Review on Analysis of Structural Behavior of CFST Structures in Bridge Constructions

S Vivek and P Brightson

December 7, 2021

REVIEW ON ANALYSIS OF STRUCTURAL BEHAVIOUR OF CFST STRUCTURES IN BRIDGE CONSTRUCTIONS

Vivek S[1] and Dr.P Brightson[2]

[1]M.Tech Scholar, Department of Civil Engineering, Rajadhani Institute of Engineering and Technology, Attingal, Thiruvananthapuram, Kerala. viveksurendranvc@gmail.com

[2]Associate Proessor, Department of Civil Engineering, Rajadhani Institute of Engineering and Technology, Attingal, Thiruvananthapuram, Kerala. drbright.sa@rietedu.in

Author Note

Vivek S

Dr.P Brightson

We have no conflict of interest to disclose

Correspondence concerning this article should be addressed to Vivek S, Rajadhani Institute of Engineering and Technology, Attingal, Thiruvananthapuram, 695102:

viveksurendranvc@gmail.com

ABSTRACT

Concrete-filled steel tubes are gaining increasing prominence in a variety of engineering structures, with the principal cross-section shapes being square, rectangular and circular hollow sections. Concrete-filled steel tubular (CFST) structure offers numerous structural benefits, and has been widely used in civil engineering structures. This review paper outlines the structural behaviour of CFST structures, innovative experimental investigations conducted on CFST columns and the load deflection response characteristics of columns. More recently, the outer steel tube was replaced with fiber-reinforced polymer (FRP) tube creating hollow-core FRP–concrete–steel (HC-FCS) columns which is also discussed in this review paper. A comprehensive summary of various analytical and numerical studies on modelling of CFST members is portrayed in this paper. Finite element analysis (FEM) is also done in order to predict the strength with a given set of data. FEM software used here is ABAQUS.

Keywords: CFST, FEM, FRP, Structural behaviour

1. INTRODUCTION

This review paper presents the latest technologies, designs and techniques which have been used to determine the structural behaviour of Concrete Filled Steel Tubes (CFST). Moreover, this review paper has included past researchers in the field since 2004 up to 2020. Different types of CFSTs like Concrete Filled Stainless Steel Tubular (CFSST), High Strength Concrete-Filled Steel Tubular (HSCFST), Concrete Filled Steel Tubular - CFST structural elements strengthened with Fiber Reinforced Polymer (FRP), Reinforced Steel Concrete Filled Steel Tubular (RSCFST), Partially Concrete-Filled Steel Tubular (PCFST) structural elements and materials subjected to various loading conditions load were discussed. It is observed that structural behaviour and properties varies depending on certain parameters like geometrical properties, type of analysis, material properties, cross sectional dimensions and boundary conditions of CFST.

Concrete filled steel tubes (CFST) are a type of composite member with high strength concrete infill inside. A steel covering was provided at the outer surface in filled with concrete, hence a combination of different materials having particularly high strength. Due to the utilization of advantages of both steel and concrete, it exhibits high structural stiffness, integrity of cast-on-site and ease of handling and erection of a structural network as compared to the conventional type RC structures. Because of its high strength and structural performance CFSTs are mainly used in bridge construction where heavy loads are to be taken and should withstand extreme conditions of loading. Mainly, CFSTs are used as piers of the bridges were structural load to be withstand and safely transferred. Recent construction methods (which should transfer heavy loads in extreme conditions) are replacing conventional type structures to CFST structure mostly in developing countries where concrete is still more economical than steel. CFSTs are widely and initially adopted by Japan. Due to its ease of construction and flexibility in any condition, CFTs are highly recommended for heavy structural purpose.

One of the few drawbacks of Concrete filled steel tubular members is that they get deteriorated due to the environmental effects like corrosion and ageing. The external strengthening by using fiber reinforced polymer (FRP) materials emerging as a new trend in enhancing the structural performance of CFST members to counteract the drawbacks in the past rehabilitation work. Recent years, FRP is becoming a popular material for rehabilitation due to its superior material properties like corrosion and weather resistance, high mechanical strength, less weight, ease of handling, good fatigue resistance and ductility.

Concrete-filled steel tubes (CFSTs) represent an economical solution for arch bridges owing to their high axial compressive strength and their ease of construction. Arch bridges are particularly suitable for spanning over river valleys and deep ravines with high-gradient rocky riverbanks (Fig.1), which can provide the adequate reactions to resist the thrust at the arch base.

Fig 1. CFST arch bridge

[Source: https://images.app.goo.gl/gcu6ucjcCrb18EJc7]

CFSTs are of different shapes, mainly circular CFST, square CFST, and rectangular CFST (Fig.2). Shape of the structure influence the overall behaviour and response to certain loading conditions and is discussed in this paper.

