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Concrete Filled Plastic Stub Columns Strength under Axial Compression

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Abstract

The development of Concrete Filled Plastic Tube (CFPT) Stub Columns, is commonly used in the areas where the concrete structures interact with marine and saline environments, compared to regular concrete columns. Several CFPT stub column samples were prepared to investigate their behaviour under certain loading conditions. The main objective of this study was to conduct an experimental investigation to observe the effect of using CFPT with different diameters on the final strength of the concrete columns. In order to achieve this target, two types of loading conditions were applied, including separate load on the concrete and combined load on the concrete and the plastic tube simultaneously. The study revealed a significant improvement in the compressive strength of CFPT columns with different diameters (70 - 100 - 150 mm). Overall results show that the use of CFPT columns provides better mechanical performance compared to ordinary concrete columns. An evaluation of using the available calculation methods to predict the load-carrying capacities of CFPT. The study suggested the use of CFPT columns in situations where common concrete may cause significant issues related to its deterioration and disintegration in response to severe weather conditions.

Keywords

Concrete, Plastic, CFPT, Composites, Columns, Compressive

1. Introduction

The construction industry is one of the areas that have remarkable research potential which is also required to improve the conventional construction practices. Better construction elements are supposed to have better mechanical properties, low-cost, and longer shelf life. Concrete filled tube (CFT) column is one of the emerging technologies used in the construction industry. Different materials including steel and fiber-reinforced polymer (FRP) have been examined and used as confinement tubes in these columns. Over the few past decades, a significant amount of research has been conducted to understand the behaviour of CFST and FRP composite columns [1] [2] [3].

The prevention of steel material from corrosion in wet environments has been a great challenge in terms of economics. The use of FRP is the most favourable option in these kinds of situations but its high cost is a significant drawback.

A huge amount of money has been spent every year on the repair and maintenance of concrete bridges piers in coastal regions and those exposed to water bodies. The conventional reinforced concrete and concrete-steel composite elements pose significant strength issues and are highly susceptible to deteriorate if they get exposed to wet environmental conditions e.g. in marine and saline environmental conditions [4]. The reinforced concrete piers deteriorate at a faster rate when exposing to the solutions containing chloride, sulphates, acclimate weather, with abundance of oxygen and water molecules [5].

This study utilizes the plastic pipes to investigate their use as an alternative confined material in CFT columns under axial compression. These tubes are available in abundance in the market at relatively low prices [6]. A few common examples include; Unplasticized polyvinyl chloride (UPVC), post-chlorinated polyvinyl chloride (CPVC) acrylonitrile butadiene styrene (ABS) and many other types of plastic tubes suitable to utilize in CFT columns.

Various studies conducted by a number of researchers [4] [7] [8] [9] [10], concluded that the use of plastic tubes to confine concrete columns to increase the ultimate compressive strength, ductility, and other mechanical properties of CFT columns. The effects of axial loading on CFPT columns (with having diameter and thickness of 150 mm, 7.11 mm respectively) was studied by Usha and Eramma (2014) in their investigations, the effective lengths of the specimens were taken as 500 mm, 600 mm, and 700 mm. The results indicated that the failure of all the columns was because of the local buckling effect with increasing the length of samples. In addition, the experimental results were compared to the theoretical calculations which indicate about 1.6% increase in the section comparative capacity of CFPT columns from the theoretical value.

Another experimental study [7] aimed to investigate the compressive behaviour of CFPT Stub columns subjected to concentric compressive axial loads. Different geometries of CFPT with different concrete design strength were utilized in their study. The results illustrated that the compressive strength of the column specimens increases with increased concrete strength and decreases with increased column height. Additionally, the execution of PVC within the samples improved the ultimate strength between 1.18 to 3.65 times of unconfined strength. Similar results were obtained by Gupta [8]. The comparison of the results of the experimental load capacity of CFPT samples and predicted values (obtained from the available developed models in the literature) show that the predicted result values range within ±6% of the experimental capacities.

The behaviour of CFPT long columns was experimentally examined by Soliman (2011) [9]. The study concluded that by employing the plastic tube as confinement material significantly influenced the failure mechanisms of concrete columns. The study also concluded that the stiffness of the tested long CFPT columns increased as the slenderness ratio decreased.

