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Journal of Mechanical Materials and Mechanics Research
https://ojs.bilpublishing.com/index.php/jmmmr

ARTICLE

Study of Concrete Filled Unplasticized Poly-Vinyl Chloride Tubes as Columns under Axial Loading

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ARTICLE INFO

Article history
Received: 7 March 2022
Revised: 12 April 2022
Accepted: 22 April 2022
Published Online: 29 April 2022

Keywords:
Unplasticized Poly-Vinyl Chloride (UPVC) tubes
Composite column
Tube confinement
Column strength

ABSTRACT

This article aims to examine the behavior of Unplasticized Poly-Vinyl-Chloride (UPVC) bounded reinforced columns with polypropylene fibers under axial compression. To develop this model, samples of concrete filled UPVC pipe (CFUT) with different geometric properties were tested. To obtain the specimens different class pipes with three different diameters were used to investigate the sensitivity of these columns to various parameters. The effect of each variable on the ultimate strength, ductility and confinement efficiency of the samples was investigated. All specimens were compressed by applying load only to the concrete core to obtain the load-displacement variations and the corresponding deformation mode. A finite element model was developed using the proposed stress-strain variation of confined concrete with UPVC tubes to simulate axial compression of CFUT specimens. According to the results obtained, the effect of the change in diameter-thickness ratio failure stress of concrete limited by (D/t) is obtained and discussed with empirical relationship. Polypropylene fibers were found to slightly increase column strength up to a certain volume fraction, after which the strength generally experienced a decrease.

1. Introduction

Concrete filled tube is a type of composite column that consists of a tubular encasing of any shape with concrete filled into it. The tube may be made up of different material like steel, fibre reinforced plastic (FRP) and Poly Vinyl Chloride (PVC)/Unplasticised PVC. Plastics have outstanding properties such as low cost, high resistance to severe environmental attack and high strength-to-weight ratio. Because of these properties, plastics used for different purposes, including commercial and engineering. UPVC pipes are often used for worldwide water supply. These pipes are designed for the induced internal pressure of the flowing water. These pipes are divided into different classes on the basis of resistance to water pressure and depending on the nominal pressure exerted by the flowing water.

Yu et al. [1] performed investigations on the CFRPPVC confined long and short columns under cyclic displacements and determined the failure mechanisms and the general performance. Gao et al. [2] performed experimental and

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DOI: https://doi.org/10.30564/jmmmr.v5i1.4494

numerical studies on the recycled aggregate concrete confined with PVCPFRP tube. Studies have been performed on plain concrete-encased with PVC tubes to measure the axial load and deformation characteristics [3]. Wang and Yang [4] studied the effects of material mechanical parameters of PVC-confined plain concrete and proposed a simple relation to calculate the increase in load capacity due to PVC confinement. Wang et al. [5] validated a finite element (FE) model for a wide range of experimental concrete-filled steel columns and used it to generate parameter variance in over 499 circular and rectangular stub columns. The parameters included steel tube yield strength, concrete core compressive strength, diameter-to-thickness ratio (for circular stubs), height-to-width ratio and height-to-thickness ratio (for rectangular columns). They subsequently proposed regression models for the prediction of compressive strength, stiffness, and deformation of the composite columns. Saadoon [6] to study parameters such as concrete strength, tube thickness and slenderness ratio. Saadoon also investigated the effect of transverse steel reinforcement in these PVC confined columns. An important characteristic of the thermoplastic family is its durability against harsh and undesirable environments, where exposed concrete or steel would deteriorate quickly. Machine Hsie et al. [7] studied the combined effects of two types of PP fibers and observed an increase in compressive strength as high as 17%. An investigation with scanning electron microscope (SEM) was performed by Sun and Xu [8] and it was observed that PP fibers cause widespread alteration in the microstructure of concrete, and therefore have positive effects on various mechanical properties of concrete. Gupta and Verma [9] immersed a series of samples of varying diameter-thickness and length-thickness in artificial seawater and then tested them under axial compression to examine the coating effectiveness of PVC pipes in the marine environment. No significant difference in sample response was observed and it was concluded that the PVC coating effectively protected the concrete. Wang and Yang [10] presented an experimental study on plastic pipe wrapped concrete (PPC). Plastic pipes are taken as HDPE pipes. They reported that the thickness and unconfined compressive strength of the concrete affect the ultimate strength and post-peak behavior of the PPC. They observed that at the lower constraint, the breaking mode was shear, and at the higher constraint, the drum type. According to Ragab et al. [11] tested rigid PVC pipes with a diameter of 60 mm (2.36 inches) and biaxially 5.3 mm (2.09 inches) thickness with 1 MPa (145 psi) working pressure. The tension system covering the four quadrants of the plane-stress space. Upload done tension, compression, torque, and internal and external pressure. They tested the samples at different strain rates and temperatures. They planned yield's location various strain rates and temperatures. They observed that rigid PVC pipes followed the von Mises criterion. A study with scanning electron microscopy (SEM) was conducted by Sun and Xu [12] and it has been observed that PP fibers cause widespread changes in the microstructure of concrete and therefore have positive effects on various mechanical properties of concrete.

