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THE INFLUENCE OF STEEL FIBRES AND RPC THICKNESS ON THE BEHAVIOUR OF HYBRID COLUMNS UNDER CONCENTRIC LOADING

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In this paper a test was performed on six reinforced concrete rectangular columns subjected to concentric loading up to failure. The material used in this investigation included normal concrete, NC, and reactive powder concrete, RPC. Two columns were cast as control specimens with NC and RPC. The remaining four were of hybrid combination having the NC in the centre and the RPC surrounded it. Variables investigated were the effect of steel fibre volumetric ratio, V_f (0.5, 1 and 1.5) as well as the thickness of the external RPC part, (40 and 20) mm. The columns were of rectangular section having the dimensions of (100×200×740) mm. Data recorded included: crack and ultimate loads as well as the longitudinal and lateral strains. Experimental results indicated that the behaviour of the hybrid reinforced concrete columns were approaching that of the full RPC.

Key words: hybrid concrete, normal concrete, reactive powder concrete, short columns, steel fibres, concentric loading, rectangular section

INTRODUCTION

For more than 20 decades, concrete was and still considered as the principal construction material. The development of this material is progressing, from normal concrete, NC, through high strength concrete, HSC, reaching to ultra-high-performance concrete (UHPC) referred to as reactive powder concrete (RPC). The latter two are produced by adding steel fibres with other additives to the normal concrete. Cracks in HSC or UHPC loaded members are bridged by the fibres used, improving the ultimate tensile strength, toughness and energy absorption capability as compared with members cast with concrete without fibres, as shown in Figs.1, 2 and 3.



Figure 1: Bridging Action of Steel Fibres on Concrete [3]

This improvement was registered over the last 5 decades. Although the properties of HSC or UHPC are so good, their use was rather limited because of the extremely high prices (about 20 times the cost of NC). [4, 5 and 6] UHPC (or RPC) mechanical and durability properties allowed for longer service lives and decreased maintenance costs. [4 and 7] HSC and RPC are more uniform and homogeneous than NC but more brittle. Fractures in NC are normally appeared with the emergence of micro-

cracks followed by the widening of macrocracks resulting in a quasi-brittle behaviour. The use of normal reinforcement will help in limiting the widening of macrocracks. To decrease the production cost of these kinds of concrete, some scientist introduced the hybrid concrete, HC, by constructing structural elements cast monolithically from NC with other types of concrete such as HSC, RPC and self-compacting concrete, SCC. This production helped in improving the quality of NC construction into becoming more robust. [8, 9, 10, 11 and 12] HC structural elements should only be used in portions of the construction that are likely to be exposed to harsh environments, mainly to increase the strength of the structure without increasing its weight; such structural elements will be stronger and more economical than those cast with plain NC. This paper includes an experimental investigation on six reinforced concrete rectangular columns subjected to concentric loading until failure.

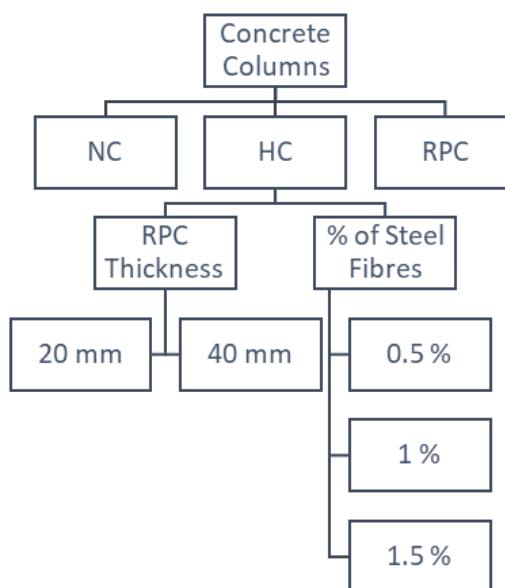
AIM OF WORK

This paper investigated the effect of steel fibre volumetric ratios and the thickness of the external RPC part on the failure load and toughness in short HC columns of rectangular sections. The first variable studied was the steel fibre volumetric ratio, V_f , (0.5, 1 and 1.5), these ratios were selected based on research in literature [13] that suggested the volumetric ratio to be less than 2 to produce better strength and workability. The other variable was the thickness of the RPC layer, (40 and 20) mm.

