International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES),(UGC APPROVED)
Impact Factor: 5.22 (SJIF-2017),e-ISSN:2455-2585
Research Symposium on
"Advancements in Engineering, Science, Management, and Technology"
Volume 5, Special Issue 04, April-2019.

Mechanical Behaviour of Cold-Formed Steel Column with Infill: A Review

Sunil Mahato[1], Saranya Ilango[2*]

[1,2]*Department of Civil Engineering, School of Engineering and Technology, Sharda University, Greater Noida, U. P*

Abstract*— Composite steel-concrete construction utilising the benefits of both materials has extensively been used in structural engineering. Concrete-filled tube columns can provide excellent seismic resistant structural properties such as high strength, high ductility, and large energy absorption capacity. In addition to the enhancement in structural properties, a considerable amount of construction time can be reduced due to the prevention of permanent formwork. In this type of column, the steel tube can support considerable amounts of loads while providing permanent formwork to the concrete. Likewise, the steel tubes add confinement to the concrete whereas the concrete infill delays the local buckling of the steel tubes. In recent years, stainless steel tube members have become popular due to the high corrosion resistance, ease of construction and maintenance as well as aesthetic appearance. Concrete-filled hollow steel sections are more and more frequently used as compression members in structures nowadays. This paper investigates the mechanical behaviour such as Buckling behaviour, Load carrying capacity and Seismic resistant of cold formed steel column with infill.

Keywords*— Cold-formed steel, Composites columns, Buckling, Load Carrying capacity, Stainless steel tubes, Axial loads, Confinement.

I. INTRODUCTION

Concrete-filled steel tubular (CFST) members have been immensely investigated and widely applied in the practical engineering, especially in high rise even super high-rise buildings and long-span bridges. Besides the conventional CFST members using single layer tubes made of carbon steel, there have been some improved types of steel concrete composite tubed sections proposed by researchers around the world. Like concrete-filled stainless steel tubular members and concrete-filled dual steel tubular members with outer stainless steel tubes. One major purpose of the derived members is to increase the rust and corrosion resistance, which would be the controlling factor, is structural design under some special circumstances. Stainless steel is well known for its extreme durability, high resistance to rusting and corrosion, and easy maintenance. Recently, there has been a fast increasing interest in the use of stainless steel in construction all over the world [1]. However, this type of advanced material is much more expensive and could only be applied in structures when the relatively cheap lean duplex material is used. Since past few decades, composite steel-concrete construction of column is being used in the construction industry. These composite sections have the rigidity and formability of reinforced concrete with the strength and speed of construction associated with structure, thereby making them economical. The steel and the concrete element in a composite member complement each other ideally. Composite members consisting of rectangular steel tubes filled with concrete are extensively used in structures involving very large applied moments, particularly in zones of high seismic risk. Concrete Filled Tubes (CFTs) have been used as girder, beam and columns in frame structures.

A steel hollow section in-filled with concrete has higher strength and larger stiffness than the conventional structural steel section and reinforced concrete. Composite column are structural members, which are mainly subjected to forces and end moments. The steel tube serves as a formwork for casting the concrete, which reduces the construction cost. No other reinforcement is needed since the tube itself act as a longitudinal and lateral reinforcements for the concrete core. The continuous provided to the concrete core by the steel tube enhances the core's strength and ductility. The concrete core delays bending and buckling of the steel tube, while steel tube prevents the concrete from spalling. Also concrete filled tube (CFT) columns are suitable for tall buildings in high seismic regions since concrete delays the local buckling of steel hollow sections and increases the ductility of the section significantly and. While there is a large number of studies on the behaviour of CFT columns and beam-columns; there is relatively little research reported on the flexural behaviour of concrete-filled hollow structural steel column. The structural behaviour of a CFT is governed by the member strength, reflecting the fact that the load resistance is dependent not only on the material properties but also on the geometric properties of the entire member.

