforcement allows better adhesion, that is, anchoring, because the bars can be shaped (textured/ribbed) in the fabrication process, which provides a larger specific area for binding with concrete [11]. The NSM reinforcement can be more easily pre-stressed. Besides, thermal protection becomes easier, ant his is one of the basic issues in application of FRP reinforcement, due to the thermal instability of adhesives. Durability, which may become compromised due to the aggressive action of the environment, [8] or due to the physical damage is also enhanced when applying the NSM system, which makes this technology particularly suitable for reinforcement of the regions in beams and slabs where negative momentums occur.

4. REZULTATS OF NSM GFRP REINFORCED BEAMS

At the Faculty of Civil Engineering and Architecture of Niš experimental testing of bearing capacity of beam girders reinforced by the GFRP reinforcement by loading until failure was performed. In figure 7, dimensions, reinforcement details and load application method are presented.

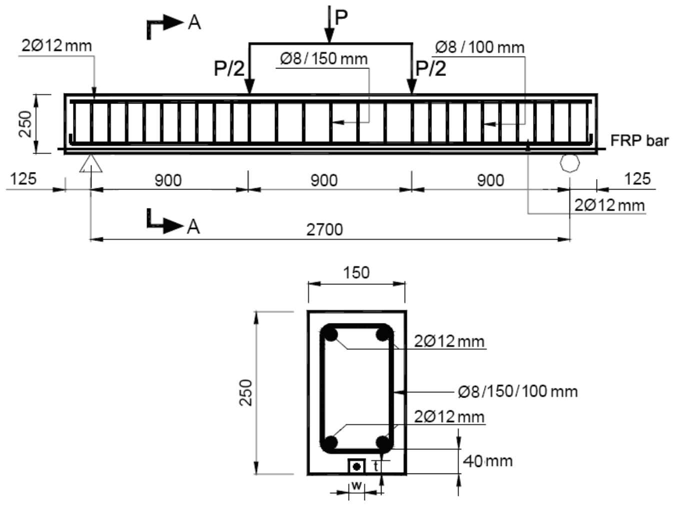

Fig. 7 Details of reinforcement and load application method.

In Figure 8 a presentation of a beam with the GFRP reinforcement is given, and its deformed shape under the maximum load. The load is applied with two concentrated forces at the thirds of the span (four point load). For reinforcement, the FRP bars G-rod Ø10 mm were used and the epoxy adhesive MapeWrap 11, by the Italian manufacturer MAPEI [5]. Recording of measuring data was performed by the acquisition system MGCplus, and the quasi-dynamic by reading of instruments for one second.

Fig. 8 Experimental setup – prior to loading and under loading.

Experimental results presenting the relation load-deflection at the half of the span for a beam reinforced by a GFRP bar and for the control beam are given in the figure 9. It can be observed in the diagram that the maximum load achieved by reinforcement was for 73% higher, that is, that by applying the NSM method, the maximum force was increased from 45 kN to 78 kN. Also notable is the satisfactory ductility of the reinforced beam which makes this method advantageous for seismic reinforcement. Until onset of the first cracks there is no difference in rigidity of the beams, it is generated in the part of the diagram from the first cracks to the onset of yielding in the reinforcement, and particularly after that point. The failure occurred due to separation of the epoxy resin and concrete due to tensile overstressing of concrete.

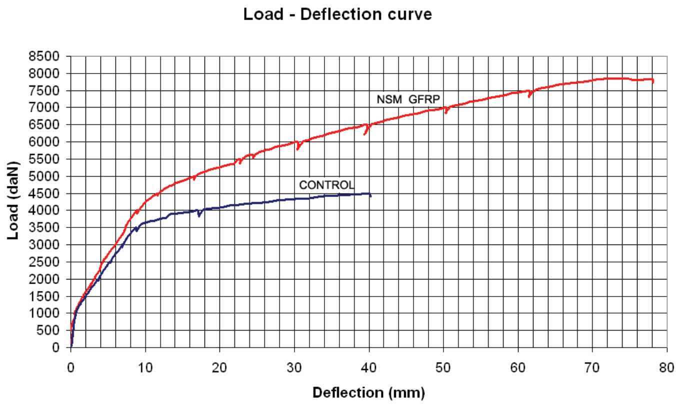

Fig. 9 Diagrams load-deflection in L/2 of the reinforced and control beam.