EXPERIMENTAL WORK

Six short rectangular columns, with a cross-sectional area of (100×200) mm and a height of 740 mm, reinforced with 4 ϕ 10 longitudinal bars confined with ϕ 6 ties

spaced at 100 mm, were cast for this investigation. Materials used included NC and RPC. Two specimens were cast with NC and RPC as control columns. The remaining four were cast with HC locating the NC at the centre surrounded by the RPC. A flowchart of the experimental work is illustrated below:



The 40 mm thickness-RPC layer of three HC columns, contained 0.5, 1 and 1.5% micro steel fibres, while the 20 mm thickness-RPC layer of the last HC columns contained 1 % micro steel fibres. Specimens were designated based on material used, steel fibre ratios and the thickness of RPC layer (variable studied). For example, the specimen (HC-1-20) refers to a hybrid concrete column with 1% steel fibre ratio and 20 mm thickness of RPC; details of specimens are shown in Table 1.

Table 1: Details of Research Specimens Studied

No.	Specimens	% V _f	Thickness [mm]	Variables
1	NC	0	Full NC, 100	Control Specimens
2	RPC-1	1	Full RPC, 100	
3	HC-1-40	1	RPC, 40	
4	HC-0.5-40	0.5	RPC, 40	Steel fibre ratio%
5	HC-1.5-40	1.5	RPC, 40	
6	HC-1-20	1	RPC, 20	RPC thickness mm

Properties of Materials Used

(1: 1.2: 1.75) (Cement: Sand: Gravel) were the proportions for the NC mix having a cement content of 400 kg/m³ and compressive and tensile strengths of 28 MPa and 4 MPa respectively; whereas (1: 1: 0.25: (0.005,0.01 and 0.015)) (Cement: Fine Sand: Silica Fume: Steel Fibre) were the proportions for the RPC mix having a cement content of 900 kg/m³ and compressive and tensile strengths of 84 MPa and 16 MPa respectively. The water/cement ratios for both mixes were 0.5 and 0.22 respectively. For the latter mix, RPC, a 6% super plasticizer was used with straight steel fibres (0.2 mm in diameter and 15 mm length with 75 aspect ratio and 2600 MPa tensile strength) were used in the RPC mix.

Casting Procedure

Horizontal steel moulds were used for casting all specimens. The two types of concrete used were mixed earlier then the casting of HC columns was performed in three steps:

1. The 1st step started with applying the RPC (20 or 40) mm layer into the form.
2. The 2nd step started after inserting two steel plates into the form (the location of the plates depends on the thickness of the RPC layer); these plates will separate the two types of concrete used to cast the HC combination. The NC will be poured in the centre while the RPC will be poured on the sides of the plates.
3. The last step will include completing the casting by applying the RPC mix to the end of the mould. After finishing casting, the two plates must be removed slowly.

To get the properties of the concrete used in this research, destructive tests were performed on control specimens (previously cast following the ASTM standards [14, 15, 16 and 17]. One of the moulds with the reinforcement cage and the concrete is illustrated in Fig. 2.



Figure 2: The Photos of the Moulds with the concrete cast within

Specimens' Curing

Demolding of all specimens were done after two days then curing started for 28 days. The specimens were left for a week to be dried at ambient temperature before testing.

Test Setup

Research specimens were tested at the University of Technology / Civil Engineering Department labs using the Avery testing frame system shown in Fig. 3. Which shows the test set-up as well for each specimen in this study.



Figure 3: The Avery Testing Frame System

The load was applied concentrically on a steel bearing plate at the top of each column. Two steel rings were supporting the top and bottom of each column to prevent the crush of concrete throughout the test. To register the vertical and horizontal displacements of each column, two LVDTs were attached to the columns at the centre (Fig. 4).



