PARAMETRIC STUDY ON GFRP REINFORCED SHORT CONCRETE COLUMNS

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ABSTRACT

This paper summarizes the results of eight parametric columns reinforced with GFRP rebars. Nonlinear 3D finite element models have been developed using ABAQUS finite element code to investigate the compressive behaviour of GFRP reinforced square concrete columns. The load versus deflection response of the parametric columns was formulated using the static riks solution strategy. The parametric study was conducted to investigate the influence of -- the concrete compressive strength, reinforcement ratio and spacing of ties on ultimate axial load capacity and deflection of GFRP reinforced short columns. The results are presented in detail in the paper.

Keywords: Fibre Reinforced Concrete, Finite Element (FE) Modelling, Glass Fibre Reinforced Polymer (GFRP), Non Linear Analysis, Parametric study.

INTRODUCTION

Most of the building columns and bridge piers are often in need of high corrosion resistance and high yield strength. The use of concrete structures reinforced with fibre reinforced polymer (FRP) composite materials has been growing to overcome the common problems caused by corrosion of steel reinforcement (ACI Committee 440 2007). The use of internal reinforced FRP bars can be a cost-effective alternative for upgrading the performance of concrete columns.Extensive experimental research have been conducted by research groups on the behavior of GFRP rebars used as internal reinforcement for beams, slabs and pavements (ACI Committee 440, CSA S806- 02,Benmokraneet al., 1998). These efforts have contributed greatly in improving our knowledge on analyzing and designing concrete structures reinforced with FRP bars in flexure and shear. On the other hand, the behavior of GFRP RC compression members is less defined. Previous experiments carried out by Kobayashi et al., 1995, De Luca et al. 2009, Tobbi et al.2012, etc. studied the behavior of FRP reinforced columns.Tobbi et al., 2012conducted an experimental researchstudying the behaviour of square concrete columns reinforced with GFRP bars under concentric loading. To extend the range of applications of GFRP reinforced columns in practice and to enhance the limited data on square columns reinforced by GFRP rebars, a parametric analysis is required using a validated analytical model.

METHODOLOGY

A nonlinear finite element model for GFRP reinforced column was developed using ABAQUS finite element code. Detail description of the model has been included in Morshed et al. 2016. A damage plasticity model was used in the analysis to simulate the behaviour of reinforced concrete. The perfect bonding between FRP rebars and concrete was simulated using embedded element algorithm. A static Riks formulation was implemented to trace the stable load-displacement history of FRP reinforced concrete up to failure. The load was applied through displacement control technique. This model have been verified against the results from Tobbi et al. 2012. The numerical analysis results of the model are found to be in good agreement with the experimental results. The FE model as shown in Figure 1 is used here to conduct the parametric study. A comparative graphical results have also been plotted and shown in Figure 1.