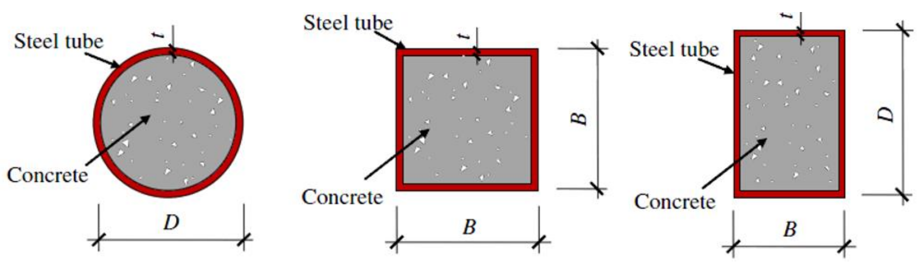


Fig 2. CFST columns of different shapes bridge

[Source: https://images.app.goo.gl/gcu6ucjcCrb18EJc7]

Review of their structural behaviour is done by changing different parameters like load conditions, geometry, material properties, temperature changes in order to observe the strength parameters like their bearing strength (with which buckling and compressive strength is taken into consideration), fire resistance and response to blast load and also the time depended behavior which is a major issue in case of CFSTs.

2. Study on Bearing Capacity

While bearing strength is taken into consideration for any structure, effect of buckling and influence of compressive strength that is observed under different parameters like change in geometry of the structure, proportion of materials used, types of loading, rise-span ratio, are to be considered. Here in CFST structures (especially columns), under the influence of above mentioned test parameters, with the help of experimental results, predictions, mainly FEM analysis carried out by previous discussed papers are observed and the overall review of strength parameters like concrete strength, influence of temperature effect, yield strength of the steel tube, diameter-thickness ratio (D/t), failure modes, stress strain characteristics, concrete confinement strength are done.

Apart from CFST columns, CFST arch bridge that is under service is also subjected for the strength analysis. For structures under service, a perfect experimental is not possible in practical case since tests are done till the failure of the particular structure. Instead non-destructive testing (mainly ultrasonic field scanning) is done and with the field scanning data and, it is analysed in a FEM analysis software (ABAQUS is most used here).

Large diameter steel tubes are taken into consideration in order to determine their structural behaviour under temperature influence and due to small axial compression. Here, structures with transverse bracing and spiral weld are taken for analysis. Temperature effect in the sense, mostly extreme atmospheric temperature is considered in normal cases.

For the analysis and prediction, material properties and constitutive models are considered (Chao Guo and Zhengran Lu.2020). Ultrasonic field scanning data were collected and was analyzed by FEM. For this mostly steel tubes of valid strength ranging from 200Mpa to 800Mpa were introduced.

For quantitative evaluation of the influence of the spiral-welded seam (SWS) strength and circumferential gap composite defects on the CFST bearing capacity, a strength index SI is defined (Chao Guo and Zhengran Lu.2020)

$$SI = \frac{Nc-def}{Nn-def}$$

Where N_{c-def} is the maximum value of the CFST rib N–ε curves with composite defects and N_{n-def} is the maximum value of the e CFST rib N–ε curves without defects. According to experimental datas reported by Chao Guo and Zhengran Lu.(2020), new index was more accurate and versatile in calculating CFST ribs with composite defects. The new index SI expression quantitatively illustrates that centrifugal gap (χ) has a more significant impact on the

CFST bearing capacity than SWS-S, and therefore, a key index for ensuring the CFST arch bridge bearing capacity was the reduction of circumferential gap.

As mentioned earlier, types of materials and their proportion were also changed in order to determine the structural behaviour. For that, instead of normal aggregate, when light weight aggregate were used in CFST (SLCFST) stub columns which was then subjected to axial compression test (Xianggang Zhang et al. 2019) and response of two D/t ratios were considered. Model Verification by Concrete-Filled Circular Steel Tube columns were done and was observed that in case of axial compression, buckling of the external steel tube occurs in SLCFST stub columns and the core SLC is crushed to varying degrees, indicating strength damage. Also the ultimate bearing capacities and peak displacements of the C-SLCFST and S-SLCFST stub columns increased with an increase in normal gravel replacement ratio. So by increasing the percentage of normal aggregates, strength seems to be increased. We can conclude from the test carried (Xianggang Zhang et al. 2019), that normal aggregate has more validity as compared to the light weight aggregate. While adopting different types of concrete (normal concrete, ultra high strength concrete, engineered cementitious composite, light weight concrete, self-consolidating concrete and crumb rubber concrete), and analyzing (Khandaker et al. 2019), it was observed that Columns with higher-strength concrete failed by shear more often than those with low concrete strength. Also Columns with comparatively lower-strength concretes transitioned from elastic to plastic stages without a significant peak load. In general, an increase in axial strength with the increase in slenderness of columns was observed with exceptions of few columns.