In this study, axial load was applied to empty plastic tubes, concrete, and concrete with plastic tubes. Also, analyse the behaviour of these samples with various lengths and diameters under full and partial axial compression load and evaluate the possibility of using the available calculation methods to predict the load-carrying capacities of CFPTs.

2. Data and Methods

2.1. Materials Properties

2.1.1. Plastic Properties

Two types of un-plasticized polyvinyl chloride (UPVC) tubes with thicknesses of 2 mm and 3 mm were selected to be utilized as a confinement material of the plain concrete. To determine the tensile properties of the plastics (UPVC) material, tensile plastics test (ASTM D638 - 10) was performed on 6 coupons that were prepared with the dimensions as illustrated in **Figure 1**. These samples were tested in the tensile strength test machine with a loading rate of 50 mm/min.

Figure 2 shows the resulting stress-strain curve. As shown, the stress-strain relationship of both thicknesses samples was almost similar as the ultimate tensile strength (fp) was measured as 33.4 MPa and 34.2 MPa for 2 mm and 3 mm thickness coupons, respectively. Additionally, the modules of elasticity of UPVC (Ep) tube were measured as 2038 MPa and 2186 MPa for 2 mm and 3 mm thickness, respectively.

2.1.2. Concrete Properties

Two series of concrete (C15 and C35) were designed according to the methodology of the American Concrete Institute (ACI) standards [11]. The concrete mix design incorporated the tap water and ordinary Portland cement product,

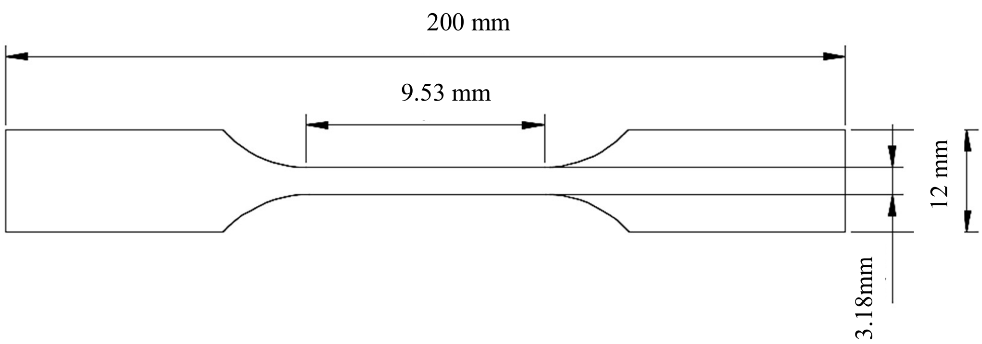


Figure 1. The dimensions of tensile test specimen model.

complying with the Libyan specification [12]. The fineness of the cement was examined using sieve No. 200 and it was found as 19.1% (<22%) which complies with American specifications [13]. The natural aggregate, available in Al-Jufra area (Libya) was selected for this study, the properties of fine and coarse aggregate are summarized in Table 1. The concrete mix design specifications are given in Table 2.

3. Test Setup and Instrumentation

A total of 63 stub columns were prepared and tested in the research work. The specimens include 18 plain concrete columns, 9 empty plastic tube and 36 CFPT as shown in Figure 3 and Figure 4. The properties and dimensions of all the

