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Experimental and Analytical Study of PVC Confined Concrete Cylinders

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Abstract: This study presents results of an experimental research on the concrete filled Poly Vinyl Chloride (PVC) tubes short columns with various typical strengths of the infill concrete; C20, C25, C40. A total of 36 Concrete Filled Tube columns using PVC tubes (CFT PVC) were tested to investigate the column's behaviour and 18 cylinder concrete column. The columns are 200 mm height, 100 mm external diameter and 3.5 and 4.8 mm tube thickness. The results presented include the maximum axial load, thickness effect, the mode of failure and concrete compressive strength effect. The column resistance shows an increment of between 32.24-83.25% higher compared to the control column specimens. The design equations for the CFT PVC tube columns are proposed.

Key words: Axial load, tube thickness, axial displacement, concrete strength, axial strain, resistance

INTRODUCTION

Columns whose length are considerably greater than the cross-sectional dimensions is generally designed to transfer a compressive load. Such members may also carry other types of loadings and may have different kinds of end conditions. The structures typically constructed from conventional concrete material, steel and timber. One type of material could not provide all the structural requirements such as availability, strength, durability and workability; therefore, using two or more materials and connecting them together in order to make full advantage of their properties. The structural member of two or more materials is known as a composite structure.

The Concrete Filled Tube (CFT) columns are composite members which involves of a tube and concrete infill. As a comparison with the conventional reinforced concrete columns, the CFT columns have some of advantages such as the steel tube uses as a longitudinal steel reinforcement and formwork at the same time and having high tensile and compressive capacities. Moreover, the concrete infill confines buckling of the tube which increases the strength, stiffness and deformability of the section (Moon *et al*., 2013). Besides steel, many researches have been investigated on CFT column with different tube materials such as Fiber Reinforced Plastics (FRPs), aluminum and Unplasticized Poly Vinyl Chloride tube (UPVC) as a confinement for concrete column (Zuboon 2014; Gathimba *et al*., 2014; Zhu *et al*., 2005; Saafi *et al*., 1999). Also, the cross section shape of composite columns like circular (CCFT), Rectangular (RCFT), Square (SCFT) and Elliptical (ECFT) has been investigated as another important and effective parameter on outline results of composite columns (Jamaluddin *et al*., 2013; Dai and Lam, 2012; Law and Gardner, 2013; Ozbakkaloglu *et al*., 2007; Rochette and Pierre, 2000; Cai and He, 2006; Shahidzade *et al*., 2011).

The CFST have been continued for many decades because it has advantageous qualities like enhanced strength, ductility and stiffness. However, information on the Concrete Filled-PVC Tubes (CF-PVCT) is still limited. Therefore, further studies on the CF-PVCT should be carried out as an alternative for composite column structures. PVC has advantages such as low cost, lightweight and is easy to handle and install. It is not affected by corrosion or other forms of degradation; therefore, it is used as an alternative to the metal in many applications where corrosion can compromise functionality and increase maintenance cost. The PVC tube does not only protect the concrete core from the environment but it is the cheapest material and locally available in abundance.

The development of the CFT column using this material could be an achievement for the local

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construction industries. An attempt to use composite columns with plastic tubes can be traced back from the research done by Kurt (1978) and recently an alternative new way to confine the concrete column by using Unplasticized Poly Vinyl Chloride tube (UPVC) was used by several researchers (Gathimba *et al.*, 2014; Gupta and Verma, 2013). However, not only fewer studies were found on the CFT columns using PVC tubes, its successful design and application requires adequate recognition of its more complex stress/strain and stress/fracture behavior. The concrete filled PVC tube columns were studied by Marzouck and Sennah (2002). They provide that the considerable lateral confinement to the concrete columns and the compressive strength of the concrete filled PVC tubes decreases when the slenderness ratio increases. The stress-strain response of PVC depends on the time and temperature. The strain behavior is complex when a constant static load is applied to PVC pipe (Vinidex, 2016). In addition, the PVC tube having a non-stick inner surface resulted in lower friction factors and expected to affect the lateral confining pressure on the concrete core.

