FACTA UNIVERSITATIS
Series: **Architecture and Civil Engineering** ONLINE FIRST
https://doi.org/10.2298/FUACE230630037R

Original Scientific Paper

STRENGTHENING OF REINFORCED CONCRETE BEAM ELEMENTS USING ROD-FORM COMPOSITE MATERIALS

UDC 624.012.45
693.557:677.494.7

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

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

Abstract. *The paper emphasizes the advantages of using FRP (fiber reinforced polymer) materials for strengthening reinforced concrete structures. The results of experimental research on the effects of strengthened reinforced concrete beam elements exposed mainly to bending using FRP rod-shaped elements are presented. The load disposition (experimental setup) was in accordance with the "four point load" scheme, and the measurements were made using modern measuring techniques. The results regarding the increase in the bearing capacity of strengthened beams using the NSM (near surface mounting) and EB (externally bounding) methods were compared. In particular, the load-deflection ratio until failure was analyzed, as well as the change in stiffness depending on the load level. It has been shown that the load capacity of beams strengthened with carbon fiber rods (NSM CFRP) increases by 89%, and the load capacity of beams strengthened with glass fiber rods (NSM GFRP) by 73%. The bearing capacity of beams strengthened with EB CFRP laminates increases by 51%. The ductility of strengthened beams was analyzed and it was shown that it is higher when using GFRP rod-shaped elements (DI=6.5) compared to CFRP rods (DI=5.3). The ductility of the beams strengthened by the EB CFRP method was not satisfactory (DI=2.6).*

Key words: *strengthening, NSM method, FRP reinforcement, testing*.

Received June 30, 2023 / Revised August 1, 2023 / Accepted August 15, 2023
Corresponding author: Slobodan Ranković - University of Niš, Faculty of Civil Engineering and Architecture, Niš, Serbia
e-mail: rankovics@gmail.com

*Selected paper presented at the International Conference Sinarg 2023 held in Niš, Serbia on 14-15 September 2023.
© 2023 by University of Niš, Serbia | Creative Commons License: CC BY-NC-ND

1. INTRODUCTION

Fiber reinforced polymers - FRP are a type of composite materials, composed of high-strength fibers: carbon (CFRP), glass (GFRP) and aramide (AFRP), which are impregnated with polymer resins (matrix) [1-3]. Along with them, fillers and additives are present in the mixture, giving the required characteristics to the final product. As a result of combining the input components with a special technological process (most often pultrusion), a new material with mechanical characteristics between fibers and resin is obtained. Figure 1 shows the mechanical characteristics of the materials from which FRP materials are made, while Figure 2 shows the mechanical characteristics of FRP composites.

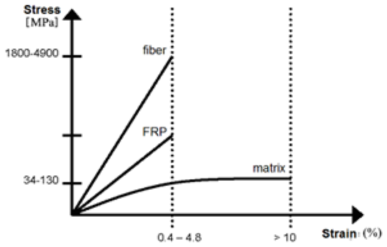

Fig. 1 σ-ε tension diagrams of the basic components of FRP

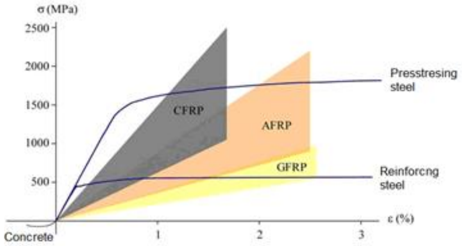

Fig. 2 σ-ε tension diagrams for the most commonly used materials (Pilakoutas, 2000)

The tendency of increasing the use of composites in relation to conventional materials, in almost all areas, is evident. The use of fiber composites as reinforcement in concrete dates back to the 60s of the last century. The reasons for attempts to replace steel reinforcement with non-metallic ones, in concrete reinforcement, lie in the desire to prevent the harmful corrosion behavior due to the aggressive effect, above all, of salt. The first FRP bars were available in the late 70s of the last century, and practical application, as the main reinforcement, in the form of GFRP bars began in 1983 in the USA. FRP products available today for construction purposes are made in various forms: rods, cables, laminates, canvases, nets and three-dimensional elements (Figure 3).

