Experimental investigation of the behavior of columns reinforced with GRP casing and CFRP wrapping under eccentric load

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Abstract

High-strength concrete (HSC) columns, despite their superior compressive strength, are characterized by brittle behavior and limited ductility. This study investigates the effectiveness of confinement using GRP (Glass Reinforced Polymer) tubes and CFRP (Carbon Fiber Reinforced Polymer) wrapping in enhancing the structural performance of HSC columns. The primary objective is to mitigate the inherent brittleness of HSC through improved confinement, with load-bearing capacity serving as a secondary performance indicator. An experimental program was conducted on 18 circular columns (150 mm in diameter and 600 mm in height), categorized into tubed and non-tubed specimens. The columns were subjected to axial loading tests at eccentricities of 20 mm and 50 mm. The results demonstrate that the application of one and two layers of CFRP wrapping increased the load capacity of non-tubed columns by an average of 14% and 44%, respectively. In contrast, for tubed columns, these increases were 7.3% and 12.2%, respectively. Notably, the integration of GRP tubes, both independently and in synergy with CFRP wrapping, resulted in more than a threefold increase in load-bearing capacity compared to the control specimens. The findings indicate that while both confinement techniques are effective, GRP tubes provide significantly higher lateral confinement pressure, leading to superior improvements in both the ductility and ultimate load capacity of circular reinforced concrete columns. Consequently, this study emphasizes the necessity of confinement strategies for high-strength concrete structures to ensure ductile performance. Consequently, this study emphasizes the necessity of confinement strategies for high-strength concrete structures to ensure ductile performance

Keyword: Reinforced concrete columns (RCC's), Rupture, Ductility, GRP casing, CFRP wrapping.

1. Introduction

Repairing and strengthening primary structural members is essential in various scenarios to prevent potential damage. Consequently, employing practical and effective solutions for the repair and strengthening of concrete structures is unavoidable. Within these structures, reinforced concrete columns—which serve as vertical load-bearing members subjected to pure axial loads or a combination of axial loads and bending moments—are considered among the most vulnerable components.

Previous research has demonstrated that strengthening and retrofitting existing concrete columns using jackets or confinement (wrapping) techniques can enhance their load-bearing capacity [1–5]. High-strength concrete is regarded as a relatively modern material, and its application in structural construction has expanded significantly over the years. The definition of high-strength concrete has evolved over time; in the 1950s, concrete with a strength of 34 MPa was classified as high-strength. By the 1960s, concrete with a compressive strength ranging from 41 to 52 MPa was categorized as such, and by the early 1970s, concrete with a strength of 62 MPa had been developed—a trend that has continued to the present day. Currently, concrete with a compressive strength exceeding 140 MPa is utilized in the construction industry worldwide. Columns constructed with such high-strength concrete require substantial confinement to reach their ultimate load-carrying capacity; the use of jackets or wrapping techniques effectively provides this necessary confinement. Therefore, this experimental study investigates the effects of using a casing and a wrap—both individually and in combination—on the capacity and failure behavior of circular reinforced concrete columns constructed with high-strength concrete. To this end, 18 columns (each 150 mm in diameter and 600 mm in height) were fabricated—with and without casings and wraps—and subjected to compression tests under eccentric loading to determine their axial deformations.

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Table 1– Mechanical properties of the wrapping and casing used [6]		
Composite properties	casing	wrapping
Thickness (mm)	8.0	0.166
Density (kg/m^3)	1800	1900
Areal weight (g/m^2)	------	300
Linear weight (g/m)	6786	------
Tensile strength (MPa)	75	4900
Static modulus of elasticity (GPa)	120	230
Poisson's ratio	0.4	0.3
Ultimate strain (%)	1.3	2.5

The mechanical properties of the wrap and sheath used are presented in Table 1, in accordance with the ASTM D2996-98 standard [7].

2- Experimental program

To determine the compressive strength of the concrete used in the construction of the columns, cylindrical specimens—measuring 150 mm in diameter and 300 mm in height—were prepared in accordance with ACI 211 [8] recommendations. Following curing in a water tank, the specimens were subjected to compressive strength testing at 7 and 28 days of age. The water-to-cement ratio was 0.20, and the concrete slump at the time of specimen preparation was 120 mm. Details of the concrete mix design are presented in Table 2.

Table 2 – Details of the concrete mix design used in the construction of the columns (kg/m^3)				
w/c	Sand	Gravel	Water	Cement type 2
0.2	720	930	111.5	550

The results of the compressive strength test are presented in Table 3.

Table 3 - Compressive strength test results for standard cylindrical specimens at 28 (days (MPa				
Average	Third specimen	Second specimen	First specimen	Cement
63.1	64.3	64.5	60.5	Ramhormoz Type 2

Table 4 presents the specifications of the 18 experimental columns used in the research.