MATERIALS AND METHODS

Experimental details

Generals: A total of 54 specimens of the PVC-CFT columns and concrete cylinders were tested to failure. There were a control specimen (C C20, C C25 and C C40) and the PVC-composite columns (P C20 t1, P C20 t2, P C25 t1, P C25 t2, P C40 t1, P C40). Table 1 tabulated the details of the column specimens.

There are two types of specimens involved in this study; PVC-CFT columns and concrete cylinders. All specimens were classified into three groups depending on the typical strength of the concrete as summarized in Table 1. All specimens are having the same height of 200 mm and for the PVC-CFT column specimens two-difference PVC tube thicknesses of 3.5 mm (t1) and 4.8 mm (t2) were considered. The specimens of concrete cylinders that tested in this study are for the comparison purpose.

All specimens were labelled such that the size and nominal concrete strengths could be identified from the label. For instance, P C25 t2 the first letter P symbolizes a PVC-CFT column and C25 is the typical concrete strength, whilst t2 indicates the PVC tube thickness of 4.8 mm. As for the concrete cylinder specimens, for example C C20, the C letter symbolized the specimen from concrete cylinder and C20 represents the typical concrete strength.

Table 1: Details of the specimens

Group No. Column designation	Number of specimens	Cube compressive strength (N/mm^2)	Diameter D (mm)	Tube thickness t (mm)	Length L (mm)
G1					
C C20	6	26	96.5	-	200
P C20 t1	6		100.0	3.5	
P C20 t2	6		100.0	4.8	
G2					
C C25	6	30	96.5	-	
P C25 t1	6		100.0	3.5	
P C25 t2	6		100.0	4.8	
G3					
C C40	6	50	96.5	-	
P C40 t1	6		100.0	3.5	
P C40 t2	6		100.0	4.8	

Table 2: Physical properties of PVC pipes

Parameter	Values
Relative density	1.42-1.48
Elastic tensile modulus	3.0-3.3 GPa
Poisson ratio	0.4
Ultimate tensile strength	52 MPa
Elongation at break	50-80%
Elastic flexural modulus	2.7-3.0 GPa

Table 3: Coupon mechanical properties

Average Modulus of elasticity (MPa)	Average ultimate tensile stress (Mpa)
2770	49.4

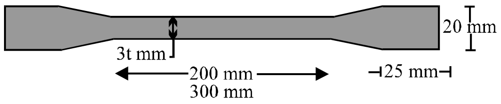

Fig. 1: Coupon scheme

Poly Vinyl Chloride (PVC) tube: Table 2 shows the physical properties of PVC tubes. The PVC tubes were cut into several pieces for the preparation of tensile coupon specimens and the dimension of the coupon is as in Fig. 1. The behaviour of PVC is described through the stress-strain relationship from the test and the stress-strain graphs are plotted in Fig. 2 with the average of ultimate tensile stress for these coupons is 49.4 MPa as shown in Table 3.

Concrete: Three different concrete strengths were considered to investigate the effect on the behavior of PVC-concrete composite columns. The concrete mix design was determined in accordance with the American Specification (ACI., 2008). Table 4 summarizes the average compression strength of the concrete mixture obtained from 150 mm cubes and standard 100×200 mm cylinders. The cylinder and cube strength on the day of testing the columns are the average of two samples. As can be seen from the table, the measured values were close to the targeted strength whilst the strength of the cylinder specimens were consistently about 82.1% of the concrete cube strengths.