Cracks distribution and their propagation have been measured during loading at 5 kN, which as a consequence has a certain decrease of force, particularly at high loading levels. For this reason, the curve is not ideally smooth. At the half of the span, the strain meter was installed whose LVDT measuring instrument is located at 20 mm from the upper and lower edge of the beam respectively. The strain meter in the tensed zone (with the gauge length of 200 mm) continuously measured the cracks width, that is, the sum of cracks widths along 200 mm of gauge length, and the results of local deformations are presented in the figure 11.

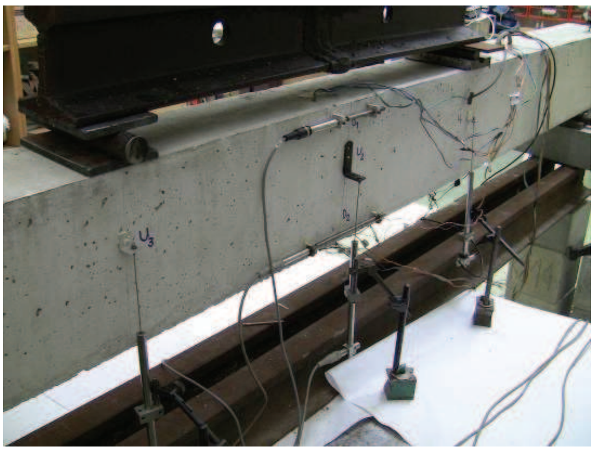

Fig. 10 Distribution of measuring instruments on L/2 (LVDT and strain meter)

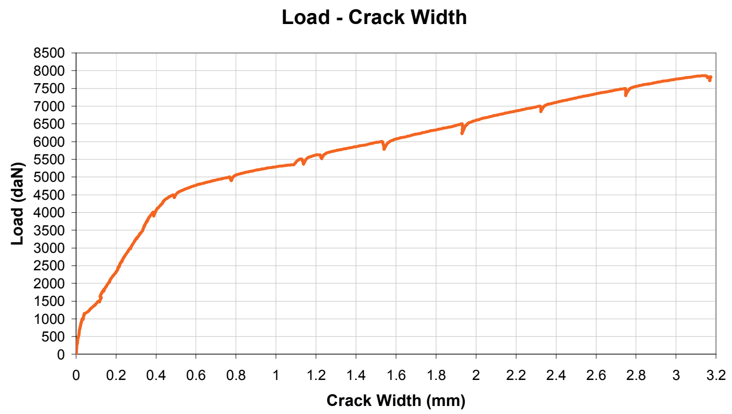

Fig. 11 Diagram loading – crack width reinforced by the GFRP reinforcement.

From the diagram in figure 11, the sum of crack widths along the length of 200 mm in function of the loading can be analyzed. The same form of diagram, as in deflection can be observed, that is, occurrence of three characteristic zones: 1) until onset of the first cracks (0.04 mm), 2) since onset of the first cracks until the occurrence of yield in steel reinforcement (0.5) and 3) since the onset of the reinforcement yield until failure (3.15 mm). The same instrument measured elongation on the concrete surface at the level of the GFRP reinforcement, i.e. strain (figure 12). Through application of this procedure, it is possible to directly determine tensile strength of concrete at bending. Namely, via the value of strain obtained with the onset of the first crack, the tensile stress in concrete can be defined, which will be the subject of another paper.