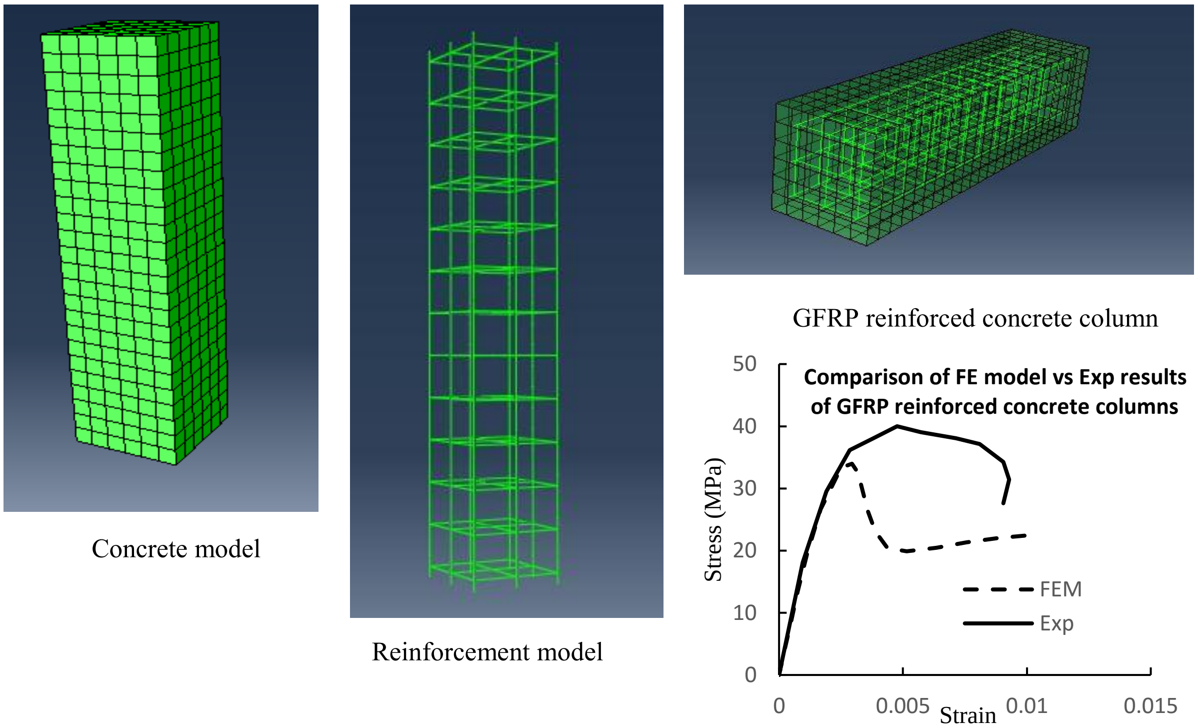

Fig. 1: FE Model of validated GFRP reinforced concrete columns (Morshed et al., 2016)

DESIGN OF PARAMETRIC STUDY

The finite element model generated in the published research will be used to conduct a detailed parametric study on the behaviour of GFRP reinforced square concrete columns.

Variable Parameters

For designing the parametric study, the concrete compressive strength, reinforcement ratio and spacing of ties are identified as the most important geometric variables. The geometric and material properties of the columns designed for parametric study are included in Table 1. The specimens are named as PCX-Y-Z where X, Y and Z represent concrete compressive strength in MPa, reinforcement ratio (%) and tie spacing in mm respectively.

Table 1 Geometric and material properties of parametric columns

Column Specimen	**Concrete compressive strength f_{cu}** MPa	**Reinforcement**	**Reinforcement Ratio** %	**Tie spacing** mm
PC33-1.85-120	33	8-φ19 mm bars	1.9	120
PC33-3.21-120	33	8-φ25 mm bars	3.2	120
PC33-1.85-330	33	8-φ19 mm bars	1.9	330
PC33-3.21-330	33	8-φ25 mm bars	3.2	330
PC25-1.85-120	25	8-φ19 mm bars	1.9	120
PC25-3.21-120	25	8-φ25 mm bars	3.2	120
PC25-1.85-330	25	8-φ19 mm bars	1.9	330
PC25-3.21-330	25	8-φ25 mm bars	3.2	330

Fixed Parameters

For all column specimens following parameters have been kept constant:

- Column dimensions: 350 X 350 X 1400 mm(Tobbi et al., 2012, Morshed et al., 2016)
- Loading pattern: Displacement Controlled until failure at a rate of 0.002mm/s
- Boundary conditions: One end fixed.

RESULTS AND DISCUSSIONS ON PARAMETRIC STUDY

The output parameters that have been extracted from the analysis are: Load and deflection. The axial load and deflection data are directly obtained from the Abaqus simulation. The summary of the results is shown in Table 2. The load versus deflection curves are then generated from the numerical analysis is investigated in this study.

Table 2 Results of parametric study

Column Specimen	**Ultimate Load, P_u** (KN)	**Deflection at ultimate load Δ_u** mm
PC33-1.85-120	4161	2.6
PC33-3.21-120	4318	2.6
PC33-1.85-330	4109	2.4
PC33-3.21-330	4258	2.6
PC25-1.85-120	3225	2.4
PC25-3.21-120	3350	2.2
PC25-1.85-330	3179	2.2
PC25-3.21-330	3306	2.4

Effect of Concrete Compressive Strength, fcu

To evaluate the influence of varying concrete compressive strength on axial load capacity, two compressive strength of concrete 33 MPa and 25 MPa were considered as presented in Figure 2.