II. LITERATURE REVIEW

2.1 Buckling Behaviour

Yong Ye et al. (2018) conducted studies on square concrete-filled stainless steel/carbon steel bimetallic tubular stub columns under axial compression [1]. The bimetallic tubes in the CFBT columns in this research comprised an outer layer made of stainless steel and an inner layer made of carbon steel as shown in Fig.1. 14 CFBT columns and two conventional concrete-filled steel tubular (CFST) counterparts were tested to failure under axial compressive loading. The test parameters included the stainless steel grade (Grade 316, 304, and 202), wall thickness of the stainless steel tube layer (t_{ss} = 0.84, 1.32, and 1.88 mm), and cube compressive strength of concrete (f_{cu} = 54.5, 68.4, and 80.5 MPa). A finite element analysis (FEA) model was established and validated against the experimental measurements. All the square CFBT and CFST columns behaved in a ductile manner, local buckling of the steel tube accompanied with obvious axial shortening of the entire specimen was observed. Local buckling occurred at the ends of the tube in specimens t2c3-316-2, t1c2-316-2, t2c2-202-1 and t2c2-202-2, primarily due to the slightly fastened clamps as shown in Fig.2. The failure mode of square CFBT stub columns is multiple outward local buckling in the bimetallic tube and the crush of core concrete at the corresponding positions. Compared with the reference CFST column specimens, more bulges appear in the CFBT columns at failure.

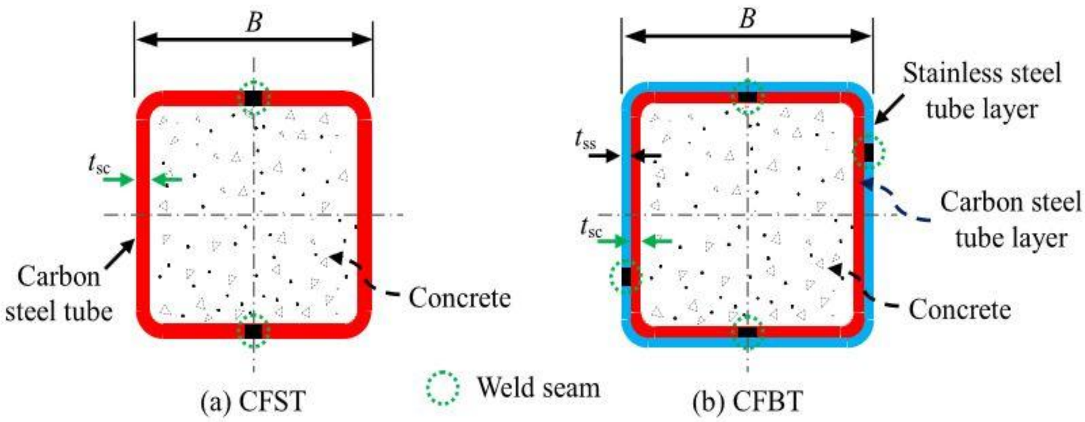

Fig.1. Cross Sections of Square CFST and CFBT Columns [1]

