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Ana Trombeva-Gavriloska[1], Marijana Lazarevska[2], Meri Cvetkovska[3]

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UTICAJ ČVRSTOĆE BETONA PRI OJAČANJU AB GREDE CFRP ARMATUROM

Rezime:

Tokom životnog ciklusa veliki broj AB konstrukcija, bez razilke dali su izveđene iz betona normalne čvrstoće ili iz betona visoke čvrstoće, pokazuju nesodvetne performanse izraženih preko smanjenje nosivog kapaciteta i pokazuju potrebu za njihovo ojačanje. Ovaj rad prezentira numeričku analizu uticaja jakosti betona na performanse CFRP ojačanoj AB gredi. Analiza je sprovedena za dva karakterističnih slučaja: kada veza između betona i spoljašne CFRP armature je kontinuirana po celoj dolžini grede i kada veza je nepravilno izvеđena formirajuči diskontinualne zone između AB grede i CFRP armature.

Ključne reči: ojačanje, čvrstoća betona, CFRP

INFLUENCE OF THE COMPRESSIVE STRENGTH OF THE CONCRETE ON CFRP STRENGTHENED RC BEAM

Summary:

A large number of existing RC structures, whether they have been built of concrete with usual compressive strength or of concrete with high compressive properties, exhibit non adequate performance in terms of diminished bearing capacity and there is a need of post strengthening during their service life. This paper presents numerical analysis of the influence of the compressive strength of the concrete on the performance of the CFRP strengthened RC beam. Analysis is performed for two characteristic cases: when the bond between concrete and external reinforcement is continuous along the length of the beam and when the bond is improper executed creating discontinuity zone between RC and CFRP plate.

Key words: strengthening, concrete compressive strength, CFRP

[1] PhD, Assoc. Prof. , Faculty of Arcitecture, Skopje, Macedonia, e-mail: agavriloska@arh.ukim.edu.mk
[2] PhD, Assist. Prof. , Faculty of Civil Engineering, Skopje, Macedonia, e-mail: marijana@gf.ukim.edu.mk
[3] PhD, Prof., Faculty of Civil Engineering, Skopje, Macedonia, e-mail: cvetkovska@gf.ukim.edu.mk

1 INTRODUCTION

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, ccontemporary structures can significantly change their performance. This may lead to decreasing of bearing capacity or structural safety during service life of the construction. Thus a number of reinforced concrete structures exhibits non-adequate performance and need of post strengthening during their service life. In the recent years, increasing the load capacity and structural safety of the flexural loaded structural members is carried out by external bonding of additional FRP (fibre reinforced polymer) reinforcement.

In order to achieve successful external strengthening of the reinforced concrete structures by FRP strips it is required a thorough understanding of the effects that FRP reinforcement has on beam failure mode. Key role in the failure of the externally strengthened construction has the bond layer between reinforced 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 [1]. The failure modes due to loss of composite action are very often observed, but due to the brittleness of the failure, they also represent a significant threat to the structural safety of the strengthened structure and therefore deserve special attention. When de-bonding starts at the end of the plate, where concrete is uncracked, local shear failure is exhibited which is driven by a biaxial tension state composed by the interfacial stresses and the normal tension induced on concrete by the flexure [1]. With the help of the theory proposed by Taljsten [2], 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 can thus be neglected. It is clear that the bond between the concrete substrate and the FRP plate plays a crucial role in the occurrence of failure mode with loss of composite action.

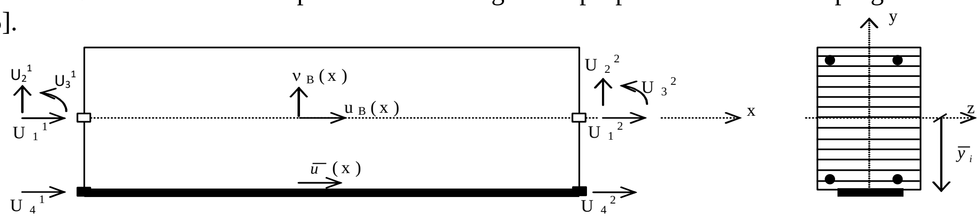
It is clear that the failure behaviour of a plated beam can be very strongly influenced by the integrity of the bond between the plate and the concrete. One of the problems that can be encountered during the strengthening of reinforced concrete structures in the practice is inadequate execution of the bonding process. This may lead to weakening of the bond layer in some positions along the length of the plate, and to creating discontinuities within the bond layer. In such case significant changes of the bearing capacity may be observed, but it is extremely diffucult to evaluate the influence of these weak zones within the bond layer upon structural response of the strengthened beam.

