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Structural Behavior of Steel Tubes and Concrete Filled Steel Tubes(CFST) Retrofitted with Glass Fiber Reinforced Polymer(GFRP)

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ABSTRACT

Concrete-Filled Steel Tubes (CFTs) are composite members consisting of an steel tube infilled with concrete. In current international practice, CFT columns are used in the primary lateral resistance systems of both braced and unbraced building structures. There exist applications in Japan and Europe where CFTs are also used as bridge piers. Moreover, CFTs may be utilized for retrofitting purposes for strengthening concrete columns in earthquake zones. This paper presents the results of an experimental study into the behavior of concrete-filled steel tube columns confined by fiber-reinforced polymer (FRP). Eleven columns were tested to investigate the effects of the FRP layer number, the thickness of the steel tube and concrete strength on their load capacity and axial deformation capacity. The experimental results indicated that the FRP wrap can effectively confine the concrete expansion and delay the local buckling of the steel tube. Both the load capacity and the axial deformation capacity of concrete-filled steel tube columns can be substantially enhanced with FRP confinement. A model is proposed to predict the load capacity of the FRP-confined concrete-filled steel tube columns. The predicted results are generally in good agreement with the experimental ones obtained in this study and in the literature.

Keywords-Concrete-filled steel tube (CFST) columns; Fiber-reinforced polymer (FRP); Axial load; Confinement

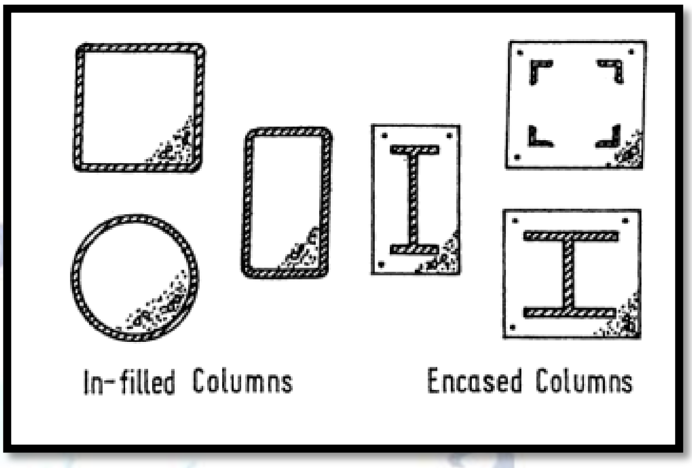
1. INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Steel-concrete composite columns were used for over a century. At the beginning it was used to provide fire protection to steel structures. Afterwards, the concrete encased columns' strength properties were also considered in the design. However, the research into concrete filled steel tubes (CFST) did not begin until the 1960s. At the present time, the concrete filled steel tube columns are widely used in construction. Actually, this type of structural elements is favored in practice because of its small cross sectional area to load carrying capacity ratio. Hence, mega concrete columns in tall buildings' lower floors can be substituted by smaller sections of CFST columns. Moreover, CFST elements can be used as piers for bridges at congested areas. Therefore, such structural elements should be thoroughly investigated before used in critical structures. Despite being a research topic for around 50 years, the behavior of the CFST columns under different loading conditions is not fully studied. Thus, intensive parametric studies should be performed in order to fully understand the CFST columns behavior. This study, addresses some parameters that affect the CFST column behavior which are the steel tube outer diameter to thickness ratio, the concrete infill compressive strength, the loading rate, and the GFRP jacketing. The CFT structural member has a number of distinct advantages over an equivalent steel, reinforced concrete, or steel-reinforced concrete member. The orientation of the steel and concrete in the cross section optimizes the strength and stiffness of the section. The steel lies at the outer perimeter where it performs most effectively in tension and in resisting bending moment. Also, the stiffness of the CFT is greatly enhanced because the steel, which has a much greater modulus of elasticity than the concrete, is situated farthest from the centroid, where it makes the greatest contribution to the moment of inertia. The concrete forms an ideal core to withstand the compressive loading in typical applications, and it delays and often prevents local buckling of the steel, particularly in rectangular CFTs. Additionally, it has been shown that the steel tube confines the concrete core, which increases the compressive strength for circular CFTs, and the ductility for rectangular CFTs. Therefore, it is most advantageous to use CFTs for the columns subjected to the large compressive loading.

1.2 CONCRETE FILLED STEEL TUBE (CFST)

Nowadays, the composite structural elements are increasingly used in tall buildings, bridges and other types of structures. Because of its composite effects, the disadvantage of two materials can be compensated for and the advantages can be combined providing efficient structural system. The steel-concrete composites are considered as an advantageous system for carrying large axial load benefitting from the interaction between the concrete and the steel section. The steel section reinforces the concrete to resist any bending moments, tensile and shear forces. The concrete in a composite column reduces the potential for buckling of the steel section in addition to resisting compressive loading. There are two types of steel-concrete composite columns which are commonly used in buildings. Those with steel section in-filled with concrete and those with steel section encased with concrete as shown in Figure 1.1.



[Fig.1.1: Types of composite column]

The use of composite columns, encased or in-filled, results in significant reduction of the column size when compared to regular reinforced concrete columns needed to carry the same load. Hence, considerable economic savings can be obtained. Also, the column size reduction is advantageous where floor space is at a premium, such as in office blocks and car parking's. In addition, closely spaced composite columns connected with spandrel beams can be used around the outsides of the high rise buildings for lateral loads resistance by the tabular concept.

Concrete encased steel composite sections are favored for many seismic resistant structures. When the concrete encasement cracks under severe flexural overloading, the stiffness of the section reduces but the steel core provides shear capacity and ductile resistance to subsequent cycles of overload. Additionally, the surface area of the enclosed steel sections is intact by the concrete cover, thus required no painting and fireproofing costs. Concrete filled steel tube (CFST) columns are favored for many earthquake resistant structures, columns in high rise buildings, bridge piers subject to high strain rate from traffic and railways decks. Concrete filled steel tubes necessitate supplementary fire resistant insulation if fire protection of the structure is crucial. The CFST structures have better constructability because the steel tubes can be used as the formwork and the shoring system for casting concrete in construction. Moreover, CFSTs provide high compressive and torsional resistance about all axes when compared with concrete encased steel composite sections.