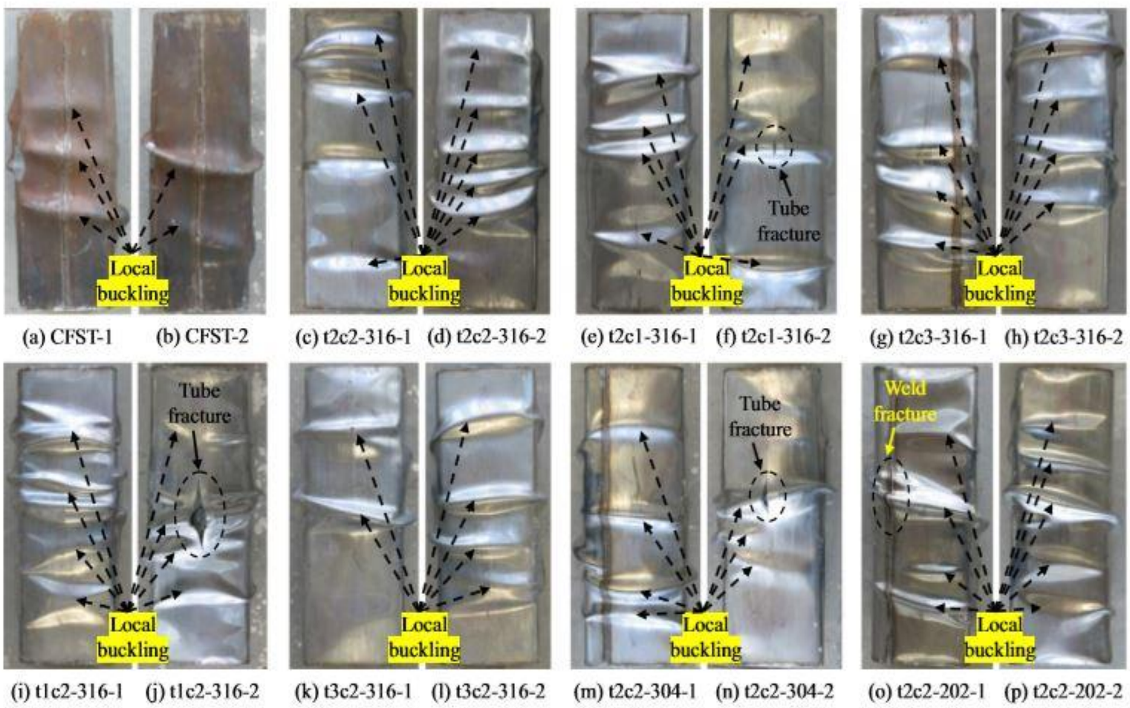

Fig.2. Overall Failure modes of the CFST and CFBT Specimens [1]

M.F. Hassanein et al. (2018) conducted studies on finite element modeling of concrete-filled double-skin short compression members with CHS outer and SHS inner tubes [2]. This paper provides the behaviour of CFDST short columns under concentric compressive loads. The specimens studied consist of an outer skin, which is a circular hollow section (CHS), and an inner skin, which is a square hollow section (SHS), with the annulus filled with concrete while the inner tube is completely empty. The best combination of the constitutive models of both the steel (suiting the cold-formed tubes) and the concrete (filled in double-skin tubes) is found based on previous research and considered. The comparison of the final shape of these two specimens demonstrated that both the axial shortening and the buckling, which occurred around the same height, are very close to the test results. Mizan Ahmed et al.(2018) studied nonlinear analysis of rectangular concrete-filled double steel tubular short columns incorporating local buckling [4]. The paper describes a computationally efficient fiber-based modeling technique developed for determining the behavior of concentrically-loaded rectangular CFDST short columns including the local buckling effects of the external steel tube and the confinement offered by the internal circular steel tube. The rectangular CFDST column made of an outer non-compact or slender steel section is susceptible to local buckling. When the applied axial load attains the initial local buckling stress of the steel plate, the plate undergoes local buckling. The D/t ratio of the column was 99.5, which was so large that the local buckling of the external square steel tube under compression occurred.

Craig Buchanan et al. (2018) conducted studies on testing, simulation and design of cold-formed stainless steel circular hollow section (CHS) columns [3]. The flexural buckling tests were conducted which consisted of 17 austenitic, 9 duplex and 11 ferritic concentrically loaded, pin-ended column specimens with a wide range of local and global slendernesses. The load versus mid-height lateral deflection curves was presented. The most common failure mode was global buckling which starts with the axial load of 100KN, 50KN, 50KN and 45KN for the specimens 106*3, 88.9*2.6, 104*2 and 80*1.5 CHS respectively. Experimental load versus mid-height central deflection curves for these specimens are shown below.

