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An Experimental study on the behavior of circular RCC enclosed GRP casing and FRP wrapping

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ABSTRACT: Nowadays, strengthening of the column using fiber-reinforced polymer (FRP) composites is considered as the strengthening technics of these loading elements in a structure. In this technique, increasing the surrounding pressure on radial levels of the concrete column increases the compressive and tensile strengths of the concrete element, reduces slenderness, and increases the buckling load and ductility of this element. Moreover, using glass-fiber reinforced plastic pipes (GRP) as the concrete column casing in addition to the independence of the need for framing leads to confinement effect on the concrete, high ductility and energy absorption, reduction in shrinkage and creep of concrete, lack of contact of the concrete with the corrosive factors, high construction speed, and proper loading capacity. In this research, a compressive capacity test was conducted on 6 cylinders reinforced concrete columns (RCC) of 150 mm and diameter 600 mm height, with and without GRP casing, and the effect of FRP wrapping was studied on them as the confining factor. The research results showed that using FRP wrapping and GRP casing improved the compressive capacity and ductility of the RCC. Adding one or two FRP wrapping layers increased the compressive capacity by 18.5% and 26.5% on the average, while using GRP casing increased the compressive capacity up to 4 times on the average and this shows that although FRP wrapping and GRP casing are both confined, GRP casing is more effective in increasing the compressive capacity due to its higher confinement with RCC.

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1. INTRODUCTION

One major factor that destroys the reinforced concrete structures such as bridges, buildings, and ports is their aging and decay under environmental conditions. This decay includes concrete rapture, reinforcement corrosion, and deformation of the structural elements which can significantly reduce the performance and safety of the structure. In the past decades, steel materials have been used more for strengthening but increased weight and corrosion have shifted the attention towards composite layers as a simpler and more economical choice of strengthening instead of steel reinforcement. In addition, applying the change of structures, increasing the loads on the structures, or developing some present structures parts in some cases, necessitates the strengthening of structures.

Using FRP increases the compressive strength and ductility of the confined concrete columns by supplying the confinement effect of the concrete core under compression loadings. Effective factors influenced on strength of CFRP wrapped columns are fiber type, elastic modulus and tensile strength of the fibers, fibers thickness, number of CFRP layers, the angle of application of the fibers, and so on. Recently, studies have been performed on composite columns, which are concrete columns filled with GRP pipes. In these columns, GRP pipes act as a durable framework and provide radial confinement for column core and limit the rupture of micro-cracks. At the same time, the concrete core prevents the buckling of GRP casing. Xiao et al. [1] and Park et al. [2] investigated both reinforced and unreinforced concrete columns confined in GRP casings. The results of these studies showed that GRP casing increased compression strength, hardness, and ductility of confined columns in the GRP casing. Tested under eccentric loading, it was reported that GRP confined column performance was better than columns without casing. Hadi et al. [3] and Wang et al. [4] investigated cylindrical concrete columns with GRP casing inner core and showed that the columns had higher compression capacity and better ductility than columns without casing.

The purpose of this research is an experimental study of the individual and simultaneous effects of GRP casing and FRP wrapping on reinforced concrete columns with a circular section which was obtained by constructing 6 reinforced concrete cylinder specimens of 150 mm diameter and 600 mm height, with and without the presence of GRP casings. The compressive strength tests and determination of their axial and radial deformation were conducted.

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Table 1. The mechanical properties of FRP wrapping and GRP casing [5-7]

Composite characteristics	FRP wrapping	GRP casing
Thickness (mm)	0.166	8
Density (kg/m^3)	1900	1800
Weight in surface unit (g/m^2)	300	-
Weight in length unit (g/m)	-	6786
Tensile stress (MPa)	4900	75
Modulus of Elasticity (GPa)	230	120
Poisson ratio	0.3	0.4
Ultimate strain (%)	2.5	1.3

2. RESEARCH METHODOLOGY

2.1. Mechanical properties of FRP and GRP

The used composite layers in this research are uniaxial CFRP made by TORAY Co. of Japan. The mechanical properties of FRP material were provided based on the manufacturing company's information and the tests based on ASTM D7565 [5] and ASTM D2996 [6] are presented in Table 1. The used epoxy glue was made by Paya Co. in two-partials of resin and stiffener, which were combined in ratio 1:3 and mixed manually for 5 min. The necessary time for the evolving of resin and its protection was influenced by the temperature of the environment and is between 5-7 days under normal condition based on the recommendation of the manufacturing company. The tolerable tensile stress of glue was 30 MPa and the tensile rapture strain was 3.6%. The characteristic of the mentioned glue was obtained based on the reports of the manufacturing company and the conducted tests were based on ASTM D638 [7]. GRP composite casings were made in Mashhad Sadra Shargh factory by imbrued glass fiber to the resin. These casings were classified based on the tolerable internal pressure. In this research, GRP casings with 10 bar internal pressure tolerance were used. The characteristics of GRP casings from the conducted tests based on ASTM D2996 [6] standard are presented in Table 1 based on the information of the manufacturer. GRP casings with 600 mm height, 150 mm internal diameter, and 8 mm thickness were used.

