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BEHAVIOUR OF CONCRETE SHORT COLUMNS WITH GFRP REINFORCEMENTS

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ABSTRACT

The need for evaluating the strength of short columns is felt necessary as these columns are susceptible to fail under lateral loads due to seismic loads. In this experimental work, nine short concrete columns reinforced with Glass Fiber Reinforced Plastic (GFRP) main bars and helical stirrups were tested. The reinforcements were fabricated in-house by using a simple semi-mechanized technique. While keeping the amount of column main reinforcement constant for the all the specimens, the pitch of the spiral reinforcement and grade of concrete were varied to investigate the short concrete columns. The pitch distances adopted were 75 mm, 100 mm, and 150 mm and the grades of concrete were M 20, M 30 and M 40 respectively. A slenderness ratio of 4.66 was kept constant for all the columns. Strain gauges were used to determine the strains developed in concrete and GFRP reinforcements due to the applied load. The short column specimens were subjected to testing under pure axial load condition to evaluate the compressive load carrying capacity of these columns.

Key words: Short columns, glass fiber, polymer, spiral, reinforcement.

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1. INTRODUCTION

Columns are one of the important structural members transmitting the entire load of the building to the foundation. The dimensions of the column depend on the factors such as the height of the structure, the types of loads acting which in turn depends upon the spacing of columns, type of flooring system, the number of storey. Columns are designed to resist axial compression along with biaxial bending moments which occurs by frame action due to gravity and lateral loads. A column can be reinforced with bars and ties or can be reinforced spirally. The advantage of providing spiral reinforcement is that the spirals confine the core concrete and exhibits considerable resistance to deformation before the outer concrete shell spalls off. Thus the spiral reinforcement substantially improves the strength of circular concrete columns [1]. The circular columns are used in the construction of bridges, berths structures in ports, buildings and other structures. The conventional method is to construct them with steel reinforcement which is susceptible to corrosion due to various environmental conditions and exposure conditions such as cold cycles, rain water, ice, salt and much more. Despite the 50 year life period of these structures, they are deteriorated earlier due to the spalling of concrete which in turn is due to the corrosion of steel reinforcement [2].

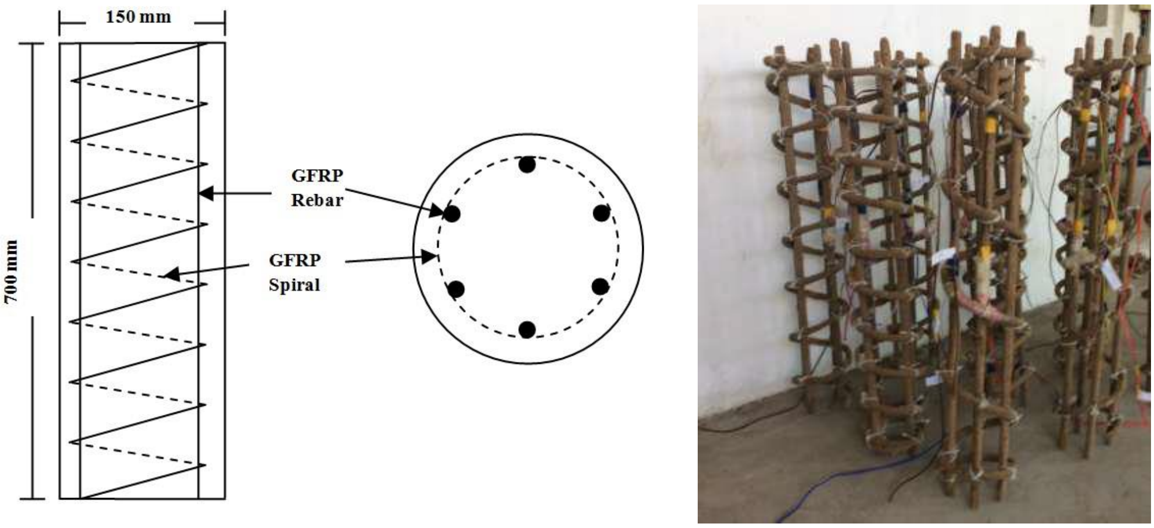
Egidijus et.al studied the strength of circular concrete column reinforced with FRP bars and spirals made of both glass and carbon fibers. Theoretical and analytical investigations were made for columns reinforced with spiral reinforcements and concluded that the spiral reinforcement enhanced the strength of concrete which depend upon the intensity of the spiral dimensions [2]. Zaki investigated the strength of short concrete columns reinforced with both FRP and steel spiral reinforcements. Strain gauges were used to measure the deformations. The test results concluded that the use of GFRP bars enhanced the load carrying capacity and ductility of the columns when they are reinforced with smaller diameter bars of closer spacing [3].

