BEHAVIOR OF CONCRETE-FILLED PVC TUBE COLUMNS UNDER AXIAL LOAD

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ABSTRACT

A concrete-filled tube (CFT) column system offers numerous advantages due to its large axial stiffness and capacity. In the system, steel is a common type of material and has been widely used. However, the application of FRP and PVC came into the picture as the alternative to the steel application in the system. In this study, the concrete-filled PVC tube (CF-PVCT) columns subjected to axial load were considered in both experimental and numerical analysis. The PVC tube is a low-maintenance material and locally available in abundance. The investigation on such columns was carried out to study their potential and the success of such columns would be a milestone achievement in the local construction industry. The study involved parameters such as variable lengths, diameters, and thicknesses of the PVC tube as well as various concrete strengths for the concrete infill. A total of 110 columns which included CFPVCT, CF-PVCT confined with plain PVC socket, hollow PVC column and concrete columns were tested under axial load. From the experimental results, the CF-PVCT columns failed in shear, outward buckling, sudden explosive as well as PVC tube rupture and most of the columns experienced sudden failure. The CF-PVCT columns have a higher capacity of around 32% to 98% compared to the unconfined concrete columns; however, the CF-PVCT columns confined by plain PVC sockets achieved more capacity (23% to 54%) than the CF-PVCT columns. The increase of the thickness and diameter of PVC tube led to a good increase in ultimate strength and the corresponding strain of the CF-PVCT columns. The displacement at ultimate load decreased as the concrete strength increased while it increase as the thickness of tube and slenderness ratio increased. The increase of the slenderness ratio led to decrease the ultimate strengths and the axial strain of CF-PVCT columns. A simulation using finite element software ANSYS v14.5 was conducted to validate the experimental work. Three empirical equations to predict the ultimate strength for CF-PVCT columns by using three approaches were proposed according to ACI 318-08. Finite element analysis by ANSYS indicated similar behaviour in terms of axial displacement and mode of failure. The empirical equations proposed in this study showed good agreement with the experimental values. The approach using PSO could predict the ultimate load of CF-PVCT column with higher accuracy.

ABSTRAK

Sistem tiub tiang terisi-konkrit (CFT) menawarkan banyak kelebihan disebabkan oleh kekukuhan paksi dan kapasiti yang tinggi. Di dalam sistem tersebut, keluli merupakan sejenis bahan yang biasa dan telah digunakan secara meluas. Walau bagaimanapun, penggunaan FRP dan PVC muncul sebagai alternatif kepada aplikasi keluli di dalam sistem tersebut. Dalam kajian ini, tiub PVC terisi-konkrit (CF-PVCT) yang dikenakan beban paksi dipertimbangkan di dalam kedua-duanya kerja eksperimen dan analisis berangka. Tiub PVC merupakan bahan rendah-penyelenggaraan dan boleh didapati secara meluas. Penyiasatan ke atas tiang tersebut dijalankan bagi mengkaji potensinya dan kejayaan kajian yang dijalankan ke atas tiang seperti ini akan menjadi pencapaian yang penting di dalam industri pembinaan tempatan. Kajian ini melibatkan parameter seperti panjang tiang, garis pusat, dan ketebalan tiub PVC serta variasi kekuatan konkrit. Sejumlah 110 tiang termasuk CFPVCT, CF-PVCT dikurung dengan soket PVC, tiang PVC berongga dan tiang konkrit dikenakan beban paksi. Daripadakeputusan eksperimen, tiang CF-PVCT gagal dari segi ricih, lengkokan keluar, letupan mengejut dan begitu juga berlakunya pecah pada tiub PVC dengan kebanyakan tiang tersebut mengalami kegagalan secara mendadak. Tiang CF-PVCT mempunyai kapasiti yang tinggi iaitu diantara 32% ke 98% berbanding dengan tiang konkrit tidak terkurung, walaubagaimanapun, tiang CF-PVCT dikurung dengan soket PVC mencapai kapasiti yang lebih tinggi (23% ke 54%) berbanding dengan tiang CF-PVCT. Penambahan ketebalan dan garis pusat tiub PVC membawa kepada penambahan kekuatan muktamad dan terikan sepadan tiang CF-PVCT. Anjakan pada beban muktamad berkurangan apabila kekuatan konkrit bertambah, manakala ianya menjadi bertambah seiring dengan penambahan ketebalan dan nisbah kelangsingan tiub. . Pertambahan nisbah kelangsingan membawa kepada pengurangan kekuatan muktamad dan juga terikan paksi tiang CF-PVCT. Simulasi menggunakan perisian unsur terhingga ANSYS v14.5 turut dijalankan bagi menentusahkan kerja-kerja eksperimentasi. Tiga persamaan empirikal bagi meramalkan kekuatan muktamad tiang CF-PVCT menggunakan tiga pendekatan telah dicadangkan mengikut ACI 318-08. Analisis unsur terhingga oleh ANSYS menunjukkan terdapatnya tingkah laku yang serupa dari segi anjakan paksi dan mod kegagalan. Cadangan persamaan emperik dalam kajian ini mencapai persetujuan yang baik dengan nilai ujikaji. Pendekatan menggunakan PSO boleh menentukan beban muktamad tiang PVCT dengan ketepatan yang tinggi.

