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Finite element modeling of frp strengthened column subjected to cyclic loading

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Abstract

Existing reinforced concrete structures are subject to damage and performance degradation under external loads. It is then necessary to improve their performance using appropriate strengthening techniques. Over the last decades, new construction materials for strengthening and design have emerged. These are referred to as fiber- reinforced polymer (FRP) composites and have unique mechanical and in-service properties.

Investigation of FRP-strengthened RC members subjected to impact loads is warranted. In addition, there is also a lack of finite element (FE) studies concerning this topic. FE analysis is a powerful and economical tool to investigate the response of structures under various loads and examine virtually endless number of variables that would be otherwise very difficult to be performed experimentally, due time, cost, and laboratory limitations.

The existing RC column was strengthened with CFRP sheets, installed at the site where plastic hinge may occur. First of all, three-dimensional FE CFRP confined column was designed. Due to the complexity of the strengthened element, every element with different material characteristics was designed separately. Every element has different meshing. The nonlinear behavior of the concrete and steel material is accounted in the modeling by introducing the actual inelastic properties in the model. The boundary conditions between the concrete and CFRP material also were taken into account. At the end, the strengthened column was subjected to cyclic loading.

As a result of the FE analysis, hysteresis loop was obtained. In order to see the benefits of strengthening with CFRP materials using FE analysis, comparison between hysteresis loops for strengthened and unstrengthen column was performed.

Key words: Repair and strengthening, CFRP, Finite element, cyclic loading

1 Introduction

A number of existing and new RC structures built in seismic prone regions, need repair and strengthening of the structural system. Most of the reasons are low material quality, as well as not fulfilling the requirements prescribed by modern standards for aseismic design. The definition of the type of strengthening is based on defining of seismic resistance estimation of the existing structural system. After that, according to the given global view of current structural condition, the next step is selecting repair and strengthening structural solution. Usually, in the construction practice the structural systems are strengthening with traditional materials (concrete and steel). However, in the last two decades more often innovative building materials (FRP) are used. So far, many experimental and analytical studies had been made for the strengthening of the RC elements and structures, whereby in some countries, specific procedures for estimating and calculations of structural elements strengthened with FRP materials are made [1-3]. However, the main problem for the researchers during these studies is the problem with the debonding of FRP material from the structural element [4-5]. As a result of the complexity of the strengthened cross-section by using of FRP material, the laboratorial boundary conditions, as well as the required time, more often analytical studies based on finite elements are made [6-7].

2. Modeling of CFRP strengthened RC column

In this paper is shown the modeling and analysis of RC column strengthened with CFRP sheets subjected to cyclic loading, by the method of finite elements. The reinforced concrete column was wrapped with CFRP sheets around the cross-section perimeter with suitable overlap. The CFRP sheets were installed on the place where plastic hinges may occur. In this case, fibers were set in perpendicular direction along the element axis. The characteristics of embedded materials are given in table 1.

Table 1. Characteristics of embedded materials

RC column	Parameters
Concrete class	C25/30
Type of reinforcement	B500B
Length	L=2.00m
Longitudinal reinforcement	8Φ14
Transversal reinforcement	Φ8/15cm
CFRP sheets with fibers in one direction	**Parameters**
Module of elasticity [kN/mm^2]	240
Fibers tensile strength [N/mm^2]	3800
Fibers weight [g/m^2]	300
Density [g/cm^2]	1.7
Thickness [mm]	0.176
Maximal dilatation of fiber rupture (εmax-%)	1.55

The numerical model of the strengthened RC column was generated by using the software program ABAQUS, which works on the principle of model calculating, based on previously generated finite element network [8]. The concrete part was composed of meshed elements with 50mm size and modeled by eight - nodes brick element (C3D8R). The longitudinal and transversal reinforcement were modeled by two-node linear displacement truss elements (T3D2), which was assumed to be embedded in the concrete part. The CFRP sheets were modeled by four-node shell elements (S4R) [9-10], while the connection between the CFRP material and concrete was simulated by eight-node three-dimensional cohesive elements (COH3D8) [8]) (Figure 1). In case of numerical calculations with the use of the method of finite elements, it was necessary some idealizations to be made for the embedded materials according to the given recommendations.

