doi:10.5937/jaes10-1661 Paper number: 10(2012)1, 217, 27 - 30

# NEURAL NETWORK PROGNOSTIC MODEL FOR RC BEAMS STRENGTHENED WITH CFRP STRIPS

***MSc Marijana Lazarevska****
***University of Skopje, Faculty of Civil Engineering, Skopje, Macedonia***
***Dr Ana Trombeva-Gavriloska***
***University of Skopje, Faculty of Architecture, Skopje, Macedonia***
***Dr Miloš Knežević***
***University of Podgorica, Faculty of Civil Engineering, Podgorica, Montenegro***
***Dr Todorka Samardžioska***
***University of Skopje, Faculty of Civil Engineering, Skopje, Macedonia***
***Dr Meri Cvetkovska***
***University of Skopje, Faculty of Civil Engineering, Skopje, Macedonia***

*Improper execution of bonding of FRP plates to the RC beam can result into appearance of zones where the bond is substantially weaker, and air pockets are present. This paper presents an attempt to model the weak bond zone and its influence on the global response of the externally CFRP strengthened RC beam. A numerical displacement-based fibber model was used for the prediction of the response of RC beams externally strengthened with CFRP. Also, using the concepts of artificial neural networks and the results of the performed numerical analyses, another prediction model has been made. Both models generated excellent results and some of them will be presented further below in this paper.*

*Keywords: CFRP, neural network, RC beam, strengthening, discontinuous bond*

## INTRODUCTION

Performance of the materials used in the contemporary structures can significantly change as a result of change in the environmental conditions and the increasing of the loads, which were not taken into account in the design process. All these factors may decrease the bearing capacity or structural safety of the construction during their service life. The non adequate performance of the constructions imposes the need for repairing and strengthen¬ing. Increase of the load capacity and structural safety of the flexural loaded structural members is often carried out by external bonding of additional reinforcement. In the recent years, typical retrofitting technique involves the use of external bonded lighter, stronger and more durable FRP (fibre reinforced polymer) strips.

In order to achieve successful external strengthening of the reinforced concrete structures by FRP strips, a thorough understanding of the effects that this type of FRP reinforcement has on beam failure mode, is required. Key role in the failure of the externally strengthened construction has the bond layer between concrete surface and FRP strip. Experimental researches show that the most often type of failure of the strengthened construction, caused from the maximal shear stresses, is followed by peeling of the FRP strip initiated at the end of the plate, where concrete is uncracked. Local shear failure is driven by a biaxial tension state composed by the interfacial stresses and the normal tension induced on concrete by the flexure [4]. From the theory proposed by Taljsten [5], it can be concluded that for the cases of sufficiently thin strengthening plates, the influence of the peeling stresses on the principal stresses is minute and therefore it can be neglected.

For a proper determination of the bearing capacity of the RC structure strengthened with externally added FRP reinforcement, a model has to be used, which can accurately describe the stresses in the bond layer [3].

Artificial neural networks are a typical example of one modern interdisciplinary field which gives the basic knowledge principles that can be used for solving of many different and com-

* *Faculty of Civil Engineering, Bulevar Partizanski odredi 54, PF 560 Skopje, Macedonia; marijana@gf.ukim.edu.mk*

plex engineering problems which could not be solved otherwise (using the traditional modeling and statistical methods). Neural networks are capable of collecting, memorizing, analyzing and processing large number of data gained from some experiments or numerical analyses. They have an excellent success in data prediction and they can be used for creating prognostic models that could solve various engineering problems and tasks. Their operation is reasonably simple and easy, yet correct and precise. These positive effects completely justify their application, as prognostic models, in many engineering researches [1, 2].

The bond between reinforced concrete beam and CFRP plate in this paper is modelled by a numerical displacement-based fibber model. Discontinuous bond zone is modelled by modification in the constitutive law for description of the bond between the reinforced concrete beam and CFRP plate. A simple approach for the weak zone in the bond description is proposed and the implemented modification is analysed by the distribution of the tensile force in the CFRP sheet along the externally strengthened reinforced concrete beam. Besides the numerical modeling, another objective of the research presented in this paper, was to build a prognostic model which could generate accurate outputs for the response of RC beams externally strengthened with CFRP. For this purpose artificial neural networks were implemented in the prognostic modeling of the given engineering problem. The results obtained by the neural network's model for the analyzed case applied on the numerically generated data from the proposed modeling of the weak zone show excellent accuracy.