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LIST OF SYMBOLS

$\bar{Y}$	Predicted ultimate axial load value
ε_{co}	Axial strain for concrete columns
ψ	Load factor
ω	Reinforcement index
ρ_t	Reinforcement ratio
ϕ	Strength reduction factor
ϕ_t	Strength reduction factor of CF-PVCT column
ε_{cc}	Axial strain for CF-PVCT columns
E_x	Elastic modulus
v_{xy}	Poisson's ratio
μ	Micro
A_c	Cross-sectional area of the concrete core
A_t	Cross-sectional area of the PVC tube
D	Diameter of tube
D/t	Diameter to thickness ratio
$f\,(pc)$	Empirical function
F1, F2, F3, F4, F5	Coefficients
f'_c	Concrete cylinder compressive strength
f_{cu}	Strength of concrete infill
f_t	Ultimate strength of the PVC tube
L	Length of tube
L/D	Length to the diameter ratios
L/r	Slenderness ratio
L_i	Various service loads
P_{cc}	Ultimate load for CF-PVCT columns
P_{co}	Ultimate load for concrete columns

$P_{compact}$	Ultimate strength of the corresponding short column
P_{exp}	Ultimate load of experimental results
P_{FEM}	Ultimate load of simulation results
P_n	Nominal load
$P_{slender}$	Ultimate strength of the slender column and
R^2	Correlation coefficient
t	thickness of tube
V_i	Velocity
X_i	Position
y	Actual value of the axial load
y'	Predicted ultimate axial load value
$\tilde{y}$	Average of the actual values
n	Number of data samples
Δ	Displacement

LIST OF ABBREVIATIONS

2D	Two-dimensional
3D	Three-dimensional
ACI	American Concrete Institute
ANSYS	Analysis System
CFST	Concrete filled steel tube
CFT	Concrete filled tube
CCFT	Circular concrete filled tube
SCFT	Square concrete filled tube
RCFT	Rectangular concrete filled tube
FRP	Fiber Reinforced Plastics
PVC	Polyvinyl Chloride
RACFST	Recycled aggregate concrete filled steel tube columns
SFRC	Steel fiber reinforced concrete
CFST	Concrete filled steel tubular
SHS	Square hollow section
CHS	Circular hollow section
RHS	Rectangular hollow section
GFRP	Glass fiber reinforced polymer
SR	Steel spiral reinforcement
CFFT	Concrete filled fiber-reinforced polymers FRP tube
UPVC	Unplasticized Poly-vinyl chloride
FEA	Finite element analysis
PSO	Particle swarm optimization position
SVM	Support vector machine
CoV	Coefficient of variation
RC	Reinforced concrete
MAE	Mean absolute error
RMSE	Root-mean-square error

CHAPTER 1

INTRODUCTION

1.1 General

Compression members are the key elements of all skeletal structures, and the study of their behaviour is usually based on the testing of concentrically loaded members. Columns can be defined as members that carry axial compressive loads, which length is considerably greater than the cross-sectional dimensions. Such members may also carry other types of loadings, and may have different types of end conditions.