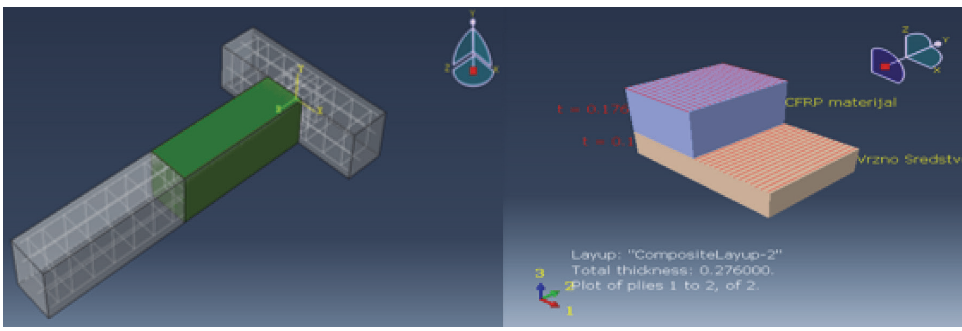

Figure 1. Modelling of RC column strengthened by CFRP sheets

The material characteristics of the concrete were defined by the Kent and Park model [11]. The model was implemented in the software program ABAQUS as a concrete damage plasticity (CDP) model. In order to define the model in full, it was necessary to input the required parameters. Based on the recommendations given by ABAQUS SIMULIA [9], the CDP parameters are given in table 2.

Table 2. CDP concrete parameters, based on ABAQUS recommendations

Parameter	Value	Description
Ψ	30	Dilation angle
ε	0.1	Eccentricity
f_{bo}/f_{co}	1.16	The ratio of initial equibiaxial compressive yield stress to initial uniaxial compressive yield stress.
K	0.667	Kc, the ratio of the second stress invariant on the tensile meridian
M	0.0001	Viscosity Parameter

The CFRP sheets are orthotropic elastic materials which materials characteristics are given in table 1. The maximal tensile and compressive strength of the fibers, the matrix shape and the internal shear, are directly defined by the manufacturer. The onset of CFRP rupture is defined using the Hashin's formulation [12].

The connection between the concrete and the CFRP sheets was defined by the force-debonding law, which is mostly used for simulating of the connection between these two different materials. In this case is assumed that the debonding occurs as a result of lack of cohesion in the adhesive layer. The relation between the CFRP sheets and the concrete is defined by formulations given by Lu,et.al [13].

3 Analysis and results

After the modelling of the strengthened RC column with CFRP sheets, the next step was analysis of the column subjected to cyclic loading (Figure 2). It has to be mentioned that during the analysis the overlap between the CFRP sheets was neglected.