Based on the above discussion, composite use of PVC and concrete addresses some important mechanical and environmental challenges. In addition to the advantages of UPVC pipes such as no mold demand, fast construction, chemical and mechanical improvements due to mechanical protection and containment for core concrete.

It can be seen that only a few researchers have studied the behavior of concrete-filled plastic pipes subjected to axial compression. The investigation of such columns with the help of computer modeling is still not reported. In this study, a systematic experimental and computational study is attempted to understand and model the behavior of concrete filled PVC pipes subjected to axial compression.

2. Experimental Study

2.1 Specimen Configuration

Column specimens were manufactured and tested under axial compression applying only on concrete core. CFUT specimen is made with tube of different class having different nominal diameter filled with plain concrete of grade M30 & M40. The pipes are placed in the circular mold before casting the samples. Freshly prepared concrete was placed in three layers and appropriate vibration and compression have been made in each layer. The samples were tightly covered with a thick polyethylene sheet to avoid evaporation of water. So sample identificated as 200P5PC40; where 200 indicates the outer diameter of the pipe, PC40 is that the plain concrete of grade M40, P5 is used for class 5 pipe with nominal pressure of 1.0 MPa. These specimens and their corresponding parameters are listed in Table 1 and Table 2, respectively. D is the outer diameter (including the pipe thickness), h is the height of the specimen, and t is the thickness of pipe.

2.2 Material Properties

2.2.1 Concrete

Samples are made of Ordinary Portland cement, fine and coarse aggregates and admixture with mix designs of M30 & M40. Superplasticizer was added as a percentage of cement weight to increase the workability of the samples and increase their strength by reducing the water content. Concrete mix proportions are listed in Table 1.

Table 1. Concrete Mix proportions used in this study

Grade	M30	M40
w/c ratio	0.45	0.40
Water (kg/m^3)	171	160
Cement (kg/m^3)	380	400
Fine Aggregate (kg/m^3)	673	675
Coarse Aggregate (kg/m^3)	1089	1093
Admixture (%)	0.25	0.35
Cube strength (MPa)	42.22	48.88

2.2.2 Unplasticized Poly-Vinyl Chloride (UPVC) Tubes

Unplasticized Polyvinyl Chloride is a hard form of PVC (a type of plastic) which used especially for making pipes and window frames. Although some researchers use the terms PVC and UPVC interchangeably, their industrial definitions are quite different and exhibit different mechanical properties. PVC is often used to make siding and fences, whereas UPVC is used for window and door construction. UPVC is a durable material. It does not contain phthalates or BPA. It provides a safe local product. It is also highly resistant to corrosion, weathering, and chemicals. The use of PVC in confinement of concrete specimens is investigated to some extent in the literature. Due to these desirable characteristics, this study attempts to evaluate the enhancement behavior of columns confined with UPVC tubes.

Different classes of pipes are usually specified with the maximum nominal pressure procured from the market. These UPVC pipes of class 3, 4 and 5 with nominal pressure of 0.6 MPa, 0.8 MPa and 1.0 MPa and the diameters of 160 mm, 200 mm and 225 mm used in this study. The specimen length of 800 mm made by this different class of UPVC Pipes. The authors conducted a series of tests to determine the mechanical properties of the UPVC tube. To determine the tensile behaviour of the UPVC, standard specimens (Figure 1) were extracted from pipes. The material properties of the UPVC element were determined in accordance with the tension test of the UPVC specimen shown in Figure 2, and the stress-strain curve of UPVC is shown in Figure 3, which finds an ultimate tensile stress of approximately 52 MPa at 20 °C.