Table 4 - Specifications of the experimental columns used in the research									
Specimen name	e (mm)	Casing	wrapping	No of layers	Specimen name	e (mm)	Casing	wrapping	No of layers
H-0	0	None	None	0	GH-0	0	It has	None	0
H-20	20	None	None	0	GH-20	20	It has	None	0
H-50	50	None	None	0	GH-50	50	It has	None	0
HF1-0	0	None	It has	1	GHF1-0	0	It has	It has	1
HF1-20	20	None	It has	1	GHF1-20	20	It has	It has	1
HF1-50	50	None	It has	1	GHF1-50	50	It has	It has	1
HF2-0	0	None	It has	2	GHF2-0	0	It has	It has	2
HF2-20	20	None	It has	2	GHF2-20	20	It has	It has	2
HF2-50	50	None	It has	2	GHF2-50	50	It has	It has	2

3- Research Methodology

The testing of concrete columns under uniaxial compressive loading was conducted using a hydraulic jack with a capacity of 5000 kN at the Soil Mechanics Laboratory of the General Directorate of Roads and Transportation of Khuzestan Province. The specimens were tested under displacement control at a loading rate of 10 kN/s [9]. To measure the longitudinal displacement of the columns, two displacement transducers were installed on opposite sides of each column. Displacement data were recorded via two channels of an electronic data logger

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connected to a computer. To plot the load-displacement curves for the specimens, the instantaneous applied load was automatically recorded using a 5000 kN load cell.

4- Analysis of Test Results

4-1- Ultimate Capacity of Columns

The axial load was increased uniformly at a rate of 10 kN/s until the columns failed due to concrete crushing. This loading rate corresponds to 0.23 MPa/s. According to the ASTM C39 standard, the loading rate for determining the compressive strength of cylindrical concrete specimens should be within the range of 0.14–0.34 MPa/s. The ultimate capacity and corresponding displacement (averaged) for the columns are presented in Table 5.

Table 5 – Capacity and ultimate displacement of the columns under study

Row	Column name	Ultimate capacity	Final average displacement (mm)	Row	Column name	Ultimate capacity	Final average displacement (mm)
1	H-0	66.82	5.403	10	GH-20	205.29	21.551
2	HF1-0	75.90	8.645	11	GHF1-20	220.17	22.197
3	HF2-0	96.66	12.968	12	GHF2-20	230.14	22.619
4	GH-0	231.63	19.580	13	H-50	53.77	14.118
5	GHF1-0	252.21	20.559	14	HF1-50	61.59	14.443
6	GHF2-0	260.26	21.146	15	HF2-50	69.64	15.136
7	H-20	57.80	10.080	16	GH-50	196.97	20.800
8	HF1-20	62.91	11.034	17	GHF1-50	201.60	23.370
9	HF2-20	77.68	13.241	18	GHF2-50	211.77	23.837

4-2- Failure Mode of Columns

Table 6 – Ratio of the ductility factor of the strengthened specimens to the ductility factor of the reference specimen (μ/μ_{ref})

Column name	Ductility factor	Ductility factor of the column relative to the reference column	Column name	Ductility factor	Ductility factor of the column relative to the reference column
H-0	2.0	1.0	GH-0	3.0	1.0
H-20	1.0	1.0	GH-20	2.5	1.0
H-50	1.8	1.0	GH-50	1.5	1.0
HF1-0	4.0	2.0	GHF1-0	4.3	1.43
HF1-20	2.0	2.0	GHF1-20	3.4	1.36
HF1-50	2.3	1.27	GHF1-50	1.7	1.13
HF2-0	5.0	2.5	GHF2-0	3.5	1.76
HF2-20	3.0	3.0	GHF2-20	4.4	1.76
HF2-50	3.3	1.83	GHF2-50	2.4	1.6

Table 7 - Evaluation of the technical-economic efficiency of various column retrofitting schemes

Specimen name	Total cost (Toman)	Casing length (m)	Casing cost (Toman)	Wrapping area (m^2)	Wrapping cost (Toman)	Cost of column construction (Toman)	Cost ratio	Strength ratio
H	65000	*	*	*	*	6500	1.18	1.28
HF1	65000	*	*	0.4	36000	101000	1.84	1.44
HF2	65000	*	*	0.8	72000	137000	2.49	1.79
GH	55000	0.6	60000	*	*	115000	2.09	4.72
GHF1	55000	0.6	60000	0.4	36000	151000	2.74	5.19
GHF2	55000	0.6	60000	0.8	72000	187000	3.40	5.43

5- Conclusions

The key research findings are as follows:

1- The use of a casing- serving as both a formwork and a reinforcement- in reinforced concrete columns significantly increased their load-bearing capacity; specifically, the capacity of the encased columns was at least double that of comparable columns without a casing.

2- Strengthening columns with external wrapping (confinement) enhances their capacity. On average, the application of one and two layers of wrapping increased the compressive capacity of columns without a casing by 14% and 44%, respectively, while for columns with a casing, the increases were 7.2% and 12%. This indicates that the impact of external wrapping is less pronounced in columns that are already encased.

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3- An examination of columns at a practical, full-scale size revealed that the use of external wrapping for confinement effectively improves ductility, while the use of a casing is capable of significantly increasing column capacity.
4- Observations of column failure showed that, in columns without a casing, failure typically occurred locally and gradually. In contrast, failure in encased columns was total—manifesting as a sudden, explosive collapse along the entire length of the column.
5- Load-bearing capacity decreased as eccentricity increased. Specifically, compared to a zero-eccentricity condition, the average reduction in capacity was 15% for an eccentricity of 20 mm and 24% for an eccentricity of 50 mm.
6- Reinforced concrete columns constructed using high-strength concrete exhibited more brittle behavior; consequently, these columns require strengthening to enhance their ductility.
7- An economic evaluation based on the strength-to-cost ratio revealed that the jacketed specimen (GH) achieved the highest economic efficiency—with an index of 2.62—due to the elimination of formwork costs and a 4.72-fold increase in load-bearing capacity. Furthermore, the combination of a jacket and an additional wrapping layer (specimen GHF1) resulted in a 5.19-fold increase in strength and an efficiency index of 1.98, representing an optimal technical-economic performance.

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