To overcome the problem of corrosion of the reinforcement this experimental work was based on the fabrication of FRP (Fiber Reinforced Polymer) bars and stirrups using a simple in-house technique. Nine short concrete columns of grades M 20, M 30 and M 40 with a slenderness ratio of 4.66 were made and reinforced with spiral reinforcement with three varying pitch distances such as 75 mm, 100 mm and 150 mm respectively. Strain gauges were used to measure the strain developed in the longitudinal reinforcement, transverse reinforcement and the concrete in both directions – vertical and horizontal respectively. The columns were subjected to axial compression and evaluated for its compression carrying capacity. In addition to this the effect of spacing of the transverse reinforcement was analyzed.

2. EXPERIMENTAL PROGRAM

2.1. Materials and Preparation of Specimens

Sand coated GFRP bars and spirals were used as reinforcement for the short concrete columns as shown in Figure 1(b). The GFRP rods of 8 mm diameter was used as longitudinal reinforcement and GFRP spiral reinforcement of 6 mm diameter were manufactured using Eglass fibers and epoxy resin. The spiral reinforcements were fabricated with three varying pitches- 75 mm, 100 mm and 150 mm. Three grades of concrete namely M 20, M 30 and M 40 were made as per the Indian standards [4]. In total 9 short concrete columns having diameter of 150 mm and height 700 mm were made and each specimen was provided with 4 strain gauges for- the longitudinal reinforcement; the spiral reinforcement; along the vertical direction on concrete and; along the horizontal direction on concrete respectively. In this experimental work the columns were named alphanumerically according to the variation in the grade of concrete and the pitch of the spiral reinforcement “GRSC” indicates Glass fiber Reinforced Short Column followed by “20” indicates the grade of concrete which is followed by “75” indicates the pitch of the transverse reinforcement. Figure 1(a) shows the schematic diagram of the Glass Fiber Reinforced short column.



(a) (b)

Figure 1 Glass Fiber Reinforcements used in short columns

2.2. Testing of Specimens

The short columns were fabricated and tested using the standard Universal Testing Machine. The columns were placed in between the loading plates of the UTM and the axial compressive load was applied gradually. A dial gauge was used to measure the deflection in concrete and the corresponding strains were measured using a digital strain meter. All the 9 column specimens reinforced with GFRP bars and spiral reinforcement with varying three pitch distances- 75mm, 100mm and 150 mm for three grades of concrete M 20, M 30 and M 40 were tested and the results were tabulated as follows. Testing of the GFRP short columns are shown in Figure 2 (a) and (b).

(a) (b)

Figure 2 GFRP Columns tested in UTM

3. RESULTS AND DISCUSSION

Table 1 shows the maximum compressive stress and strain of the columns.

Table 1 Maximum Stress, Confining strength and Strain of the columns

Specimen Id	P_{max} kN	f_{cc} N/mm^2	ε_b	ε_s	ε_{ch}	ε_{cv}
GRSC – 20 – 75	320	40.96	0.0155	0.0083	0.0044	0.0036
GRSC – 20 – 100	220	35.94	0.0157	0.0086	0.0046	0.0037
GRSC – 20 – 150	180	28.82	0.0158	0.0088	0.0047	0.0038
GRSC – 30 – 75	380	52.81	0.0141	0.0073	0.0033	0.0034
GRSC – 30 – 100	280	46.60	0.0144	0.0074	0.0034	0.0035
GRSC – 30 – 150	200	39.46	0.0145	0.0077	0.0035	0.0036
GRSC – 40 – 75	480	63.48	0.0130	0.0065	0.0030	0.0031
GRSC – 40 – 100	380	56.44	0.0131	0.0064	0.0030	0.0032
GRSC – 40 – 150	260	47.58	0.0133	0.0067	0.0032	0.0034

