# Case study of flexure and shear strengthening of RC beams by CFRP using FEA

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Abstract

In the paper the preliminary results of study on strengthening RC beams by means of CFRP materials under mixed shear-flexural work condition are presented. The Finite Element Method analyses were performed using numerical models proposed and verified earlier by the results of laboratory tests [2,3] for estimation of effectiveness of CFRP strengthening of RC beams under flexure. The currently conducted analyses deal with 3D models of RC beams under mixed shear-flexural loading conditions. The symmetry of analyzed beams was taken into account (in both directions). The application of Concrete Damage Plasticity (CDP) model of RC beam allowed to predict a layout and propagation of cracks leading to failure. Different cases of strengthening were analyzed: with the use of CFRP strip or CFRP closed hoops as well as with the combination of above mentioned. The preliminary study was carried out and the first results were presented.

*Keywords: FEM analysis, CFRP strips, CFRP hoops, load carrying capacity of RC beams, shear/flexural strengthening*

## 1. Introduction

Strengthening of RC elements by bonding to their tension and/or shear zones composite strips, hoops or mats of carbon fibers (CFRP) is nowadays well-known and often used method in civil engineering. Numerical analyses using FEM and 2D as well as 3D models of strengthened RC beams by means of applying CFRP strips on bottom concrete surfaces have been reported recently by many researches [2÷5, 8]. There is much less study of analyses of strengthening in shear-flexural work conditions [9]. The presented study pertains to FEM analyses of strengthened RC beams under mixed shear-flexural work conditions.

## 2. Scope of analysis

The tests of simply supported RC beams strengthened for flexure were carried out in the laboratory of the Institute of Civil Engineering in Poznan University of Technology [2] and the results were presented in [2, 3].

All beams of length 3.0m were subjected to four-point bending. The beams were divided into five groups which differed from each other by level of applied loads before application of CFRP strips. The beams were strengthened in flexure in passive way on bottom sides with CFRP strips S&P Lamelle CFK type 150/2000. The strips of length of 2.8m, width of 0.05m and a thickness of 1.2mm were bonded to concrete surfaces by means of 2-component epoxy resin adhesive type Resin 220 Standard.

The FEM models of these beams as well as whole procedure of numerical modeling were performed and the main results of these analyses are given in [3]. The validation results of FEA 3D models based on the results of laboratory tests for beams without and with CFRP strip are shown in Fig.1, where the graph of the mid-span deflections (B-4) vs load are shown for both, not strengthened (Br) and strengthened beams (Bz) respectively. As it is seen in the figure very good consistency of results was observed which allowed to apply FE models and procedures to parametric analyses. In this paper, on the basis of previous experiences, preliminary results of parametric numerical analysis of different cases of flexural, shear or mixed flexural/shear strengthening using 3D models are presented.

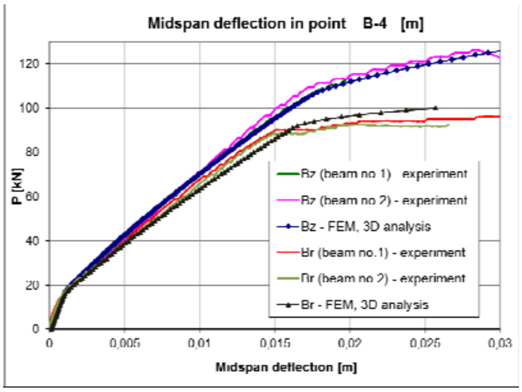


Figure 1: Comparison of FEA and the experimental results: deflection in the mid-span for not strengthened (Br) and strengthened beams (Bz)

## 3. FEM Analysis

The numerical analysis was performed using the finite element method. All models of beams were created and calculations were carried out using Abaqus/Standard code.

The main attention was focused on the analysis of 3D models. The symmetry of analyzed beams was taken into account (in both directions). Hence the model of a quarter beam was built with the appropriate displacement constraints imposed on the appropriate symmetry planes.

