Analytically Investigation of FRP Ductility Effect on Retrofitted RC Columns

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ABSTRACT

Retrofitting of currently used buildings has come into question with the determination of buildings' performance levels due to earthquake force effect. In this sense, lots of retrofitting techniques have been applied for the retrofitting of current buildings. Columns, beams, joints and slab can be reinforced on the basis of member, with the retrofitting techniques. By this way, building safety is provided by increasing the performance level of the buildings. Within the scope of this study, force-deformation relationship of a single column reinforced with FRP (Fiber Reinforced Polymer) compared with not reinforced column was analysed with regard to finite element method. In the analyses, a column in 300x300 mm in size, 2000 mm in height was modelled. Load was applied step by step as lateral load from 50 nodes which are on 1/7 top of column. After the force-displacement relationship of not retrofitted column was revealed, analysis was repeated by modelling FRP material through plastic hinge area of not damaged column. In conclusion, it is found out that FRP material increases energy consumption capacity of a single column up to 30%.

INTRODUCTION

In the world and also in Turkey with the increase of FRP applications, analytical studies on working principle of this material with reinforced concrete have increased. With the analytical studies, behaviours of buildings retrofitted with FRP have been revealed. Retrofitting systems with fiber polymer are used to increase endurances and/or ductility of reinforced concrete, masonry wall and wood elements against bending, shear effects and axial loads and impacts.

Fiber polymers have immense tensile strength and elasticity module. Without emptying the building in retrofitting application, retrofitting procedures are maintained while industrial site or building is still used with partial regulations. Furthermore, these materials are very light [1]. In literature, studies showed that capacities of systems or structure members retrofitted with FRP increased. For instance, retrofitting of joint with FRP analysed by doing pushover analysis in a program based on finite elements method. Consequently, it was revealed that FRP material increased the ductility and lateral load capacity [2]. In another study, FRP material was applied to beams. In this application, endurances of beams against shear and bending were increased. Furthermore, in the study this application was modelled analytically with a package program based on finite elements model [3]. Generally, programs based on finite elements method were used in analytical studies in literature. In a study carried out on columns, experimental and analytical data were compared and it was modelled with ANSYS program. At the end of the study, it was emphasized that reliable results could be obtained only from analytical model without doing an experiment in order to understand the behaviour of a jacketed column [4]. In another study in which column-beam joints were analysed, three different types of FRP material was analysed with ANSYS program. It was concluded that FRP material in the joint increases bending capacity by 49%; stress in the rebar decreases by 42%, stress in concrete by 26% and rotations by 49% [5]. In another study, the effect of FRP material on reinforced beams was analysed with ABAQUS program based on finite material. In the study, it was concluded that FRP material increases the bending endurance of beams [6]. In this study, ANSYS package program was used for analytical modelling. The program provides many facilities for modelling. Many elements can be defined with the ready models in the program. Moreover, many intended features can be entered to these elements. The aim of this study is to determine the effect of FRP on the column behaviours without doing experiment. Another aim is to show that a study can be analytically modelled before doing an experiment on an element reinforced with FRP.

ANALYTICAL MODEL

In literature, SOLID 65 element type in the program was used as a concrete model, for FRP SOLID 46 element type was used. Features of SOLID models used in the study are shown in Table 1 and 2.

Table 1. Element Proporties of SOLID 65

Material	Element Type	Material Properties of Confined Concrete		
		Linear Isotropic		
		EX (MPa)	13248	
		PRXY	0.3	
		Multilinear Kinematic Hardening		
			Strain	**Stress (MPa)**
		Point 1	0	0,0
		Point 2	0,000625	8,3
		Point 3	0,00125	14,4
1	**SOLID 65**	Point 4	0,0025	20,1
		Point 5	0,005	18,1
		Point 6	0,0075	15,7
		Point 7	0,01	13,4
		Point 8	0,0125	11,1
		Point 9	0,015	8,8
		Point 10	0,0175	6,5
		Point 11	0,02	4,2

Table 2. Element Proporties of SOLID 46

Material	Element Type	Material Properties of FRP	
1	**SOLID46**	**Linear Isotropic**	
		EX (MPa)	240000
		PRXY	0.22

In the modelling of this study, these element types were used. Loading to model was applied as load step. Program provides two options for rebar definition as smeared and discrete. In the article, smeared rebar model was used. Stress-strain curve of confined concrete was defined for SOLID 65 concrete model according to elasticity module, poisson rate and Modified Kent-Park model [7].