In civil engineering, the merits of a material are based on factors such as availability, structural strength, durability, and workability. The properties of construction materials differ from each other; thus, there is no single material that can provide all structural requirements. The engineer's problem include an optimization involving different materials and methods of construction, with the objective of constructing any building structure at minimum cost to meet its requirements. This is the reason for using two or more materials and connecting them together in order to take full advantages of their properties. The structural member of two or more materials is known as a composite structure.

Having the advantage of the composite structure, composite columns such as concrete filled steel tube (CFST) is known to have more merit compared to the bare steel or reinforced concrete columns. The concrete infill in the tube of the CFST column prevents inward buckling modes of the steel tube, and the tube provides effective lateral confinement to the concrete inside the tube.

The stiffness, strength and ductility of a composite column are considered to be greater than those of thin-walled steel columns with the same cross-section as the outer steel plates of the composite column, because the encased concrete itself gives stiffness strength, and also because the buckling deflection of the outer steel plates toward the inside of the box cross-section is prevented by the encased concrete (Kitada, 1998) as is illustrated in Figure 1.1.

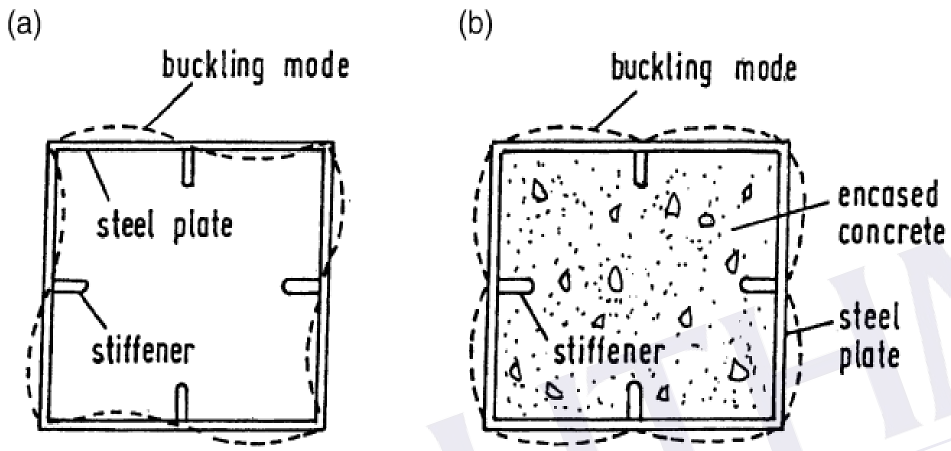

Figure 1.1: Difference in buckling modes between cross-sections of steel and composite columns (a) Steel cross-section; (b) composite cross-section (Kitada, 1998)

Composite columns can be in the form of concrete-encased sections as shown in Figure 1.2; (a) to (c), concrete-filled hollow sections Figure 1.2 (f) to (i) and partly concreted-encased sections Figure 1.2 (d) and (e).

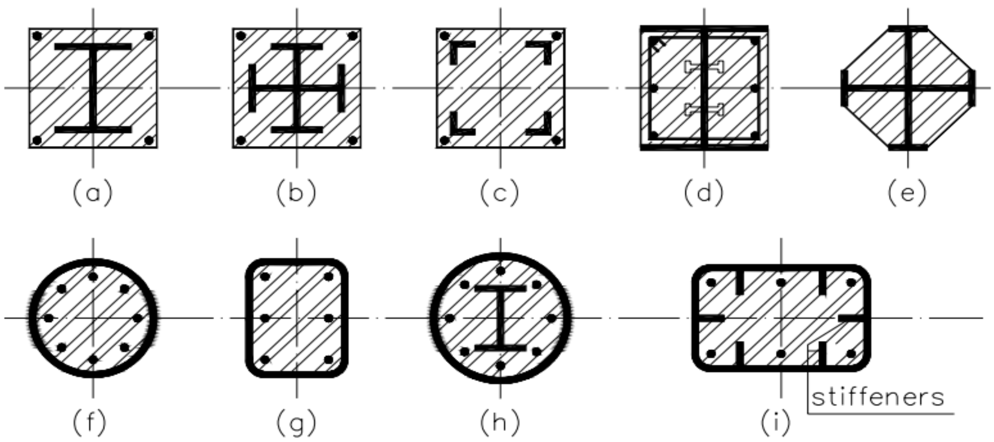

Figure 1.2: Typical cross-sections of composite column (Zhang, 2004)