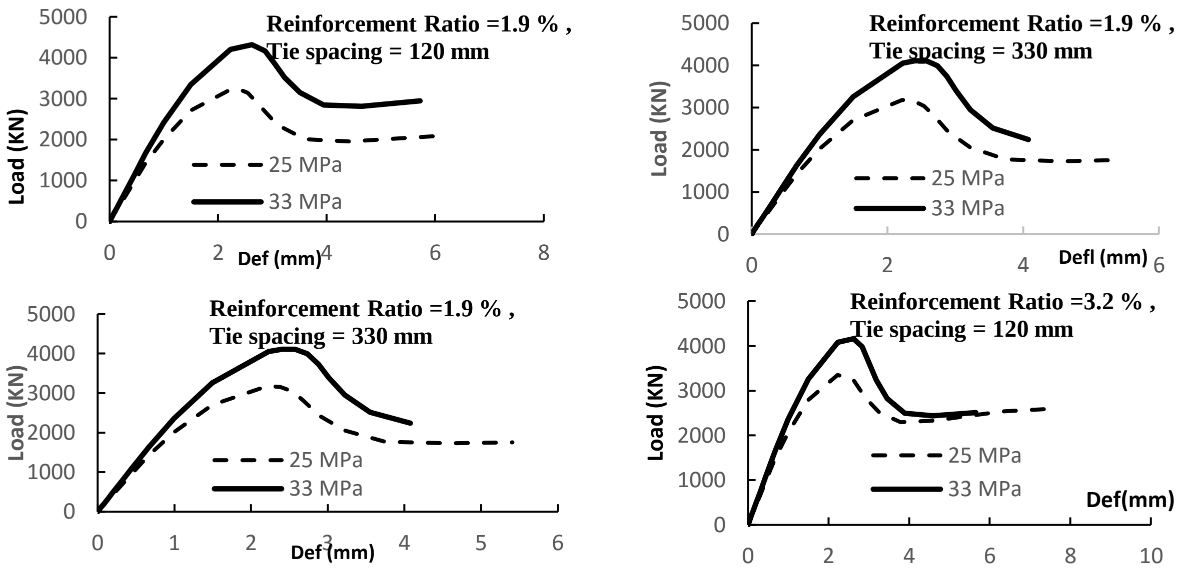

Fig. 2: Effect of concrete compressive strength

All of the specimens confirmed significant increase of an average of 23% in ultimate capacity when characteristic concrete compressive strength was increased by 25 %. The curves show a higher initial stiffness for that of compressive strength 33 MPa. However, no noteworthy change was observed in deflection at peak strength.

Effect of Reinforcement Ratio, ρ %

To evaluate the influence of varying reinforcement ratio on axial load capacity, two reinforcement ratio of 1.9% and 3.2% were considered as presented in Figure 3.