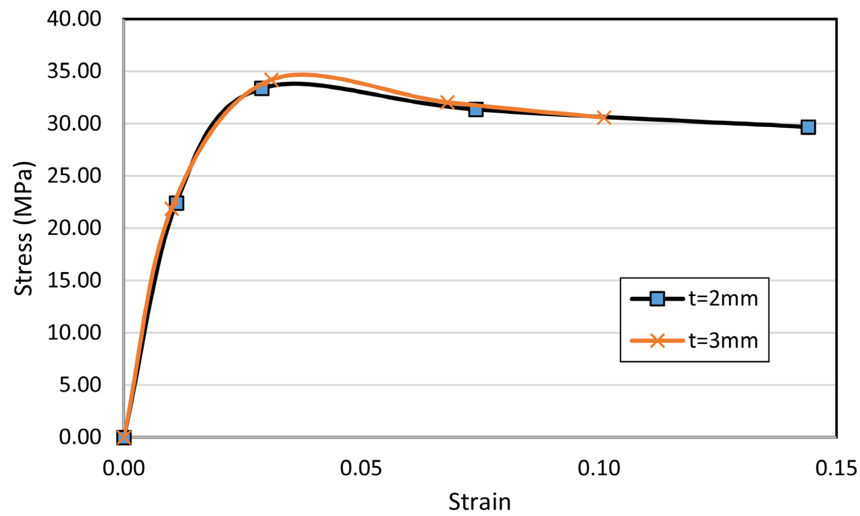


Figure 2. Typical stress-strain relationships of UPVC samples.

Table 1. Physical and mechanical properties of fine aggregates.

Test	Tests Results	Standards
Specific Gravity	2.7	BS 812 Part2:1995
Compacted Unit Weight (kg/m^3)	1.034	ASTM C29
Voids Ratio %	18.8	ASTM C29
Fineness Modulus (FM)	3.05	ASTM C125
Nominal Maximum Size of Aggregate (mm)	2.36	ASTM C125
Clay Lumps and Friable Particles in Aggregate (%)	20	ASTM C142

Table 2. Concrete mix design.

Concrete grade	Water/cement ratio	Cement	Sand (kg/m^3)	Aggregates (kg/m^3)	Compressive strength at 28 (MPa)
C15	0.69	279	884	1151	15
C35	0.42	459	730	1151	35

Figure 3. Empty plastic tubes.

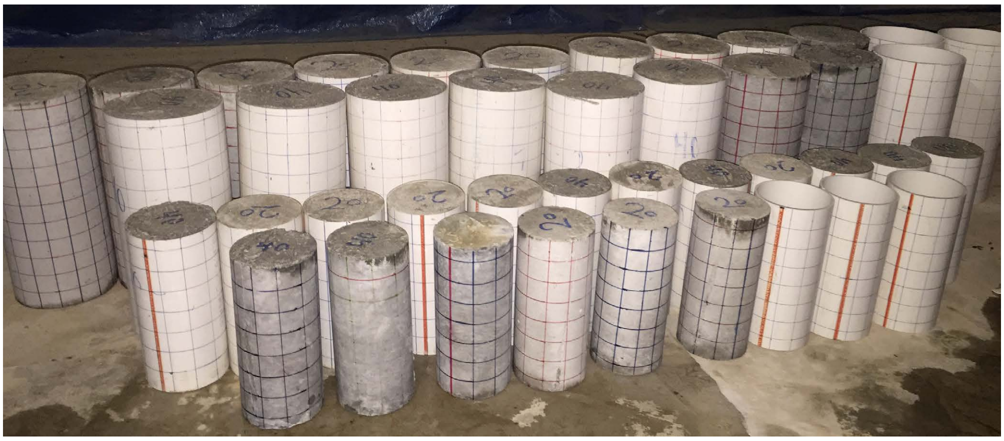
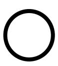


Figure 4. CFPT column specimens.

columns are listed in Table 3. As illustrated in Table 3, the main parameters were the plastic ratio, concrete strength and plastic strength; where plastic tubes with different outer diameters (70, 100 and 150 mm) with different yield strengths (33.4 and 34.2 MPa); and with concrete compressive strengths (15 and 35 MPa) were utilized in these experimental investigations.

Moreover, two types of load conditions were applied including the partial compression load on the concrete core separately and the full loading on the concrete and the UPVC tube together. The diameter of the bearing plate was different to get different local compression area ratio (ß). ß =Ac/AL; in whish, Ac is the concrete cross-sectional area, and AL is the loading area. The tests were conducted after 28 days of curing period with gunny bags, which were wetted 3 times daily until the final testing. The test set up for concrete and concrete with UPVC specimens for this study is illustrated in Figure 5. The test specimens were placed in between the top and bottom endplates. The compressive load was applied on the test samples through the top endplate and LVDTs were attached to each specimen to measure the deformation. The columns were loaded continuously until the failure.