2.2. Specimens' characteristics

The experimental specimens of this research included 6 concrete columns with a circular section having 150 mm diameter and 600 mm height. All columns were reinforced concrete with three of them having GRP casing and the remaining three without GRP casing. One column of each group was not wrapped, one column was wrapped with one layer of CFRP and the other columns were wrapped with two layers of CFRP.

Columns were named according to their components as follows: For the column with normal concrete N, the column with FRP wrapping F and column with GRP casing G was considered. The number after (F) shows the number of FRP layers in columns having FRP wrapping. Table 2 presents the characteristics of research columns.

Table 2. Characteristics of the laboratory specimens of research

Specimen name	GRP casing	FRP wrapping	FRP Layer No.
N	NO	NO	0
NF1	NO	YES	1
NF2	NO	YES	2
GN	YES	NO	0
GNF1	YES	YES	1
GNF2	YES	YES	2

Table 3. Ultimate strains and capacity of columns

Column name	ultimate Capacity (kN)	Mean axial strains (10^{-6} mm/mm)	Lateral strain (10^{-6} mm/mm)
N	566	* -3848	1356
NF1	715	-4144	1579
NF2	763	-5432	2022
GN	2485	-15229	4051
GNF1	2765	-18738	5347
GNF2	2940	-22075	5993

3. ANALYSIS OF TEST RESULTS

3.1. The ultimate capacity of columns

Columns were loaded by the 500-ton machine at the rate of 12 kN/s until the moment of failure. The ultimate strains and capacity of columns are shown in Table 3.

As can be observed in Table 3, using single and double of FRP layer in columns without GRP casing caused 26% and 35% increase, and in columns with GRP casing it caused 11% and 18% increase of the columns ultimate capacity. Therefore, it confirms that using FRP wrapping can provide very good effects in increasing the ultimate capacity of reinforced concrete columns. In addition, using single-layer FRP wrapping was more economical than the double layer. Moreover, using FRP in columns with GRP casing caused a slight increase in columns' ultimate capacity, because of the effect of high confinement of this casing. Therefore, if these casings are used, FRP is not economical to strength the reinforced concrete columns.

On the other hand, using GRP casings was much more effective than FRP wrapping. For example, using GRP casing without using FRP wrapping increased the compressive capacity by 339% in reinforced concrete columns, while using single and double layer FRP wrapping increased the compressive capacity by 26% and 35%, respectively.

3.2. Study of columns rupture

Failure of most columns happens because of bars buckling of columns. In columns without GRP, most ruptures occurred locally and gradually in these columns, the rupture occurred on either of the two ends, The reason for this event is the lower confinement of concrete core at the two ends of reinforcement network. In column N, that was without any confinement, the rupture was due to the formation of compression cracks in the concrete above the column and finally the removal of concrete pieces in this section and the buckling of the longitudinal bars. Column NF1 had a CFRP wrapping layer; a rupture on top of the column also occurred due to the crushing of the concrete and eventually tearing of the carbon sheet. In this column, unlike column N, the confinement caused by the CFRP led to less concrete crushing, no bars ruptures and column capacity increment. The ruptures in column NF2 was similar to that of the NF1 column, except that the breakdown and rupture of the carbon reinforcement sheet occurred at the bottom of the column. Ruptures in columns with a GRP casing were different. In column GN, the rupture was completely destroyed and with a loud voice in the total length of the columns, due to the very high confinement caused by the GRP casing. This confinement reaching all the points of the column to its maximum tolerable strain, yielding longitudinal bars, and finally the columns ruptured. In column GNF1, the rupture was similar to column GN, except that the greater confinement by the CFRP layer caused that concrete withstand more compressive stress, and eventually, in the middle of the column, with the buckling of the longitudinal bars and the cutting of spiral bars, the column was ruptured. In column GNF2, the rupture was similar to that of the previous columns, with the exception that the greater confinement caused by double CFRP layer caused the overall rupture to occur throughout the length of the column with buckling longitudinal bars and cutting spiral bars.

4. CONCLUSIONS

1- By examining the failure of the columns, it was found that most of the columns were broken due to buckling of the longitudinal bars. In columns without a GRP casing, most of the rupture occurred locally and gradually; in these columns, the rupture occurred on either of the two ends; The reason for this result was the lower confinement of concrete core at the two ends of reinforcement network, while in the columns with a GRP casing, the rupture was different and completely destroyed with loud voice in total length of the columns, The reason for this was the very high confinement caused by the presence of the GRP casing; This confinement prevents the early buckling of the bars, reaching all the points of the column to its maximum tolerable strain, yielding longitudinal bars, cutting the spiral fittings and then, the columns ruptured.

2- The technical and economic comparison of the studied columns showed that using GRP casings to capacity columns was more economical than using FRP wrapping, as the capacity increment in columns with the casing was more than the cost of their strengthening. However, the ratio of the obtained strength by FRP wrapping in columns with and without casing was less than the cost of strengthening with these materials.

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