Figure 4: LVDT used in Testing

RESULTS

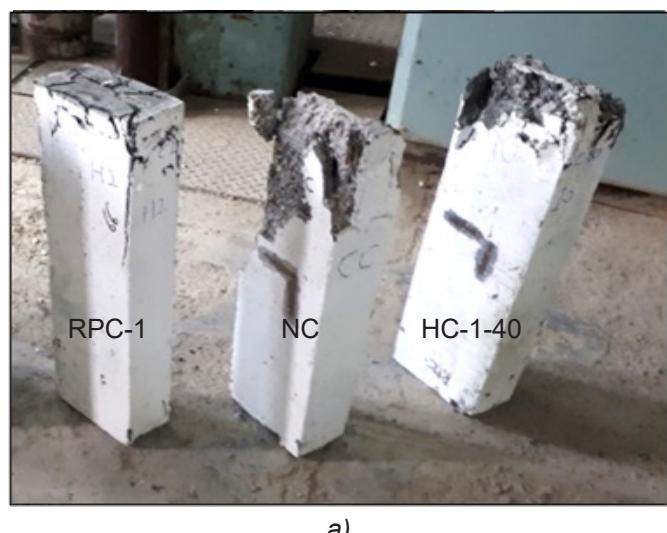
Test results are listed in table 2. Cracking loads and displacements were not 100% accurate but were thought to be close to it based on eye vision and accompanying voices during the test procedure.

Table 2: Summary of All Specimens' Test Results

№	Name	P_{cr} [kN]	Δ_{cr} [mm]	P_u [kN]	Δ_u [mm]	% Inc. in load-wrp* NC
1	NC	220	0.121	340	0.155	0
2	RPC-1	600	0.065	1030	0.12	203
3	HC-1-40	540	0.089	950	0.185	179
4	HC-0.5-40	660	0.145	720	0.170	112
5	HC-1.5-40	700	0.045	1050	0.062	209
6	HC-1-20	400	0.130	550	0.163	62

*wrp = with respect to

Fig. 5. shows the photos of all specimens tested throughout this research work. Specimens in Figure (5-a) represent the control specimens NC, RPC-1, and HC-1-40; Fig. (5-b) shows the hybrid columns HC-0.5-40 and HC-1.5-40, finally Fig. (5-c) shows the hybrid column HC-1-20.



a)



b)



c)

Figure 5: Photos of Tested Specimens

From economy point of view, the results obtained were considered effective. The tested HC specimens bore higher loads and eventually lower cost than the pure RPC specimens.

Discussing the Mode of Failure

As shown in Figure 5, the mode of failure for the tested specimens were due to minor cracks starting from the upper and lower corners of the columns and propagating vertically toward the centre of the column. The failure of the NC column was different than the other columns which suffered from more cracks that led eventually to crushing; this crushing led to a conclusion that using the RPC or the HC combination in casting columns would be safer than the NC alone.

Discussing Failure Load (Pu)

The failure loads for the specimens tested in this research are listed in Table 2. These results showed an enhancement of 203% in the RPC column's failure load with respect to the NC column. The hybrid combination used (with 40 mm thickness of RPC) gave similar enhancement in the ultimate load with respect to the NC column. This enhancement was 112%, 179% and 209% for each steel fibers volumetric ratios used (0.5, 1 and 1.5) % respectively. The hybrid 20mm RPC thick layer combination enhanced the failure load about 62% with respect to the NC column, but this enhancement was about half the value of the hybrid columns with 40mm thickness of RPC.

Discussing the Load-Displacement Curves

Load-displacement curves for the vertical and horizontal displacements are shown in Figures 6 to 9, for the two variables studied in this research.

The first variable/volumetric ratio of steel fibers

Load-displacement curves of a different steel fibres volumetric ratios columns are shown in Figs. 6 and 7. Fig. 6, representing the vertical displacements, shows that the load-displacement curve for the NC column is less stiff than any other type of concrete used in this study. While the RPC column with 1% volumetric ratio was stiffer than the NC column. HC columns used in this research have three different volumetric ratios of steel fibres, (0.5, 1 and 1.5) and the thickness of the RPC layer was 40 mm. Load-displacement curves for these columns showed that by adding steel fibres, the column will be stiffer than the NC column. For the specimen with 1.5 % of steel fibres, the curves showed that it was stiffer than the RPC column cast in this study, therefore, from economic point of view, it is recommended to use HC columns with high percentage of steel fibres (1.5%), because their cost will be less than the high cost of pure RPC columns.