## ANALYZED CASE

The analyses were conducted for a reinforced concrete beam that is externally strengthened with CFRP strip. A 3200 mm beam element, presented in Figure 1, which has 2900 mm span and cross b/h=800/120 mm section is strengthened with CFRP strip with 100 mm width. Width of the external CFRP reinforcement is 100 mm. A weak bond layer with length of 504 mm, which starts at 200 mm and ends at 704 mm from the supports, is analysed. The adopted values of the Young's modulus and the yielding strength of the CFRP strip are 150 GPa and 2400 MPa, and the corresponding values for the reinforced steel are 210 GPa and 460 MPa, respectively. The strengthened beam is subjected to four-point bending. Because of the case's symmetry, only half of the beam has been analyzed.

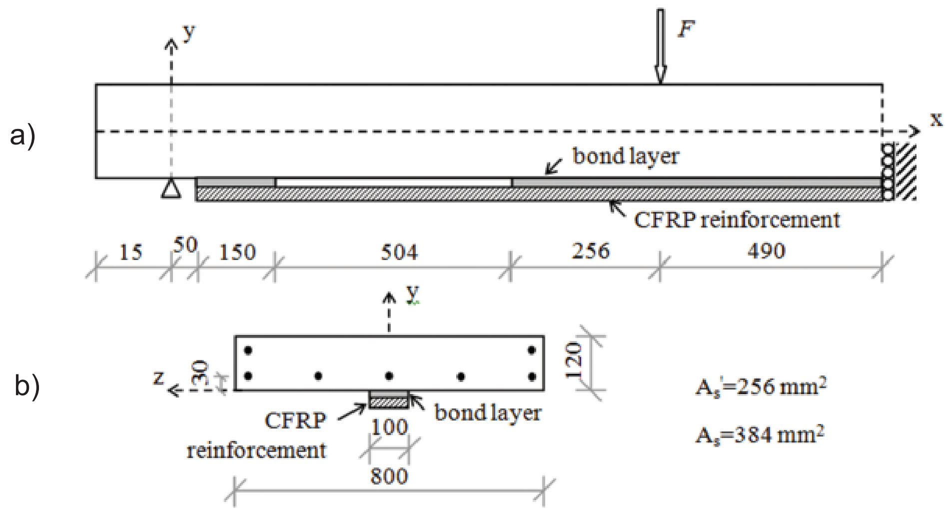


*Figure 1. Beam element strengthened with CFRP strip: a) geometry of half beam; b) cross section of the strengthened beam*

## FORMULATION OF THE PROBLEM

### Numerical formulation of the bond layer

Beam models that are based on the concept of discretization of the cross section into fibbers layers are often used because the fiber model takes into account both, axial and flexural influence. With appropriate modifications fibber model can be used for the analysis of the RC elements strengthened with externally added FRP plates with discontinuous zone in the bond layer.