1.2.1 Behavior during loading

In the initial concentric axial loading stages of the CFST column, both concrete infill and structural steel will deform longitudinally. Of course, it is assumed that the concentric loading is applied uniformly across the CFST section. The Poisson's ratio of the concrete infill (ranges between 0.15-0.25) is smaller than that of structural steel (roughly 0.28) at these initial strains. Thus, the lateral expansion of the confining tube is larger than the confined concrete. As a result, localized separation between the two composite materials takes place along the column. Moreover, minimal interaction between the two materials occurs if any. The concrete and the steel bear their shares of the applied load independently during this phase. At a certain strain, the expansion of the concrete infill laterally increases until it reaches the lateral expansion of the steel. Keep in mind that the structural steel expansion remains constant in this stage and micro-cracking in the concrete begins to take place.

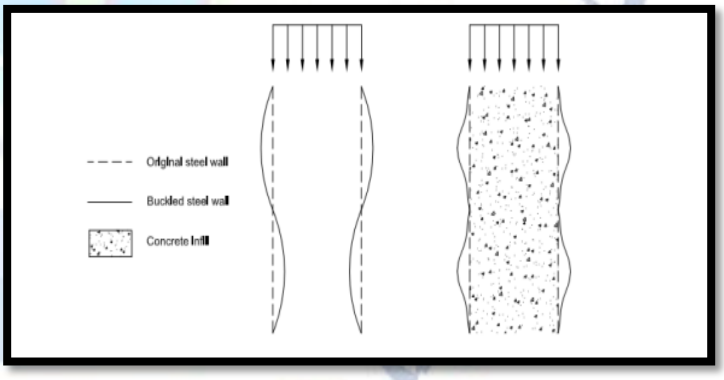
This acceleration in the concrete expansion results in an interactive contact between the two materials. Hence, bond stresses are developed and the concrete will be subjected to tri-axial stresses while the structural steel to biaxial stresses. Longitudinal stress in the confining tube varies based on the transfer of force between the concrete and steel. The strain level at which confinement occurs is debated among researchers to range from 0.001 to 0.002. Some scientists such as Knowles and Park concluded that concrete confinement happens suddenly at a about (strain of 0.002) just as the concrete starts dilation. While other researchers as Tsuji, et al. and Zhang, et al. proposed a steady increase in the concrete confinement starting right after the occurrence of micro-cracking in the concrete (strain of 0.001), till full confinement is met at a strain around 0.002. In the second stage of loading where the confinement of the steel tube on the concrete is present, circumferential stresses are developed in the structural steel due to two factors:

1. Longitudinal stresses from loading
2. Lateral pressure from concrete dilation

Based on the steel utilized in the composite element, the steel could have reached its capacity prior to their yield in this stage. If tube yielding occurs before this biaxial state of stress, the tube would not be able to sustain the normal yield stress, resulting in a transfer of load from tube to the concrete core. Conversely, if the confining tube has not yet yielded, the extra axial capacity needed from the steel tube before yielding will be reduced. Unlike the effect biaxial state of stress on the steel tube capacity, the concrete infill performance enhances when experiencing triaxial state of stress. The presence of confinement on the concrete infill increases its axial capacity. Despite the decrease in its steel tube capacity, the circular CFST column's overall capacity increases because the increase in the concrete infill capacity due to confinement is far greater than the strength loss in the steel tube.

1.2.2 Failure modes

There are various modes of failure for the CFST based on their material properties and geometric configuration. However, the most dominant failure mode is the local buckling of the steel tube. When compared with the empty steel tube, the local buckling in the CFST column is delayed due to the presence of concrete infill. The concrete prevents the steel tube from buckling inward; instead it forces the tube to buckle in an outward mode as shown in Figure 1.2.



[Fig.1.2: Changes in buckling mode with length due to the presence of infill]

The outward buckling mode of the steel tube has three advantages for the behavior of the CFST element:

1. The delay in tube buckling keeps the steel in the elastic range longer which often allows for the yield stress to develop before buckling.
2. The element modulus does not decrease rapidly during this type of failure because the distance between the cross section's edges increases.

3. The localized steel tube buckling is forced to spread over a larger region of the column height limiting the occurrence of strain concentrations.

1.2.3 Shapes of CFST elements

There are several shapes for the concrete filled steel tubes based on the confining steel tube's shape, such as rectangular, elliptical, circular, square, L-shaped,…etc. Circular and square sections of CFSTs are the widely used ones in construction. The load carrying capacity of CFST column is considerably affected by the shape of its cross section, diameter-to-thickness and width-to-thickness ratios of the steel tube. When static load is applied, the deformation for circular CFST columns experience elastic-perfectly-plastic or strain-hardening behavior after yielding. On the other hand, hollow structural steel columns exhibited a degrading type load deformation curve after yielding under the same loading.

1.2.4 Advantages and disadvantage of CFST columns

A designer could think of using larger steel cross sections instead of composite section in order to avoid complexity of construction. Or even mega RC column in high rise buildings. However, the bare steel sections and RC columns have several drawbacks that can be addressed by using steel-concrete composite columns, such as:

1. **Maintenance costs:** when exposed to air and humidity, the steel structures are vulnerable to corrosion, thus they have to be painted periodically. This issue occurs in the case of CFST structures but not in the encased concrete composite element because the steel section is protected by the surrounding concrete.
2. **Buckling failure:** the steel sections are considered economical because of their low strength to weight ratio. However, with the increased slenderness of the steel column the carrying capacity decreases because of the buckling failure domination. In the composite columns the concrete delays the buckling when compressively loaded which enhances the capacity of the element. Also, thinner steel section would be required in the presence of concrete thus the cost is reduced.
3. **Fireproofing costs:** the steel sections has high load carrying capacity at normal range temperatures, but its strength reduces immensely when exposed to high temperatures, thus fireproofing is essential. This issue occurs in the case of CFST structures but not in the encased concrete composite element because the steel section is protected by the surrounding concrete.
4. **Construction ability:** the structural steel tube in the CFST performs as in-place framework. Of course, fixing the steel tube for casting concrete is much easier and less time consuming than fixing and removing frame work. Also, the presence of steel tube minimizes the need for rebar fixing which is one of the most tedious work packages in the RC construction.
5. **Ecology:** the reduction in wood consuming needed for the formwork is environmentally advantageous. Also, it is much easier to reuse the concrete and the steel of CFST elements compared to regular RC members.
6. **Cost:** due to the previously mentioned reasons the cost of using CFST member in construction is more attractive than many other alternatives. For instance the reduction in labor cost needed for reinforcement fixing or removable frameworks.