Figure 1. Specimen

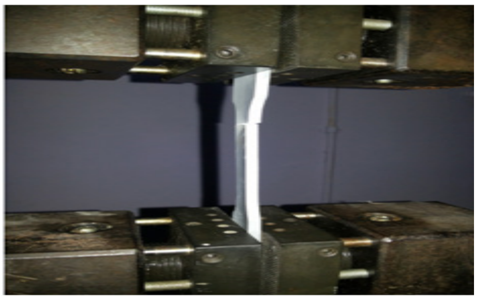

Figure 2. Tension test of UPVC

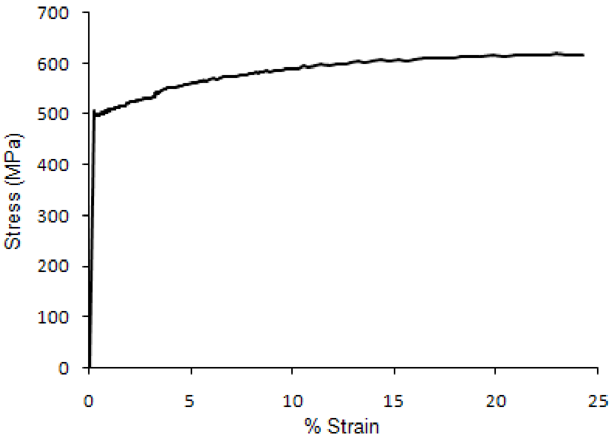

Figure 3. Stress-strain curve of UPVC

Table 2 summarizes the mechanical properties of the UPVC pipes that were provided in the manufacturer's, such as young's modulus, density and Poisson's ratio. Internal hydrostatic pressure test of UPVC pipes was conducted in the laboratory to get confining pressure. It's set up shown in Figure 4 and the confining pressure is given in Table 3.

Table 2. Physical properties of UPVC provided by the manufacturer

Characteristics	Value
Density	1.3 gm/cm^3
Elastic modulus	880 MPa
Ultimate tensile strength	22.5 MPa
Poisson's ratio	0.35
Service life	>50 years

2.3 Test Setup and Apparatus

The test was performed using a servo-hydraulic Universal Testing Machine (UTM) with a loading capacity of 25000 KN. Template testing and setup tools are shown in

Table 3. Confining pressure of UPVC pipes tested by the authors

Class of pipe (Nominal pressure)	Dimensions (mm)			Confining pressure (MPa)	
	Nominal Outer diameter (D)	Internal diameter (d)	Thickness (t)	Experimental	Calculated p= *fu(2t/d)*
Three (0.6 MPa)	160	152.17	3.99	1.15	1.18
	200	187.97	5.22	1.35	1.42
	225	207.48	7.02	1.72	1.87
Four (0.8 MPa)	160	149.44	5.94	1.52	1.57
	200	183.34	8.11	1.99	1.99
	225	205.42	8.89	2.00	2.09
Five (1.0 MPa)	160	146.15	8.65	2.15	2.16
	200	181.44	9.58	2.25	2.20
	225	204.59	9.97	2.17	2.19

Figure 4. set up for find confining pressure

Figure 5. It is noteworthy that capping is done precisely to produce a thin layer. All column models were loaded with a displacement control rate of 0.4 mm/min until they reached approximately 1.2%-2.5% strain. Although some of these closed models can often be overcrowded, testing has been discontinued following a significant reduction in load capacity. The displacement used only concrete. Tubes were used only for confinement purpose. Deformation was recorded from 2 LVDTs placed on opposite sides of the crossheads to record the entire length of the samples. The load-displacement curves were recorded by the machine automatically.