In Table 1 P_{max} represents the maximum compressive strength of the column and f_{cc} represents the confined concrete strength. ε_b indicates the strain in the GFRP rebar; ε_s indicates the strain in the spiral reinforcement; ε_{ch} and ε_{cv} indicates the axial strain of concrete in the horizontal and vertical directions respectively.

From the test results it is observed that the compressive stress is maximum for columns with closer spacing of transverse reinforcement. This can be attributed to the fact that with the closer spacing of the transverse reinforcement, the confining area is increased thereby enhancing the strength of the columns. During testing, the concrete cover along the spiral reinforcement started spalling only on application of higher loads, which indicates the straining of spiral reinforcement. The grade of concrete also has a significant effect in enhancing the strength of the columns.

3.1. Confined Concrete Strength of GRSC

The passive confinement in circular columns is provided by the spiral reinforcement adopted in this study. Providing spiral confinement enhances the concrete strength against crushing and dilation effects. The spiral spacing plays a major role in providing effective confining strength when the column is subjected to various loads. Therefore the level of confinement strength offered by the transverse spiral reinforcement was analyzed using numerical models developed by the earlier researchers. The confined concrete strength is calculated using the numerical model developed by Mander et.al [5] as follows

$$f_{cc} = f_c\left[-1.254 + 2.254\sqrt{1 + \frac{7.94f'}{f_c}} - \frac{2f'}{f_c}\right]$$

Where

$f_{cc} = confined\ concrete\ strength$

$f_c = characterstic\ compressive\ strength\ of\ concrete$

$f' = effective\ lateral\ confining\ stresses\ from\ the\ spiral\ reinforcement$

The result of the confinement strength f_{cc} is tabulated as shown in table 1. It can be seen from the results that the confinement strength is maximum for column with the spiral reinforcement spacing of 75 mm irrespective of the grade of concrete. Also the confined concrete strength decreases with increase in spiral spacing. During testing it was observed that the columns were able to withstand higher loads without causing the column to crush but with small cracks developed in concrete cover region just above the spiral reinforcement. This can be attributed to the fact that at low levels of load application, the transverse spiral reinforcement did not undergo much stress and hence the concrete inside the transverse reinforcement was unconfined. As the load increases the concrete becomes confined and the transverse strain increases which is indicated by the formation of micro cracks in Figure 2 (a). This activates the transverse spiral reinforcement to apply confining pressure to the concrete which can be seen from Figure 2 (b) by the formation of cracks along the axis of the spiral reinforcement. By providing the transverse reinforcement in the form of spirals is said to delay the process of damage thereby enhancing the column strength. Since the confined concrete strength was found to be maximum for columns with spiral reinforcement with smaller spacing, it can be concluded that smaller spacing spirals offered sufficient resistance against buckling of the longitudinal bars thereby enhancing the confinement efficiency and resisting compression failure.

