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Experimental Investigation of Partially Reinforced Concrete-Filled Plastic Tubular Columns

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ABSTRACT

Previous tests on PVC-concrete composite columns showed that most of tested columns had failure regions near the top or bottom of the columns. Therefore it is intended, in this study, to reinforce the ends of these columns in an attempt to improve their behavior. A series of unreinforced and partially reinforced PVC-concrete composite columns were tested under axial compressive loading. It was found that the strength of partially reinforced PVC-concrete composite column is greater than that of corresponding unreinforced column by about 3%, and that the ultimate strain of partially reinforced PVC-concrete composite column is less than that of corresponding unreinforced column by about 4.4%. Although the increase in strength was unnoticeable, the steel reinforcement at the ends was adequate to prevent failure to occur at these ends.

1. Introduction

The term 'composite column' implies a column constructed from two or more different materials in such a way that they work together in resisting stresses and strains induced by forces or conditions external to the column. Strictly speaking, ordinary reinforced concrete columns fall within the scope of this definition. However, the term is normally used to indicate applications like either concrete-encased sections or concrete-filled tubes of rectangular or circular cross-section (Fig. 1).Concrete filled tubes offer a number of advantages in both design and construction:

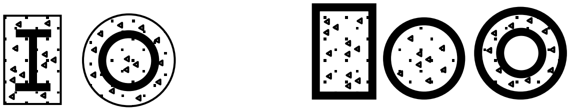
1. The tube confines the concrete. This results in an increased strength and ductility of the concrete.

2. The concrete prevents the tube from local buckling.

3. The tube provides well-distributed reinforcement.

4. The tube protects the surface of the concrete from physical damage and deterioration by environmental effects such as carbonation and chloride penetration.

5. The tube provides a formwork for the casting of the concrete, which stays in place and does not need to be removed. This results in time and cost savings on site.



(a) Concrete-encase (b) Concrete-filled

Figure (1) Different types of composite columns

Composite columns, made of structural steel tubing filled with concrete, have been used in building construction with great efficiency for many years. Theoretical and experimental investigations were conducted on the behavior of concrete-filled steel columns [1–4]. Advances in the field of advanced composite materials have resulted in development of fiber reinforced polymers (FRP) to confine existing concrete columns. This leads to enhancing the compressive strength and ductility and improving the durability over conventional methods [5-8].

The use of commercially available PVC pipes in composite columns was investigated [9,10] to study the behavior of plastic columns with concrete core.

Previous tests [11,12] on PVC-concrete composite columns showed that most of tested columns had failure regions near the top or bottom of the columns. Therefore it is intended, in this study, to reinforce the ends of columns in an attempt to improve their behavior. A total of nine columns were tested under axial compression; six of these tested columns were partially reinforced at the ends while the three columns were unreinforced columns as control columns. Thus, the main objective of the present study is to investigate the structural behavior of PVC-concrete composite columns, consisting of a PVC tube filled with concrete, reinforced partially with steel reinforcement at the ends of the columns. Two different column slenderness ratios and reinforced portion lengths are used in order to assess the effect of these variables on the strength of columns.

2. Experimental Work

2.1. Materials

Ordinary Portland cement, natural silica sand and crushed natural gravel were used. Ordinary potable water was used in making and curing concrete. Deformed bars of 5 mm diameter were used for the transverse and longitudinal reinforcement. The PVC tubes used were commercially available PVC tubes with an ultimate tensile stress (f_t) of 51.7 MPa as given by the manufacturer. The tubes were of circular cross section with 110 mm external diameter and wall thicknesses of 3.2 mm and 5.3 mm. The mix proportions of the concrete ingredients, by dry weights, were [1 cement : 2 sand : 3.2 gravel], and the water cement ratio (w/c) was 58% (which gave a cube compressive strength of about 30 MPa at age of 28 days).

2.2. Test Specimens

The tested columns were divided into three groups (C, R1, and R2). For each group, three specimens were prepared with heights of 600, 800, and 1000 mm.

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The studied variables were the column length L (600, 800 and 1000 mm) and length of the transversely reinforced part of the column (*L/4* and *L/3*, as shown in Fig.(2)). The specimen external diameter was (110 mm), tube thickness was (3.2 mm) and concrete cube compressive strength was (30 MPa). Group C contains the unreinforced columns (control columns). For group R1, the length of the reinforced upper and lower portions of the specimens was (*L/4*) while it was (*L/3*) for group R2. Table (1) shows the details of the tested columns including their designation. The specimen designation, as shown in the second column of Table (1), includes the length of the column in mm and the length of the transversely reinforced portion of the column, 'L/4' refers to a reinforced portion of length of one quarter of the column length and 'L/3' refers to a reinforced portion of length of one third of the column length.