In order to determine properly with adequate accuracy the bearing capacity of the reinforced concrete structure strengthened with externally added FRP reinforcement must be used a model, which can properly describe the stresses in the bond layer [3]. Very often are used beam models based on the concept of discretization of the cross section into fibbers layers, which in the same time take into account axial and flexural influence. These models could be combined with any model of beam element based on displacement method, as well as based on the force method. With appropriate modifications fibber model could be used for the analysis of the reinforced concrete elements strengthened with externally added FRP plates.

This paper presents numerical analysis of the influence of the compressive strength of the concrete on the performance of the CFRP strengthened beam. Analysis for the influence of the compressive strength of the concrete on the performance of the CFRP strengthened beam is performed for two characteristic cases: when the bond between concrete and external reinforcement is continuous along the length of the beam and when the bond is improper executed creating discontinuity zone between reinforced concrete and CFRP plate. The bond between reinforced concrete beam and CFRP plate in this paper is modelled using 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 to the weak zone in the bond description is proposed. Influence of the compressive strength of the concrete on the performance of the CFRP strengthened beam is analysed by using bond stress distribution and tensile plate force distribution along the externally strengthened RC beam. Numerical analysis carried out shows that compressive strength of the concrete has not huge influence on the performance of the externally strengthened RC beam whether the bond between concrete and CFRP plate is perfect or not.

2 NUMERICAL MODEL

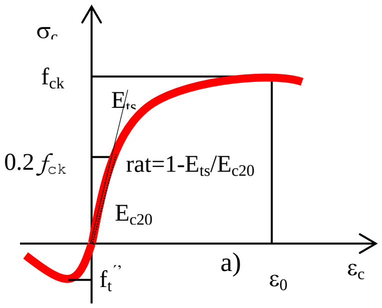
The numerical model used for the analysis of the strengthened beam element is based on a fibre model [4]. Beam element based on two-node displacement has been used. It has two components: a two-node concrete beam and a strengthening plate. The nodal degrees of freedom of the concrete beam and of the strengthening plate are different to permit slip. The cross section of the reinforced concrete section beam is subdivided into layers as shown in Figure 1. Cubic transverse and linear axial displacement fields are assumed for the beam, and linear axial displacements for the strengthening plate. The distribution of the bond slip is quadratic. The element is implemented in the general purpose finite element program FEAP [5].



$$U = \{U_1^1 \quad U_2^1 \quad U_3^1 \quad U_4^1 \quad | \quad U_1^2 \quad U_2^2 \quad U_3^2 \quad U_4^2\}^T \qquad u(x) = \{u_B(x) \quad v_B(x) \quad | \quad \bar{u}(x)\}^T$$

Figure 1 - Node and field displacement of the for reinforced concrete beam model with slip in plate

In the numerical model, the concrete is described by one-dimensional model proposed by Mohd-Yassina [4], while the behaviour of inner and external reinforcement for the strengthening are defined by Menegotto-Pinta model [4]. Models for the constitutive laws of the concrete and reinforcement are shown on Figure 2. Constitutive bond law between concrete and external FRP reinforcement is described by a linear relation between displacement and shear stresses in the bond layer up to the maximal bond strength. When this value of bond shear stresses is reached, slip occurs, which means that displacement is increasing while the corresponding shear stress is zero.



f_{ck} compressive strength of the concrete
ε_0 deformation at f_{ck}
ε_{cu} deformation at 20% f_{ck}
rat $1-E_c/E_{c20}$
f_t' tensile strength of the concrete
E_{ts} initial Young's modulus
E_c concrete Young's modulus at 20% f_{ck}

f_{yk} yielding strength
E_{s0} initial Young's modulus
b_1 E_{su}/E_{s0}
E_{su} modulus of elasticity of the steel after f_{yk}

b)

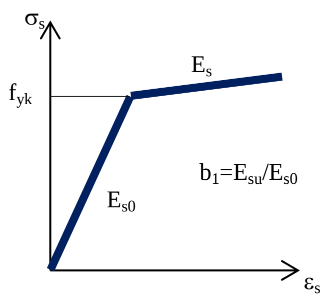


Figure 2 - Constitutive laws of the used materials: a) concrete; b) inner reinforcement

Values of the parameters for the concrete, inner, as well as external reinforcement used in the analysis are according to the Table 1.

Table 1 - Mechanical properties of the materials: a) concrete; b) reinforcement

a)

f_{ck} [MPa]	ε_0 [‰]	ε_{cu} [‰]	rat	f_t' [MPa]	E_{ts} [GPa]
-30	-0.0021	-0.01	0.1	1	100
-100	-0.0021	-0.01	0.1	1	100

b)

Reinforcement type	f_{yk} [MPa]	E_{s0} [GPa]	b_1 [%]
Inner reinforcement	460	210	0.1
External CFRP reinforcement	2400	150	0.1

In order to model weak zone in the bond layer, a modification was introduced in the original constitutive bond law. Maximal shear stress, τ_1, remains unchanged, while displacement at slip is significantly increased. By this modification a much more flexible bond is achieved compared to the perfectly bond area. The perfect bond is described by values $u_{1,cont}$=0.0013 mm and τ_1=3.1 MPa.