Table 3. Details of specimens used for this study.

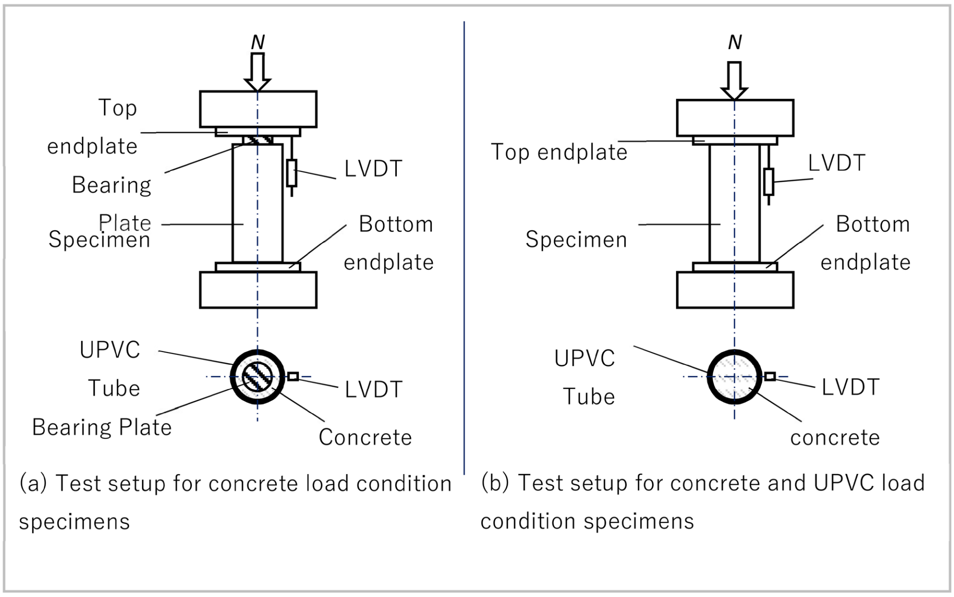
Type	Specimens	Num.	f_c (MPa)	f_p (MPa)	L (mm)	D (mm)	t (mm)	L/D	D/t	ß	Load condition
	CFP-C14-D70 C	3	14	33.4	158	70.0	2.0	2.25	23.3	1.16	On concrete
	CFP-C14-D70 CT	3	14	33.4	158	70.0	2.0	2.25	23.3	-	On concrete & tube
	CFP-C14-D100 C	3	14	34.2	225	100.0	3.0	2.25	33.3	2.04	On concrete
	CFP-C14-D100 CT	3	14	34.2	225	100.0	3.0	2.25	33.3	-	On concrete & tube
	CFP-C14-D150 C	3	14	34.2	338	150.1	3.0	2.25	46.9	1.03	On concrete
	CFP-C14-D150 CT	3	14	34.2	338	150.1	3.0	2.25	46.9	-	On concrete & tube
	CFP-C35-D70 C	3	35	33.4	158	70.0	2.0	2.25	23.3	1.16	On concrete
	CFP-C35-D70 CT	3	35	33.4	158	70.0	2.0	2.25	23.3	-	On concrete & tube
	CFP-C35-D100 C	3	35	34.2	225	100.0	3.0	2.25	33.3	2.04	On concrete
	CFP-C35-D100 CT	3	35	34.2	225	100.0	3.0	2.25	33.3	-	On concrete & tube
	CFP-C35-D150 C	3	35	34.2	338	150.1	3.0	2.25	46.9	1.03	On concrete
	CFP-C35-D150 CT	3	35	34.2	338	150.1	3.0	2.25	46.9	-	On concrete & tube
	C14-D70	3	14	33.4	158	70.0	2.0	2.25	23.3	1	On concrete
	C14-D100	3	14	34.2	225	100.0	3.0	2.25	33.3	1	On concrete
	C14-D150	3	14	34.2	338	150.1	3.2	2.25	46.9	1	On concrete
	C35-D70	3	35	33.4	158	70.0	2.0	2.25	23.3	1	On concrete
	C35-D100	3	35	34.2	225	100.0	3.0	2.25	33.3	1	On concrete
	C35-D150	3	35	34.2	338	150.1	3.0	2.25	46.9	1	On concrete
	C0-D70	3	-	33.4	158	70.0	2.0	2.25	23.3	1	On tube
	C0-D100	3	-	34.2	225	100.0	3.0	2.25	33.3	1	On tube
	C0-D150	3	-	34.2	338	150.1	3.0	2.25	46.9	1	On tube