Preparation of the column specimens: In Fig. 3, the 100 mm diameter PVC tubes were cut to the desired length

Table 4: Compressive loads of concrete cubes and cylinders

Mix designation	Cube compressive strength (MPa)	Cylinder compressive strength (MPa)
C20	26.23	21.20
C25	30.12	24.16
C40	50.20	40.12

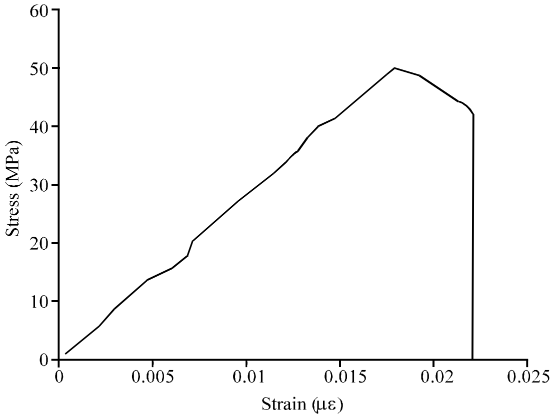

Fig. 2: Stress-strain curve

Fig. 3: Preparation of specimens

of 200 mm. Before the concrete pouring, the tubes were positioned vertically and fixed on the laboratory floor. The tubes were then filled with concrete with approximately equal layers of 10 cm deep until its full depth and each layer was compacted by a steel rod. After the tube was filled, the top surface was flush in order to ensure the loading was evenly distributed across the cross section as shown in Fig. 4. The columns were then covered with Hessian for curing. The specimens were moistened with water every day after 24 h after casting.

Fig. 4: Casting the composite columns

Fig. 5: Compression testing machine

Fig. 6: Preparation of specimens to test

Test setup and procedure: All specimens were tested under axial compression using a compression-testing machine as shown in Fig. 5. The top and bottom specimens were grinding to remove surface imperfections in order to maintain uniformity of loading on the surface as shown in Fig. 6. The column specimens were then positioned at the center of the testing machine to avoid any eccentricity during the testing. The data of loads and displacements were recorded during the tests until the specimen failed.

RESULTS AND DISCUSSION

Two types of failure modes were observed during tests, the outward buckling and shear failure due to the crash of the concrete core as shown in Fig. 7. From this Fig. 7, it can be seen that the concrete core failed because it was no longer able to sustain the axial load. The failure occurred suddenly, thus, the compression machine stopped and the data could not be recorded afterward.