1.2 Concrete Filled Tube, CFT Columns

Concrete-filled tube (CFT) columns provide great seismic resistant structural properties such as high strength, high ductility, and large power absorption capacity. In addition to the improvement in structural properties, construction time can be decreased substantially due to the prevention of permanent formwork. CFT columns are generally designated by the cross-section of the tube, with the circular (CCFT), square (SCFT) and rectangular (RCFT) are still widely used in construction. Other column shapes that are aesthetically used are elliptical, polygon or round-ended rectangular as shown in Figure 1.3.

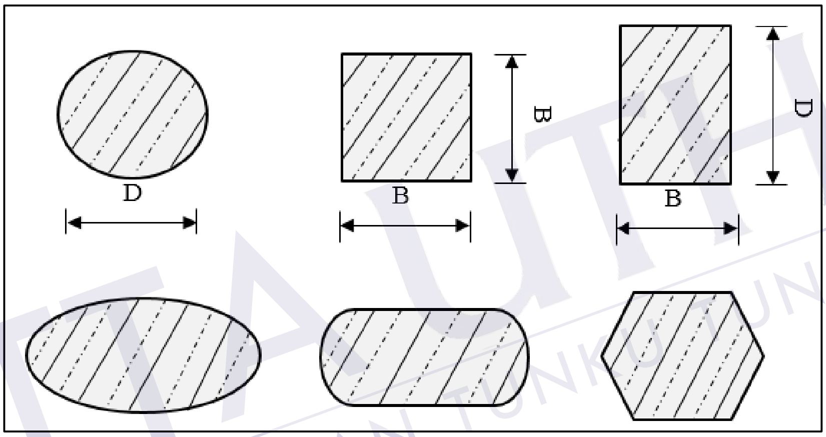

Figure 1.3: Typical cross-sections of concrete filled tubular sections

The ultimate strengths of CFT columns are affected by their material properties like the compressive strength of the concrete, the yield strength of the steel and the nonlinear behaviours of these materials. Apart from the material properties, the ultimate strengths are also significantly affected by the concrete confining pressure and the geometric properties of the tubes such as the shape of the cross-section, the slenderness ratio, and the width to thickness ratio.

The use of concrete in-filled steel tube columns has increased throughout the world in many years (Li *et al*., 2010). Besides steel, newly discovered materials such as Fiber Reinforced Plastics (FRP), and aluminium, can be introduced as the caged reinforcement material. Other advantages may be added through the use of these material substitution.

The study on concrete-filled PVC tube composite columns (CF-PVCT) is limited, but it is useful on the application such as for pile foundation or aggressive environments (Jiang *et al*., 2014). The PVC tube has adequate stiffness to resist cracks and deformations of concrete core (Marzouck and Sennah, 2002). Besides, the PVC tube can act as formwork, improves the construction speed, and protects the core concrete from corrosions caused by atrocious environment.

1.3 Polyvinyl Chloride (PVC)

Polyvinyl Chloride PVC, commonly referred to as vinyl, is a plastic material (polymer) made on the basis of salt and oil. Since a significant proportion of its mass is chlorine, creating a given mass of PVC requires less petroleum than many other polymers. PVC is a thermoplastic material, which means it can be melted several times. After being heated up to a certain temperature it will harden again as it cools. It is used to make durable products, often with a life expectancy exceeding 60 years.

PVC has many uses such as in water butts, window frames, mud flaps, water pipes and garden furniture. It is a durable material and sturdier than many other plastics, difficult to burn, has great resistance to strong acids and bases, to other chemicals, and to many organic solvents. Additionally, polyvinyl chloride is one of the least expensive plastics.