Role of Fiber Reinforced Polymer (FRP) is not finite in the practice of CFST structures. With a layer or covering of FRP, a considerable amount of concrete can be reduced, which results in a hollow structure of FRP outer covering and steel inner covering and concrete sandwiched in between. It is the interaction of different materials like FRP, concrete and steel. HC-FCS columns use 60%–75% less concrete material because they have a hollow core. The reduction in the quantity of concrete depends on the design of the column. The inner steel tube is well protected from corrosion using the FRP tube and concrete shell. Strength parameters analyzed are concrete strength, steel tube thickness, concrete wall thickness, width to thickness ratio (B/ts) of steel tube, confinement ratio, steel tube diameter, and provision of infilling concrete. Columns were subjected to combined Axial and lateral loading and FE analysis were carried out. Failure mode was also taken into consideration (Fig.3). According to the experimental analysis done (Mohanad M et al. 2019; Togay Ozbakkaloglu & Butje Louk Fanggi. 2014), it was observed that analysis highly recommend to keep the column wall thickness (t_c) at 254 mm in order to improve the flexural capacity and in case of buckling, the buckling strength increased with a decrease in the steel tube width-to-thickness ratio (B/ts).

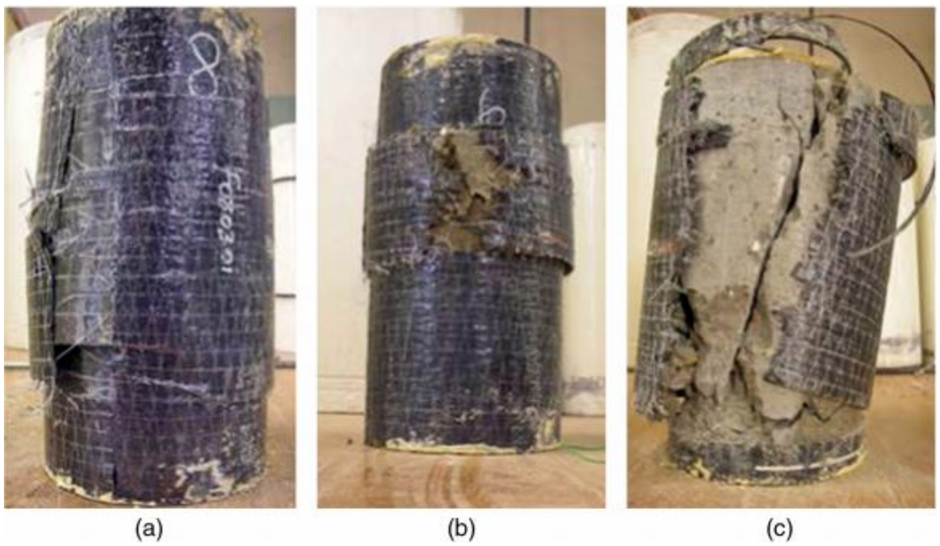


Fig 3. Failure modes of DSTCs: (a) bond failure; (b) localized hoop rupture; (c) global rupture [Source: Togay Ozbakkaloglu & Butje Louk Fanggi. (2013)]

It was noted that columns having a B/t ratio of 30 were able to reach the yield strength of the steel tube before local buckling initiation. Also the flexural strength increased with an increase in the confinement ratio (CR 0.20 outperformed all other columns in terms of strength and drift capacity). Local buckling is the main parameter that to be considered in this investigation. Local buckling nonlinearity for the inner steel tube is a crucial and complex phenomenon and must be considered in HC-FCS column design. Expressions were presented to predict the stress and strains at the onset of steel tube local buckling in HC-FCS columns.

Failure modes were analyzed inorder to observe the concrete strength and was concluded that concrete was confined effectively by FRP and steel tubes. FRP tube thickness has a significant influence on the stress strain behavior of confined concrete, increasing the FRP tube thickness leads to an increase in the ultimate axial stress (f '$_{cu}$) and strain (ε_{cu}). Also Increasing the inner steel tube diameter leads to an increase in the ultimate axial stress (f '$_{cu}$) and strain (ε_{cu}) and this influence was found to be independent of concrete strength.

As the span of CFST arch bridges increases, the design of in-plane stability is of more and more concern. Compared to CFST columns, the stability of CFST arches is dependent on not only the slenderness ratio but also the rise-span ratio. From Fig. 4, it can be observed that, for a particular span, certain rise should be considered and this rise span ratio has some influence over the structural performance.

Fig 4. Typical CFST arch bridge

[Source: Changyong Liu et al. (2016)]

It is observed from Fig.5 that concrete is pored through tubes and any discomfort in concrete infilling influence the structure thus resulting a composite damage.

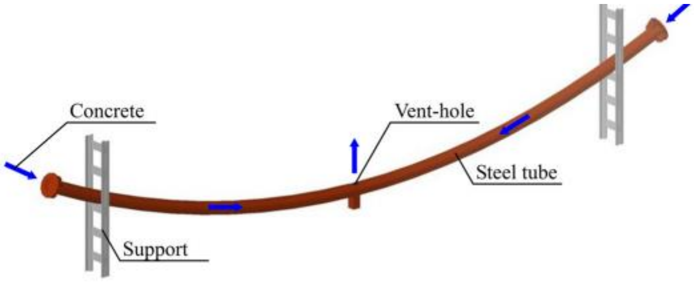


Fig 5. Pouring concrete

[Source: Changyong Liu et al. (2016)]

From the experimental data and analysis (Changyong Liu et al. 2016), it was concluded that the arches have good plastic deformation for different rise-span ratios and loading conditions. The rise-span ratio has a significant effect on the stability capacity under symmetric loading, and an insignificant effect on the stability capacity under anti symmetric loading.