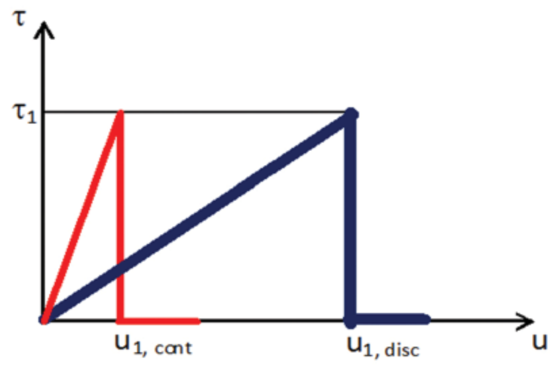


Figure 2. Comparison between the original and modified bond law

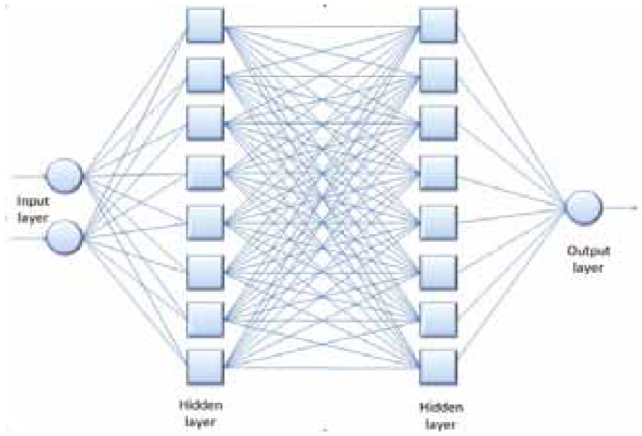


Figure 3. Neural network model used for the analyses of RC beams externally strengthened with CFRP

In order to model the weak zone in the bond layer, a modification of the original constitutive bond law was introduced. Maximal shear stress, τ1, remains unchanged, while the displacement at slip is significantly increased, Figure 2. This modification gives a much more flexible bond, compared to the perfectly bond area. The perfect bond is described by values u1,cont=0,0013 mm and τ1=3,1 MPa. Detailed analyses of the implemented modification in the constitutive bond law could be found in [6].

### NEURAL NETWORK'S PROGNOSTIC MODEL

In order to build a neural network's prognostic model which could generate accurate outputs for the response of RC beams externally strengthened with CFRP, the results from the numerical analyses carried out in [6] were used as input data. The first step of the modeling procedure was to set up the mathematical model (define the architecture of the neural network) using the given input data, followed by the training process of the network. For this engineering problem the following input parameters are used: the length of the beam and selected values of the parameter u used in the modeling process of the bond layer. The output parameter of the neural network model is the tensile force in CFRP plate expressed in $K_N$. A multilayered non-recurrent neural network, with one input layer, two hidden layers and one output layer, was chosen for training of the network, Figure 3. Each hidden layer has 8 neurons inside.

For network training 230 groups of input data were used, out of which 25 belonged to the validation data group (around 10%). The training process was conducted in specialized computer software that works under MS Excel.

### RESULTS AND DISCUSSION

Analysis of the tensile force distribution in CFRP strip along the beam for selected values of the parameter u1,disc used in the modeling process of the weak bond zone were carried out and the results are presented in Figure 4a). From the Figure 4a) it can be observed that in the section of the weak bond, the tensile force rate is smaller when a larger value of u1,disc is employed in the analysis. This is in accordance with the introduced bond modification.

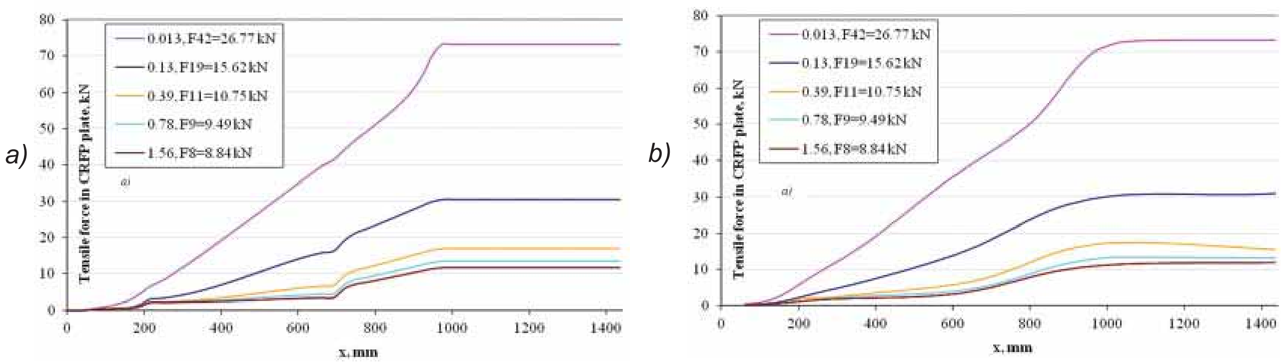


Figure 4. Results for the tensile force distribution in CFRP strip obtained by: a) Numerical analyses, b) Neural network

In order to check the network quality and accuracy, controlling tests were performed. The network was tested by using 30 different data groups, data which weren't used for the learning and training process, Figure 4b.