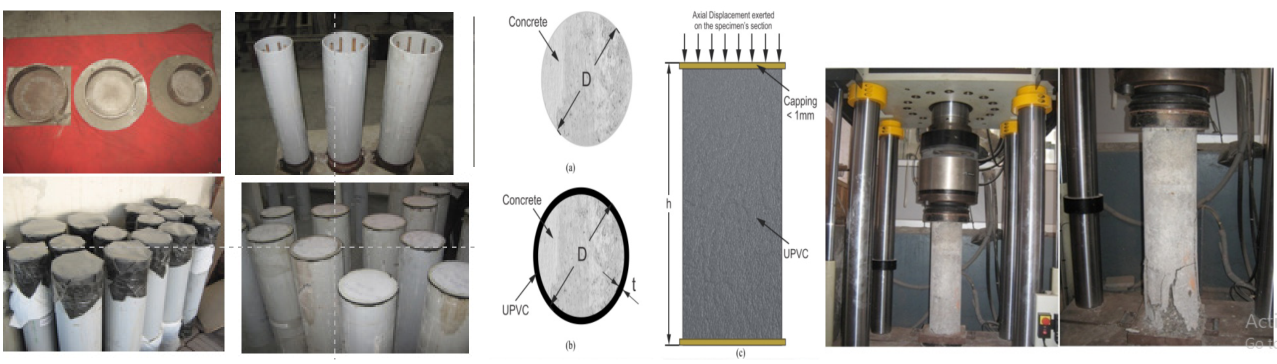

Figure 5. Casting & Testing of specimens

3. FEM Modelling and Simulation

FEM feature 3D model was developed using Abaqus software to mimic a concrete filled UPVC tube under axial pressure. For modeling a concrete core, three dimensions eight solid elements of node "SOLID 65" were used. To model tube, an eight-node solid element SOLID 45 was used. The main reinforcement and the lateral relationships are modeled by the link element "LINK8" [15]. A discrete model was used to model vertical steel. Bangash [13] unconfined concrete model was found to be suitable for modelling concrete in RCC. Contact is defined as a surface contact. The yield stress of the plate is taken as 1000 MPa. The stress-strain variation is modeled using the elastic-perfect plastic material command. The plate behaved as rigid. The mesh size was chosen from 4 mm to 8 mm for the tube, concrete core and steel plate. Load was applied to the column through the top loading plate. Surface contact interaction used between rigid plate and column surface top and bottom side. Figure 6 shows a typical finite element model adopted for modeling of concrete filled UVFC column. In the standard FEM feature model, the solid bottom plate that touches the base of the column is centered on all six points with the reference node. The solid plate over the top of the column is modeled as a language set in five directions, and movement is allowed on the column axis only in the reference area. The load is used as a removal of the vertical uniform plate on the upper plate near the center node of the solid plate. Confined concrete is subjected to triaxial compressive stresses; the effective stress and effective strain values may be represented by the uniaxial stress and strain values obtained from the stress-strain equation proposed by Saenz (1964). It is given as

$$f = \frac{E_{cc}\varepsilon}{1+(R+R_E-2)\left(\frac{\varepsilon}{\varepsilon_{cc}}\right)-(2R-1)\left(\frac{\varepsilon}{\varepsilon_{cc}}\right)^2+R\left(\frac{\varepsilon}{\varepsilon_{cc}}\right)^3}$$

where

$$R_E = \frac{E_{cc}\varepsilon_{cc}}{f_{cc}},\ R = \frac{R_E(R_\sigma-1)}{(R_\varepsilon-1)^2}-\frac{1}{R_\varepsilon},\ R_\sigma \ \&\ R = 4$$

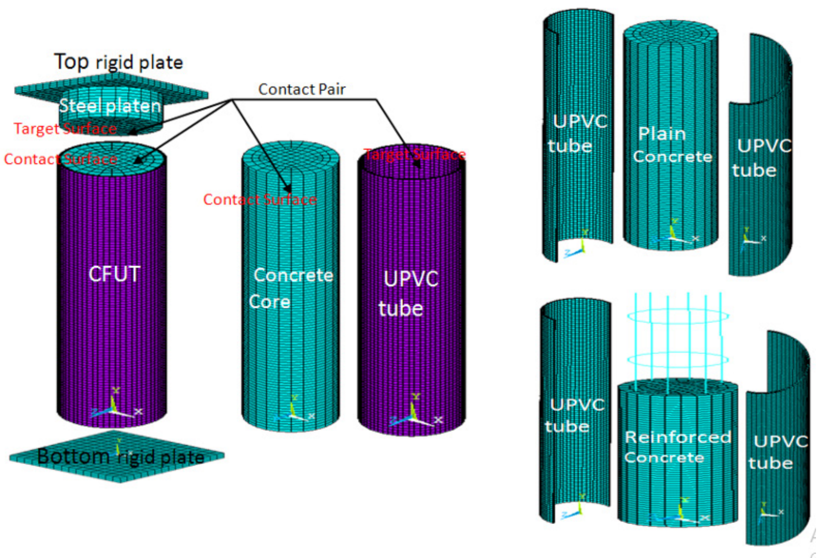

Figure 6. Finite Element modeling for concrete filled UPVC tube

4. Test Results and Discussion

In this study, further experiments were performed to determine the behavior of concrete enclosed in a UPVC tube. In this process the specimens are cast and tested using axial loading in the concrete context only. Internal hydrostatic pressure tests were performed to detect closed pressure. The confinement is the main governing factor to study the behavior of concrete filled tubes. In specimens where the jackets had lower degrees of radial strength compared to the concrete core, failure occurred mainly in the UPVC tubes and the concrete experienced relatively limited cracking in the form of shallow hairline cracks and other specimens where the influence of UPVC tube on strength of the column is more pronounced, the tube undergoes a variety of deformations such as local bulging, drumming, and buckling while it does not experience rupturing shown in Figure 7. The results of the test and numerical simulation of UPVC-filled concrete tubes are given in Table 4. Disable shape of a few tested samples and corresponding load-removable curves are planned.