1.3 SIGNIFICANCE OF THE RESEARCH

At the present time, the concrete filled steel tube columns are widely used in construction. Actually, this type of structural elements is favored in practice because of its small cross sectional area to load carrying capacity ratio. Hence, mega concrete columns in tall buildings' lower floors can be substituted by smaller sections of CFST columns. Moreover, CFST elements can be used as piers for bridges at congested areas. Therefore, such structural elements should be thoroughly investigated before used in critical structures. Despite being a research topic for around 50 years, the behavior of the CFST columns under different loading conditions is not fully studied. Thus, intensive parametric studies should be performed in order to fully understand the CFST columns behavior. This study, addresses some parameters that affect the CFST column behavior which are the steel tube outer diameter to thickness ratio, the concrete infill compressive strength, the loading rate, and the GFRP jacketing.

2. OBJECTIVES

1. Developing an experimental database for creep and shrinkage of CFST under axial and flexural loading conditions, and
2. Investigating the behaviour of CFST beams and columns with different levels of fiber reinforcement

Analysis of structure behaviour on CFST-

- Axial Load-Axial Shortening Behavior
- Effect of Fiber-Reinforced Polymer (FRP) Confinement
- Effect of the Thickness of the Steel Tube
- Effect of Concrete Strength
- Behavior of Confined Concrete
- Lateral Expansion Behavior
- Strain Efficiency of FRP Wrap

3. LITERATURE REVIEW

The terminologies referred from literatures for designing are discussed as follows.

Fardis and H. Khalili [1], a glass fiber as a new confining material for concrete is presented in this study. The new material is been termed as Fiberglass reinforced polymer (FRP). The authors have carried out an experimental investigation of FRP-encased concrete cylinders in axial compression and of rectangular FRP-encased beams in bending is presented. The results demonstrate the excellent strength and ductility characteristics of FRP-encased members. The behavior of FRP-encased concrete beamscolumns is described also, in terms of analytically obtained moment-axial load and ductility-axial-load interaction diagrams and moment-curvature relations.

H. Saadatmaneshet.al [2], Due to failures of bridges in earthquake such as the 1989 Loma Prieta earthquake. The study concentrated there study on the substandard design of Bridge Engineering and how to improve the design in order to withstand seismic forces. In this paper, a new technique for seismic strengthening of concrete columns is presented. The technique requires wrapping thin, flexible high strength fiber composite straps around the column to improve the confinement and, thereby, its ductility and strength. Analytical models are presented that quantify the gain in strength and ductility of concrete columns externally confined by means of high-strength fiber composite straps. A parametric study is conducted to examine the effects of various design parameters such as concrete compressive strength, thickness and spacing of straps and type of strap. The results indicate that the strength and ductility of concrete columns can be significantly increased by wrapping high-strength fiber composite straps around the columns.

A. Nanni and N. M. Bradford [3], the study carried out an investigation in order to develop the experimental data and check the validity of existing analytical models for the behavior of concrete members jacketed with FRP materials. The test specimen consisted of 150x300mm cylinders of normal weight, normal strength concrete. Specimens loaded statically under axial compression were studied. Three different types of passive FRP confinement technologies were investigated during the project with the objective of performing a qualitative comparison. Experimental results indicate that FRP jacketing significantly enhances strength and pseudo-ductility of concrete.

M. D. O'Shea and R. Q. Bridge [4],in this paper several design methods have been developed that can be used conservatively to estimate the strength of circular thin-walled concrete filled steel tubes under different loading conditions. The test specimen were short with a length-to-diameter ratio of 3.5 and a diameter thickness ratio between 60 and 220. The internal concrete had nominal unconfined cylinder strengths of 50, 80, 90 and 120 Mpa. The bond between the steel and internal concrete was critical in determining the formation of local buckle.

Stephan Pessikiet.al [5], the study presents the result of experimental investigation of the axial behavior of the small scale square and circular plain concrete specimens and large-scale circular and square reinforced concrete columns confined with fiber reinforced polymer (FRP) composite jackets, subject to monotonic, concentric axial loads. Improvement in the axial load-carrying and deformation capacities of FRP jacketed concrete members over unjacketed members were reported. Factors influencing the axial stress-strain behavior of FRP confined concrete, such as traverse dilation and effectively confined regions and their relationship to jacket properties, are identified and discussed.

Houssam Toutanji and Mohamed Saafi [6], the study proposes a new hybrid column. The proposed hybrid column, cast in place, consist of an exterior PVC-fiber reinforced polymer (FRP) shell with a concrete core. The exterior shell is commercially available cylindrical PVC pipe externally reinforced with impregnated continuous fiber in the form of hoops at different spacing. The proposed system uses less fibers than current FRP confining methods but has similar strength and toughness characteristics. This paper presents the results of an experimental study on the performance of hybrid concrete columns subjected to different environment conditions such as room temperature, freeze and thaw, wet and dry conditions. Test variables included the type of fiber, the spacing between the FRP hoops and the environmental exposure conditions. The stress-strain behavior was used to evaluate the effect of exposure condition on the strength, stress-strain behavior and ductility of confined specimens. Test results show that the external confinement of concrete columns by PVC-FRP tubes results in enhancing compressive strength, ductility and energy absorption capacity.

Walter O. Oyawaet.al [7], as per the findings of the study structures are rapidly emerging as one of the inevitable structural systems for earthquake resistance, as they have been known to exploit the best attributes of both steel and concrete, resulting in higher stiffness, strength and ductility. However, the limitations imposed by certain drawbacks of cement concrete and which are not alleviated or moderated by the encasing steel tube, e.g. its high shrinkage, creep, brittleness, reactivity and low tensile strength, may be a hindrance to the rapid and diversified application of CFTs, in line with current emphasis on ductility-based seismic design. In this context, studies are presently being conducted on filled steel composite members, employing lighter, more ductile, high tensile strength and inert polymer-based fill materials for the steel tube. Findings of these studies relating to the elasto-plastic response of filled steel composite stub columns subjected to axial compression highlight the significant increase in strength and or ductility of epoxy polymer concrete-filled steel columns.

Yutian Shao and Amir Mirmiran [8], the experimental investigation of cyclic behavior of concrete filled Fiber reinforced Polymer Tubes are presented. The focus of research, however, has been exclusively on their monotonic behavior, with little or no attention to the implications of using CFFT in seismic regions. A total of six CFFT specimens were tested as simple span beam columns under constant axial loading and quasi-static reverse lateral loading in four point flexure. Three of the tubes were made using centrifuge ~spin! casting with 12.7 mm thickness with the majority of the fibers in the longitudinal direction, whereas the other three were filament wound with 5 mm thickness and ±55° fiber orientation. One specimen for each type of tube had no internal reinforcement, whereas the other two incorporated approximately 1.7 and 2.5% steel reinforcement ratios, respectively. The two types of tubes represented two different failure modes; a brittle compression failure for the thick tubes with the majority of the fibers in the longitudinal direction, and a ductile tension failure for the thin tubes with off-axis fibers. The study showed that CFFT can be designed with ductility behavior comparable to reinforced concrete members. Significant ductility can stem from the fiber architecture and inter laminar shear in the FRP tube. Moderate amounts of internal steel reinforcement in the range of 1–2% may further improve the cyclic behavior of CFFT.