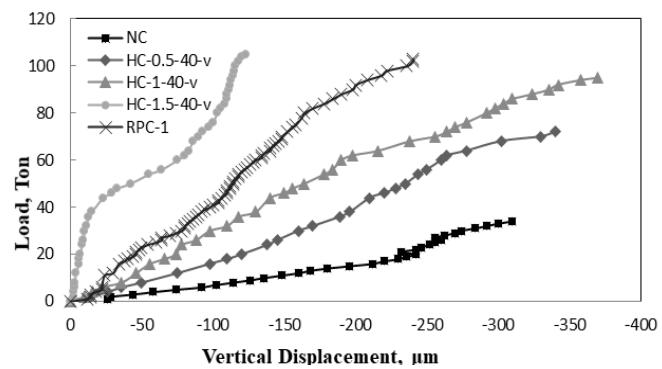


Figure 6: Vertical Load-Displacement Curves for Research Specimens (Different Volumetric Ratio of Steel Fibres)

On the other hand, the Load-horizontal displacements were shown in Fig.7. The same conclusions were obvious. The load-displacement curve for the NC column is less stiff than the other types of concrete used. HC columns used in this research have three different volumetric ratios of steel fibres, (0.5, 1 and 1.5) and the thickness of the RPC layer was 40 mm. Load-displacement curves showed that the first two percentages were closer to the NC behaviour while increasing the percentage to 1.5% made its behaviour approaching that of the RPC column.

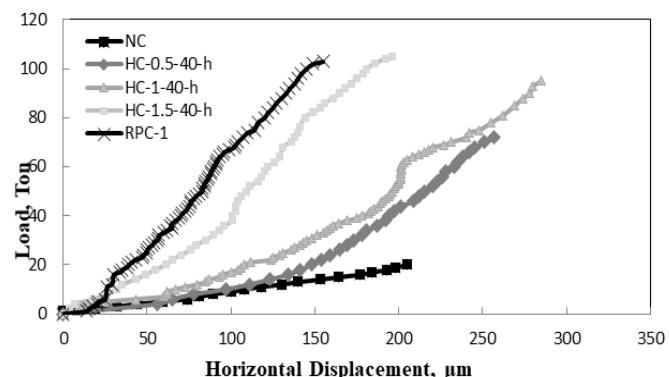


Figure 7: Horizontal Load-Displacement Curves for Research Specimens (Different Volumetric Ratio of Steel Fibres)

The second variable/RPC thickness

The load-displacement curves for this variable are shown in Figs. 8 and 9. Fig. 8, representing the vertical displacements, shows that the NC column is less stiff than the RPC column cast with 1% volumetric ratio. Using a thickness of 20 mm of RPC in casting the hybrid column gave a behaviour similar to the NC column. While increasing the thickness of RPC to 40 mm gave a significant increase in the load-displacement curve that almost approached the RPC column.

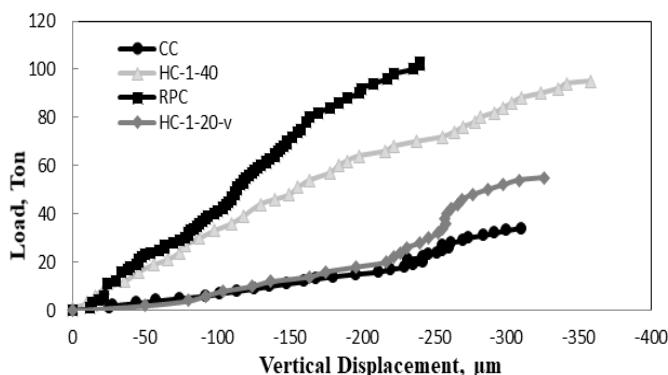


Figure 8: Vertical Load-Displacement Curves for Research Specimens (Different RPC Thickness)

For the horizontal load-displacement curve, shown in Fig. 9, both hybrid columns were similar in behaviour at the beginning of the test (about 40% of the load), then with increasing load the HC-1-40 became stiffer than the HC-1-20.

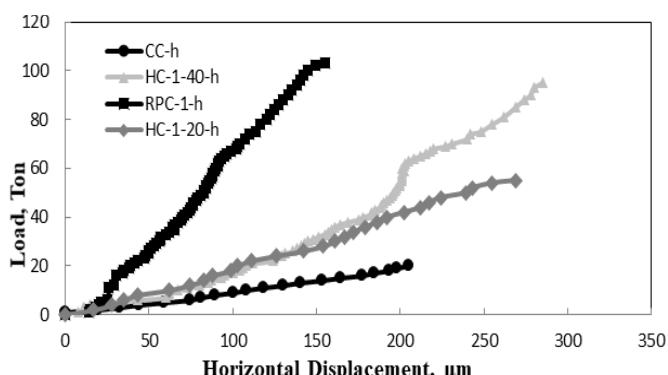


Figure 9: Horizontal Load-Displacement Curves for Research Specimens (Different RPC Thickness)

Effect of Variable Studied

Two variables were studied throughout this research work, the percentage of the volumetric ratio of steel fibres used and the RPC thickness.