3 ANALYSED CASE

A reinforced concrete beam externally strengthened with CFRP strip is analysed. A 3200 mm beam element, presented in Figure 4, which has 2900 mm span and cross b/h=800/120 mm section is strengthened with CFRP strip with 100 mm width. The strengthened beam is subjected to four-point bending. Due to the symmetry of the case, only a half of the beam is being analyzed.

Analysis is performed for two characteristic cases: when the bond between concrete and external reinforcement is continuous along the length of the beam and when the bond is improper executed creating discontinuity zone between reinforced concrete and CFRP plate. A weak bond layer with length of 504 mm, which starts at 200 mm and ends at 704 mm from the supports, is analysed. In the two calculated cases are performed numerical analyses of the influence of two different compressive strength of the concrete on the performance of the CFRP strengthened beam and the analyses are performed for compressive strength of the concrete 30 MPa and 100 MPa.

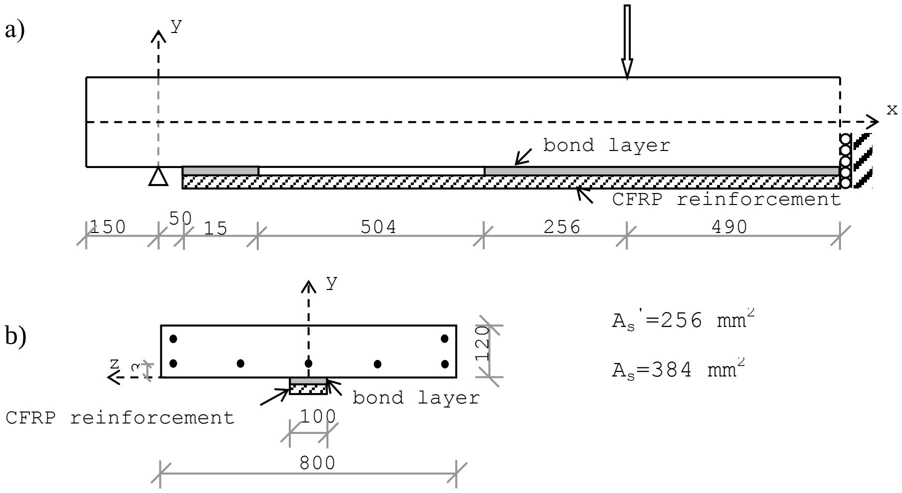


Figure 3 - Beam element strengthened with CFRP strip: a) geometry of half beam; b) cross section of the strengthened beam.

4 RESULTS AND DISCUSION

The relationship between mid-span displacement and load for analyzed cases is presented in Figure 4. In all four analyzed cases the response can be divided into the following parts: a) no cracking occurs; b) concrete cracking occurs in the middle third of the beam, which results in the decrease of the beam stiffness; c) as loading increases, cracking spreads towards the beam suports, but bottom steel reinforcing bars are still elastic. The next stage, d), occurs when reinforcing steel yields, and the second significant drop in stiffenss can be observed. At maximum load achieved, e), CFRP plate debonds. A large drop in beam strength is observed after this stage as the plate ceases to contribute to the beam stiffness.

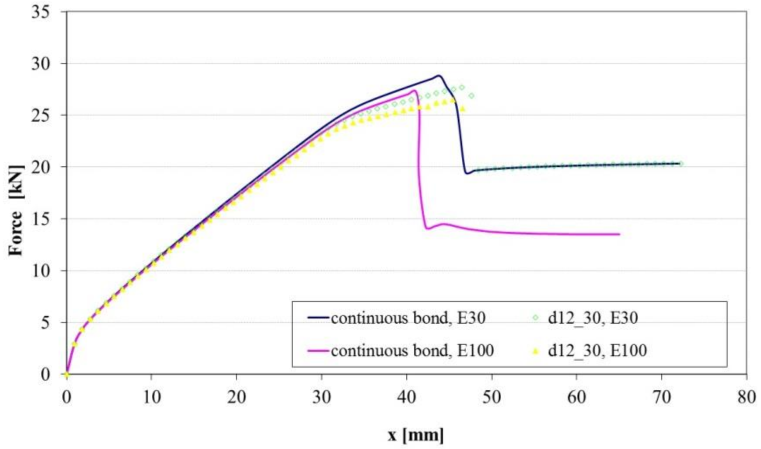


Figure 4 - Load-displacement relationship

Maximal loads of the reinforced concrete beams strengthened with CFRP strip with continuous bond along the whole length are 28.8 kN and 27.3 kN, respectively to the compressive strength of the concrete of 30 MPa and 100 MPa. Appropriate displacements are 43.9 mm and 41.1 mm. Maximal loads of the reinforced concrete beams strengthened with CFRP strip with discontinuous bond are 27.7 kN and 26.5 kN, respectively to the compressive strength of the concrete of 30 MPa and 100 MPa. Appropriate displacements are 46.5 mm and 45.4 mm. From the analysis could be concluded that the maximal load is similar regardless to the compressive strength of the concrete and bond between concrete and external reinforcement.