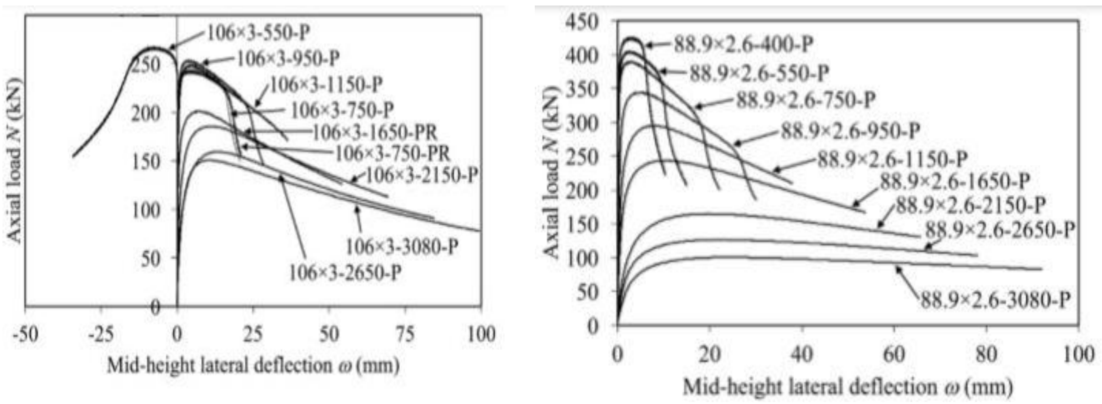

Fig.3: Experimental load versus mid-height central deflection curves for the 106*3 & 88.9*2.6 CHS Specimens [3]

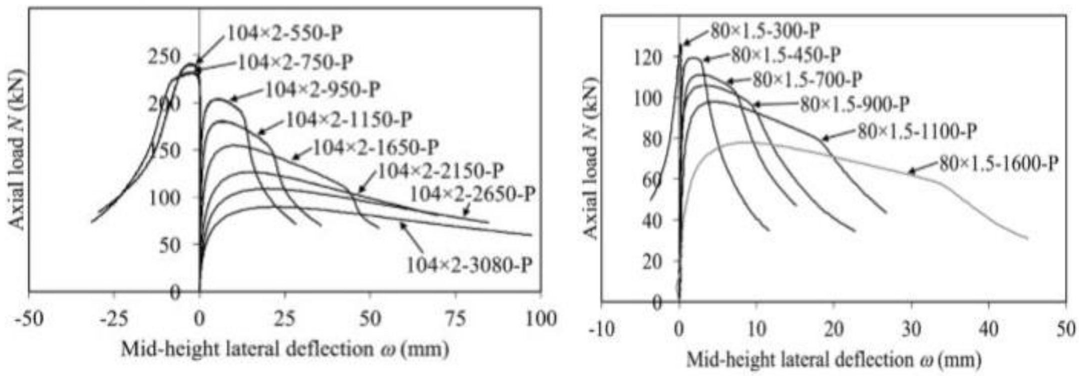

Fig.4: Experimental load versus mid-height central deflection curves for the 104*2 & 80*1.5 CHS Specimens [3]