The largest deviation of failure was observed between 10 mm and 14 mm. The angle of shear cracks from the horizontal axis is measured. It was between 63° and 65°. Post peak displacement is important with regard to the ductile behavior of objects. From the load-moving curve, it was found that the migration behind the maximum load was approximately 5 mm-10 mm. Load curves found in numerical analysis and accuracy checking. Typical variation of loading curves-removal of templates made of UPVC tubes with different width of the same class and the same width of different class respectively. It can be seen in Figure 7 that the initial slope of the curves increases as the diameter of the tubes increases and the slope of the post is almost the same.

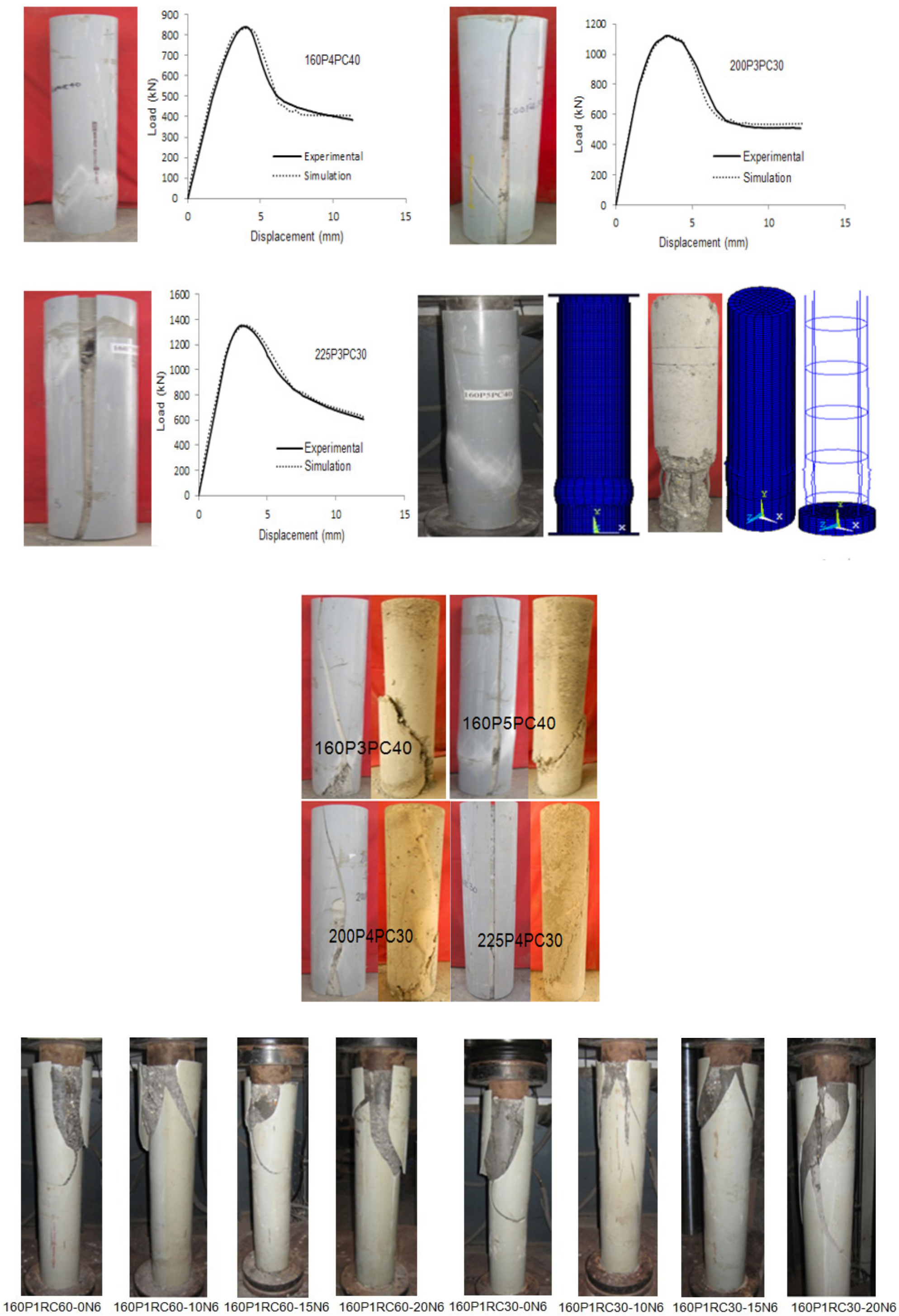

Figure 7. Experimental Results

Table 4. Experimental and fem Modeling results

Specimen	Ultimate Load (kN)		Constraining parameter $\alpha=A_p f_u/A_c f_c$	Confinement ratio $\beta=(f_l/f_c)$	Mode of failure	Failure load	Max. strain at failure
	Experimental	FEM Modeling					
160P3PC30	758	752	0.067	0.034	Shear cracks with slight bulge	348.28	0.0169
160P4PC30	769	763	0.089	0.045		350.70	0.0150
160P5PC30	793	789	0.123	0.062		372.08	0.0149
200P3PC30	1123	1128	0.081	0.041		509.40	0.0151
200P4PC30	1142	1135	0.114	0.057		656.69	0.0149
200P5PC30	1182	1177	0.125	0.063		614.16	0.0140
225P3PC30	1352	1354	0.107	0.053		607.22	0.0150
225P4PC30	1420	1412	0.119	0.059		695.44	0.0146
225P5PC30	1491	1482	0.125	0.062		772.05	0.0138
160P3PC40	816	812	0.060	0.030		324.59	0.0155
160P4PC40	839	832	0.080	0.040		383.80	0.0142
160P5PC40	850	844	0.111	0.055		456.14	0.0132
200P3PC40	1231	1222	0.073	0.036		564.15	0.0138
200P4PC40	1245	1239	0.102	0.051		598.87	0.0138
200P5PC40	1280	1276	0.113	0.056		650.86	0.0130
225P3PC40	1486	1472	0.096	0.048		693.89	0.0143
225P4PC40	1550	1539	0.107	0.054		759.42	0.0134
225P5PC40	1610	1598	0.112	0.056		806.35	0.0128

5. Concluding Remarks

In this study, a series of tests were performed on UPVC-confined columns. A new type of composite column, which can be obtained by filling a plastic container with non-plastic poly vinyl chloride (UPVC) is proposed and investigated. Based on the results obtained from the experiments and finite element analysis of UPVC-filled concrete tubes, the following conclusions can be derived.

