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Strength Evaluation of Hybrid Reinforced Concrete Columns under Eccentric Loads

Abstract- *This study presents an experimental investigation of the behavior of hybrid circular columns composed of outer precast reactive powder concrete (RPC) tubes filled with normal concrete (NC). The column specimens were subjected to an eccentric load producing both flexural and axial stresses within the section. The specimens consisting of 200 mm outer diameter with 400 mm height. The column specimens were divided into three groups, each group contains two specimens of thicknesses of outer RPC walls of 50 and 25 mm that filled with NC, in addition to RPC solid column section. The columns of first group were without any reinforcement. While the second group specimens were longitudinally reinforced, in addition to 180 mm spaced ties. The third group is composed of the same details as that of group two but with 90 mm ties spacing. The results show that, All RPC solid specimens give a higher load capacity from that of the hybrid specimens about 48%. It is noticed that increasing the RPC outer wall thickness improves the ultimate load capacity by 11% for hybrid specimens with 50 mm thickness wall than that of hybrid specimens with 25 mm thickness wall. Also, longitudinal and transverse reinforcement noticeably enhance the ductility and strength of the tested specimens compared with corresponding plain specimens.*

Keywords- *RPC short columns, hybrid columns, eccentric load, RPC tube columns filled with NC.*

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1. Introduction

Reactive Powder Concrete (RPC) is an ultra-high strength (UHSC) of high ductility cementitious composite with superior chemical and mechanical properties. RPC has ultra-dense micro structure with specific mixture content that have a high compressive strength, fracture toughness, ductility, fire resistance while permeability and porosity are low due to homogeneity of RPC with limited shrinkage [1,2]. As known, RPC is brittle material, so adding steel fibers can significantly improves its flexural, tensile strengths, and toughness. RPC gives properties of waterproofing and durability characteristics [3]. RPC provides inhanceded seismic performance by reduction of inertia loads with lighter members, allowing large deflections with reduced cross sections, and providing higher absorption [4]. Column is a vertical structural member. It transmits the load from ceiling/roof slab and beam, including its self-weight to the foundation. Columns may be subjected to a pure compressive load or subjected to a lateral load like wind load or seismic load. Column is widening of foundation so using RPC will reduce the weight of column cause reduce settlement of foundation [5]. In most of structures, it is necessary to insure that compression members (columns) should be behave in a ductile manner. Newly, observed that the confinement properties can be largely improved by using short randomly distributed fibers in the concrete matrices. The improvement is due to fiber-matrix interaction and that significantly effect on concrete tensile strength [6]. To make RPC capable to be used for structural applications, it is necessary to achieve ductile behavior. The inclusion of steel fibers into the matrix leads to an increase in the load to first crack and significantly improves the post-peak behavior. The large number of small fibers that cross the path of micro-cracks, coupled with perfect bond between fiber and matrix, provides high resistance to fiber pullout during tensile cracking, and greatly increases the ductility of the material [7]. Hybrid concrete columns have been preferred to solid columns to reduce the cost of structures, and to decrease their self-weight where it is technically necessary. Hybrid concrete sections are often used in tall bridge columns in seismic areas in order to reduce the mass and therefore minimizing the self-weight contribution

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to the inertial mode of vibration during an earthquake. In addition, it can reduce the foundation dimensions and that lead to saving in the construction cost substantially [8].

2. Experimental Program

This research presents a detailed description of production of both RPC and NC and the test programs carried out. In addition, it gives the details of the specimens used in this study and processes of the tests conducted. The constituent materials and mechanical properties of both RPC and NC will be studied first, using the conventional test procedures. For hardened concrete, the tests measure the ultimate compressive strengths, splitting tensile strengths and flexural rupture strengths. The column specimens will be subjected to an eccentric load producing both flexural and axial stresses within the section.

I. Detail of Specimens

In this study, the focus will be on hybrid short circular columns under eccentric load. Cylindrical specimens are selected here of 200 mm diameter and 400 mm length to simulate short columns. A comparison will be made with solid RPC columns with the same dimensions. The outer walls of hybrid sections are made up of RPC while the internal cores are NC. To achieve the goal of study a total of nine specimens were poured. The column specimens were put in three groups. Each group contains three specimens. The columns of first group were reinforced with eight 4 mm longitudinal deformed steel bars and 3 mm transverse ties of undeformed steel bars spaced at 180 mm. While the three columns of second group were reinforced with, same longitudinal rebars but have 3 mm transverse undeformed steel ties spaced at 90 mm. The remaining three columns of the third group are plain RPC without any reinforcement. The detailed sections of columns are shown in Figs.1 and 2. And Table 1 explains the specimens RPC wall thickness and spacing of transverse reinforcement details.