Based on the shape of cross section, structural behaviours may also vary accordingly. In case of CFST column, influence of geometry to its strength was analysed by subjecting a square CFST column under axial compression and strength parameters were analysed.

In view of the experimental results and analysis (Hong-Song Hu et al. 2018), it was observed that the difference between the compressive strength of concrete in square CFST columns and the corresponding cylinder strength were small for square CFST columns and was within the commonly accepted range. Also, for square CFST columns with small B/t ratios, the axial loads sustained by the concrete infill and steel tube reach their respective maximum at the peak total load. On the other hand, the axial load capacity for columns with large B/t ratios may be reached after developing the ultimate strength of the steel tube. Moment enhancement from confinement caused by the steel tube was minimal in square CFT columns (Eiichi Inai et al. 2004). Also the ductility becomes larger as the steel strength becomes higher except for the circular CFT specimens with 780MPa steel tube, of which θmax has been determined by the crack of steel tube. While analytically investigating global buckling behaviour of slender concrete-filled steel tubular (CFST) columns with circumferential gaps and partial debonding between the concrete core and the steel tube (Verlag. 2018), it was observed that the critical buckling load decreases as the magnitude and length of the circumferential gap increases. Apart from shape, local buckling generally occurs at lower deformations as the width to thickness ratio increases. The ductility of the square columns reduces as the ratio increases. The ratio has little influence on the ductility of circular columns within the range of variables of this test program. From all these analysis, it is concluded that ductility of circular CFT beam columns (Fig.6) was superior to that of square CFT beam columns. The ductility of square CFT beam columns decreases as the width to thickness ratio increases. The failure modes, axial load-displacement curves, and ultimate axial load of the circular tubed steel-reinforced concrete (CTSRC) columns were analyzed systematically with the existing data (Junlong Yang et al. 2019). Apart from the outer covering, profile steel was provided in order to identify the overall strength.

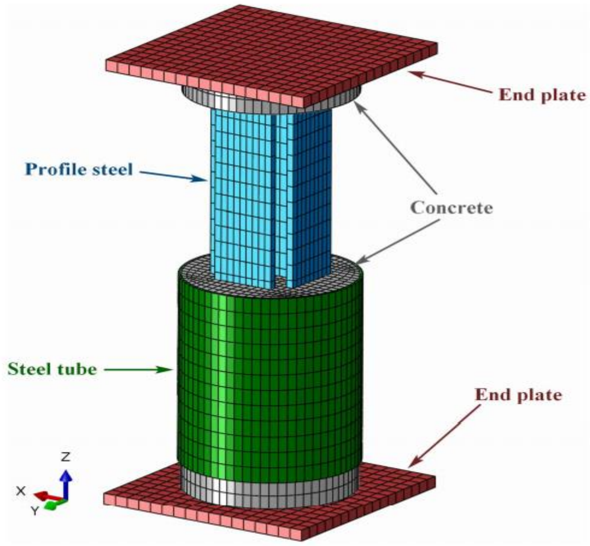


Fig 6. Circular tubed steel-reinforced concrete (CTSRC)

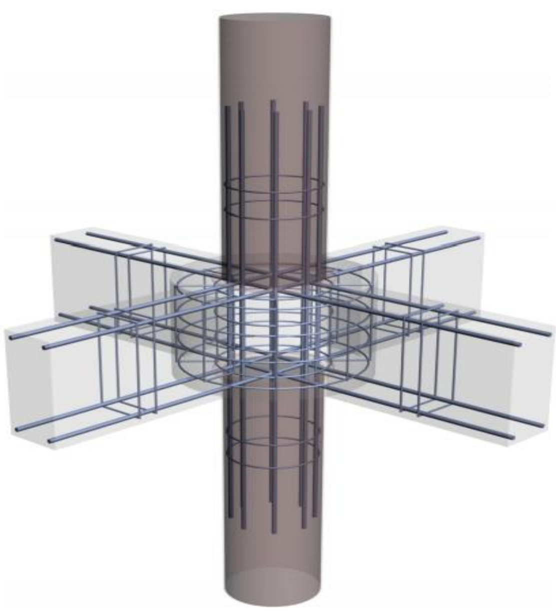
[Source: Junlong Yang et al. (2019)]

Test results and FEM analysis performed (Junlong Yang et al. 2019) concludes that due to the double confinement from the steel tube and profile steel, the strength and ductility of the core concrete are significantly enhanced and the axial strength of the CTSRC columns were improved as a result. Axial capacity increases with improvements in the concrete strength and steel ratio of the profile steel and decreases with increases in the diameter-to-thickness ratio (Jiangang Wei et al. 2020). Moreover, the diameter-to- thickness ratio of steel tube and concrete strength are two important influenced factors among all parameters. Based on above mentioned papers and the overall review, circular CFST column is highly recommended in terms of all aspects of good structural behaviour when compared to square and rectangular CFST. Results obtained by Julia Marson & Michel Bruneau (2004) also suggest that concrete-filled steel circular tubes could provide an effective mechanism to dissipate seismic energy.