Aizhu Zhu et al.(2017) conducted Experimental study of concrete filled cold-formed steel tubular stub columns. A total of 30 CFCFST stub columns were tested [5]. The cold-formed square hollow section (SHS) tubes included unstiffened sections and longitudinally inner-stiff-ened sections using different stiffening methods. Two tubular thicknesses of 6 mm and 10 mm were considered. The overall nominal dimension of the steel section was 200 × 200 mm, and the length of the stub columns was 600 mm. Normal concrete and self-consolidating concrete with a nominal compressive strength of 30 MPa were used to fill the cold-formed SHS steel tubes. For specimens with unstiffened steel sections, the buckling took place near the upper (loading) end. For specimens with Section type-b with a total of two stiffeners, outward buckling occurred at several locations in the steel plates from the unstiffened specimens, and local buckling occurred earlier in the two unstiffened walls of the tube than in the stiffened walls. At the end of loading process, the buckling deformation of the unstiffened walls was significantly larger than that of the stiffened walls. The unstiffened plate of the specimen Pb-6-2 even cracked along the central weld due to the large buckling deformation. Specimens with Section type-d had wider stiffeners with a width of 60 mm as compared to 40 mm in Section type-c. In these specimens, major longitudinal buckling tended to be effectively suppressed, and instead, local buckling occurred in multiple locations and between the adjacent stiffeners. Hua Yang et al.(2017) studied behaviour of concrete-filled cold-formed elliptical hollow section beam-columns with varying aspect ratios [6]. Experimental and numerical studies were conducted to investigate the behaviors of the concrete-filled cold-formed elliptical hollow section beam-columns. A total of 11 specimens were tested to evaluate the failure modes, load-deformation histories and strains development in the steel tube. Complementary finite element (FE) models were developed and validated against experimental results. The eccentrically loaded stub columns failed by local buckling of the steel tube at the compression side accompanied by concrete crushing. While the axially loaded and eccentrically loaded slender columns failed by global buckling, and local buckling was also observed in the compression region at mid-height of some specimens. Lui Faqi et al.(2017) investigated Behaviour of concrete-filled cold-formed elliptical hollow sections with varying aspect ratios [8]. Twenty one stub columns were tested to investigate the fundamental behaviours of these elliptical concrete-filled steel tubular (CFST) columns. The axial load versus displacement curves, longitudinal and transverse strains in steel tube and failure modes were obtained and discussed.

A constitutive model for concrete in the elliptical CFST columns was proposed. Finite element (FE) models were developed and validated against the test results. Parametric studies were carried out to identify the influence of key parameters on the load-bearing capacity. Key parameters included aspect ratio, steel tube to concrete area ratio, yield strength of steel and compressive strength of concrete. The elliptical hollow sections and elliptical CFST columns subjected to concentric loading failed by local buckling and shear failure of the concrete infill, respectively. The specimens upon removal of steel tube are also presented both inward buckling and outward buckling were observed in the elliptical hollow sections, however, only outward local buckling was observed in the steel tube of elliptical CFST columns, since inward buckling deformation of the steel tube was prevented by the concrete core. During the tests, the local buckling in the steel tube of elliptical hollow sections became apparent at load around 70% of the ultimate load. However, the local buckling in the steel tube of the elliptical CFST columns occurred at about 90% ultimate load. The delay of the local buckling in the steel tube may be attributed to the in-filled concrete. Qihan shen et al.(2018) conducted studies on performance and design of eccentrically-loaded concrete-filled round-ended elliptical hollow section stub columns [9]. A nonlinear numerical model that adopts an equivalent stress-strain model for the novel type of confined core concrete was established, and verified via experimental data. Fig.5 shows the typical FE model of CFREHS stub column under eccentric pressure. A parametric study on the mechanical behaviour of eccentrically loaded stub columns was conducted.

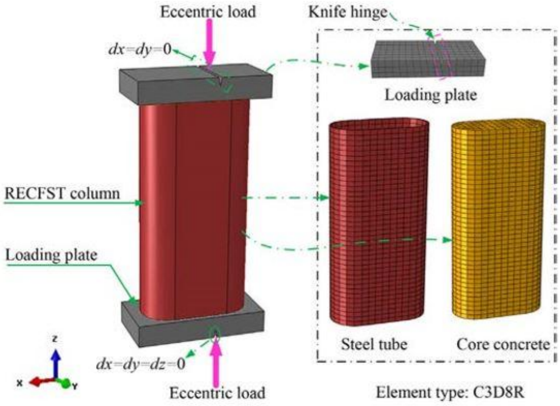

Fig.5: Typical FE model of CFREHS stub column under eccentric compression [9]