The concrete was modeled as the concrete damage plasticity (CDP) material. The model is based on the brittle-plastic degradation model developed by Lubliner [7] and next improved by Lee and Fenves [6]. Additionally, a proper value of tensile fracture energy was used to represent the behaviour of concrete in tension. The strain-softening behaviour of concrete in tension was given as the stress-displacement relationship (σ-w), according to concept of fictitious cracks model of Hillerborg [1]. Steel of rebars was modeled as linear elastic-plastic with hardening isotropic material and the CFRP elements as linear elastic isotropic material.

The reinforcement rebars were modeled in a discrete manner. Presence of an adhesive connecting the beam with the CFRP strips was neglected – all strengthening elements were bonded perfectly to concrete surfaces. The intermediate crack debonding failure [4] or plate-end debonding failure are not included in the analyzed models.

Different cases of CFRP strengthening were analyzed, namely:

- RC beam, as a reference beam,
- RC beam strengthened due to flexure using CFRP strip on bottom surface,
- RC beam strengthened only using 5 closed CFRP hoops in zone of shear/flexure between support point and load point,
- RC beam strengthened using both CFRP strip on bottom surface of beam and 5 closed hoops (Fig.2).

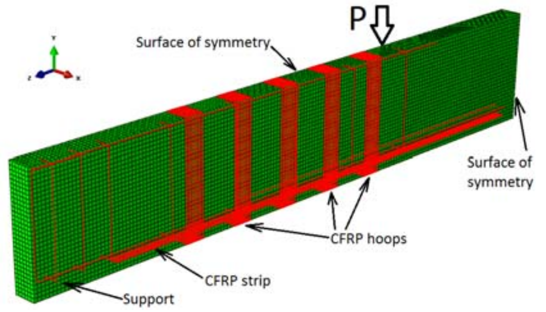


Figure 2: FE model of quarter of analysed beam with reinforcement bars and CFRP elements shown in red

## 4. FEM Results

The force-displacement curves for analysed beams at the measuring point B-4 located in the middle span of beams are shown in Fig.3. Using only CFRP strip, only hoops and all elements together results respectively in increasing both the load carrying capacity and stiffness of strengthened RC beam. The exemplary crack arrangement for beam strengthened using both strip and hoops made on the basis of maps of damage parameter $d_t$ (which mimics cracks) is presented in Fig.4.

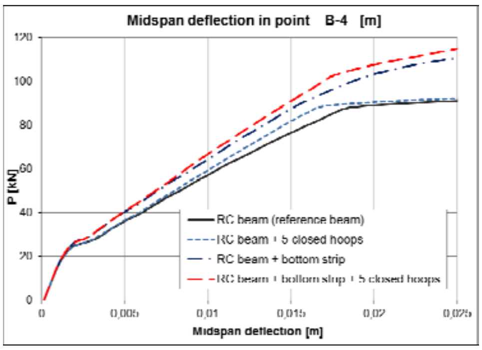


Figure 3: Deflection of point B-4 from 3D FE analysis – for RC beam and 3 cases of FRP strip and hoops application

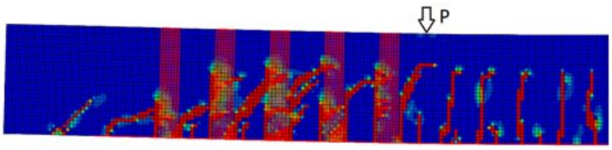


Figure 4: Map of damage parameter $d_t$ with strengthening CFRP elements (shown in red)

## 5. Conclusions

The preliminary FEM analyses of strengthened RC beams using both CFRP strips on bottom surface and CFRP closed hoops allowed to formulate the following conclusions:

- Combined strengthening of RC beams by using both strips and closed hoops of CFRP material can not only increase the load carrying capacity of strengthened RC element, but also can influence on the layout and width of cracks and by the way may have real impact on improvement of durability of whole structure.
- Closed hoops of CFRP may increase shear carrying capacity of strengthened RC element.
- Closed hoops of CFPR used at the end zone of strip in case of flexural strengthening can also be treated as additional elements which delay strips debonding from concrete cover surface.

Further investigation of strengthening RC beams for flexure and/or shear are planned to be carried out in the future.

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