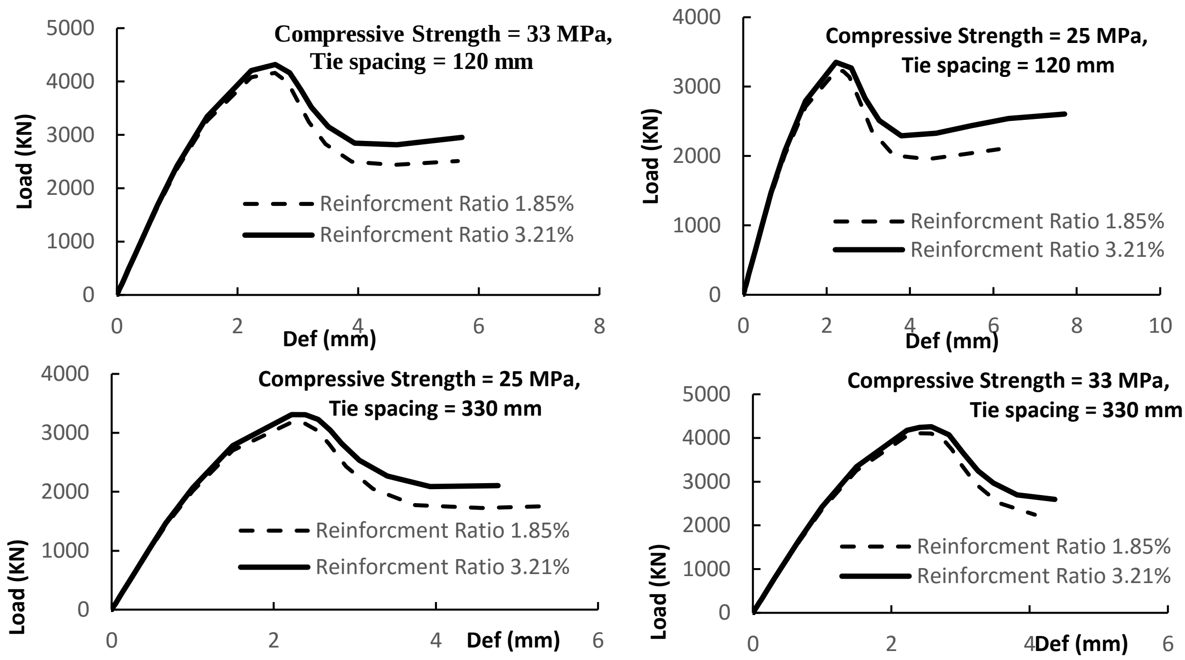

Fig. 3: Effect of reinforcement ratio

All of the specimens confirmed increase in ultimate capacity when reinforcement ratio was increased by 73%. However for the columns with concrete strength 25 MPa and tie spacing 330 mm, the increase in ultimate capacity due to increase in reinforcement ratio was more compared to others . The curves show almost same initial stiffness for the two reinforcement ratios. As predicted, the ductility of the columns increases due to increase in reinforcement ratio.

Effect of Tie spacing, s (mm)

To evaluate the influence of varying tie spacing on axial load capacity, two spacing of 120 mm and 330 mm were considered as presented in Figure 4.

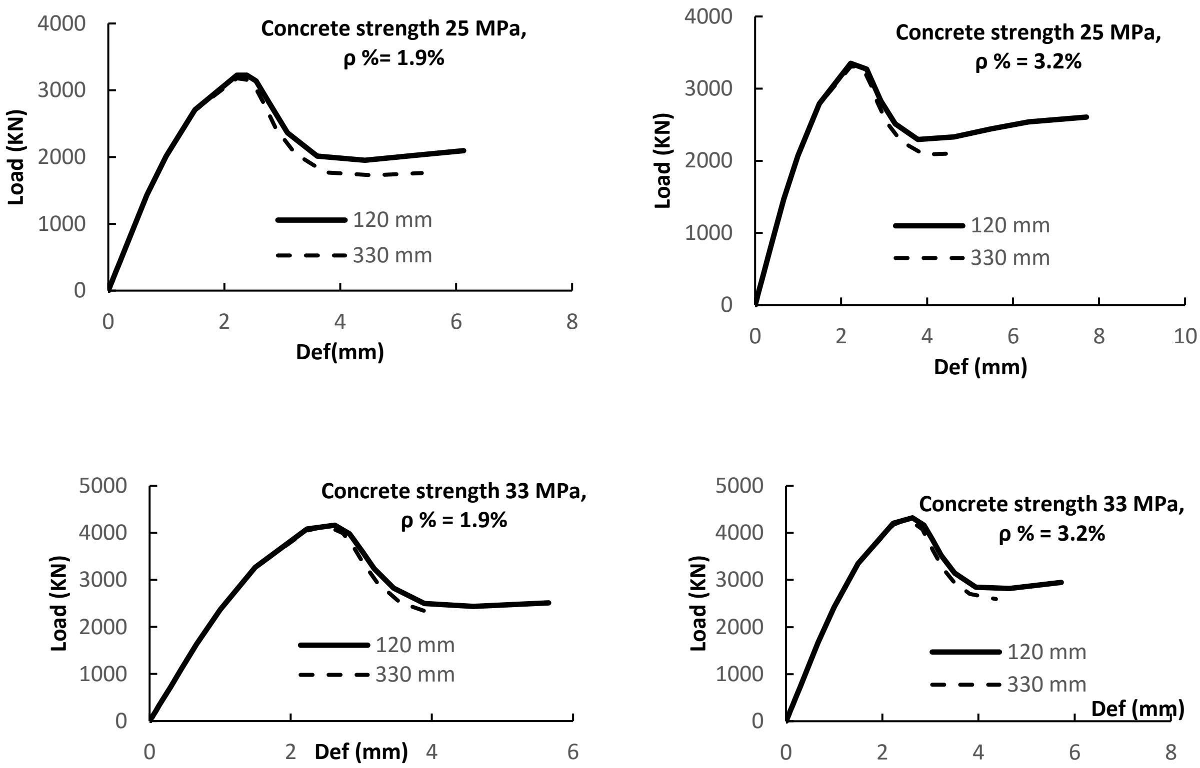

Figure 4 Effect of tie spacing.

All of the specimen confirmed increase of around 1.4% in ultimate capacity when tie spacing was decreased by almost 3 times in identical configuration. Thus, smaller the spacing, the increased confinement efficiency. In addition, the tie spacing controlled the buckling of the longitudinal bars. As predicted, the ductility and toughness (larger deformation region) of the columns improved due to increased transverse reinforcement ratio.