Effect of Steel Fibres

The effect of using different volumetric ratios of steel fibres is shown in Figure 10. Increasing the ratio used, in the HC columns, from 0.5% to 1.5% helped in enhancing the load failure loads of these columns with respect to the NC column. The percentages of increase for the HC-0.5, HC-1 and HC-1.5 were 112%, 179% and 209%, respectively. The 1.5% volumetric ratio was highly effective which gave a percentage of increase (209%) higher than the pure RPC column (203%), therefore it is recommended to use this ratio in the hybrid combination for economic reasons.

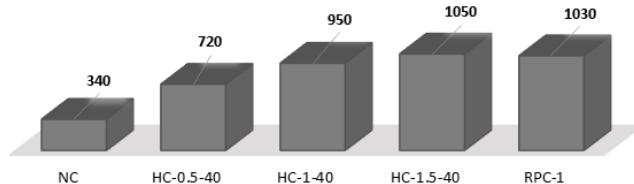


Figure 10: Effect of Steel Fibres on the Failure Loads

Effect of RPC Thickness

The effect of the RPC layer thickness used in the hybrid combination is shown in Figure 12. Four thicknesses were included in this study, 0 (pure NC), 20mm, 40mm and 50mm (pure RPC). Increasing the thickness from 0 to 50 enhanced the load carrying capacity of the columns tested in this research. The percentages of increase (with respect to the NC column) for the HC-1-20, HC-1-40 and RPC-1 were 62%, 179% and 203%, respectively. Using a small layer of RPC in the hybrid combination increased the failure load with respect to the NC column. This layer provided an extra confinement for the longitudinal reinforcement (in the NC portion of the hybrid column) in addition to the ties. Doubling the thickness of the RPC layer almost doubled the failure load. This increase in the failure load can be attributed to the inclusion of the longitudinal steel reinforcement (with the confining ties) within the RPC layer in addition to the presence of the steel fibres

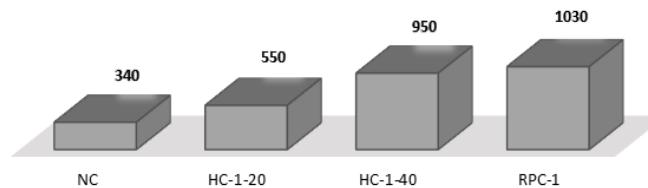


Figure 11: Effect of RPC Thickness on the Failure Loads

CONCLUSIONS

The use of the hybrid combination proved to be beneficial economically and practically, because of the good properties of the RPC layer regarding the high strength (both in compression and tension), high toughness, and durability. Therefore, the tested HC specimens bore higher loads and eventually lower cost than the pure RPC specimens. Using the small percentage of the volumetric ratio of steel fibres in the hybrid combination improved the behaviour of the columns with respect to the NC columns, but increasing these ratios gave an enhancement in the failure loads of the HC columns which made them approach the RPC columns, therefore, from economic point of view, it is recommended to use the hybrid combination with high percentage of steel fibres (1.5%), because their cost will be less than the high cost of pure

RPC columns and they produced almost the same capacity. Decreasing the RPC layer thickness from 40mm to 20mm gave 62% enhancement in the failure load with respect to the NC column; but this enhancement was about half the value of the hybrid columns with 40mm thickness of RPC. Nevertheless, this enhancement was less in the horizontal load-displacement curves, which proves that this combination provided an enhancement in the compressive behaviour more than the tension behaviour. Doubling the thickness of the RPC layer almost doubled the failure load. This increase in the failure load can be attributed to the inclusion of the longitudinal steel reinforcement (with the confining ties) within the RPC layer in addition to the presence of the steel fibres

ABBREVIATIONS

- HC Hybrid Concrete
HSC High Strength Concrete
NC Normal Concrete
LVDT Linear Variable Differential Transformer
RPC Reactive Powder Concrete
UHSC Ultra High Strength Concrete

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