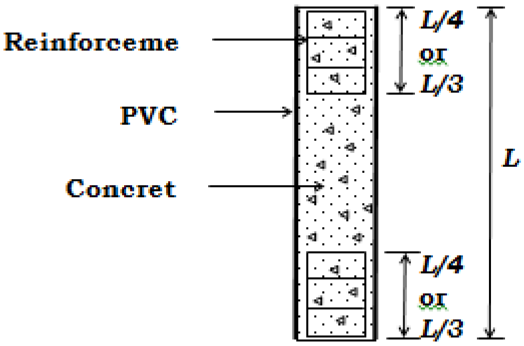


Figure 2. Partially reinforced PVC-concrete composite columns.

2.3. Fabrication of Specimens

The PVC tubes were cut to the desired length of the columns and cleaned. Tubes were positioned vertically, fixed on the laboratory floor, and filled with concrete. Reinforcement cages of required lengths (either *L/4* or *L/3* of the columns length) were made. Each reinforcement cage consists of three longitudinal bars and transverse reinforcement of 5 mm deformed bars. The transverse reinforcement was in the form of closed circular ties of spacing 80 mm each. Each column specimen contains two reinforcement cages, one at the top and one at the bottom. For casting the specimens, tubes were positioned vertically and fixed on the laboratory floor. A reinforcement cage was placed inside the tube at the bottom and the concrete was poured from the top to a specific height then, another reinforcement cage was placed inside the tube at the top and fixed manually by steel wires and adding concrete was continued. Tubes were filled with concrete in approximately 10 cm layers, and each layer was compacted by a steel rod. To prevent the leakage of cement paste from the bottom of the PVC tube, it was closed with nylon. After the tube was filled, the top surface was flattened carefully. The composite columns were left in the laboratory till the time of testing. The specimens were moistened with water every day after twenty four hours after casting.

2.4. Instrumentation and Test Setup

All specimens were tested under axial compression using a Torsee's universal testing machine with a capacity of 1000 kN at the laboratory of construction materials – University of Basrah. The column specimen was centered in the testing machine to ensure that the compressive axial load was applied without any eccentricity. The top and bottom faces of specimen were grinded and made smooth and leveled to remove surface imperfections and maintain uniformity of loading on the surface. The vertical displacement of the lower movable head of the testing machine was measured in relation to the upper head of the testing machine by a dial gauge with magnetic base. This measured displacement was assumed to be equal to the vertical shortening of the test specimen. The accuracy of the dial gauge was 0.01 mm. Readings of applied load and displacement were recorded at regular intervals during the tests. Figure (3) depicts the test setup. The application of the load was continued until the failure of columns.

Figure 3. Test setup.

3. Results and Discussion

3.1. Strength and Strain of Partially Reinforced Columns

The ultimate load and the corresponding strain for all specimens are summarized in Table (2). From this table, it can be seen that reinforcing of the ends of PVC-concrete composite columns by steel ties slightly increases the load carrying capacity of the columns. The ratio P_{ccr}/P_{cc} is between 1.02 and 1.047. The average increase in ultimate load is of the order of 3%. Although the increase in strength is unnoticeable, the steel reinforcement at the ends is adequate to prevent failure to occur at these ends (as shown in Fig. (6)). This is because the transverse steel reinforcement at the ends of the columns represents an additional reinforcement against lateral expansion of the concrete preventing failure to occur at those reinforced portions. Also Table (2) shows that reinforcing of the ends of PVC-concrete composite columns by steel ties slightly decreases the axial strain at ultimate load of the columns. For all the specimens, the ratio $\varepsilon_{ccr}/\varepsilon_{cc}$ is between 0.898 and 0.969. The average decrease in axial strain at ultimate load is of the order of 4.4%. This decrease in strain could be attributed to the presence of the longitudinal and transverse steel reinforcement at the ends which restrained the concrete during loading.

3.2. Load–Axial Displacement Relationship

Figures (4) through (6) show the axial load-axial displacement relationships for the tested PVC-concrete composite columns, respectively. The axial load-axial displacement relationships for unreinforced PVC-concrete composite columns are also shown in these figures for comparison. The followings are some general observations:

1. The load-displacement relationships of partially reinforced composite columns are generally bilinear with a transition curve between the first and third line regions, and are similar to those of the unreinforced columns.