PVC is predominantly used by equipment manufacturers because it is low cost, lightweight and easy to handle and install. It is not affected by corrosions or other forms of degradation, therefore, it is used as an alternative to the metal in many applications where corrosions can compromise functionality and increase maintenance cost.

1.4 Problem Statement

Concrete filled steel tube columns is the typical concrete filled tube (CFT) columns mostly used in buildings. Generally, CFT columns can be found in bridge and high-rise buildings, where traditional columns of the steel or concrete structure normally being used extensively in lower –rise buildings.

The steel tube which acts as reinforcement in such column is expensive and is exposed to the risk of corrosion. Products like Poly Vinyl Chloride (PVC) tubes can be used as an alternative to the metal for the application of CFT column for low – cost housing and pile foundation or in severe environments attacks due to its exceptional properties. Cheaper PVC that is locally available in abundance adds another advantage. It is an achievement for the local construction industry if it can develop CFT columns using PVC. However, the feasibility of using the material on the composite columns needs to be determined through experimental works to investigate its carrying capacity and associated ductility.

The concrete filled steel tube (CFST) have been used for many decades because of its advantageous qualities like enhanced strength, ductility, and stiffness (Shams, 1998). However, information on the concrete filled PVC tubes (CF-PVCT) columns is still limited. Therefore, further studies on the CF-PVCT columns should be carried out as an alternative for composite column structures.

Most of the studies on the plastic composite columns were carried out experimentally by previous researchers such as [Kurt (1978), Daniali (1992) and Marzouck and Sennah (2002)], which were focused on the effects of slenderness ratio for concrete filled plastic tube columns. In reality, the existing model has not been confirmed for slender of concrete filled plastic tube columns (ACI 318, 2008). Furthermore, there are restraints to add the length effect for plastic composite columns. Therefore, in this research an empirical equation for CF-PVCT column has been proposed to predict the strength of plastic tubular columns.

1.5 Objectives

The aims of this study was to investigate the potentials of using the PVC tube in concrete filled PVC tubes columns, (CF-PVCT columns). In order to achieve this, the investigation on such columns was carried out with the following objectives:

1. To study the effects of various thicknesses, length, diameter, slenderness ratio, compressive strength and concrete confinement on the structural behaviour of CF-PVCT columns under axial load.
2. To validate and simulate the experimental results by means of finite element method using ANSYS software.

3. To propose an empirical equation to predict the ultimate load of the CF-PVCT columns under axial load.

1.6 Scope of study

This study was focused on experimental works and FE models to study the structural behaviour of the (CF-PVCT) columns. Therefore, in order to achieve the objectives of the study, one hundred ten (110) specimens were casted and tested. This included sixty-eight (68) PVC-confined concrete columns, thirty-four (34) unconfined concrete columns, four (4) hollow PVC tube and four (4) concrete filled PVC tube with PVC plain sockets in order to study the confinement pressure. Various lengths (200, 500, 700, 1000mm), diameters (75,100,150, 200mm) and thickness (3.5, 4.8, 6.8, 9.8mm) of the CF-PVCT were considered to study their effects on the structures. The specimens were grouped into seven groups based on the values of diameter and concrete compressive strength. Short CF-PVCT had identical design details with different concrete compressive strength of (21, 24 and 40) N/mm² for cylinder test. The parameter involves concrete strength, diameter effect, slenderness ratio, thickness effect and confinement pressure by plain PVC socket.

The experimental performance observation consisted of concrete strength, the displacement of the specimens, ultimate load, strain and failure mode of PVC tube. To simulate the CF-PVCT, finite element analysis software (ANSYS v14.5) was conducted. The FEA is used to analysis the theoretical behaviour of the columns to compare with the experimental results. Three empirical equations were proposed to predict the ultimate load of CF-PVCT columns by using three approaches. In the first approach, the PVC tube was treated as an external reinforcement to the concrete core in the CF-PVCT column while the PVC tube was treated as an individual component of the composite column in the second approach. The third equation was proposed by using the practical swarm optimization (PSO) algorithm that was implemented in the MATLAB.

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