The values of the tensile force obtained by numerical analyses and the results generated from the trained neural network were compared, Figure 5.

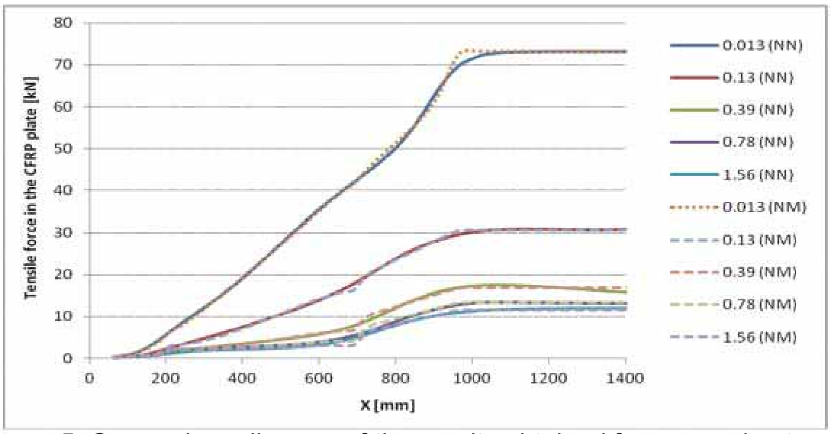


*Figure 5. Comparison diagram of the results obtained from neural networks' prognostic model (NN) and numerical method (NM)*

From the Figure 5 could be seen that the corresponding curves constructed on the basis of the numerically achieved results and on the basis of the results from the neural networks approach are similar and give close results. After the comparison of both methods it could be concluded that neural networks present an excellent tool for prognostic modeling and can be used for determination of the tensile force in CRFP plates used for straightening of RC beams, especially in those cases when there are no (or very few) numerical results.

## CONCLUSIONS

This paper presents an attempt for verification of the modified numerical model used for modeling the bond law between RC beam and CFRP strip. A simple approach that consists of a bond constitutive model modification which can be easily incorporated into the existing numerical model is proposed for modeling the weak zones. The application of neural networks for building a prognostic model which can be used for prediction of the response of RC beams externally strengthened with CFRP is of huge importance for the design process in civil engineering. Researches show that most of the experimental models for determination of the response of RC beams are extremely expensive, and analytical models are quiet complicated and time consumed. That is why a modern type of analyses, such as modeling through neural networks, can help a lot, especially in those cases when some prior analyses were already made.

## REFERENCES


1) Knežević M.: "Risk management of civil engineering projects", Doctoral dissertation, Civil Engineering Faculty of University in Belgrade, Serbia, 2005
2) Knežević M. and Radomir Z.: "Neural networks – application for usage of prognostic model of the experimental research for thin reinforced-concrete columns", scientific research work, Materials and constructions, 2008
3) Monti, G. and Spacone, E., "Reinforced concrete fibber beam element with bond- slip", Journal of Structural Engineering, 126, 6, 2000, pp 654-661
4) Spacone, E., Limkatanyu, S. 2000. "Responses of Reinforced Concrete Members Including Bond-Slip Effects", ACI Structural Journal, 97, 6, pp 831-839
5) Täljsten, B., "Strengthening of Beams by Plate Bonding", Journal of Materials in Civil Engineering, 9, 4, 1997, pp 206-212
6) Trombeva A., Modeling of CFRP external strengthening of reinforced concrete structures with the weak zones in the bond layer, master thesis, University in Ljubljana, Faculty of Civil and Geodetic Engineering, 2004.


*Paper sent to revision: 07.03.2012.*

*Paper ready for publication: 29.03.2012.*