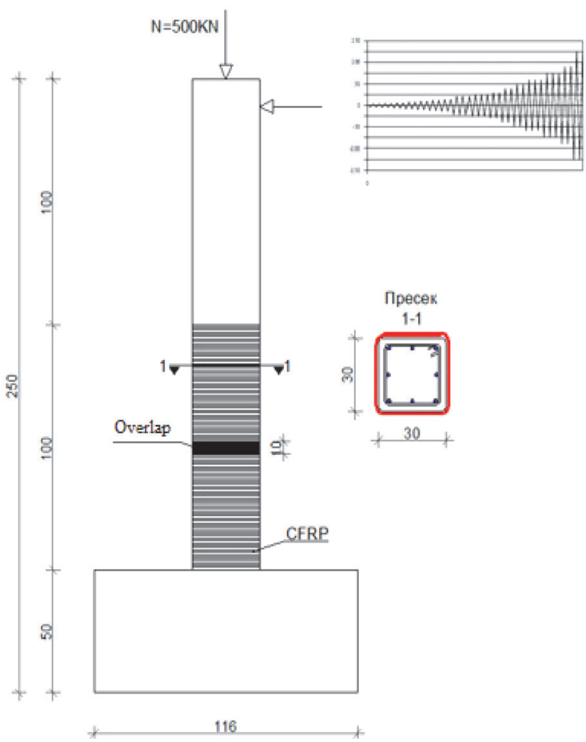

Figure 2. Strengthened RC column subjected to cyclic loading

As a result of the performed analysis, using the finite element method in the software program ABAQUS, the following results are given for both RC column (referent RC column and strengthened RC column using CFRP sheets):

Stresses

According to the obtained results, it can be noticed that the CFRP sheets enable stress and compressive strength increasing in the concrete, before the element failure happened. In addition, this type of strengthening resulted with element failure by concrete crash, as a result of concrete stress increasing. The biggest stresses occurred on the contact between the column and foundation (Figure 3).

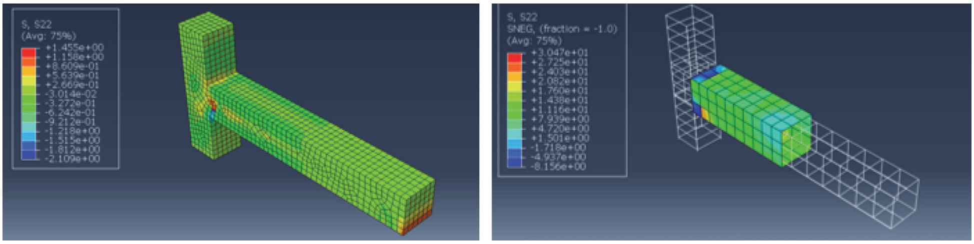

Figure 3. Stresses in a) The concrete of strengthened column, b) CFRP sheets

Relation force – displacement (hysteresis loop)

As a result of the cyclic loading, two hysteresis loop were obtained. These curves represent the relation between the pushing force and its suitable displacement in certain time. Based on the obtained results, it can be concluded that CFRP sheets with fibers perpendicular to the element axis, although enabling the increase of the compressive concrete strength, significantly increase the ductility of the RC element (Figure 4).

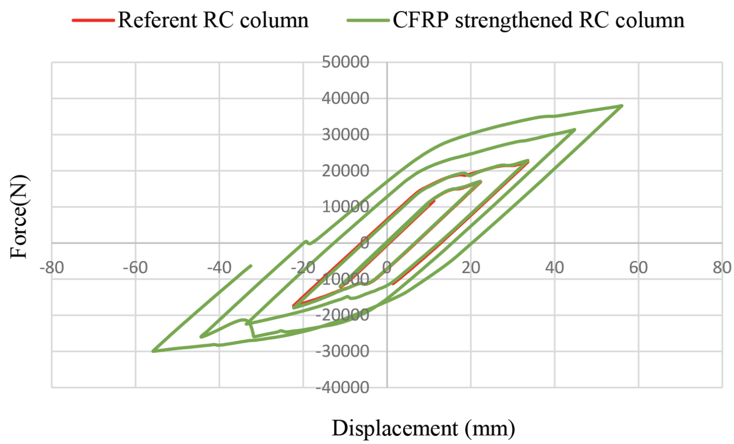

Figure 4. Relation force-displacement

4 Conclusion

According to the results obtained by the performed analysis it can be concluded that CFRP sheets with fibers perpendicular on the element axis, increases the compressive strength of the concrete, as well as increasing the dilatation of the concrete before failure. In this case, the failure of the RC element was a result of the concrete crash, which means that the maximal dilatation of the fibers was not succeeded. This CFRP sheets allow bigger displacements of the RC column before collapse of the element, which means bigger ductility of the element.

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