S. Matthyset.al [9], presented an experimental and analytical results of axially loaded large-scale columns confined with FRP wrapping reinforcement. The effective circumferential FRP failure strain and the effect of increasing confining action were investigated. One of the main objective of this study was to compare different existing compressive strength models to the results presented in the study.

G. Wu et.al [10], the research covers a number of parameters in reference to the confinement of concrete cylinder. In this research was carried out around 300 specimens of FRP confined concrete cylinder. This paper covered the parameters like, the analysis of confinement effect and failure mechanisms. Special attention is given to predict whether FRP-confined concrete cylinder has a strain-hardening or a strain-softening response. In the case of FRP-confined concrete cylinder with a strain-hardening response, it is found out that the ultimate Poisson's ratio of FRP-confined concrete tends to an asymptotic value.

Yong-changGuoet.al[11], This study carried out an experimental investigation on axially loaded normal strength concrete columns confined by ten different types of materials, including steel tube, glass fiber confined steel tube (GFRP), PVC tube, carbon fibre confined PVC (CFRP), glass fiber confined PVC tube (GFRP), (CFRP), polyethylene (PE), PE-hybrid CFRP and PE hybrid GFRP. The deformation, macroscopical deformation characters, failure mechanism and failure nodes are studied in this paper. The ultimate bearing capacity of these 10 types of confined concrete columns and the influences of the confining materials on the ultimate bearing capacity are obtained. The advantages and disadvantages of these 10 types of confining methods are compared.

Ata El-kareimShoeibSoliman [12], the behavior of long concrete columns confined by means of proper plastic tube is investigated including failure mechanisms and subsequently their failure model for calculation of the column capacity is studied. The influence of column slenderness ratio on their axial load capacity, axial strains and radial strains is also investigated. The experimental program was classified into three different groups with slenderness ratios from 9 to 18. Test results show that, utilizing plastic tube for confinement significantly influences the failure mechanism of concrete columns. Results also show that the stiffness of the tested long confined concrete column specimens increases as slenderness ratio decreases.

M. Dundu [13], This study includes an experimental study was undertaken to investigate the behavior of 24 concrete-filled steel tube (CFST) columns, loaded concentrically in compression to failure. Variables in the tests include the length, diameter, strength of the steel tubes and the strength of the concrete. The large slenderness ratio caused all composite columns in Series 1 to fail by overall flexural buckling. Although overall flexural buckling was also experienced in the composite columns of Series 2 tests, the stockier columns failed by crushing of the concrete and yielding of the steel tube. A comparison of the experimental results with the loads predicted by the South African code (SANS 10162-1) and Eurocode 4 (EC4) shows that the codes are conservative by 8.4% and 13.6%, respectively, for Series 1 tests, and 10.5 and 20.2%, respectively, for Series 2 tests. A plot of the compressive load versus the vertical deflection shows the composite columns to be fairly ductile.

TogayOzbakkalogluet.al [14] an important application of FRP composites is as a confining material for concrete, in both the seismic retrofit of existing reinforced concrete columns and in the construction of concrete-filled FRP tubes as earthquake resistant columns in new construction. Reliable design of these structural members necessitates clear understanding and accurate modeling of the stress– strain behavior of FRP-confined concrete. To that end, a great number of studies have been conducted in the past two decades, which has led to the development of a large number of models to predict the stress–strain behavior of FRPconfined concrete under axial compression. This paper presents a comprehensive review of 88 models developed to predict the axial stress–strain behavior of FRP-confined concrete in circular sections. Each of the reviewed models and their theoretical bases are summarized and the models are classified into two broad categories, namely design-oriented and analysis-oriented models. This review summarizes the current published literature until the end of 2011, and presents a unified framework for future reference. To provide a comprehensive assessment of the performances of the reviewed models, a large and reliable test database containing the test results of 730 FRP-confined concrete cylinders tested under monotonic axial compression is first established. The performance of each existing stress–strain model is then assessed using this database, and the results of this assessment are presented through selected statistical indicators. In the final part of the paper, a critical discussion is presented on the important factors that influenced the overall performances of the models. A close examination of results of the model assessment has led to a number of important conclusions on the strengths and weaknesses of the existing stress–strain models, which are clearly summarized. Based on these observations, a number of recommendations regarding future research directions are also outlined.

P. K. Gupta [15], the experimental results are presented to investigate the effectiveness of UPVC tube for confinement of concrete columns. UPVC tubes having 140 mm, 160 mm and 200 mm external diameters were used to confine the concrete having compressive strength 20 MPa, 25 MPa and 40 MPa. The concrete has been designed using IS code 10262-1982(Reaffirmed−2004) (BIS:10262–1982, Reaffirmed −2004). The testing of the specimens was carried out on a displacement controlled Instron make Universal Testing Machine of 2500 kN capacity. During the experiments mode of deformation and corresponding load-compression curves were recorded and obtained results are compared with the existing models for confined concrete available in the literature. It is found that the predicted capacities of columns using different models are within ±6% of the experimental capacities. It is found that UPVC tubes can be effectively used for confinement of the concrete columns and to enhance their load capacity, ductility as well as energy absorbing capacity.

J. Shaofeiet.al [16], this study presents experimental results on the behavior of circular concrete columns reinforced by BFRPPVC tubes under uniaxial loading. A total of six specimens were prepared and tested under uniaxial loading. The main parameters varied in the tests were strengthening ratio and strengthening approach of BFRP. The performance, such as failure modes, ultimate bearing capacity and stress-strain curves, was investigated in details and a formula was proposed to predict the compressive ultimate strength. The results show that this kind of confined columns obviously improves the ultimate bearing capacity, and the ultimate bearing capacity increases with the strengthening layers The formula proposed is applicable and efficient for prediction of the ultimate bearing capacity as well.