f_c: concrete strength; f_p: UPVC yield strength; L: specimen height; D: specimen diameter; t: UPVC tube thickness

4. Results and Discussion

4.1. Failure Modes of Specimens

Figure 6 ((a), (b), (c), and (d)) illustrate the typical failure modes of full loaded CFPT, partial loaded CFPT, unfilled hollow UPVC tube, and plain concrete stub columns, respectively. Overall, at the beginning of the test, there were no cracks observed in the specimens that were because columns were in the elastic stage. However, during the loading CFPT columns showed a much better ductility than unfilled UPVC and concrete stub columns. In the unfilled UPVC columns, inward and outward buckling occurred within the tube. In plain concrete stub columns, a significant number of diagonal cracks appeared on the outer surface of the concrete. Additionally, all plain concrete columns were crushed suddenly when the axial displacement reached in the range of 0.84 - 1.36 mm. For CFPT



Note:

- For specimens with diameter of 70 mm, the dimeter of bearing plate = 63mm.
- For specimens with diameter of 100 mm, the dimeter of bearing plate = 63mm.
- For specimens with diameter of 150 mm, the dimeter of bearing plate = 142mm.

Figure 5. Test set up for specimen in the laboratory.

Figure 6. The typical failure modes of (a) full loaded CFPT, (b) partial loaded CFPT, (c) unfilled hollow UPVC tube and (d) plain concrete stub columns.

specimens, only outward local buckling was observed in UPVC plastic tubes.

4.2. Experimental Section Capacity

Figure 7 illustrates a comparison of the experimental load-bearing capacity of the specimens under axial compression load. For each graph, the geometric dimensions and the material properties were kept the same for the UPVC, concrete and CFPT columns. The terms "CFPT (Load on Con.)" and "CFPT (Load on Tube & Con.)" in **Figure 7** represent the load-carrying capacity of CFPT