II. Materials and Mix Design

In both RPC and NC, ordinary Portland cement OPC conforming to Iraqi Standards (IQS 5/1984) [9] was used. It is produced by United Cement Company (Tasluja)/ Iraq.

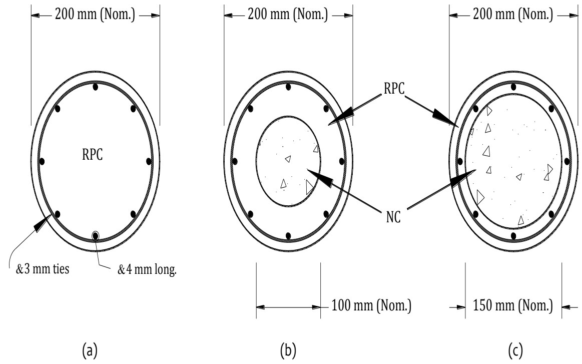

Figure 1: Column specimens, (a) solid section, (b) hybrid section with 50 mm thick wall, (c) hybrid section with 25 mm thick wall

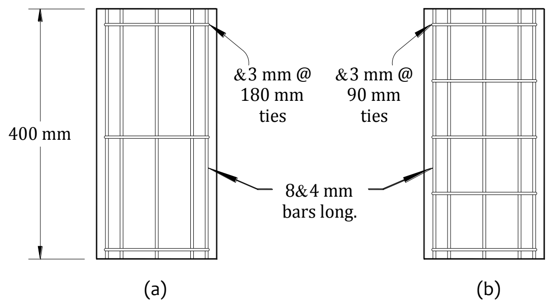

Figure 2: Longitudinal reinforcement details with (a) lateral ties at 180 mm spacing, (b) lateral ties at 90 mm spacing

Table 1: Column specimens details

Group	Specimen	RPC wall thickness (mm)	Lateral ties spacing (mm)
	GST3	-	180
1 st	GH25T3	25	180
	GH50T3	50	180
2 nd	GST5	-	90
	GH25T5	25	90
	GH50T5	50	90
3 rd	GSN	-	-
	GH25N	25	-
	GH50N	50	-

Silica fume is MasterRoc® MS 610 from BASF chemical company with chloride content less than 0.1% has been used as additive to the RPC mixes. The percentages used were 25% as a partial replacement of cement weight (ASTM C1240) [10].Very fine sand (glass sand) with maximum size 600μm was used for RPC mixes from Sika (Sikadur 504 C). For NC, fine aggregate from Al-Ukhaidher with a maximum size 4.75 mm and coarse aggregate from Al-Nebaee region with a maximum size of 10 mm were used. Both aggregates were conforming to the requirements of (IQS no.45/1984) [11]. Sika ViscoCrete® - 5930 was used which is a third generation superplasticizers, which meets the requirements of ASTM-C- 494. High carbon copper coated micro steel fiber used in this study with length of 15 mm and diameter of 0.2 mm which gives an aspect ratio l_f/d_f of 75 and using volume fraction (V_f) of 2%. The fibers have the properties described in Table 2. Two types of steel reinforcement were used. The longitudinal reinforcement was Ø4 mm deformed bars and for transverse reinforcement (ties) was Ø3 mm plain bar were used. The tensile strength for 4 and 3 mm steel bars were 602.5 and 749.17 MPa, respectively. The mixing design of RPC is indicated in Table 3 and for NC the mix design illustrated in Table 4.

Table 2: Properties of steel fiber*

Description	straight
Length	15 mm
Diameter	0.2 mm
Density	7800 kg/m^3
Tensile strength	2500 MPa
Aspect ratio	75

*Manufacturer Catalog

Table 3: Proportions of constituent materials in RPC mix.

parameter	Concrete mix(1m^3)
Cement (kg\m^3)	900
Quartz Sand(kg/m^3)	990
Silica fume (kg\m^3)	225
Silica fume % *	25%
Water (L\m^3)	157.5
Water to cementitious ratio w/B	0.16
Admixtures (Sika® ViscoCrete-5930) (kg\m^3)	67.5
Admixtures (Sika® ViscoCrete-5930) %**	6%
Steel fibers (kg\m^3)	156
Steel fibers V_f % ***	2%

*Percent by weight of cement.
** Percent of cementations materials (cement + silica fume) weight.
*** Percent of mix volume.