Usha. C. M and Dr. H. Eramma [17], in this study, unplasticised poly vinyl chloride (UPVC) tubes filled with concrete are axially loaded until failure of the specimen to investigate their load carrying capacity. Total eighteen specimens of UPVC tubes of diameter 150mm, thickness 7.11mm with effective lengths of 500mm, 600mm, and 700mm were cast. M20 grade of concrete of two different mixes having two different sizes of coarse aggregate 6.3mm and 10mm was filled inside the tubes for casting of UPVC concrete filled tube (CFT) column specimens. The column specimens were tested for axial loading in the UTM machine of capacity 1000kN. Their load-displacement curves and stress strain curves were recorded. All the columns fail by local buckling. As the length increases the strength was increased and it was higher for the mix which have 6.3mm size of coarse aggregate compared to 10mm size of coarse aggregate. It was found that about 1.6% increases in compressive strength of UPVC CFT columns experimentally when compared with theoretical value.

T. M. Pham [18], the study aims to investigate the structural behavior and failure modes of fiber-reinforced-polymer (FRP) confined concrete wrapped with different FRP arrangements. A total of twenty four specimens were cast and tested, with three of these specimens acting as reference specimens and the remaining specimens wrapped with different types of FRP (CFRP and GFRP) by different wrapping arrangements. They include fully wrapped, partially wrapped and non-uniformly wrapped concrete cylinders. The non-uniformly wrapped concrete cylinders provided higher compressive strengths and strain for FRP-confined concrete, in comparison with conventional fully wrapping arrangements. The effect of confinement level on the effectiveness of FRP confinement is also investigated. In addition, the partially wrapping arrangements changes the failure modes of the specimens and the angle of the failure surface.

D. Nandan and A. Pahal [19], presented the results of an experimental programme which investigated the effect, on compressive strength of concrete, of using steel, FRP & UPVC tubes in compression. Concrete filled tubes are new areas of application and Investigation for the confinement. Major researches so far has been with concrete filled steel tubes (CFST).Confinement helps in improving the compressive strength of the column and increasing in its energy absorption prior to failure. Although because of the limitations of the corrosion of the steel tubes, in recent years, some investigations with fibre reinforced polymer (FRP) tubes and with PVC tubes have been investigated.

D. H. Galpade [20], this review study explains the use of confined materials in columns in order to use it as stay-in-place formwork. Experience gained over the years in countries such as Japan, Europe and the USA reveal that existing construction technology has not delivered the reliability needed. The rapid deterioration of infrastructure, especially those constructed in severe environments such as bridge piles, has increased the demand for rehabilitating and retrofitting existing concrete columns in building and bridge substructures. It is necessary to strengthen the deteriorated and damaged concrete columns to increase their carrying capacity (axial load and bending moment). The cost of formwork was about 40% of the cost of concrete works, the rest being accounted for by labour and the cost of materials. Eliminating or reducing this formwork in construction can significantly reduce the cost of construction. The use of plastic tubes will act as a confinement material as well as a permanent formwork and this will eliminate the need for temporary formwork. Steel and FRP tubes have been widely researched on and used to confine concrete in CFT columns systems. However steel is prone to corrosion, weathering, and chemical attacks especially when used in severe environments such as under-sea piling.

S. W. N. Razviet.al [21], In this study experimental programme a series of nine one-third scale square reinforced concrete column specimens having cross sectional dimension as 150mm with height of 960 mm were tested. The experiment is performed for control column, columns with ferromesh jacket as confinement reinforcement in addition to stirrups and column with ferromesh jacket only as confinement reinforcement. The overall response of the specimens was investigated in terms of load carrying capacity, axial displacement, stress, strain, lateral displacement and ductility. The test results indicated that column wrapped with additional ferromesh as confinement gives 20% increase in axial strength compared to regular control column. It is observed that columns with ferromesh jacket as confinement reinforcement in addition to stirrups gives better ductility and the column wrapped only with ferromesh as additional confinement fails in ductile manner.

4. PROPOSED METHODOLOGY

4.1 TEST SPECIMENS

A total of eleven specimens, including seven CFRP-confined concrete-filled steel tube (CFCCFST) specimens, three glass fiber-reinforced polymer (GFRP)-confined concrete-filled steel tube (GFCCFST) specimens and one CFST specimen, were tested under axial load. The tested parameters were the FRP layer number nf (1, 2 and 3), the steel tube thickness ts (3.0, 4.0 and 5.0 mm) and the concrete strength fcu (40, 50 and 60 MPa). Each specimen had a length (L) of 400 mm with a length-to-diameter ratio (L/D) ranging between 3 and 3.5. The details of the columns are provided in Table 4.1. The nomenclature consists of three items: the letters CF and GF in the first item denote the CFRP-confined specimens and GFRP-confined specimens, respectively, followed by the FRP layer number; the letter t and the following number in the second item indicates the steel tube and its thickness; the letter C (for concrete) in the third item is followed by the nominal concrete strength.

Table 4.1: Details of the specimens

Specimens	L (mm)	D (mm)	FRP type	nf	ts (mm)	fcu (MPa)	fy (MPa)	ξs	ξf
t4C40	400	128	-	-	4	44.9	248	0.95	0.00
CF1t4C40	400	128	CFRP	1	4	44.9	248	0.95	0.39
CF2t4C40	400	128	CFRP	2	4	44.9	248	0.95	0.78
CF3t4C40	400	128	CFRP	3	4	44.9	248	0.95	1.17
GF1t4C40	400	128	GFRP	1	4	44.9	248	0.95	0.48
GF2t4C40	400	128	GFRP	2	4	44.9	248	0.95	0.97
GF3t4C40	400	128	GFRP	3	4	44.9	248	0.95	1.45
CF2t3C40	400	126	CFRP	2	4	44.9	243	0.69	0.77
CF2t5C40	400	130	CFRP	2	4	44.9	242	1.17	0.79
CF2t4C50	400	128	CFRP	2	4	54.2	248	0.79	0.65
CF2t4C60	400	128	CFRP	2	4	60.0	248	0.71	0.58