- A stress-strain model enclosed by a UPVC tube is proposed. This model is achieved by changing the stress-strain model of concrete bound with different materials such as steel.
- For specimens made from lower concrete strength, the UPVC tube in a concrete filled UPVC tube column contributed significantly to the axial load carrying capability. The load-carrying capacity in a confined state for a column with an aspect ratio of two (h/D=2) was 1.12-1.65 times the sum of individual capacity in an unconfined state.
- The concrete was complete with shallow cracks and cracking occurred in the UPVC tube. On the other hand, when the tube was relatively strong, the concrete navel had deep and wide cracks while the tubes maintained their integrity without cracking and damage to the surface. Failure of all specimens leads by development of shear crack and macrocracks with slight bulging.
- This study used to propose a model to predict the ultimate strength of UPVC confined concrete columns.
- The strain at break for short specimens tested ranges from 1.25% to 1.70%. The 2t/D ratio and h/D ratio both had an effect on the post-peak stress-strain behaviour of UPVC confined concrete. As the 2t/D ratio increased, the absolute value of the slope decreased.
- The behavior of the load-compression curve depends on the ambient pressure of the pipe and the compressive strength of the concrete. The absolute value of the slope of the curve increases with increasing concrete strength and decreases with increasing ambient pressure.
- The UPVC confinement improved the columns' ductility and energy absorption.

Credit Authorship Contribution Statement

Manish Sharma: Investigation, Formal analysis, Re-sources, Writing - original draft. **Md. Imteyaz Ansari:** Overall guidance, Methodology and Supervision. **Nazrul Islam:** Conceptualization, Writing - review & editing, Visualization, Supervision.

Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

Acknowledgments

The authors warmly acknowledge the computing facilities provided by the Head of the Civil Engineering Department, Faculty of Engineering and Technology, Jamia Millia Islamia, New Delhi-110025, India. For carrying out the present finite element simulations. Sincere thanks are also due to learned Reviewers for their critical review and suggestions to improve the manuscript in the present form.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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