Test results and analysis of Jian-Guo Nie et al (2017) reveals that, any kind of CFST column with adequate design was a better alternative of conventional type RC structure considering their overall structural behaviour irrespective of their geometry.

When load-deflection curves and ultimate bearing capacity of short and long concrete filled steel tubular (CFST) members under eccentric compression were discussed (Wang Wei. 2009), calculating method of the ultimate bearing capacity of CFST members under eccentric compression was proposed and proved correct and reliable.

All these discussions were based on the structural behaviour and performance of CFST structures. A joint formed in a CFST is also an important factor. While observing the axial compressive behavior of through beam connection in CFST column and RC beams with proper design considerations, certain experiments as shown in Fig.7(b) are performed and analyzed (QingJun Chen et al. 2015). A strengthening ring beam was used to enlarge the connection zone in order to compensate for the possible decrease of the axial load-carrying capacity as a result of the discontinuity of the steel tube that encases the column which is illustrated in Fig.7(a). It was shown that the height and the area ratio of the reinforcement in the ring beam have significant influence on the axial load-carrying capacity of the connection zone.



a

b

Fig 7. (a) Through-beam connection system (b) Overview of specimens

[Source: QingJun Chen et al. (2015)]

Taking into consideration of the confinement produced by multiple layers of ring bars and the effect of local compression, empirical formula for predicting the ultimate axial compressive strength of the connection between CFST columns and RC beams were proposed as,

$$N_{cal} = \beta_{cs}\,(\beta 0.85 f_c A_1\sqrt{A2/A1}\,)$$

3. Temperature Response and Blast Load

In CFST bridges, temperature action is not only an important but also a special load that must be considered in bridge design, construction and structural evaluation. Apart from blast loads, in normal cases, atmosphere heat results in temperature change in structures. In-depth investigations of the contributions of temperature influencing factors can help to effectively reduce the adverse temperature effects on CFST bridges in the design stage.

In order to determine the fire response, ISO-834 standard fire was used and is cooled under room temperature in almost all the cases. After exposure to fire, specimen was subjected to axial compression and gradually increasing flexural cyclic loading and the test results were analyzed in FEA. As we see in the bearing capacity, here also different conditions were made to observe which suits more in a fire exposure case. Certain changes are made in shape, type of loading, relative slenderness, orientations and inclinations, addition of FRP and time span to which the structure is exposed to fire.

While, FEA models were used to analyze load versus deformation relation of steel beam to CFST column connections (Lin-Hai Han et al. 2007), it was observed that P–Δ relations of steel beam to CFST column connections can be predicted with generally good precision. Also, at a higher axial load level in the column, the column lateral load carrying capacity was slightly reduced, but its ductility suffers a large reduction. As a result, the connection energy dissipation had also greatly reduced and only the damping coefficient were slightly increased. Initially, there was a slight increase in the column lateral rigidity at low deflection, but the degradation in column lateral rigidity was much greater at large lateral deflections. It should be noted that energy dissipation ability of the columns with circular section was higher than those of the specimens with square sections. Also circular steel tube–confined reinforced concrete (STCRC) based on the test results (Faqi Liu et al. 2019), temperatures across the cross sections of the STCRC and CFST columns decrease from the outer steel tube to the center of the concrete, and that the temperature of the concrete remains at around 100°C for some time, due to the energy absorption associated with the moisture evaporation and migration. The STCRC columns under combined thermal and structural loading failed by global buckling accompanied by local buckling but compared with the CFST column, the STCRC columns provided much higher fire resistance, owing to the contribution of the embedded reinforcing bars.

In normal cases, long term analysis were made to observe the temperature response to structural behavior with simultaneous meteorological parameters, including solar radiation, air temperature, and wind speed. It was observed that distinctions do indeed exist in the sun-side temperature differences of CFST members with different inclinations. Fig.8 illustrates the different angle sun radiation that is incident on the structure. Inclination also affects the behaviour of the structure.

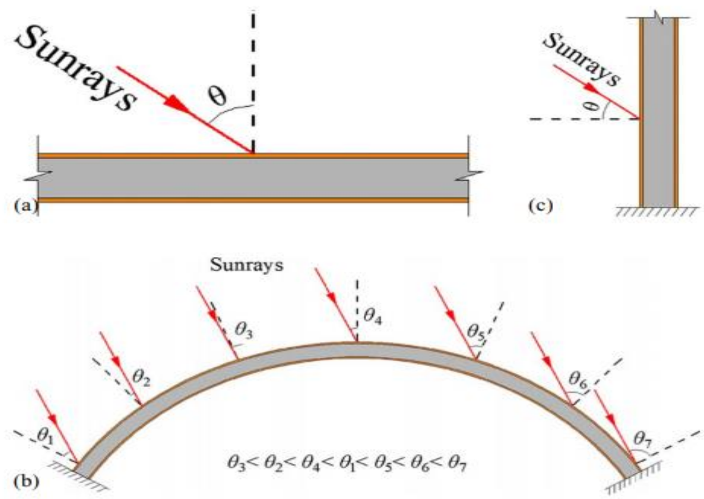


Fig 8. Sunrays cast on CFST members with different incident angles: (a) CFST girder (horizontal member); (b) CFST arch (inclined member); and (c) CFST pylon or pier (vertical member)