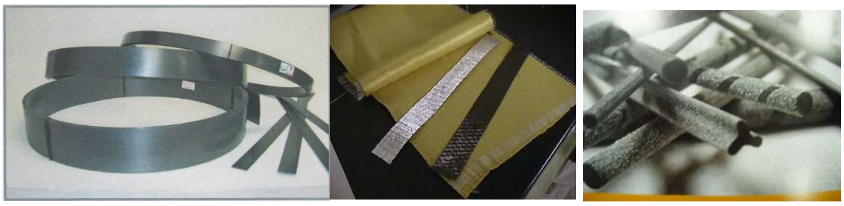

Fig. 3 The shapes of FRP elements: (a) laminates, (b) canvases, (c) rods -‘’bar’’ elements

2. NSM FRP TECHNIQUE FOR STRENGTHENING CONCRETE STRUCTURE

Two basic methods of strengthening concrete structures using FRP elements are externally bonded laminates (EB) and reinforcement placed inside the protective layer of concrete (NSM-near surface mounted FRP) (Figure 4) [4-8].

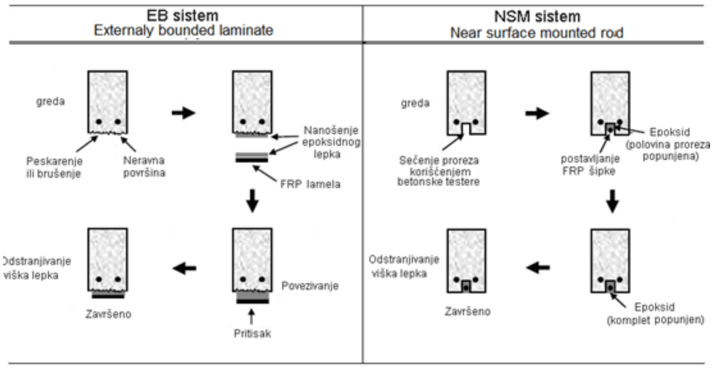

Fig. 4 Procedures for strengthening beam girders exposed to bending using EB and NSM method (Han-Choi, 2008)

Given that the adhesion of FRP elements to the concrete structure has a dominant effect on the strengthening effects and on the possibility of premature failure, numerous studies have shown the advantage of the NSM strengthening method [4-11] in this sense. The basic conclusion of those researches is that the connection properties, i.e. adhesion is influenced by a number of factors: bond length, cross-sectional dimensions of the element, type of he FRP material, cross-sectional shape of the FRP bar, degree of roughness of the FRP bar, strength of concrete (tensile and shear), strength of slot fill (tensile and shear), size, aspect ratio and the height and position of the slits, the degree of roughness of the slits. Due to the large number of influential parameters, extensive research, analytical and numerical, but above all experimental [6-9], was necessary.

In the following, some results of independent experimental research on the application of the NSM FRP strengthening method and a comparison with the EB strengthening technique are presented.

3. EXPERIMENTAL RESEARCH

In order to determine the behavior of RC beam girders, strengthened with FRP elements, under the effect of short-term loading, experimental research was conducted on samples in laboratory conditions [12-13].

This experimental analysis includes two variants of application of the additional FRP reinforcement for strengthening RC beam girders exposed to the influence of bending moments according to the "four point load" scheme (Figure 5): 1) installation of the rod-shaped FRP reinforcement inside the concrete protective layer (NSM method) and 2) external gluing of FRP laminate to the concrete surface (EB method). In the research, the FRP reinforcement was used, the composition of which consists of two types of fibers: laminates and rods with carbon fibers (CFRP) and rods with glass fibers (GFRP). An unstrengthened (control) girder was also tested, in order to determine the effects of strengthening and to compare the obtained results.