Outward buckling in steel tube was occurred with an increased load-eccentricity ratio at mid height of section. It was also observed that outward local buckles in the thin-walled steel tubes were accompanied by shear failure of core concrete, and these were observed from the top to middle parts of the columns. T. Sheehan et al.(2012) investigated Structural response of concrete-filled elliptical steel hollow sections under eccentric compression [10] . Laboratory test were carried out using eight stub columns of two different tube wall thicknesses and axial compression force was applied under various eccentricities and full 3D finite element model was developed, comparing the effect of different material constitutive models, until good agreement was found. Specimens failed by local buckling of the steel on the compression side. Specimen such as MA100-5 and MI25-5 buckled at the mid height whereas other specimens buckled at lower location. From the above literatures, it is evident that local buckling occurred at the ends of the specimens in most of the case. Concrete-filled double steel tubular column made of outer non-compact or slender steel section is susceptible to local buckling whereas Global buckling occurred in cold formed stainless steel circular hollow section columns. The buckling deformation of the unstiffened wall was significantly larger than that of stiffened walls.

2.2 Load Carrying Capacity

Yong Ye et al.(2018) carried out studies on square concrete-filled stainless steel/carbon steel bimetallic tubular stub columns under axial compression [1]**.** Fourteen CFBT columns and two conventional concrete-filled steel tubular (CFST) counterparts were tested to failure under axial compressive loading and a finite element analysis (FEA) model was established and validated against the experimental measurements. As the cross-sectional area of the stainless steel tube layer increases, the axial load carried by the stainless steel tube layer increases accordingly. When thickness of steel tube increases from 0.84 to 1.88 load carrying capacity increases as 1200 KN and 2500 KN respectively. On the other hand, different stainless steel grades (316, 304, and 202) seem to have minor influence on the overall behavior and load-carrying capacity of CFBT columns, mainly due to the similar mechanical performance of the three grades of stainless steel. M.F. Hassanein et al.(2018) carried out studies on finite element modeling of concrete-filled double-skin short compression members with CHS outer and SHS inner tubes [2]. FE models with concentric axial loads are developed and compared against results from past experiments. The behaviour of CFST specimens was analysed with various steel yield strengths ranging from 350 to 700, 1050 and 1400MPa. Four curves of steel yield strengths 350, 700, 1050, and 1400 was plotted as shown in Fig.6 and the results showed that increasing the steel yield strength considerably improves the axial capacity of CFDST short columns.

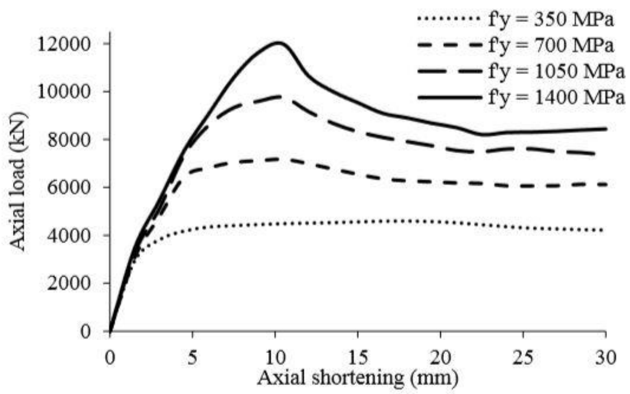

Fig.6: Axial Load-Displacement curves for CFDST with different steel yield strength [2]

A nonlinear analysis of rectangular concrete-filled double steel tubular short columns incorporating local buckling was carried out by Mizan Ahmed et al. (2018) Comparative studies are undertaken to verify the fiber-based model with the relevant test results [4]. The computational model is then employed to investigate the axial load–strain responses of rectangular CFDST short columns with various key design variables. The author concluded that the load carrying capacity of axially loaded CFDST short column increases with the compressive strength of concrete is increasing. Craig Buchanan et al. carried out studies on testing, simulation and design of cold-formed stainless steel circular hollow section (SHS) columns. A comprehensive experimental program had been undertaken to provide benchmark data to validate numerical models and underpin the development of revised buckling curves; in total 17 austenitic, 9 duplex and 11 ferritic stainless steel CHS column buckling tests and 10 stub column tests have been carried out.

Five different cross-section sizes (covering class 1 to class 4 sections) and a wide range of member slendernesses had been examined. The load carrying capacity for specimens 106×3, 104×2, 88.9×2.6 and 80×1.5 was 260KN, 240KN, 430KN and 120KN respectively. It showed that load carrying capacity of 88.9×2.6-400-P SHS column had maximum load carrying capacity than any other column.