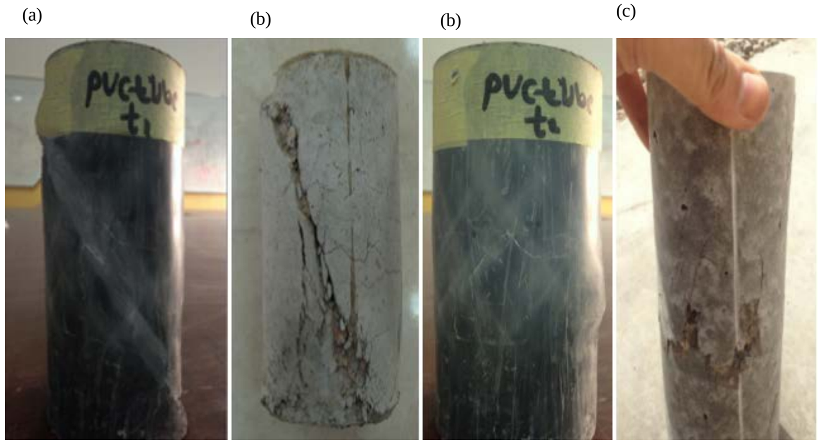

Fig. 7: a-d) Failure mode of specimen

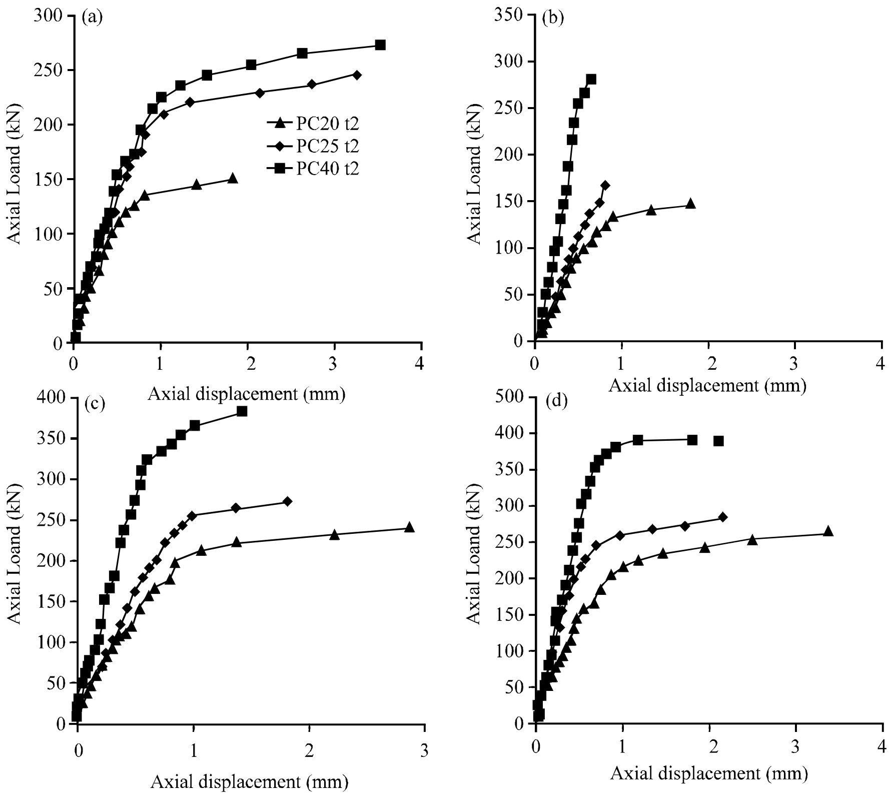

Fig. 8: Load-displacement relationship of stub columns

Column strengths: Comparison of the ultimate load was made between the control specimen of C C20, C C25 and C C40 and the CFT-PVC columns with two types of thicknesses, 3.5 and 4.8 mm. In general, CFT-PVC columns have higher strength compared to the cylinder concrete Table 5. As tabulated in the table, the tube thickness has a significant effect on the ultimate load of the composite columns. As the concrete strength and the tube thickness increase, the ultimate strength of the columns increases.

The strength of the CFT-PVC columns experienced minimum increment of 32.2% compared with their concrete cylinders. This indicates that in the CFT-PVC columns a triaxial stress developed within the confined concrete, constraining it during expansion and resulted in increasing the load carrying capacity. The increase in strength of the CFT-PVC columns due to the PVC tube are in the ranges from 32.2-83.3%.