Modified Kent - Park Model [7]

Parabolic Curve Zone:

- For Unconfined Concrete:

$$\sigma_c = f_c\left[\frac{2\varepsilon_c}{\varepsilon_{co}} - \left(\frac{\varepsilon_c}{\varepsilon_{co}}\right)^2\right]$$

ε_{co}, can be accepted as 0.002 for conventional concrete

- For Confined Concrete:

$$\sigma_c = f_c\left[\frac{2\varepsilon_c}{\varepsilon_{coc}} - \left(\frac{\varepsilon_c}{\varepsilon_{coc}}\right)^2\right]$$

$$\varepsilon_{coc} = K.\varepsilon_{co}$$

Linear Zone:

- For Unconfined Concrete:

$$\sigma_c = f_c\left[1 - Z_u(\varepsilon_c - \varepsilon_{co}\right]$$

$$Z_u = \frac{0.5}{\varepsilon_{50u} - \varepsilon_{co}}$$

$$\varepsilon_{50u} = \frac{3 + 0.285 f_c}{142 f_c - 1000} \geq \varepsilon_{co}$$

- For Confined Concrete:

$$K = 1 + \frac{\rho_s f_{wk}}{f_c}$$

$$\sigma_c = f_{cc}\left[1 - Z_c(\varepsilon_c - \varepsilon_{coc}\right] \geq 0.2 f_{cc}$$

$$Z_c = \frac{0.5}{\varepsilon_{50u} + \varepsilon_{50h} - \varepsilon_{coc}}$$

$$\varepsilon_{50h} = 0.75\rho_s\left(\frac{b_k}{s}\right)^{\frac{1}{2}}$$

$$\rho_s = \frac{A_0 x l_s}{s x b_k x h_k}$$

Elasticity module, poisson rate and layers for SOLID 46 material were defined [1]. In the program, loading was applied as load step [8]. Load was applied as lateral load in 5 steps from 50 nodes which are on the top of column. Loading steps applied to model at a single point is shown in Table 3.

Table 3. Applied Load Steps For Single Node

LOAD STEP	FORCE (N)
1	0- 180
2	180-250
3	250-350
4	350-400
5	400-1325

In each step, displacement on the top point of model was measured. Model was separated to mesh objects in 30x30x30 in size. Booleans commands were used for FRP materials definition on concrete surface. Result is shown in Figure 1 [9].