4.2 MATERIALS PROPERTIES

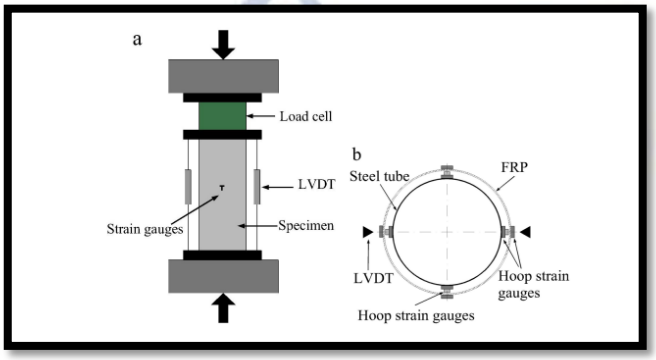
The columns were cast using three different concrete mixtures. Three concrete cubes were tested for each mix design to determine the concrete compressive strength. The average cube strengths (fcu) of the concrete cubes are shown in Table 4.1. Seamless steel tube was used as the steel formwork for all columns in this study. Steel tubes with thicknesses of 3, 4 and 5 mm were used to achieve different diameter-to-thickness ratios. The steel tubes of 3 and 4 mm were made by machining the seamless steel tube of 5 mm. The properties of the steel tube were determined by a coupon test. The measured values of yield strength (fy) and elastic modulus (Es) were 248 MPa and 191 GPa.Carbon fiber and glass fiber were used in this study to provide the confinement. The tensile properties were determined from the tensile tests of flat coupons according to ASTM D3039. The nominal thickness (tf), ultimate strength (ffu), ultimate strain (εfu) and elastic modulus (Ef) of the CFRP were 0.111 mm, 3550 MPa, 1.34% and 250 GPa, respectively; those of the GFRP were 0.169 mm, 2930 MPa, 2.58% and 109 GPa, respectively. Epoxy resin based on two-component solvent-free epoxy resin was used in this study. The mixing ratio was 4:1 of component A (resin) and component B (hardener) by weight. The elastic modulus, tensile strength and shear strength provided by the manufacturer were 15 GPa, 35 MPa and 13 MPa, respectively.

4.3 PREPARATIONS OF SPECIMENS

The circular steel tubes were accurately cut and machined to the required length. The insides of the steel tubes were wire brushed, and deposits of grease and oil were removed. A stiffened end-cap of 10 mm was attached at the base of the steel tube. Concrete was filled in layers and vibrated by a poker vibrator. The specimens were left to cure in the laboratory for 28 days, and then, the CFRP or GFRP was wrapped. The FRP wrap was formed by using the wet lay-up method with fibers in the hoop direction. The steel tube surface was first cleaned with alcohol, and then, a single continuous fiber sheet was wrapped around the steel tube to form a wrap with the required number of plies, with the finishing end of the fiber sheet overlapping its starting end by 150 mm. A paddler roller was used to squeeze out the air bubbles and ensure a uniform bond thickness. Prior to testing, the top surface of the concrete core was roughened with a wire brush, and a thin layer of high-strength cement was poured on the roughened surface. This procedure was adopted to minimize the effect of concrete shrinkage, so that the steel tube and the concrete core can be loaded simultaneously during testing.

4.4 TEST AND EXPERIMENTAL SETUP

The tests were conducted using a universal testing machine with a capacity of 5000 kN. The test arrangement for the specimens is shown in Figure 4.1a. The load was applied in increments of 50 kN before peak load. Each load interval was maintained for 2–3 min. The load was slowly applied near and after the maximum load to investigate the post-peak behavior of the columns.



[Fig.4.1: Test arrangement and instruments: (a) test arrangement; (b) layout of strain gauges for fiber-reinforced polymer (FRP)-confined concrete-filled steel tube (FCCFST) specimens. LVDT, linear variable differential transducer]

Two linear variable differential transducers (LVDTs) were located vertically to measure the axial shortening. For each FCCFST specimen, eight strain gauges were placed on the steel to measure the vertical deformations and perimeter expansion of the steel tube at mid-height, and four strain gauges were mounted to the mid-height of the FRP wrap to observe the lateral confinement, as shown in Figure 4.1b. The layout of the strain gauges mounted to the steel tube of each CFST specimen was exactly the same as that for the FCCFST specimens. To assure uniform compression, preliminary tests within the elastic range were conducted by carefully adjusting the position of the specimen, based on the measurements of strain gauges attached at the mid-height of the test specimen. The adjustment was terminated until the difference between the measured strain and the average value was no more than 5%.

5. RESULTS AND DISCUSSIONS

5.1 OBSERVAIONS

The CFST specimen experienced continuous dilation in the mid-height region and localized outward buckling of the steel tube near the tube ends at large axial shortenings, as shown in Figure 5.1a. All FCCFST specimens failed by rupture of the FRP wrap in the mid-height region, as a result of the lateral expansion of the concrete. The typical failure modes are shown in Figure 5.1b,c. The volume expansion of concrete and the local buckling of the steel tube in FCCFST specimens was not as obvious as that of the CFST specimen.

[Fig.5.1: Typical failure modes: (a) concrete-filled steel tube (CFST) specimen; (b) GFCFST specimens; (c) CFCFST specimens]

5.2 AXIAL LOAD- AXIAL SHORTENING BEHAVIOR

The axial load-axial shortening curves for the specimens are shown in Figures 5.2, 5.3 and 5.4, in which the axial shortening is the average value of the two LVDTs. The relationships between axial load and axial shortening up to the ultimate state of the specimens can be seen in these figures. For the FCCFST specimens, the ultimate state is defined as the state when the explosive rupture of the FRP wrap occurs at the mid-height region. The load at the ultimate state of the FCFST specimens is the same as their maximum load. The ultimate state for the CFST specimens is defined as the state when the load reaches their maximum load.

The initial portion of axial load-axial shortening responses of a FCCFST specimen essentially followed the curve of the corresponding CFST specimen till a characteristic axial shortening was attained, which is the point when the axial load of specimen t4C40 increased up to about 75% of its ultimate load. After attaining the characteristic strain, the axial load-axial shortening relationships of FCCFST specimens show a higher modulus than those of the CFST specimen and eventually exhibited an almost linear behavior until the rupture of the FRP in the mid-height region happened. The experimental results for all specimens are shown in Table 5.1. Here, Ny is the axial load when the steel tube yielded; Nf is the axial load when the fracture of the FRP wrap was audible or visible; Nu and δu are the ultimate load and the axial shortening of the specimens at the ultimate state; εf is the maximum hoop strain of the FRP at the ultimate state. As expected, the additional FRP confinement led to enhancements in both load capacity and axial deformation capacity, and the degree of enhancement increased with the increasing of the FRP layer number for both CFCCFST and GFCCFST specimens.