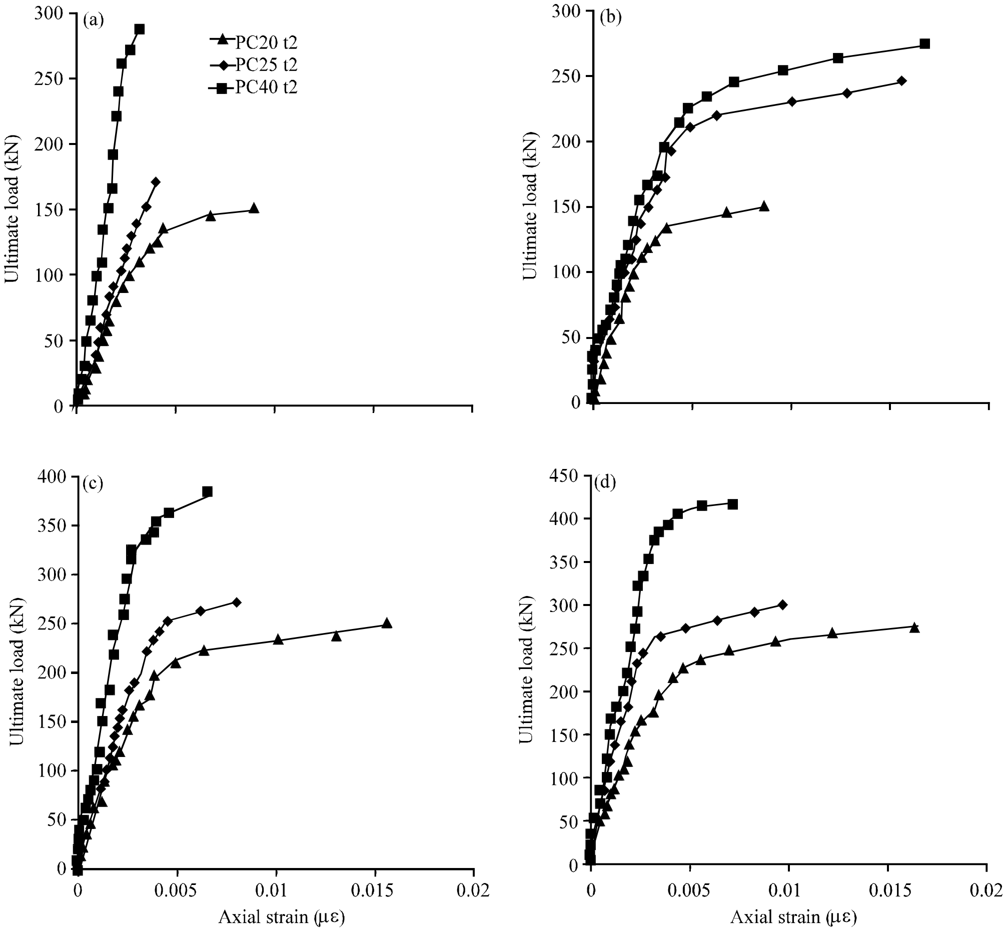

Fig. 9: Axial strain profile

Table 5: Experimental results

Column designation	Compressive strength (N/mm^2)	Ultimate load (kN)	Strain	Enhancement of ultimate load (%)
C C20	26.30	149.45	0.00600	-
P C20 t1	26.30	246.18	0.01050	64.72
P C20 t2	26.30	273.87	0.01300	83.25
C C25	30.15	170.82	0.00400	-
P C25 t1	30.15	268.78	0.00850	57.34
P C25 t2	30.15	296.88	0.01020	82.84
C C40	50.22	284.65	0.00310	-
P C40 t1	50.22	376.43	0.00675	32.24
P C40 t2	50.22	411.43	0.00775	44.53

Load-axial displacement response: The load-displacement relationships of all PVC-concrete composite columns are generally trilinear in nature with a small transition zone. Figure 8a shows that the cylinder concrete columns are less stiffer compared to the CFT-PVC columns for the same concrete compressive strength. This indicates that the PVC tubes contributed to stiffen such columns and hence the strength. The thicker the tubes are the stiffer the column and strength. The effect of concrete strength for columns on the load-displacement relationship can be seen from Fig. 8b-d. From Fig. 8a-d, the stiffness and the ultimate load increase as the concrete strength increase while the displacement at ultimate load decreases as the concrete strength increases.

Strain behaviour of short PVC-concrete composite columns: The axial strain of the PVC tubes increases once the columns achieved the ultimate as shown in Fig. 9a. The increases in strain could be attributed to the containment of concrete inside the PVC tube, hence, restrained the lateral expansion of the concrete during the loading phase. The axial strain of the CFT-PVC columns with a large tube thickness (t2 = 4.8 mm) at the ultimate load was higher compared to the CFT-PVC columns with 3.5 mm thick (t1) and the axial strain decreases as the concrete strength increases as shown in Fig. 9. From the results, the PVC tubes are able to withstand up to certain strain values with the maximum strain of 0.0085. As can be observed, there were no load reduction recorded during the course of the test due to the sudden failure on all

CFT-PVC columns. This indicates that such columns are having no ductility and the PVC tubes seem not contributes to ductile response particularly for column with higher compressive loads.

Proposed design equations: From the experiment results, the PVC tubes were proven to be able to provide confinement to the concrete core of the composite columns. The PVC tubes were also proven to stiffen the columns thereby increases the strength of the columns. However, these enhancements of concrete-filled PVC tube columns due to the confinement action are not considered in the design codes. In this study, the ultimate strengths (P_{cc}) formulae of the concrete-filled PVC columns for short columns are proposed as follows:

Each structural element CFT-PVC columns were considered as an individual component of the composite column and the interaction between the concrete core and the PVC tube was assumed as full interaction.