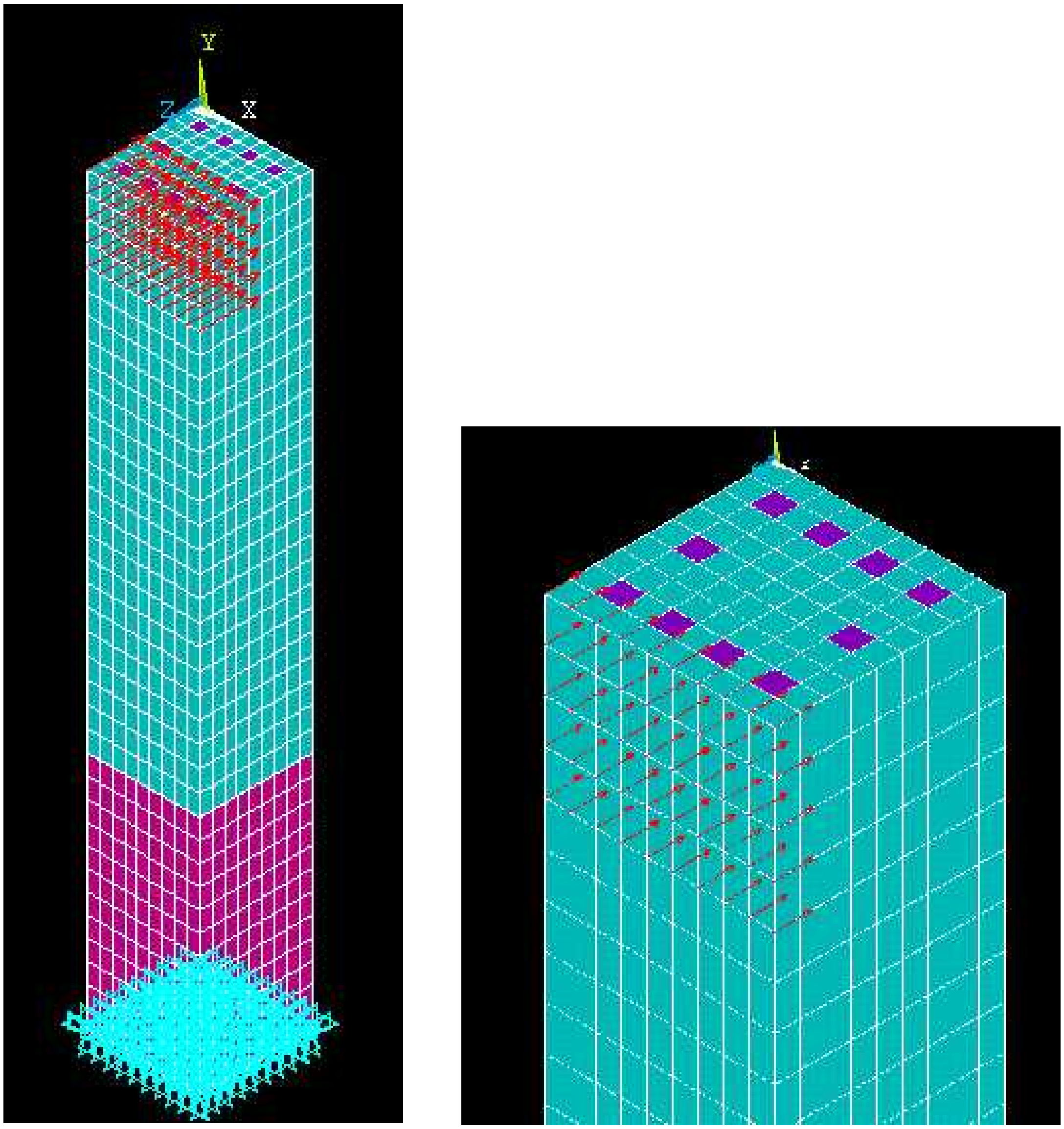

Figure 1. RC Column Model and Load Points [9]

With these commands, 0.117 mm thick material was glued to zone in which plastic hinge formation was expected. The model of glued FRP element is shown in Figure 2 [10].

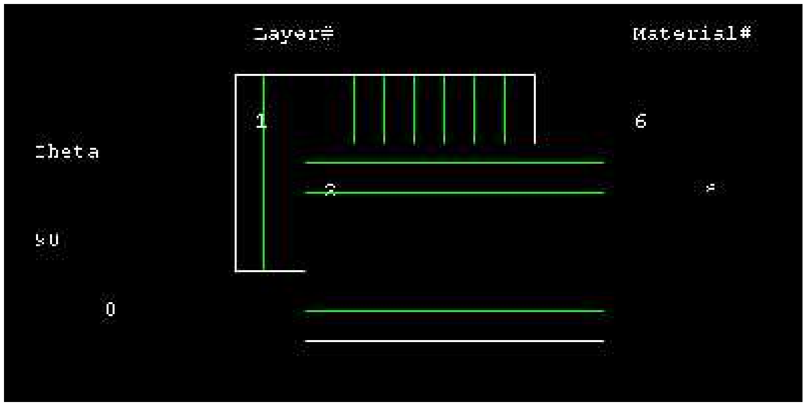

Figure 2. Layer Model of FRP

The bottom of column restrained in the way that three direction translation and rotation would be prevented. Deformed shape of model is given in Figure 3.