Table 5.1: Test results for the columns

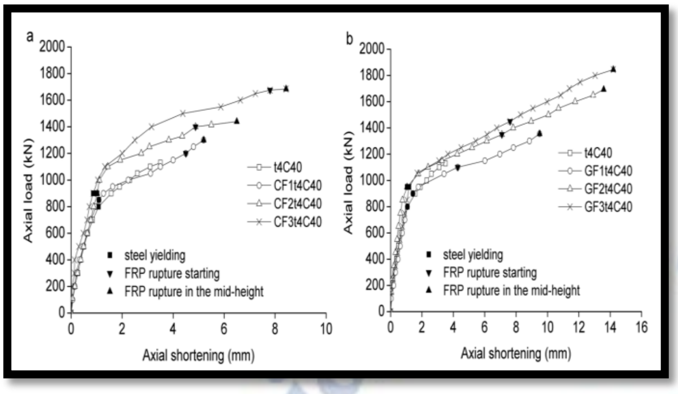
Specimens	Ny (kN)	Nf (kN)	εf (με)	Nu (kN)	δu (mm)	kε2	Nup (kN)	Nu/Nup
t4C40	800	-	-	1130	3.5	-	1101	1.03
CF1t4C40	850	1200	10227	1300	5.2	0.76	1283	1.01
CF2t4C40	900	1400	11025	1440	6.5	0.82	1466	0.98
CF3t4C40	900	1670	10821	1685	9.4	0.81	1648	1.02
GF1t4C40	900	900	19890	1355	9.5	0.77	1327	1.02
GF2t4C40	850	1350	22288	1693	11.8	0.86	1554	1.09
GF3t4C40	950	1450	24282	1845	13.6	0.94	1780	1.04
CF2t3C40	800	1330	10816	1330	7.1	0.81	1271	1.05
CF2t5C40	1150	1550	11104	1650	7.3	0.83	1631	1.01
CF2t4C50	900	1430	10189	1548	8.3	0.76	1550	1.00
CF2t4C60	950	1658	8853	1658	8.5	0.66	1602	1.03

5.3 EFFECT OF FIBER REINFORCED POLYMER (FRP) CONFINEMENT

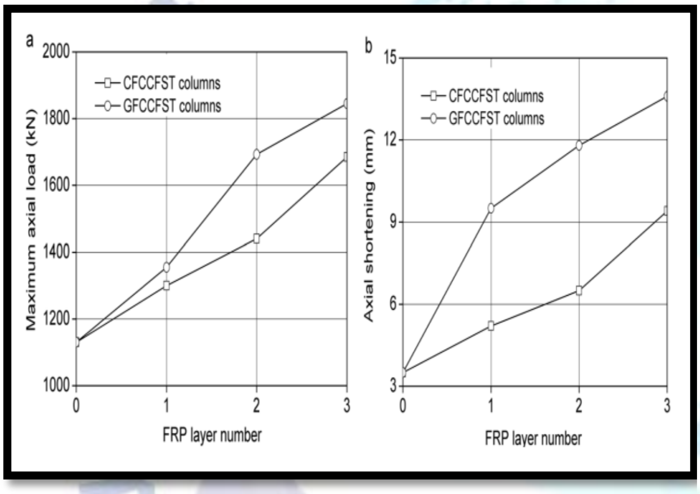
Figure 5.2 shows the comparison of axial behavior for the FCCFST specimens and the corresponding CFST specimens. The CFST specimen and the FCCFST specimens behaved similarly till the steel tube yielded. When the steel tube yielded, the axial load of the FCCFST specimens increased in an approximately linear way. This is because the FRP wrap provided confinement to the steel tube and the concrete when the steel tube yielded; thereafter, the decrease of the rigidity of the CFST columns was delayed.The FCCFST specimens exhibited a higher yielding load, but a similar axial shortening with the yielding load. It also can be seen from Figure 5.2 that for the FCCFST specimens, when the FRP layer number increased, the axial shortening at Nf increased. It is worth noting that for the CFCCFST specimens, the axial shortening at Nf was close to that at Nu, but for the GFCCFST specimens, the axial shortening at Nf was much smaller than that at Nu. This accorded with the fact that the failure of CFCCFST specimens was much more abrupt than that of the GFCCFST specimens.

With the increasing of the FRP layer number, the ultimate loads and the corresponding axial shortening increased, as shown in Figure 5.3. With the additional CFRP confinement, the ultimate load and the axial shortening at the ultimate load was increased by 50% and 169%, respectively. When GFRP wrap was used, the ultimate load and the corresponding axial shortening was increased by 60% and 289%, respectively. By comparison, the GFCCFST specimens obtained more enhancements in ultimate load and axial deformation capacity than the

CFCCFST specimens, particularly in terms of axial deformation capacity.



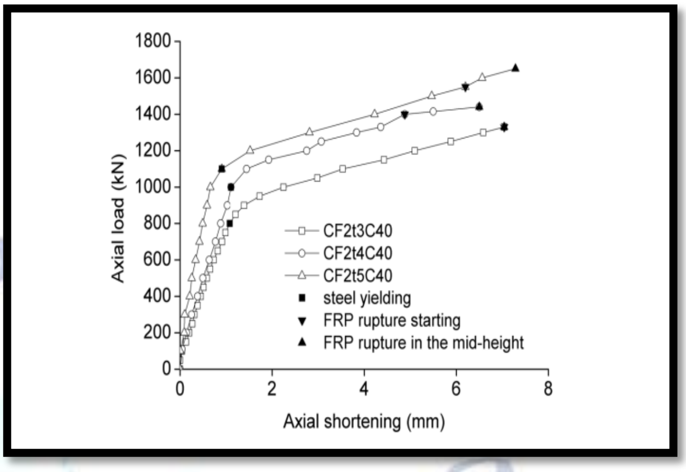
[Fig.5.2: Axial load vs. axial shortening curves in terms of the FRP layer number: (a) CFCCFST specimens; (b) GFCCFST specimens]



[Fig.5.3: The effect of FRP confinement: (a) ultimate load; (b) axial shortening at the ultimate load]

5.4 EFFECT OF THE THICKNESS OF THE STEEL TUBE

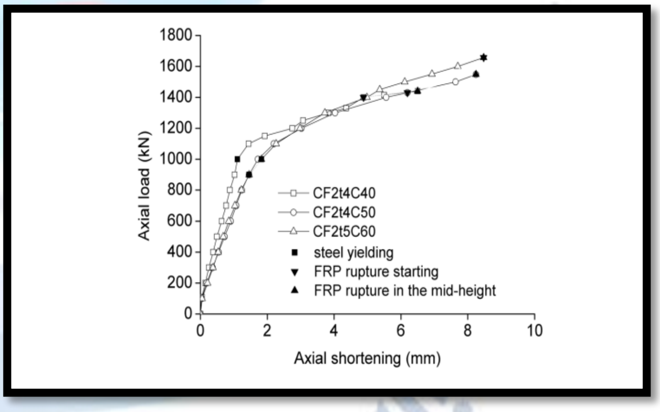
Figure 5.4 shows the effect of the thickness of the steel tube on the behavior of axially loaded FCCFST specimens. When the thickness of the steel tube increased, the ultimate load increased. However, increasing the thickness of the steel tube had no obvious effect on the axial shortening at the ultimate load. In the first ascending branch, the curve of the column with the thicker steel tube had a larger slope, indicating a higher rigidity. In the second ascending branch, the curves of the three columns were parallel to each other. This situation can be explained by the fact that after the yielding of the steel tube, the increase of the axial load is attributed to the confinement by the FRP wrap, which behaves in a linear elastic way. In this stage, the confinement provided by the FRP wrap dominates its behavior.