[Source: Jiang Liu et al. (2020)]

With comprehensive understanding of the temperature gradients of a CFST member with an arbitrary inclination on the basis of experimental and analytical investigations (Jiang Liu et al. 2020; Jiang Liu et al. 2019; Sun Hang et al. 2009), it was concluded that, different inclinations have different annual variation characteristics for sun-side temperature differences, which are large in summer and small in winter for the horizontally placed member, small in summer and large in winter for the vertically placed member, and more evenly distributed in the whole year for the inclined member.

4. Time dependent Behaviour

The time-dependent behaviour of CFST is greatly influenced by concrete creep and shrinkage. In order to study the time-dependent behaviour of CFST structure, FEM analysis was observed (by ABAQUS). As before, along with CFST, FRP is also considered. Properties were also made to change for analysis of various test parameters and their influence.

It is important to predict accurately the static response of overall structure induced by creep and shrinkage effects of concrete core inside the hollow steel arch members. With various FEM analysis performed (Yue Geng et al. 2014), a simplified method was proposed for predicting the long-term response of CFST arch bridges with the maximum underestimation of 4.9% both for the displacement and the stress in steel tubes from the SBS method which is capable of accounting for the construction process, the aging of the concrete, the geometric nonlinearity and time effects. While using a summation procedure in computer for analysis (Xudong Shao et al. 2010), it was observed that maximum relaxation of creep-induced stress in the concrete was 52.7% of the initial concrete stress, and the maximum increment of stress in the steel tube was 27.3%. Stresses in the concrete were gradually transferred to the steel tubes, which may result in overstressing of the steel tubes. When the concrete material is changed to recycled aggregate concrete–filled steel tube (RACFSTs) and subjected to sustained loading (Yue Geng, et al. 2015), it was found that the time-dependent deformation of the RACFST members increases linearly with the aggregate replacement ratio. Replacing the natural coarse aggregate with the recycled ones also increases the scatter of the time-dependent deformations for the composite members. However, the incorporation of recycled coarse aggregates does not affect the rate of creep development of RACFST specimens.

All these papers considered CFSTs as compression members. While turning into tension members, CFST structures proved to be of considerable structural strength to withstand long term tension loading in a corrosive environment (Lin-Hai Han et al. 2017). Test results and analysis (Wassim Naguib and Amir Mirmiran. 2003) suggests that creep rupture life expectancy of FRP was not less than 100 years for D/t ratios larger than 40 at 70% of static capacity. CFFT columns with D/t ratios of less than 80 have a creep rupture life expectancy of 75 years at 70% of static capacity.

Conclusion

This paper comprehensively review researches on structural behaviour of CFST structures as well as influencing factors of CFST bridges like temperature actions with different classifications, bearing capacity with varying parameters and materials, time dependent effect and response on CFST structures with varying physical conditions. The conclusions of the review are summarized as follows:

1. CFST columns possess better structural behaviour compared to conventional RC structures and are ease in construction.

2. In accordance to the shape and geometry of the structure, strength parameters may vary. Also both in bearing capacity and temperature response of the structure, circular CFST overrides square CFST and rectangular CFST. Hence application of circular CFST is highly recommended.

3. CFST section provide high ductility, strength and stiffness properties which are important in resisting earthquake forces hence the seismic behavioral study of structure using CFST section becomes essential.

4. Use of FRP in CFST structures is highly recommended on the base of their overall structural performance.

5. It is observed that, as D/t ratio of CFST section increases, reduction in compressive strength occurs due to less confinement.

6. Apart from blast load, temperature effect (mostly from sun side) causes temperature variation within the structure and may leads to composite defects.

7. Blast, fire, and seismic damages reduced the axial capacity, axial stiffness, and axial ductility of the RC system while CFFT columns resisted the extreme events while maintaining their performance under axial loads.

8. Increasing the rate of normal aggregates (than light weight aggregate and recycled aggregate) exhibited better bearing capacity.

There are further more predictions and analysis to be done in this area. With the available set of data, and analysis method (FEM which is done by ABAQUS software) review is done and observations are mentioned.