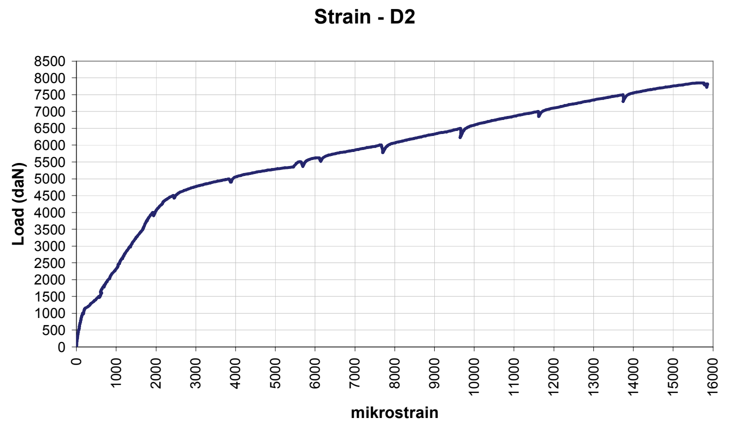

Fig. 12 Tension strain diagram on the concrete surface.

From the diagram in figure 12 it may be observed that the first cracks occur at dilatation of approximately 200 με, that is, elongation of about 0.04 mm on the gauge length of 200 mm. Almost the same values were obtained on the control beam, while the elongations occurring at yield and failure are lower than in the beam reinforced by the GFRP reinforcement.

5. Discussion of Results and Conclusion

It is progressively evident that composite materials in the field of construction engineering are becoming the materials of the future. Price difference, which is a principal limiting parameter preventing wide application, is reducing each passing year, and the development of technology enhances the quality of the materials. It is the reason that the FRP reinforcement is becoming a very likely alternative to the conventional reinforcement method of addition of missing steel reinforcement. Application of the NSM reinforcement method, as a relatively new one, offers great potential in restorations and strengthening of concrete structures and extension of their service life.

Analysis of the data from the available literature and independent research conducted in 2009 at the Faculty of Civil Engineering and Architecture of Nis, exhibited considerable increase of bearing capacity of the tested beams reinforced by the NSM method. In the actual case, when only one (additional) GFRP Ø10 mm is applied, a 73% higher maximum load was registered. In the higher loading phases and after monitoring of failure mechanisms, a significant ductility of beams reinforced by the GFRP reinforcement was manifested. The failure occurred at the joint of epoxy paste and concrete. In the situations when the rigidity is not the limiting parameter the GFRP reinforcement should be favored over the CFRP bars because its cost is considerably lower.

Numerous advantages of the NSM FRP method of internal reinforcement are in many cases superior to the externally-applied FRP laminates. With a more complete regulations, and information of designs and easier accessibility of the FRP materials in the market, its wider application in practice can be expected.

This paper has been a result of the research projects no. 16001 and 16018 financed by the Ministry of Science of the Republic of Serbia.

We would like to thank the MAPEI company (the representatives in Belgrade) for the assistance in FRP material, used in experimental research.

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EFEKTI OJAČNJA AB GREDA ŠIPKAMA OD VLAKNASTIH KOMPOZITA POSTAVLJENIM UNUTAR ZAŠTITNOG SLOJA BETONA

Slobodan Ranković, Radomir Folić, Marina Mijalković

U radu je analizirana primena savremene tehnike ojačanja armiranobetonskih (AB) greda upotrebom elemenata od FRP materijala (polimera ojačanih vlaknima, tj. vlaknastih kompozita). Prikazane su osnovne karakteristike FRP materijala i metode postavljanja FRP šipki unutar zaštitnog sloja betona, tj. blizu površine greda (NSM metoda). Analizirana su svojstva ove metode i njene prednosti u odnosu na spolja lepljene FRP laminate (EBR metoda). Prikazani su i diskutovani rezultati merenih ugiba i širine prslina ispitivanja grednih nosača, ojačanih GFRP šipkama, zavisno od opterećenja, uz upoređenje sa rezultatima dobijenim na neojačanoj gredi. Eksperimentalna istraživanja su obavljena na GAF u Nišu 2009. godine.

Ključne reči: *Ojačanje, FRP kompoziti, NSM metoda, GFRP šipke, ispitivanje*