2. The slope of the first region of the response of partially reinforced columns almost coincides with that of the unreinforced columns.

3. The slope of the third region of the response is independent of the length of the reinforced portion of the columns.

Table 1. Details of columns.

Group No.	Column Designation	Concrete Strength f'_c (MPa)	Tube Diameter D (mm)	Tube Thickness t (mm)	Length L (mm)	Slenderness Ratio L/r
C	600A1	30	110	3.2	600	21.8
	800A1	30	110	3.2	800	29.1
	1000A1	30	110	3.2	1000	36.4
R1	600L/4	30	110	3.2	600	21.8
	800L/4	30	110	3.2	800	29.1
	1000L/4	30	110	3.2	1000	36.4
R2	600L/3	30	110	3.2	600	21.8
	800L/3	30	110	3.2	800	29.1
	1000L/3	30	110	3.2	1000	36.4

Table 2. Test Results.

Group No.	Column Designation	P_{cc} (kN)	P_{ccr} (kN)	ε_{cc}	ε_{ccr}	P_{ccr}/P_{cc}	$\varepsilon_{ccr}/\varepsilon_{cc}$
C	600A1	265.6	-	0.00580	-	-	-
	800A1	254.3	-	0.00513	-	-	-
	1000A1	240.1	-	0.00474	-	-	-
R1	600L/4	-	276.3	-	0.00575	1.040	0.983
	800L/4	-	260.1	-	0.00490	1.023	0.956
	1000L/4	-	244.9	-	0.00461	1.020	0.966
R2	600L/3	-	278.1	-	0.00567	1.047	0.969
	800L/3	-	261.4	-	0.00460	1.028	0.898
	1000L/3	-	245.4	-	0.00460	1.022	0.964

* P_{ccr} and ε_{ccr} are the ultimate load and the corresponding strain of partially reinforced PVC-concrete composite columns, respectively, and P_{cc} and ε_{cc} are the ultimate load and the corresponding strain of corresponding unreinforced PVC-concrete composite columns, respectively.

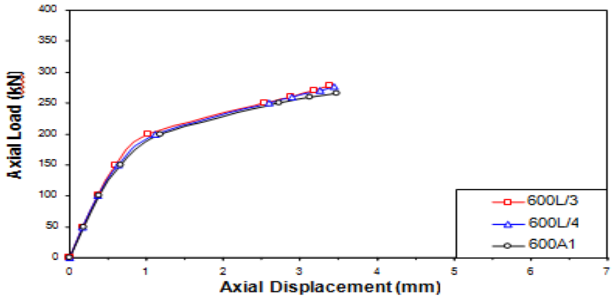


Figure 4. Load-displacement relationship of specimens with L/r = 21.8.

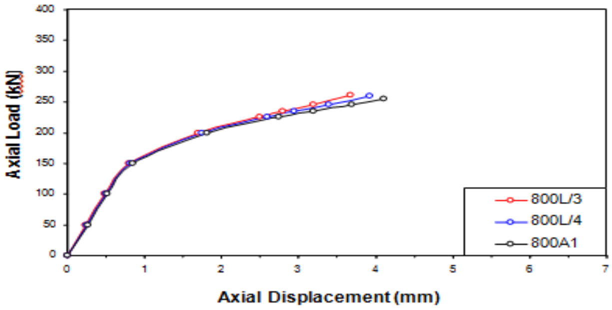


Figure 5. Load-displacement relationship of specimens with L/r = 29.1.