From the studies conducted by Hua Yang et al. (2017) on behaviours of concrete-filled cold-formed elliptical hollow section beam-columns with varying aspect ratios, it was found that the load-carrying capacity of the elliptical CFST columns decreases with the increase in load eccentricity [6]. A total of 11 specimens were tested to evaluate the failure modes, load-deformation histories and strains development in the steel tube. Assessing the stub column specimens S-8, for example, the load-carrying capacity of the column with 25 mm and 50 mm eccentricity decreases by 24.7% and 44.4%, respectively, relative to that of the axially loaded stub column. The load-carrying capacity significantly decreases with the increase of slenderness ratio. Assessing the specimens with a load eccentricity of 25 mm for example, the load-carrying capacity decreases by 15.6% and 29.7% for columns with slenderness ratio of 35 and 50, respectively, relative to that of the stub column ($\lambda = 8$). Zhi-Bin Wang et al. (2018) carried out study on axial compressive behaviour of concrete-filled double-tube (CFSDT) stub columns with stiffeners [9]. A total of 14 stub columns were prepared and tested, including 12 CFSDT stub columns and 2 thin-walled CFST counterparts. The author concluded that the load carrying capacity of CFSDT stub column increases with increase in compressive strength of column. The axial load carrying capacity for compressive strength of 42.1 MPa was found to be 2500KN whereas for compressive strength of 69.8 MPa was 3300KN. The measured compressive strengths (Nue) of all the stub columns are compared in Fig. 7.

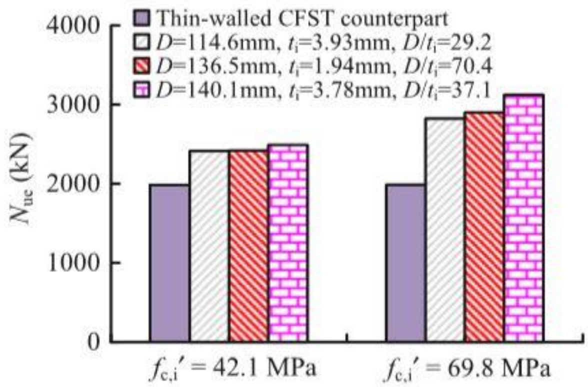

Fig.7: Effects of different variables on ultimate strength [9]

Qihan shen et al.(2018) conducted studies on performance and design of eccentrically-loaded concrete-filled round-ended elliptical hollow section stub columns [11]. A nonlinear numerical model that adopts an equivalent stress-strain model for the novel type of confined core concrete was established, and verified via experimental data. Steel hollow sections with various nominal yield stress (i.e. 235, 345, 420, and 550 MPa) were examined to determine the effect of the material properties on the eccentric compressive performance of CFREHS stub column. The results showed that eccentric load bearing capacity of this type of stub composite column increased with an increase in the steel strength. An investigation of the effect of the cross-sectional area was also conducted and the results suggested that the eccentric load bearing capacities of the CFREHS stub column evidently improved as the cross-sectional area increased, although the steel ratios was constant. T. Sheehan et al.(2012) investigated Structural response of concrete-filled elliptical steel hollow sections under eccentric compression [10]. Laboratory test were carried out using eight stub columns of two different tube wall thicknesses and axial compression force was applied under various eccentricities and full 3D finite element model was developed. Axial load-displacement curves were plotted. For test specimens MA100-6.3 and MA100-5, only a slight decrease occurs in axial load after yield. Specimens M175-6.3 and M175-5 yield at significantly lower loads than the major axis bending specimens and undergo gradual decrease in axial load under increasing axial displacement.

The load carrying capacity of square concrete-filled stainless steel/carbon steel bimetallic tubular stub column increases with increase in thickness and cross-sectional area of steel tube. In concrete-filled double steel tube column, increasing the steel yield strength and concrete compressive strength considerably improves the axial capacity of CFDST short columns. Load carrying capacity of the elliptical Cold-formed steel tube columns decreases with the increase in load eccentricity.