ULTIMATE CAPACITY AND CODE PROVISIONS

The nominal capacity of an axially loaded RC column $P_n$is given by the following equation

$$P_n = 0.85\, f'_c(A_g - A_s) + f_y A_s \qquad (1)$$

The 0.85 reduction factor suggested by the ACI Building Code (ACI Committee 318 2008) in capacity is mainly attributed to the differences in size and shape of RC columns and the concrete cylinder.CSA S806-02 permits the use of FRP bars as longitudinal reinforcement in columns subjected to axial load only, without taking into account the FRP bars' contribution in calculating the ultimate capacity of the columns, as shown in the following equation

$$P_n = 0.85\, f'_c(A_g - A_s) \qquad (2)$$

Figure 5 compares the axial strength computed,P_n, according to the equation as suggested by Kobayashi and Fujisaki, 1995 (Eq. (3)) considering the contribution of GFRP bars in compression to be equal to 35% of GFRP tensile strength.

$$P_n = 0.85\, f'_c(A_g - A_s) + 0.35\, f_y A_s \qquad (3)$$

Clearly, Eq. (1) overestimates column maximum capacity by 25% as evident from the Pn / Pu factor from figure 5. Conversely, ignoring the contribution of FRP longitudinal bars would underestimate maximum capacity. Setting GFRP compressive strength at 35% of the GFRP tensile strength made it possible to accurately predict the maximum axial load, as shown in Fig.5

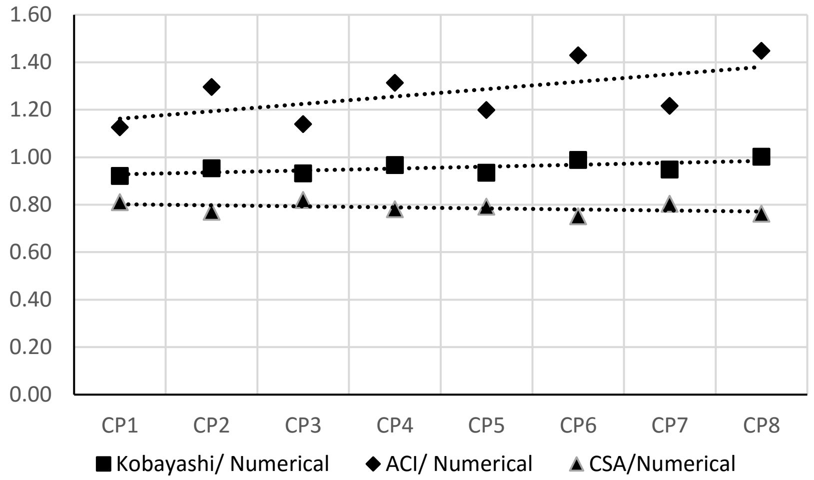

Fig. 5:Comparison of theoretical model to numerical model.

Table 2: Comparison between numerical and theoretical values by Kobayashi (1995) model, Eq. (3)

Column Specimen	**Numerical Load. P_u**	**Theoretical Load, Pn, by Eq3**	**% Error (%Δ)**	$\frac{P_n}{P_u}$
	KN	KN	%	
PC33-1.85-120	4161	3832	8.6	0.92
PC33-3.21-120	4318	4120	4.8	0.95
PC33-1.85-330	4109	3832	7.2	0.93
PC33-3.21-330	4258	4120	3.3	0.97
PC25-1.85-120	3225	3014	7.0	0.93
PC25-3.21-120	3350	3314	1.1	0.99
PC25-1.85-330	3179	3014	5.5	0.95
PC25-3.21-330	3306	3314	0.2	1.00

SUMMARY AND CONCLUSIONS

A parametric study was undertaken to study the behaviour of GFRP reinforced concrete columns. It was found that the gain in ultimate axial load capacity ranges from 22-23% with 24% increase in concrete compressive strength. The reinforcement ratio was increased by 73% and the gain in ultimate load capacity varied from 3.5-5.8 %. The reinforcement ratios modelled were 1.9% and 3.2%. The gain in ultimate axial load capacity was found to be around 1.4% with reduction in tie spacing by 3 times. Finally,setting the GFRP compressive strength at 35% of the GFRP maximum tensile strength in code provisions produced a reasonable estimate of ultimate capacity compared to the experimental results.

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