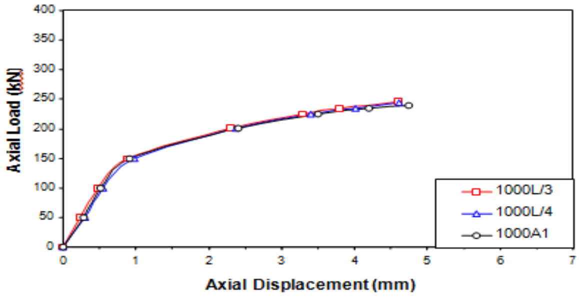


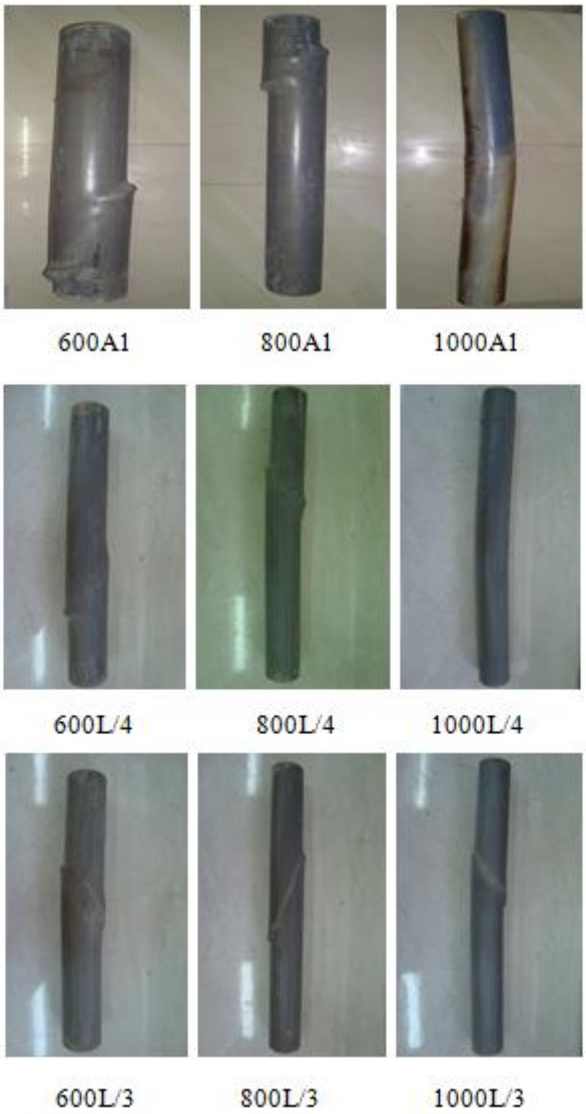
Figure 6. Load-displacement relationship of specimens with L/r = 36.4

3.3. Effect of Length of Reinforced Portions

The length of the steel reinforced portion at the ends of the columns has been changed to study the effect of this variable. Two lengths (*L/4* and *L/3*) are selected. It can be seen from Table (2) that the length of reinforced portions has approximately no influence on the ultimate strength and the corresponding strain of the columns. The average values of ultimate loads P_{ccr}/P_{cc} ratio and of ultimate strain $\varepsilon_{ccr}/\varepsilon_{cc}$ ratio are 1.03 and 0.956, respectively. This could be attributed to the fact that there is a region at the midheight, between the two reinforced portions, which is still not transversely reinforced and represents a weaker region at which the failure occurs.

3.4. Failure Modes

Figure (7) shows the failure modes of tested specimens. The failure mode for all (partially reinforced and unreinforced) intermediate length columns (L/r = 21.8 – 29.1) is a classical shear mode failure. The concrete core typically failed in a shear mode with angle of failure of approximately 45°. It was noticed that for unreinforced specimens, the failure occurs near the columns end (the upper or lower end). While for partially reinforced columns, the failure does not occur within the reinforced portions (the upper or lower ends), instead it moves towards the midheight of the columns (usually at the end of a reinforced portion). For the most slender composite columns (L/r = 36.4), buckling of columns is recorded. The failure mode of specimens 1000A1 and 1000L/4 is a typical long column buckling mode shape, while specimen 1000L/3 buckles laterally during loading, but it finally fails in a shear mode as shown in Fig. (7).


600A1 800A1 1000A1

600L/4 800L/4 1000L/4

600L/3 800L/3 1000L/3

Figure (7) Failure modes of specimens

4. Conclusions

The most important conclusions that can be drawn from the present study are the followings:

1. The ultimate strength of partially reinforced PVC-concrete composite column is greater than that of corresponding unreinforced column by about 3%.

2. The ultimate strain of partially reinforced PVC-concrete composite column is less than that of corresponding unreinforced column by about 4.4%.

3. The load-displacement relationships of partially reinforced composite columns are generally bilinear with a transition curve between the first and third line regions, and are similar to those of corresponding unreinforced columns.

4. The length of reinforced portions has approximately no influence on the ultimate strength and the corresponding strain of the columns.

5. The failure mode of partially reinforced columns is similar to that of unreinforced columns. The intermediate length columns (L/r = 21.8 – 29.1) have a classical shear mode failure, while the slender columns (L/r = 36.4) fail by long buckling.

6. Although the increase in strength was unnoticeable, the steel reinforcement at the ends was adequate to prevent failure to occur at these ends.

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