[Fig.5.4: Axial load vs. axial shortening curves in terms of the thickness of the steel tube]

5.5 EFFECT OF CONCRETE STRENGTH

Figure 5.5 shows the effect of concrete strength on the compressive behavior of the FCCFST specimens. These three specimens exhibited similar behavior. When the concrete strength increased, the ultimate load and the axial shortening at the ultimate load increased slightly.



[Fig.5.5: Axial load vs. axial shortening curves in terms of concrete strength]

5.6 BEHAVIOR OF CONFINED CONCRETE

Without considering the small axial stiffness of the FRP wrap, the axial load carried by the concrete core can be obtained by deducting the axial load carried by the steel tube from the measured ultimate load. The axial load carried by the steel tube is calculated by the product of the cross-sectional area (As) and the yield strength (fy) of the steel tube. Then, the axial stress of the confined concrete can be obtained by dividing the deduced axial load by the cross-section of the concrete core. On the basis of the previous definition of ultimate state, the axial strain of the columns is also the axial strain at the ultimate state of the confined concrete.

The values of the stress and the strain of the confined concrete at the ultimate load are summarized in Table5.2, in which fccf is the concrete stress of an FCCFST specimen at the ultimate load; fcc is the concrete stress of a CFST specimen at the ultimate load; εccf is the axial strain at the ultimate load of an FCCFST specimen; and εcc is the axial strain at the ultimate load of a CFST specimen. The nominal axial strain of the specimens, obtained by dividing the axial shortening by the height of the columns, is used for interpreting the εccf and εcc of confined concrete. It is evident from Table 5.2 that both the stress and the axial strain at the ultimate state can be significantly enhanced as a result of FRP confinement.

Table 5.2 Stress and strain of the confined concrete at the ultimate load

Specimens	fcc, fccf	fcc/fccf	εcc, εccf	εcc/εccf
t4C40	65.80	-	0.0088	-
CF1t4C40	80.83	1.23	0.0130	1.49
CF2t4C40	93.22	1.42	0.0163	1.86
CF3t4C40	114.89	1.75	0.0235	2.69
GF1t4C40	85.70	1.30	0.0238	2.71
GF2t4C40	115.60	1.76	0.0295	3.37
GF3t4C40	129.05	1.96	0.0340	3.89

6. CONCLUSION

This project presents an experimental study aimed at gaining a further understanding of the compressive behavior of FRP-confined concrete-filled steel tube columns. The external FRP wrap is provided to constrain outward local buckling deformation of the steel tube and to better confine the concrete core. The examined parameters were the FRP layer number, the thickness of the steel tube and the concrete strength. On the basis of experimental results, the following conclusions can be drawn:

- The load capacity and the axial deformation capacity of concrete-filled steel tube columns can be effectively improved by the FRP wrap. All specimens failed by the explosive rupture of the FRP in the mid-height region because of the lateral expansion of the concrete.
- The FRP wrap can delay the outward local buckling deformation of the steel tube and suppress the lateral expansion of the concrete in the CFST column. The strength and the strain capacity of the concrete can be enhanced by the additional confinement from the FRP wrap.
- The GFRP wrap has higher strain efficiency than the CFRP wrap. The CFRP efficiency increases with the increasing of the CFRP layer number, but decreases with the increasing of the concrete strength.
- A simple model is proposed to predict the load capacity of the FCCFST columns. The model can accurately predict the load capacity of the FCCFST columns with not too strong FRP confinement. However, it overestimates that of the FCCFST columns with strong FRP confinement. Therefore, there is further research needed to develop a more accurate design approach when strong FRP confinement is exerted on CFST columns.

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Conflict of interest statement

Authors declare that they do not have any conflict of interest.

References

[1] Lam, L.; Teng, J.G. Strength Models for Fiber-Reinforced Plastic-Confined Concrete. J. Struct. Eng. 2002, 128, 612–623.

[2] Standard Test Method for Tensile Properties of Polymer Matrix Composite Material; ASTM D3039/D3039M-08; American Society for Testing and Materials (ASTM), West Conshohocken, PA, USA, 2006.

[3] Yu, T; Hu, Y.M.; Teng, J.G. FRP-confined circular concrete-filled steel tubular columns under cyclic axial compression. J. Constr. Steel Res. 2014, 94, 33–48.
[4] Liu, L.; Lu, Y.Y. Axial bearing capacity of short FRP confined concrete-filled steel tubular columns. J. Wuhan Univ. Technol. Mater. Sci. Ed. 2010, 25, 454–458.
[5] Dong, J.F.; Wang, Q.Y.; Guan, Z.W. Structural behaviour of recycled aggregate concrete-filled steel tube columns strengthened by CFRP. Eng. Struct. 2013, 48, 532– 542.
[6] Fam, A.; Qie, F.; Rizkalla, S. Concrete-filled steel tubes subjected to axial compression and lateral cyclic loads. J. Struct. Eng. 2004, 130, 631–640.
[7] Samaan, M.; Mirmiran, A.; Shahawy, M. Model of Concrete Confined by Fiber Composites. J. Struct. Eng. 1998, 124, 1025–1031.
[8] Tam, V. W. Y., Wang, Z.-B., and Tao, Z. (2014). Behaviour of recycled aggregate concrete filled stainless steel stub columns. Mater. Struct. 47 (1-2), 293–310. doi:10.1617/s11527-013- 0061-1
[9] Wang, Y., Chen, J., and Geng, Y. (2015). Testing and analysis of axially loaded normalstrength recycled aggregate concrete filled steel tubular stub columns. Eng. Struct. 86, 192–212. doi:10.1016/j.engstruct.2015.01.007