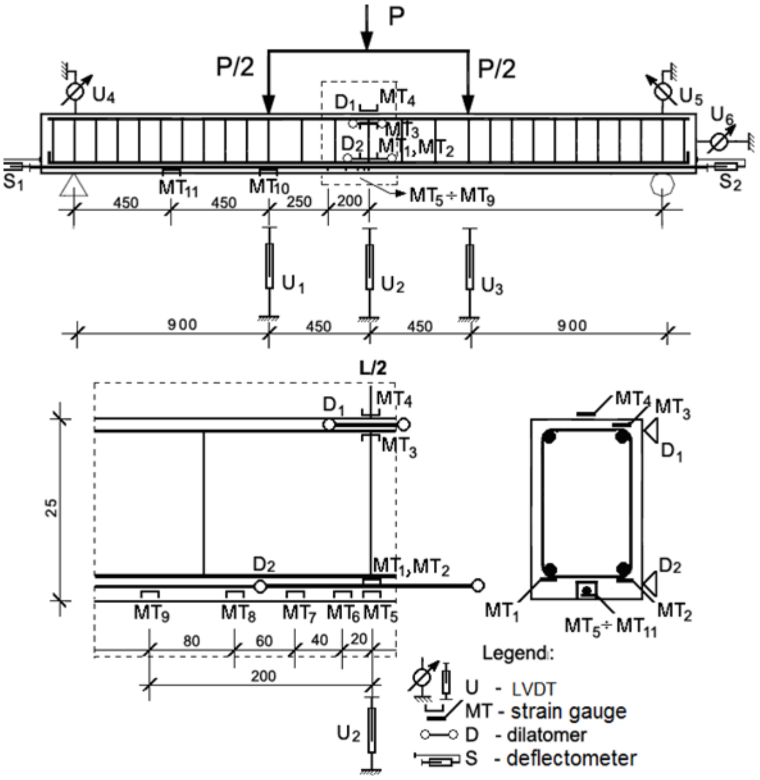

Fig. 5 Arrangement of instruments in the examined beam RC girders

Figure 6 shows the failure mechanism in the externally bonded laminate (EB) method, while Figure 7 shows the failure mechanism in the near surface mounted (NSM) method [13].

Fig. 6 Loss of bond between concrete and epoxy adhesive

Fig. 7 Failure caused by loss of adhesion of CFRP reinforcement

3.1 Analysis of test results

Global deformations (deflection), dilations in concrete, steel reinforcement and FRP reinforcement, slippage of the additional FRP reinforcement, occurrence and development of cracks, all in function of the applied load, were monitored during the loading of the girders. Due to the limited space in the paper, only the results of the load – deflection relations, as integral mechanical characteristics, for the tested variants of strengthening of beam girders are presented.

3.1.1 Deflection analysis

Deflection measurements were performed with linear displacement transducers (LVDT), eliminating the influence of support displacement. Values from the displacement transducer were read every second by the MGC plus acquisition system, using the corresponding "CATMAN" software. This provides a continuous record of the behavior of the beam element exposed to the influence of the test load. For the tested samples, the deformations of the girders under the test load are shown in Figures 8 – 11.

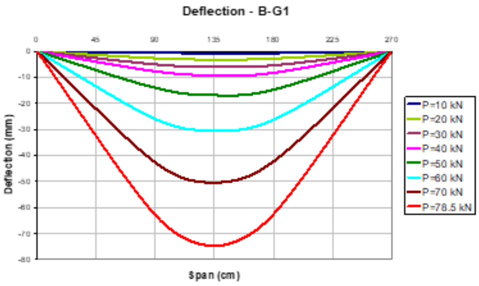

Fig. 8 Deflection of NSM GFRP beam (B-G1)

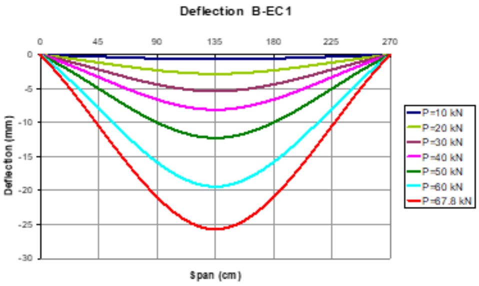

Fig. 9 Deflection of EB CFRP beam (B-EC1)

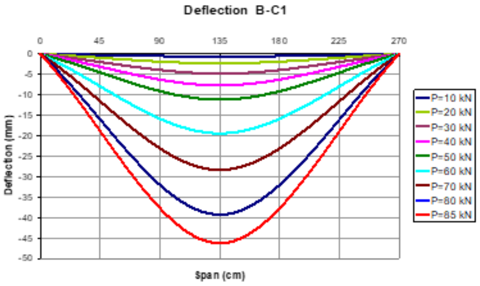

Fig. 10 Deflection of NSM CFRP beam (B-C1)

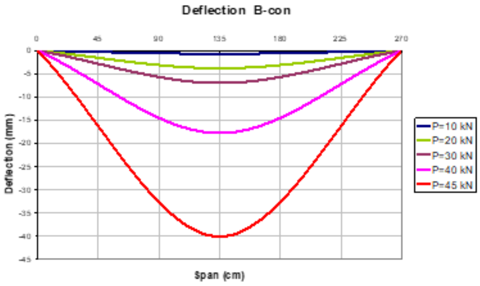

Fig. 11 Deflection of control beam (B-con)

For the purpose of comparative analysis, Figure 12 shows the results of deflections in the middle of the span obtained by testing beam girders strengthened by different methods, with the application of different materials and methods of strengthening. The comparison was made in relation to an unstrengthened (control) beam, where the reinforcement with basic (steel) reinforcement was identical for all beams [13-14].