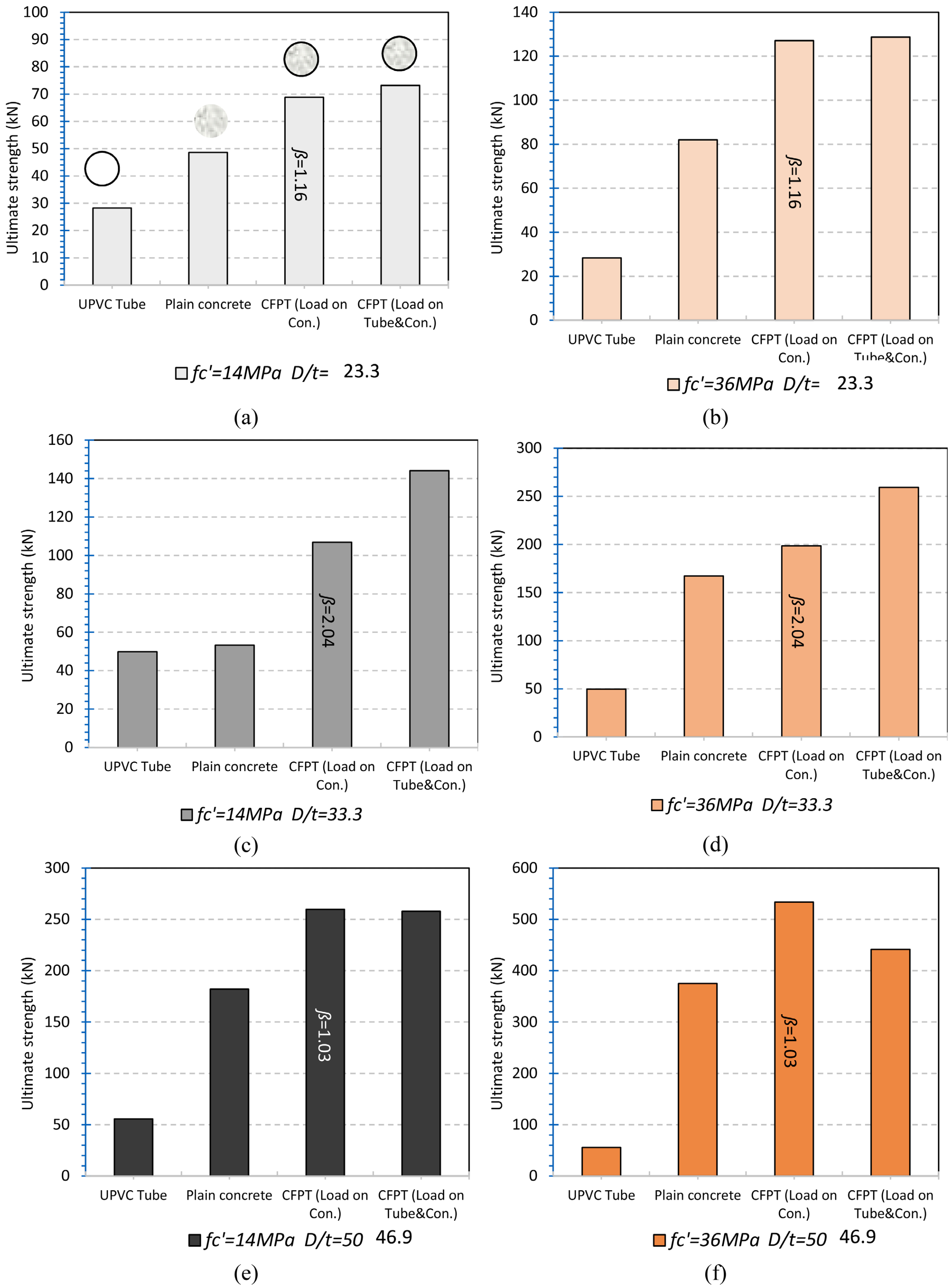


Figure 7. Comparison of the experimental axial load carrying capacity of CFPT stub columns.

specimens with concrete only loading condition and concrete-UPVC simultaneously loading condition, respectively. The results indicate that the use of UPVC tubes can clearly improve the load caring capacity of concrete columns. The presence of UPVC tubes not only improves the confinement strength of the concrete core while they also can carry a portion of the axial stresses. However, loading on the UPVC tube could not be a suitable choice in all cases as illustrated in **Figure 7(e)**. Where the sectional strength of the UPVC tube was much weaker compared to the strength of the concrete core, which resulted in early and sudden failure of the tube and losing both the axial and confinement strength resulting from the UPVC tubes. Therefore, it is recommended that to use UPVC tube to enhance the confinement of the concrete core and avoid the axial loading on the UPVC tubes.

Moreover, it also could be understood from **Figure 7** that the load-carrying capacity decreases with the increase of the ratio of in local compression area (ß), therefore, loading on the entire top surface of the concrete is the recommended option to avoid local failure of the concrete due to the stresses concentrating.

4.3. Comparison with Design Methods

A comparison between the load-carrying capacities of concrete-filled plastic stub columns determined from the laboratory experiments and from a number of the available formulations are shown in **Table 4**. These formulations were originally prepared to be used for CFST stub columns; however, this study aims to examine the possibility of using their equations to predict the load-carrying capacity of CFPT stub columns.

4.3.1. ACI Method

The formulation of designing the reinforced concrete sections adopted to determine the axial capacity of CFPT stub columns. The compressive capacity of CFPT stub columns can be found by using Equation (1) provided by the American Concrete Institute (ACI) code [14]. According to Equation (1), the design load was based on ACI (N_{ACI}) which is the summation of ultimate axial sectional capacities of the concrete core and plastic tube.

$$N_{ACI} = A_p f_p + 0.85 A_c f_c \quad (1)$$

where, A_p is the cross-sectional area of plastic tube, A_c is the cross-sectional area of concrete infill, f_p is the yield strength of plastic and f_c is the 28 day cylinder compressive strength of concrete.