Table 4 Proportions of constituent materials in NC

Parameter	Concrete mix (1 m^3)
Cement (kg/m^3)	460
Fine Aggregate Sand (kg/m^3)	625
Coarse Aggregate Gravel (kg/m^3)	969
Water (L\m^3)	216
W/C Ratio %	0.47

III. Molds of Specimens

PVC pipes with different sizes are used as molds to produce column specimens as shown in Fig. 3. The ends of the molds were made from wooden rings to assure leveled surface for the columns. These molds are of single use, so a total of nine molds were manufactured. After that, the reinforcement cages were inserted inside.

IV. Mixing Procedure of RPC

Constituent materials were weighted and prepared according to the mix design assigned to get the targeted compressive strength. The mixing processes were carried out using a power-driven revolving drum mixer.

After concrete casting and reaching initial hardening, all specimens were cured in water basins. Then all specimens were filled with the RPC mix in layers. Each layer was compacted by external table vibrator for 2 min. to minimize the air voids and to obtain well compacted concrete. The specimens were covered with plastic sheets to prevent loss of moisture. After 24 hours, the specimens were opened and then cured in a container filled with tap water.

For hybrid sections, after 60 days curing process for RPC circular tubes, NC was poured inside the tubes in layers. After NC core hardening, another 28 days curing process was carried out for column specimens. Finally, all specimens were removed from curing containers as shown in Fig. 4 and white painted and prepared for testing.

Figure 3: Molds of the tested specimens

Figure 4: Column specimens after hardening mix.

V. Concrete Properties

The control specimens of RPC were subjected to compressive strength according to **ASTM C39** specifications, splitting tensile strength **ASTM C496** and flexural strength **ASTM C78** tests at 28 and 90 days ages. Twelve 100×200 mm cylinders and six 100×100×400 mm prisms were used. For NC six 100×200 mm cylinders and three100×100×400 mm prisms were tested only at 28 days. The test results are illustrated in Tab. 5.

VI. Eccentrically Loaded Specimens

To measure for strains and lateral displacement of specimens due to eccentric loads a system of demec points were fixed on the surface as shown in Fig. 5. Also, two dial gauges were fixed at mid- height of specimen to measure lateral displacement for two sides of specimen (loaded and unloaded). The load was applied by using a calibrated electro-hydraulic testing machine (Avery) with a maximum capacity of 2500 kN.

3. Testing Results

The results shows that, ultimate load capacity of solid RPC specimens was higher than that of the hybrid specimens by about 18% for solid plain RPC specimens (GSN) and 30 %, 20 % for hybrid section of 50 mm and 25 mm thick outer RPC skin (GH50N and GH25N), respectively. Fig.6 shows the ultimate load capacity of all columns and Fig. 7 shows the failure modes of tested specimens. One of the most important notes in the tests that have to be mentioned here is the sudden explosive type of failure in plain non-reinforced columns. It was noticed that a delay in the first crack appearance for reinforced columns. For hybrid column specimens, the failure occurred by spalling the outer RPC skin followed by the inner NC core. In addition, it is clearly seen that the addition of steel reinforcement significantly enhances the strength and stiffness of the tested columns compared with corresponding plain columns. In addition, increasing in RPC wall thickness led to improvement in the ductility and stiffness of hybrid specimens. Fig. 7 shows the failure modes of tested specimens and Figs. 8 and 9 demonstrate the load-displacement relations of tested columns. The displacement on horizontal axis was colored with red to distinguish from displacements on the other opposite side.