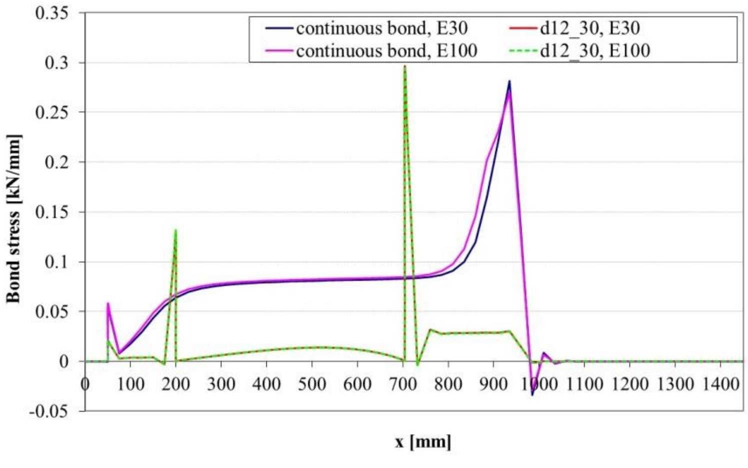


Figure 5 – Bond stress distribution between concrete and CFRP sheet

Bond stress distribution along the beam is shown on Figure 5. At the beginning of the CFRP plate can be observed a sudden increase in bond stress distribution, due to sudden change of the cross-section. Additional peaks in bond stress distribution can be observed at both ends of the weak bond section and at the place where the beam is subjected on bending force. It can be observed that bond stress distribution mainly depends from the change of the cross-section and compressive strength of the concrete has not influence on the bond stress distribution between concrete and external reinforcement.

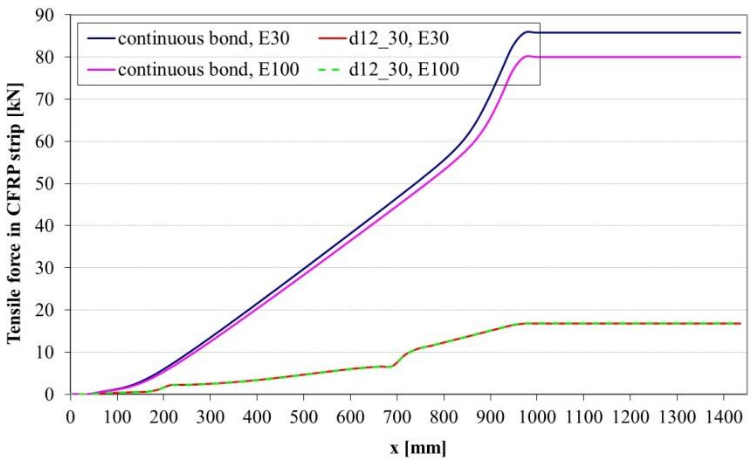


Figure 6 - Tensile force distribution in the CFRP plate along the beam

In Figure 6 is shown tensile force distribution in CFRP plate along the strengthened beam, which corresponds to the bond stress distribution depicted in Figure 5. It can be observed that in the section of the weak bond, tensile force rate is smaller and the tensile force increase with smaller intensity. This is in accordance with the obtained bond stress distribution, as bond stresses are proportional to the tensile plate force derivate. From the Figure 6 could be concluded that compressive strength of the concrete hasn't influence on the tensile force along the CFRP strip, especially when the bond between concrete and CFRP strip is imperfect.

5 CONCLUSIONS

During the strengthening of the reinforced concrete constructions with CFRP strips improper execution may occur, which can lead to the appearance of weak zones in bond layer. Influence of such phenomenon is difficult to evaluate as it can not be accounted for in the design process. This paper presents influence of the compressive strength of the concrete on the global response of the strengthened beam.

A simple approach that consists of a bond constitutive model modification which can be easily incorporated in the existing numerical mode is proposed for modeling the weak zones.

From the analysis can be concluded that the compressive strength of the concrete hasn't influence on the maximal bearing capacity of the strengthened beam. Also compressive strength of the concrete hasn't influence on the bond stress distribution between concrete and CFRP strip, as well as tensile force distribution in the CFRP sheet. Results show that local bond stress concentrations, which appear where cross-section is changed, have negative influence on the quality of the bond between concrete substrate and CFRP plate. Further validation of the proposed model and results obtained by parametric analysis using this model, has to be carried out by the experimental researches.

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