4.3.2. Giakoumelis and Lam Method [15]

Giakoumelis and Lam [15] had modified the ACI [14] equation to determine the axial load capacity of circular CFST stub columns. In this case, a revised equation is given as follows:

$$N_{GL} = 1.3 f_{cyl,150} A_c + f_p A_p \quad (2)$$

4.3.3. American Institute of Steel Construction (AISC) Method

A different approach is recommended by the AISC [16] as shown in Equation (3) to predict the load carrying capacity depending on whether the columns are encased or CFST composite columns. A revised equation is given as follows:

$$N_{AISC} = P_{0,AISC}\left[0.658^{\left(\frac{P_{0,ASIC}}{P_e}\right)}\right] \quad (3)$$

$$P_{0,AISC} = 0.95 f_{cyl,150} A_c + f_p A_p \quad (4)$$

$$P_e = \frac{\pi^2 (EI)_{eff1}}{(K_A L_A)^2} \quad (5)$$

$$(EI)_{eff1} = E_p I_p + C_3 E_{c1} I_c \quad (6)$$

$$C_3 = 0.6 + 2\left(\frac{A_p}{A_c + A_p}\right) \le 0.9 \quad (7)$$

where, P_0; AISC is the nominal, zero length strength, P_e is the elastic buckling load, K_A is the effective length factor; L_A is laterally unbraced length of the column; I_p and I_c are moment of inertia of plastic tube and concrete core, respectively; E_c is the modulus of elasticity of concrete and EI/eff_1 is effective stiffness of composite section.

4.3.4. Eurocode 4 (EC4) Method

Eurocode 4 [17] is using Equation 8 to determine the section compressive capacity of CFST CHS stub columns. However, the long-term effects are not taken into account.

$$N_u = A_a \cdot \eta_a \cdot f_{pd} + A_c \cdot f_{cd} \cdot \left[1 + \eta_c \cdot \frac{t}{d} \cdot \frac{f_p}{f_{ck}}\right] \quad (8)$$

$$\bar{\lambda} = \sqrt{\frac{N_{PI,RK}}{N_{cr}}} \quad (9)$$

$$N_{PI,RK} = A_a \cdot f_p + A_c \cdot f_{ck} \quad (10)$$

$$N_{cr} = \frac{\pi^2 \cdot (EI)_{eff}}{(K_e \cdot L)^2} \quad (11)$$

$$(EI)_{eff} = E_a \cdot I_a + 0.6 \cdot E_c \cdot I_c \quad (12)$$

$$\eta_{c0} = 4.9 - 18.5 \cdot \bar{\lambda} + 17 \cdot \bar{\lambda}^2 \ge 0 \quad \& \quad \eta_{a0} = 0.25\left(3 + 2\bar{\lambda}\right) \le 1.0 \quad (13)$$

$$\eta_c = \eta_{c0} \cdot \left(1 - \frac{10 \cdot e}{d}\right) \quad (14)$$

$$\eta_a = \eta_{a0} + (1 - \eta_{a0}) \cdot \frac{10 \cdot e}{d} \quad (15)$$

where, A_p is the cross-sectional area of CHS plastic, A_c is the cross-sectional area of concrete infilled, f_p is the yield strength of CHS plastic and f_c is the 28 days cylinder compressive strength of concrete. Where η_c is the coefficient of confinement for the concrete; η_a is the coefficient of confinement for the plastic tube; $\bar{\lambda}$ is relative slenderness; l is buckling length of the CFT column; E_c is elastic modulus of concrete. $(EI)_{eff}$ is the effective flexural stiffness for the calculation of relative slenderness; and K_e = a correction factor which is equal to 0.6.