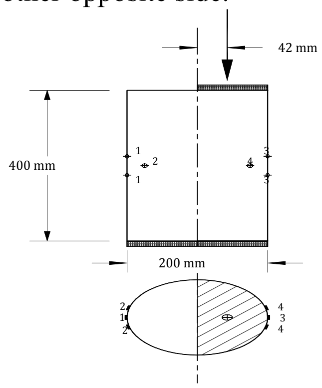

Figure 5: Demec points distribution in eccentrically loaded specimens

Table 5: Control specimens test results

Age (days)	Compressive strength (MPa)		Tensile strength (MPa)		Flexural strength (MPa)	
	RPC	NC	RPC	NC	RPC	NC
28	106.6	38.13	13.1	2.85	18.6	3.9
90	124.0	---	16.6	---	23.8	---

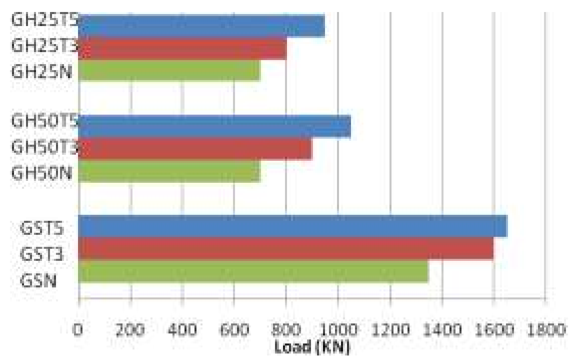

Figure 6: Ultimate load capacity for tested specimens

Table 6: test result of all tested specimens.

Columns ID	Columns under Eccentric Load			
	P cr (kN)	Δ cr (mm)	P u (kN)	Δ u (mm)
GSN	1200	2.96	1350	3.58
GST3	1500	2.84	1600	3.2
GST5	1550	2.19	1650	2.55
GH50N	550	1.33	700	2
GH50T3	-	-	900	2
GH50T5	950	1.58	1050	2.2
GH25N	600	1.76	700	2.55
GH25T3	650	1.5	800	2.1
GH25T5	800	1.78	950	2.7

4. Conclusion

The following points of conclusions can be mentioned as following.

- The RPC solid specimens gave a higher load capacity from that of the hybrid specimens.
- For unreinforced columns, the ultimate stiffness was much lower in solid columns than in hybrid columns.
- For the reinforced columns there were close displacements.
- Reinforcement plays a major role in ultimate strength enhancement. The ultimate load capacity with addition of reinforcement was increased by about 18% for solid columns and 30% and 20% for both hybrid columns with 50 and 25 mm thickness wall, respectively.

Increasing in RPC outer wall thickness increases the ultimate load capacity by 11% for hybrid columns with 50 mm thickness wall than that of hybrid columns with 25 mm thickness wall. Also, it was clearly shown an improvement in ductility and stiffness for hybrid columns with 50 mm thickness wall than the smaller thickness wall of 25mm.

Table 6 below gives first crack load, displacement at first crack, ultimate load capacity and ultimate displacement for all column specimens under eccentric and lateral load.

Figure 7: Failure modes of tested specimens.

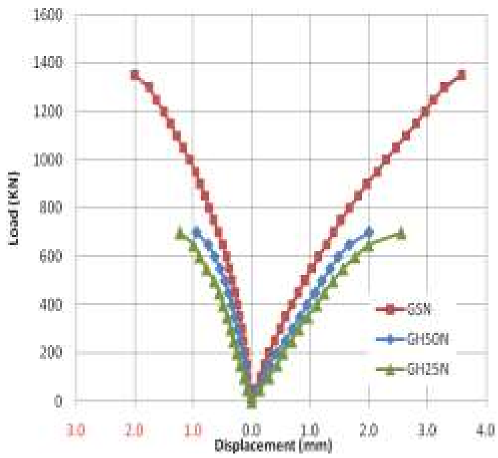

Figure 8: Load- lateral displacement curves for plain specimens

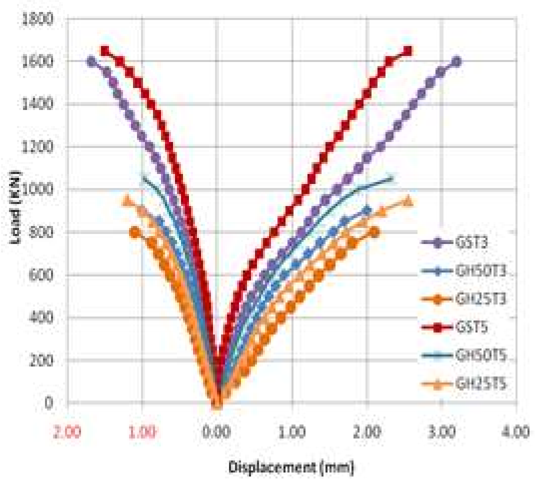

Figure 9: load – lateral displacement curvers for Reinforced specimens

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