REFERENCES

Alicia Echevarria, Ph.D, Arash E. Zaghi, Ph.D., P.E, Richard Christenson, Ph.D, & Michael Accorsi, Ph.D (2015), "CFFT Bridge Columns for Multihazard Resilience", ISSN 0733-9445/C4015002(16)/$25.00, DOI: 10.1061/(ASCE)ST.1943-541X.0001292

Alicia Echevarria, Ph.D, Arash E. Zaghi, Ph.D, P.E Vincent Chiarito, P.E, Richard Christenson, Ph.D & Stanley Woodson(2015), "Experimental Comparison of the Performance and Residual Capacity of CFFT and RC Bridge Columns Subjected to Blasts", ISSN 1084-0702/04015026(15)/$25.00, DOI: 10.1061/(ASCE)BE.1943-5592.0000762

Chao Guo and Zhengran Lu (2020), "Air Void and Cap Gap Composite Defects of Concrete-Filled Steel-Tube Arch Bridge Transverse Brace", ISSN 0887-3828, DOI: 10.1061/(ASCE)CF.1943-5509.0001479

Chao Guo and Zhengran Lu (2019), "CFST Rib with Circumferential Gap and SWS Composite Defects" Iranian Journal of Science and Technology, Transactions of Civil Engineering, https://doi.org/10.1007/s40996-020-00434-5

Changyong Liu, Yuyin Wang, Xinrong Wu, Ph.D and Sumei Zhang (2016), "In-Plane Stability of Fixed Concrete-Filled Steel Tubular Parabolic Arches under Combined Bending and Compression", ISSN 1084-0702, DOI: 10.1061/(ASCE)BE.1943-5592.0000993

Eiichi Inai, Akiyoshi Mukai, Makoto Kai, Hiroyoshi Tokinoya, Toshiyuki Fukumoto, & Koji Mori (2004), "Behavior of Concrete-Filled Steel Tube Beam Columns", Journal of Structural Engineering, Vol. 130, DOI: 10.1061/(ASCE)0733-9445(2004)130:2(189)

Faqi Liu, Yuyin Wang, Leroy Gardner, & Amit H. Varma (2019), "Experimental and Numerical Studies of Reinforced Concrete Columns Confined by Circular Steel Tubes Exposed to Fire", Journal of Structural Engineering, ISSN 0733-9445, DOI: 10.1061/(ASCE)ST.1943-541X.0002416

Hong-Song Hu, Yang Liu, Bao-Ting Zhuo, ZiXiong Guo, & Bahram M. Shahrooz (2018), "Axial Compressive Behavior of Square CFST Columns through Direct Measurement of Load Components", Journal of Structural Engineering, ISSN 0733-9445, DOI: 10.1061/(ASCE)ST.1943- 541X.0002204

Jian-Guo Nie, Wen-Hao Pan, Mu-Xuan Tao, & Yu-Zhi Zhu (2017), "Experimental and Numerical Investigations of Composite Frames with Innovative Composite Transfer Beams", Journal of Structural Engineering, ISSN 0733-9445, DOI: 10.1061/(ASCE)ST.1943-541X.0001776

Jiangang Wei, Xia Luo, Zhichao Lai, A.M, & Amit H. Varma (2019), "Experimental Behavior and Design of High-Strength Circular Concrete-Filled Steel Tube Short Columns", Journal of Structural Engineering, ISSN 0733-9445, DOI: 10.1061/(ASCE)ST.1943-541X.0002474

Jian Zheng, Ph.D, Shozo Nakamura, Yajing Ge, Kangming Chen & Qingxiong Wu (2019), "Extended Formulation of Stress Concentration Factors for CFST T-Joints", Journal of Bridge Engineering, ISSN 1084-0702, DOI: 10.1061/(ASCE)BE.1943-5592.0001502

Jiang Liu, Yongjian Liu, Guojing Zhang, Lei Jiang and Xinkai Yan (2020), "Prediction Formula for Temperature Gradient of Concrete-Filled Steel Tubular Member with an Arbitrary Inclination", Journal of Bridge Engineering, ISSN 1084-0702, DOI: 10.1061/(ASCE)BE.1943-5592.0001599

Jiang Liu, Yongjian Liu, Dr.Eng. & Guojing Zhang (2019), "Experimental Analysis of Temperature Gradient Patterns of Concrete-Filled Steel Tubular Members", Journal of Bridge Engineering, ISSN 1084-0702, DOI: 10.1061/(ASCE)BE.1943- 5592.0001488

Joao Paulo C. Rodrigues, Ant onio J. P. M. Correia and Venkatesh Kodur (2020), "Influence of Cross-Section Type and Boundary Conditions on Structural Behavior of Concrete-Filled Steel Tubular Columns Subjected to Fire", Journal of Structural Engineering, ISSN 0733-9445, DOI:10.1061/(ASCE)ST.1943-541X.0002860

Joao P. C, Rodrigues, & Luis M. S. Laim (2018), "Behavior of Concrete-Filled Circular, Square, Rectangular, and Elliptical Hollow Columns Subjected to Fire", Journal of Structural Engineering, ISSN 0733-9445, DOI: 10.1061/(ASCE)ST.1943-541X.0002035

Julia Marson & Michel Bruneau (2004), "Cyclic Testing of Concrete-Filled Circular Steel Bridge Piers having Encased Fixed-Based Detail", Journal of Bridge Engineering, Vol.9, No.1, ISSN 1084-0702/2004/1-14–23/$18.00, DOI: 10.1061/(ASCE)1084-0702(2004)9:1(14)