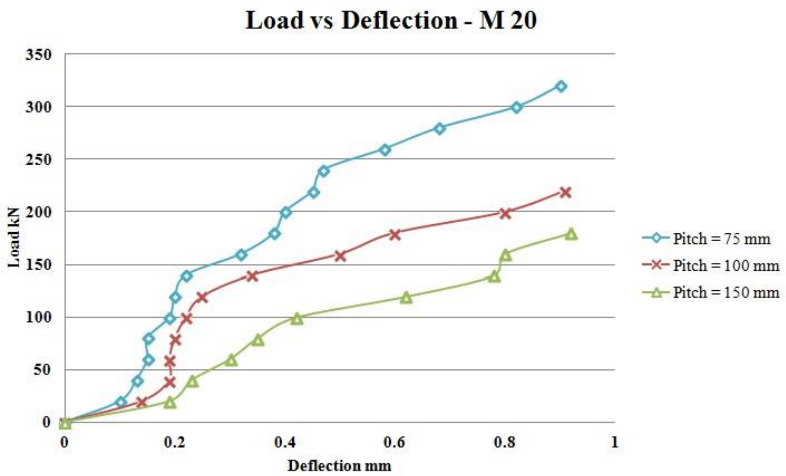


Figure 3 Load vs Deflection graph of M 20 grade column specimens

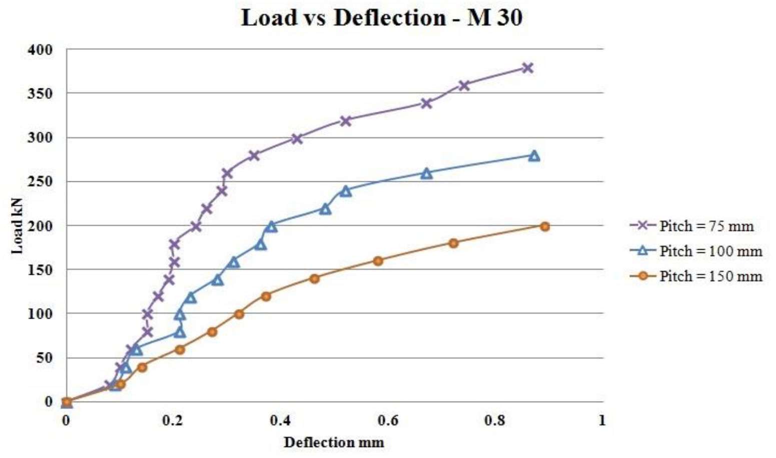


Figure 4 Load vs Deflection graph of M 30 grade column specimens

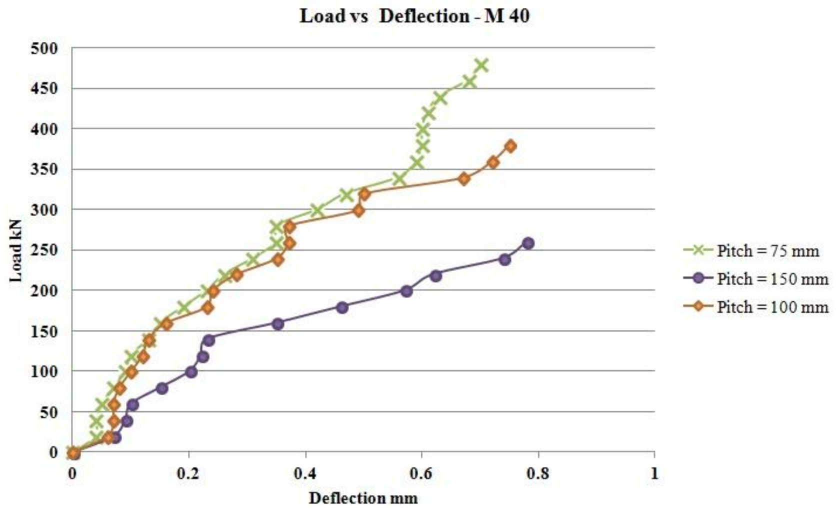


Figure 5 Load vs Deflection graph of M 40 grade column specimens

Fig. 3, 4 and 5 shows the respective graphs for the three grades of concrete columns tested. It can be concluded from the graphs that the rate of deflection increases with the increase in the pitch of the transverse reinforcement. Also the rate of deflection decreases with the increase in grade of concrete. This shows that closer the spacing of the transverse reinforcement, stronger the columns irrespective of the grade of concrete.

4. CONCLUSIONS

Based on the experimental work following conclusions were made:

- The spacing of the spiral reinforcement influences the strength of the GFRP columns. Smaller spirals were effective in providing sufficient resistance against the crushing load.
- The failure of the GFRP columns with larger spiral spacing of transverse reinforcement was controlled by the longitudinal reinforcement.
- The grade of concrete also plays an important role in enhancing the strength of the GFRP columns.
- These columns showed brittle failure rather than a ductile failure. With closer spacing of transverse reinforcement along with higher grade of concrete the load carrying capacity of GFRP short circular columns considerably increases.

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