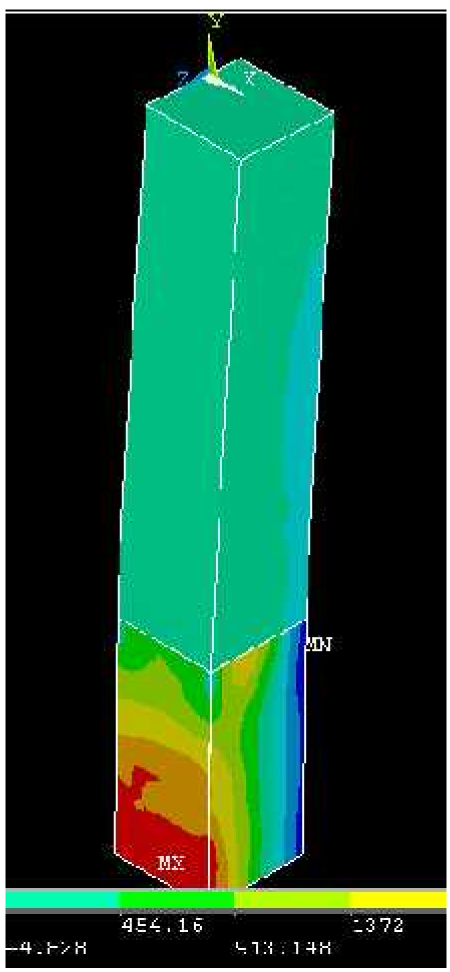

Figure 3. Elastic Curve and Stress Distributions of FRP Retrofitted RC Column [9]

Load displacement curve was obtained for the model with FRP and without FRP by specifying displacement values occurred according to lateral loads that were applied from 50 nodes. Force-displacement curves of model are shown in Figure 4.

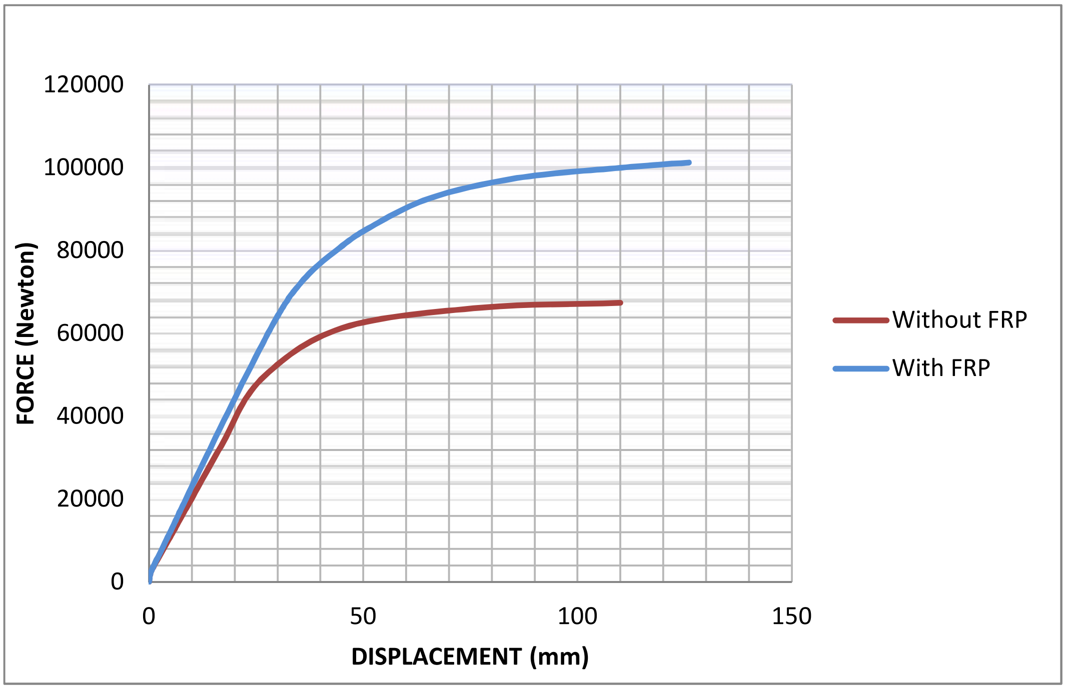

Figure 4. Force-Displacement Curve of RC Columns

conclusIon

In the analytic study carried out on two columns with and without FRP, it was concluded that FRP material increases the energy consumption capacity of columns and the behaviour of a bearing element with FRP can be modelled without an experiment. But, in modelling period all parameters require great attention for the sake of the model to reach its aim.

The other result obtained from the study is that it is really easy to get linear zone of load-displacement curve in the analyses. Obtaining non-linear zone is possible within a specific value. But, maintaining the behaviour occurred in non-linear zone is possible with the addition of new iterations and increase in step number.

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