Junlong Yang, Jizhong Wang, Xinpei Wang, Lu Cheng, & Ziru Wang (2019), "Compressive Behavior of Circular Tubed Steel-Reinforced High-Strength Concrete Short Columns", Journal of Structural Engineering, ISSN 0733-9445, DOI: 10.1061/(ASCE)ST.1943-541X.0002361

Khandaker M. A. Hossain, Katie Chu (2019), "Confinement of six different concretes in CFST columns having different shapes and slenderness", International Journal of Advanced Structural Engineering (2019) 11:255–270, Doi.org/10.1007/s40091-019-0228-2

Lin-Hai Han, Jing-Si Huo, & Yong-Chang Wang (2007), "Behavior of Steel Beam to Concrete-Filled Steel Tubular Column Connections after Exposure to Fire", Journal of Structural Engineering, Vol. 133, No. 6, DOI: 10.1061/ ASCE 0733-9445 2007 133:6 800

Lin-Hai Han, You-Xing Hua Chao Hou, and Qing-Li Wang. (2017). "Circular Concrete-Filled Steel Tubes Subjected to Coupled Tension and Chloride Corrosion". *American Society of Civil Engineers*, DOI: 10.1061/(ASCE)ST.1943-541X.0001874

Mohanad M. Abdulazeez, Mohamed A. ElGawady, Ph.D and Omar I. Abdelkarim, Ph.D (2019), "Bending and Buckling Behavior of Hollow-Core FRP–Concrete–Steel Columns", Journal of Bridge Engineering, ISSN 1084-0702, DOI: 10.1061/(ASCE)BE.1943- 5592.0001419

QingJun Chen, Jian Cai Mark A. Bradford, Xinpei Liu & Yi Wu (2015), "Axial Compressive Behavior of Through-Beam Connections between Concrete-Filled Steel Tubular Columns and Reinforced Concrete Beams", Journal of Structural Engineering, ISSN 0733-9445/04015016(13)/$25.00, DOI: 10.1061/(ASCE)ST.1943-541X.0001249

Sun Hang, Sheng Hongfei, Li Yan & Li jianglong (2009), "Observation and theoretical analysis of the temperature field on the cross section of concrete filled steel tubes arch bridge rib", ICCTP 2009: Critical Issues in Transportation Systems Planning, Development, and Management 2009

Simon Schnabl, Verlag GmbH Austria, part of Springer Nature (2018), "Circumferential gap and partial debonding effects on buckling loads and modes of slender CFST circular columns", Doi.org/10.1007/s00707- 018-2322-0

Togay Ozbakkaloglu & Butje Louk Fanggi (2013), "Axial Compressive Behavior of FRP-Concrete-Steel Double-Skin Tubular Columns Made of Normal- and High-Strength Concrete", Journal of Composites for Construction, ASCE, ISSN 1090-0268/04013027(13)/$25.00, DOI: 10.1061/(ASCE)CC.1943- 5614.0000401

WANG Wei (2009), "Ultimate Capacity Analysis of Concrete Filled Steel Tubular Structure Under Eccentric Compression", International Conference on Transportation Engineering 2009 (ICTE 2009)

Wang H J, S. Kunnath, and Y. Xiao F (2020), "Post-Earthquake Fire Resistance of Circular Concrete-Filled Steel Tubular Columns", Journal of Structural Engineering, ISSN 0733-9445, DOI: 10.1061/(ASCE)ST.1943-541X.0002632

Wassim Naguib and Amir Mirmiran. (2003). "Creep Analysis of Axially Loaded Fiber Reinforced Polymer-Confined Concrete Columns". American Society of Civil Engineers, DOI: 10.1061/(ASCE)0733-93992003(129)11(1308)

Xianggang Zhang, Xiaomei Kuang, Jianhui Yang and Yuhui Fan (2019), "Bearing Capacity of Stone-Lightweight Aggregate Concrete-Filled Steel Tubular Stub Column Subjected to Axial Compression", KSCE Journal of Civil Engineering (2019) 23(7):3122-3134 Vol. 23, No. 7 / July 2019, DOI 10.1007/s12205-019-2287-0

Xudong Shao, Jianxin Peng, Lifeng Li Banfu Yan and Jianhua Hu. (2010). "Time-Dependent Behavior of Concrete-Filled Steel Tubular Arch Bridge". American Society of Civil Engineer, DOI: 10.1061/(ASCE)1084-0702(2010)15:1(98)

Yue Geng, Yuyin Wang, Gianluca Ranziand Xinrong Wu. (2013). "Time-Dependent Analysis of Long-Span, Concrete-Filled Steel Tubular Arch Bridges". American Society of Civil Engineers, DOI: 10.1061/(ASCE)BE.1943-5592.0000549

Yue Geng, Yuyin Wang and Jie Chen. (2015). "Time-Dependent Behavior of Recycled Aggregate Concrete–Filled Steel Tubular Columns". American Society of Civil Engineers, DOI: 10.1061/(ASCE)ST.1943-541X.0001241