The strengths of the composite columns, CFT-PVC are determined from the sum of nominal strengths or theoretical full plastic capacity of the individual components in the composite columns:

$$N = A_c f_c^{'} + A_t f_t^{'} \quad (1)$$

Taking into account the confinement factor, the strength of the CFT-PVC columns can be calculated from the following proposed equation for $L/D \leq 3$. The formula relating the experimental ultimate strength of composite columns (P_{cc}) to the theoretical ultimate strength (N) may be defined in the form:

$$P_{cc} = f(pc)N \quad (2)$$

where, f (pc) is an empirical function includes the main parameters such as thickness to diameter (D/t), the ultimate tensile strength of the PVC tube (f_t), the compressive strength of concrete (f'_c) and the cross-sectional area of the concrete core:

$$P_{cc} = k\left(\frac{tf_t}{Df_c^{'}}\right)^n N \quad (3)$$

From the regression analysis between P_{cc}/N and tf_t/Df'_c as shown in Fig. 10, the coefficients of k is 1.61 and n is 0.12, thus the CFT-PVC column strength:

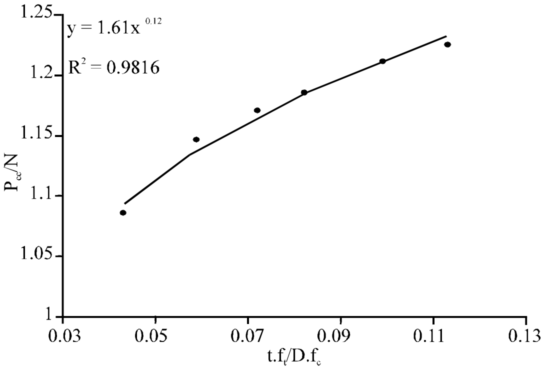

Fig. 10: The relation between (P_{cc}/N) and the (t. f_t/D. f'_c)

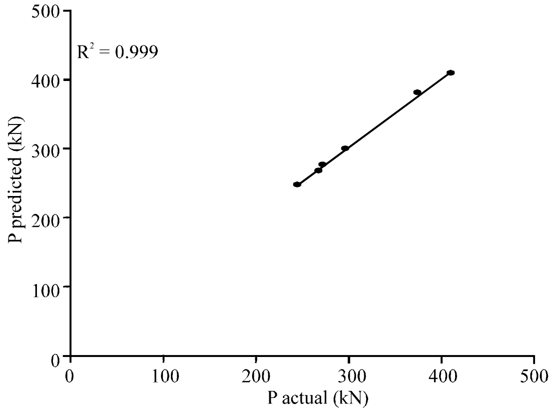

Fig. 11: Regression analysis between predicted and actual values

$$P_{cc} = 1.61\left(\frac{tf_t}{Df_c^{'}}\right)^{0.12} \left[A_c f_c^{'} + A_t f_t\right] \quad (4)$$

Where:

t = The tube thickness

f_t = The ultimate tensile strength of the tube

f'_c = The cylinder compressive strength of concret

D = The diameter of the column

As shown in Fig. 11 the regression analysis of the results of the proposed empirical equations, $R^2 = 0.9769$ and this value indicate that a good agreement is achieved between the predicted and the measured values.

CONCLUSION

This study reports the results of an experimental program of short CFT columns using plasticized PolyVinyl Chloride (PVC) tubes. From the experimental results, the plastic tube pipes were found to be effective in confining the concrete core as evidenced by the increased of ultimate loads. The ultimate load and axial strain due to confinement by using PVC tube with 4.8 mm columns is greater than thickness of 3.5 mm at same concrete strength. It is also evidence that the displacement at ultimate load decreases as the concrete strength increases while the ultimate load increase as the concrete strength increases. The column strengths calculated using the proposed equations of PVC-concrete composite columns in a good agreement with the experimental values; the correlation coefficient is 98%.

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