III. Conclusions

Based on the study done, it can be concluded that Concrete-filled steel tube column can be effectively used as it can increase the load carrying capacity of column when properly designed with efficient design parameters such as depth to thickness ratio, length to depth ratio, concrete compressive strength, shape of column and cross-sectional area. Apart from load carrying capacity, Special considerations have to be made on buckling behaviour of column as it faces local and global buckling.

References

[1] Young Ye, Shi-Jiang Zhang, Lin-Hai Han and Yang Liu, "Square concrete filled stainless steel/carbon steel bimetallic tubular stub columns under axial compression", Journal of constructional steel research, 146, pp.49-62, 2018.

[2] Hessanein M.F., Elchalakani M., Karrech A., Patel V.I. and Daher E., "Finite element modeling of concrete-filled double-skin short compression members with CHS outer and SHS inner tubes", Marine Structures, 61, pp.85-99, 2018.

[3] Craig Buchanan, Esther R. and Leroy G., "Testing, simulation and design of cold-formed stainless steel CHS columns", Thin-walled structures 130, pp.297-312, 2018.

[4] Mizan Ahmeda, Qing Quan Lianga, Vipulkumar Ishvarbhai Patelb and Muhammad N.S. Hadic, "Nonlinear analysis of rectangular concrete-filled double steel tubular short columns incorporating local buckling", Engineering Structures 175, pp.13-26, 2018.

[5] Zhu Aizhu, Xiaowu Zhang, Hongping zhu, Jihua Zhu and Yong Lu., "Experimental study of concrete filled cold-formed steel tubular stub columns", Journal of constructional steel research 134, pp.17-27, 2017.

[6] Yang Hau, Faqi Liu, Tak-ming Chan and Wei Wang., "Behaviours of concrete-filled cold-formed elliptical hollow section beam-columns with varying aspect ratios", Thin-walled Structures 120, pp. 9-28, 2017.

[7] Wang Z. -B., Tao Z. & Yu, Q., "Axial compressive behaviour of concrete-filled double-tube stub columns with stiffeners", Thin-Walled Structures, 120(11), pp.91-104, 2017.

[8] Liu Faqi, Yuyin Wang and Tak-ming Chan., "Behaviour of concrete-filled cold-formed elliptical hollow sections with varying aspect ratios", Thin-walled structures 110, pp.47-61, 2017.

[9] Shen Qihan, Jingfeng Wang, Wanqian and Zhibin Wang., "Performance and design of eccentrically-loaded concrete-filled round-ended elliptical hollow section stub columns", Journal of Constructional Steel Research 150, pp. 99-114, 2018.

[10] Sheehan T, X.H. Dai, T.M. Chan and D. Lam, "Structural response of concrete-filled elliptical steel hollow sections under eccentric compression", Engineering Structures 45, pp. 314-323, 2012.

[11] Teh-Hsuan Hu, Chiung-Shiann Huang, Ming-Hsien Wu and Yih-Min Wu., "Nonlinear analysis of Axially Loaded Concrete-Filled Tube columns with confinement Effect", Journal of Structural Engineering 129, pp.1322-2329, October 2003.

[12] Young B. and Ehab Ellobody., "Experimental Investigation of Concrete-filled Cold-formed high strength stainless steel tube columns", Journal of Constructional Steel Research 62, pp.484-492, August 2006.

[13] Umar Ayaz Lone, Megha Gupta, "Review paper on Self healing Concrete", International Journal of Technical Innovation in Modern Engineering & Science, Vol 5, Issue 2, pp.252 – 256, April 2019.

[14] Faizan Rahman, Nishant Kumar, "Voided reinforced concrete slabs: a step towards sustainable development", International Journal of Technical Innovation in Modern Engineering & Science, Vol 5, Issue 2, pp.478 – 480, April 2019.