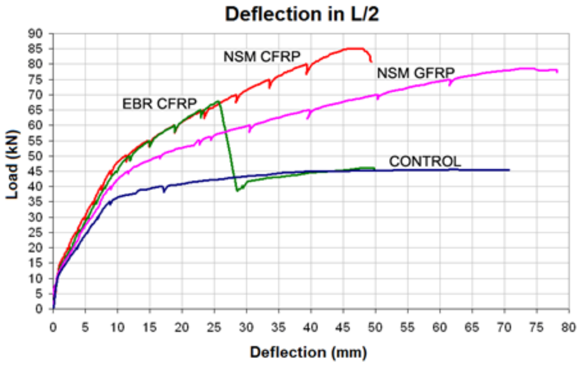

Fig. 12 Deflections in the middle of the span of the examined beams

On the diagrams, characteristic zones can be observed when applying the test load: 1) until the appearance of the first cracks, 2) from the appearance of the first cracks to the appearance of yielding in the basic (steel) reinforcement and 3) from the appearance of yielding of the steel reinforcement to failure. An almost identical behavior can be observed for all tested girders until the appearance of the first cracks, after which the strengthened girders show higher stiffness and higher ultimate load capacity. Debonding of the CFRP laminate in the EB method led to a sudden drop in force and subsequent behavior similar to that of the control beam. By comparing the deflection diagram of RC girders strengthened externally with glued laminates (EB CFRP) and in the protective layer of concrete placed (NSM CFRP), an almost identical behavior is observed until the moment of failure of the laminate by peeling.

A significant increase in load capacity can be observed with the use of the additional FRP reinforcement, which is the highest when the NSM CFRP strengthening is used, where it is as much as 89%. It is noted that the use of the GFRP reinforcement for strengthening gives very good results in terms of load capacity (by 78% higher load capacity), but also the increased deformability (bending) of strengthened girders. Considering the much lower cost of GFRP reinforcement compared to CFRP reinforcement, for cases where the stiffness of the girder is not a limiting factor, preference should be given to GFRP strengthening elements [14].

4. CONCLUSIONS

Based on, first of all, the experimentally obtained results of research on the strengthening of reinforced concrete beam girders exposed to bending to failure, it is concluded that the use of FRP reinforcement leads to a significant increase in the load capacity, stiffness and usability of strengthened beam girders, with the satisfactory ductility.

The experimental results lead to the following conclusions:

The application of composite FRP reinforcement for strengthening RC beam elements exposed to bending is a very effective method, with numerous advantages compared to other methods of strengthening.

Using only one CFRP rod with a diameter of Ø8 mm, when strengthening with the NSM technique, an increase in load capacity by 89% was found.

The beam strengthened with CFRP laminate, with the same axial stiffness as the CFRP bar, showed a 51% higher load capacity compared to the non-strengthened control beam.

With strengthening using GFRP rod with a diameter of Ø10 mm, the ultimate load capacity increases by 73%.

The bearing capacity of beams strengthened with the NSM method is higher than when using the EB method, and the use of CFRP reinforcement gives a higher load capacity compared to beams strengthened with GFRP reinforcement.

The ductility of girders strengthened by the NSM method, expressed through the ductility index (ID), has satisfactory values (ID>4) regardless of the type of FRP reinforcement and is higher when using the GFRP reinforcement (ID=6.5) compared to the application of the CFRP reinforcement (ID =5.3) by 23%.

The ductility of RC girders strengthened externally with glued laminates (EB strengthening method) is insufficient (ID=2.6). In contrast, the NSM method of strengthening shows a significantly higher ductility (ID=5.3), with the same axial stiffness of the reinforcement.