4.3.5. Goode and Narayanan Method

Goode and Narayanan [18] proposed Equation (16) to predict the confining effect of circular CFST stub columns. A revised equation is given as follows:

$$N_{GN} = 0.85 f_{cyl,150} A_c + \frac{6t}{D-2t} f_p A_p \tag{16}$$

4.3.6. Han *et al.* Method

Han *et al.*, made the Chinese code DL/T [19] much easier to use for calculating the section capacity of circular CFT stub columns by using the revised equation as shown below:

$$N_{HAN} = (1.14 + 1.02\xi) f_{ck} A_{sc} \tag{17}$$

The previously missioned equations were proposed previously to identify the load-carrying capacity of full loaded CFST columns. Thus, for the partial loaded CFPT columns a special Equation (18) will be adopted as suggested by Han *et al.* [20] [21]

$$N_{u,p} = K_p \cdot N_u \tag{18}$$

where N_u is columns caring capacity obtained, K_p is a strength index and can be calculated using the following equations:

$$K_p = A_0 \cdot \beta + B_0 \cdot \beta^{0.5} + C_0 \tag{19}$$

where:

$$A_0 = \left(-0.18\xi^3 + 1.95\xi^2 - 6.89\xi + 6.94\right)/100$$

$$B_0 = \left(1.36\xi^3 - 13.92\xi^2 + 45.77\xi - 60.55\right)/100$$

$$C_0 = \left(-\xi^3 + 10\xi^2 - 33.2\xi + 150\right)/100$$

According to the results presented in **Table 4**, the method provided by Goode and Narayanan [18] [22] gives the best result with mean value and standard deviation of 0.970 and 0.072 respectively. However, the results obtained from Giakoumelis and Lam Method [15] [23], Eurocode 4 (EC4) Method [17] [24] and Han *et al.* Method [20] [25] were less accurate to calculate the load-carrying capacities of CFPT stub columns.

5. Conclusions

This study aimed to investigate the behaviour of circular concrete-filled plastic tubes (CFPT) columns subjected to full and partial compression. Based on the

Table 4. Comparison between the experimental results the available design methods for full loaded specimens.

Specimens	N_u (KN)	N_u/N_{ACI}	N_u/N_{Giako}	N_u/N_{AISC}	N_u/N_{EC4}	N_u/N_{Goode}	N_u/N_{Han}
CFP-C14-D70 C	68.8	1.090	0.855	1.027	0.761	0.900	0.822
CFP-C14-D70 CT	73.2	1.136	0.891	1.071	0.793	0.938	0.857
CFP-C14-D100 C	106.9	1.103	0.834	1.029	0.783	0.937	0.860
CFP-C14-D100 CT	144.1	1.287	0.973	1.200	0.913	1.092	1.002
CFP-C14-D150 C	259.9	1.188	0.871	1.099	0.862	1.037	0.944
CFP-C14-D150 CT	257.8	1.154	0.846	1.068	0.838	1.008	0.917
CFP-C35-D70 C	127.1	1.068	0.764	0.982	0.824	0.964	0.831
CFP-C35-D70 CT	128.7	1.030	0.737	0.947	0.795	0.929	0.801
CFP-C35-D100 C	198.6	1.035	0.723	0.944	0.809	0.954	0.840
CFP-C35-D100 CT	259.4	1.102	0.770	1.006	0.862	1.016	0.894
CFP-C35-D150 C	533.5	1.101	0.756	1.000	0.873	1.034	0.920
CFP-C35-D150 CT	441.6	0.881	0.605	0.800	0.699	0.828	0.736
	Mean:	1.098	0.802	1.014	0.818	0.970	0.869
	SDV:	0.098	0.096	0.098	0.057	0.072	0.071

results, the following conclusion can be drawn:

1) Overall, the use of the UPVC tube improves the mechanical properties of the plain concrete stub columns by enhancing the concrete confinement effect and carrying part of the axial loading.

2) The full loading on the concrete and the UPVC tube simultaneously can result in better loading capacity of CFPTs. However, for relatively higher strength sections, the UPVC tube may fail before the concrete core reaches its maximum carrying capacity which leads to an early ending of the composite interaction between the two components and weakens the overall strength of the CFPTs.

3) The calculation method proposed by Goode and Narayanan can give the muse accrue production of the load-carrying capacities of CFPT stub columns compared with other design approaches.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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