REFERENCES

1. American Concrete Institute, Committee 440 "Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures", Farmington Hills, MI, USA, 2017.
2. Fédération internationale du béton (Fib), Bulletin no. 90 "Externally applied FRP reinforcement for concrete structures". Lausanne, Switzerland, 2019.
3. Mapei FRP System, www.mapei.com
4. De Lorenzis, L. and Teng, JG.: “Near-surface mounted FRP reinforcement: an emerging technique for structural strengthening”. Composites: Part B: Engineering, 38, 119–143. (2007)

5. Firas Al-Mahmoud, Arnaud Castel, Raoul François, Christian Tourneur, “Strengthening of RC members with near-surface mounted CFRP rods”, Composite Structures (2009).
6. Tang W.C., Balendran R.V., A. Nadeem, H.Y. Leung: “Flexural strengthening of reinforced lightweight polystyrene aggregate concrete beams with near-surface mounted GFRP bars”, Building and Environment 41, 1381–1393, (2006).
7. Nanni, A.,. “North American Design Guidelines for Concrete Reinforcement and Strengthening Using FRP: Principles, Applications, and Unsolved Issues,” Journal of Construction and Building Materials, Vol. 17, No. 6-7, pp. 439-446. (2003)
8. Bilotta, A., Ceroni, F., Barros, J. A. O. , Costa, I., Palmieri, A., Szabó Z. K., Nigro, E., Matthys, S., Balaz, G., Pecce, M. "Bond of NSM FRP-Strengthened Concrete: Round Robin Test Initiative", Journal of Composites for Construction, 20(1), pp. 4015026-1–4015026-16, 2016. https://doi.org/10.1061/(ASCE)CC.1943-5614.0000579
9. Kadhim, M. M. A., Jawdhari, A., Peiris, A. "Evaluation of lap-splices in NSM FRP rods for retrofitting RC members", Structures 30, pp. 877–894, 2021. https://doi.org/10.1016/j.istruc.2021.01.054
10. Shadravan, B., Tehrani, F. M. "A Review of Direct Shear Testing Configurations for Bond between Fiber-Reinforced Polymer Sheets on Concrete and Masonry Substrates", Periodica Polytechnica Civil Engineering, 61(4), pp. 740–751, 2017, https://doi.org/10.3311/PPci.9090
11. Taljsten B, Carolin A, Nordin H.: “Concrete structures strengthened with near surface mounted reinforcement of CFRP”, Adv Struct Eng. 6(3):201–213, (2003).
12. Coelho, M. R. F., Sena-Cruz, J. M., Neves, L. A. C. "A review on the bond behavior of FRP NSM systems in concrete", Construction and Building Materialsn 93(15), pp. 1157–1169, 2015. https://doi.org/10.1016/j.conbuildmat.2015.05.010
13. Rankovic S., Folić R., Mijalković M.: Efects of RC beams strengthening using near surface reinforced FRP composites, FACTA UNIVERSITATIS,Vol8, N°2, (pp. 177-185). (2010).
14. Ranković, S., Folić, R., Mijalković, M. "Flexural behaviour of RC beams strengthened with NSM CFRP and GFRP bars – experimental and numerical study", Romanian Journal of Materials, 43 (4), pp. 377–390, 2013.

OJAČANJE ELEMENATA ARMIRANO BETONSKIH GREDA PRIMENOM KOMPOZITNIH MATERIJALA U OBLIKU ŠIPKI

U radu su istaknute prednosti upotrebe FRP (fiber reinforced polymer) materijala za ojačanje armiranobetonskih konstrukcija. Prikazani su rezultati eksperimentalnih istraživanja uticaja ojačanih armiranobetonskih grednih elemenata izloženih uglavnom savijanju korišćenjem FRP šipkastih elemenata. Raspored opterećenja (eksperimentalna postavka) bio je u skladu sa šemom „opterećenja u četiri tačke“, a merenja su vršena savremenim mernim tehnikama. Upoređeni su rezultati u pogledu povećanja nosivosti ojačanih greda primenom metoda NSM (near surface mounting) i EB (external bounding). Konkretno, analiziran je odnos opterećenje-ugib do loma, kao i promena krutosti u zavisnosti od nivoa opterećenja. Pokazalo se da se nosivost greda ojačanih šipkama od ugljeničnih vlakana (NSM CFRP) povećava za 89%, a nosivost greda ojačanih šipkama od staklenih vlakana (NSM GFRP) za 73%. Nosivost greda ojačanih EB CFRP laminatima povećava se za 51%. Analizirana je duktilnost ojačanih greda i pokazano je da je veća pri upotrebi GFRP šipkastih elemenata (DI=6,5) u odnosu na CFRP šipke (DI=5,3). Duktilnost greda ojačanih metodom EB CFRP nije bila zadovoljavajuća (DI=2,6).

Ključne reči: *ojačanje, NSM metoda, FRP armature, ispitivanje.*