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Behaviour of Steel Concrete Composite Columns - A Review

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Abstract*: Steel-concrete composite columns are used extensively in high rise building and bridges, as a type of hybrid system. However this approach is a relatively new concept for construction industry. In concrete-filled steel tube (CFST) columns, the steel tube provides formwork for the concrete; the concrete prevents local buckling of the steel tube wall. The load carrying capacity and behavior in compression, bending and shear are all superior to reinforced concrete. This paper deals with review of the literature studied until now.*

1. Introduction

A composite column is a structural member that uses a combination of structural steel shapes, pipes or tubes with or without reinforcing steel bars and reinforced concrete to provide adequate load carrying capacity to sustain either axial compressive loads alone or a combination of axial loads and bending moments. The interactive and integral behavior of concrete and the structural steel elements makes the composite column a very cost effective and structural efficient member among the wide range of structural elements in building and bridge constructions. A typical example of a composite column subjected to bending moments around two major perpendicular axes due to wind, earthquake, or unbalanced live loads and in combination with axial compressible loads could be found in bridge piers and at the corners of a three-dimensional building frame. We could also find those columns subjected to bending moments in combination with axial tensile loads, in which case it would be necessary to have a design method that includes the overall range of combinations of axial load and bending moments. CFST columns have several advantages over the conventional reinforced concrete and structural steel columns. Firstly, the concrete infill is confined by the steel tube. This confinement effect increases the strength and ductility of the concrete core in rectangular steel tubes. Secondly, the concrete infill delays local buckling of the steel tube. Thirdly, the combined capacity of the steel and concrete significantly increases the stiffness and ultimate strength of CFST columns which makes them very suitable for columns and other compressive members. Finally, the steel tube serves as longitudinal reinforcement and permanent formwork for the concrete core, which results in rapid construction and significant saving in materials. The steel tube can also support a considerable amount of construction and permanent loads prior to the pumping of wet concrete. The in-filled concrete effectively prevents the inward local buckling of the steel tube so that the steel tube walls can only buckle locally outward. The local buckling modes of hollow columns and CFST box columns are depicted.

Concrete-filled steel tubes (CFST) are composite structures of steel tube and in-filled concrete. These members are ideally suited for all applications because of their effective usage of construction materials. Application of CFST concept can lead to 60% total saving of steel in comparison to a structural steel system concrete core enhances higher compressive strength, stiffness, damping and tensile strength by outer steel tube. Moreover, high strength CFST columns require a smaller cross-section to withstand load which is appreciated by architects and building engineers. The behaviour of CFST members in bending, shear, compression and fatigue resistance under cyclic seismic loading are also superior over reinforced members, hence widely used in earth-quake zones1. The steel concrete composite columns have several advantages such as high axial load carrying capacity, good ductility performance, energy absorption capacity ad high fire resistance as well as fast construction. First research on CFST members was started by 20th century which mainly concentrated on strength capacity2. Furthermore, recent research focused on the use of high strength concrete which enhances the capacity of the section3-4. Behaviour and strength of materials are affected by the bond between steel and concrete, strength of materials, fire resistance, and confinement of concrete.

The development of CFST members adds structural properties to the composite action. In which concrete core stiffened the steel tube and prevents the inward buckling. The steel tube acts as longitudinal and transverse reinforcement and also provides confining pressure to the concrete, which puts the concrete under a triaxial state of stress. The ultimate strength of CFST members depends on compressive strength of concrete and yield strength of steel tube. Performed tests on twelve beams of concrete-filled steel square and rectangular hollow sections for determining the effects of different depth to width ratios and different values of shear span to depth ratio. The test results showed that the ultimate flexural strengths of the composite beams are increased by about 10%-30% over that of bare steel sections. CFST members are not only good in taking compressive force but also having capacity to resist tensile forces. Research by proved that tensile strength of circular CFST members is improved by 10% than hollow steel tubes.

Different researcher included that confinement effectiveness is higher for circular steel tubes than rectangular or square steel tubes. The behaviour of short axially loaded concrete-filled steel tube columns. Fourteen specimens where tested to examine the effect of the tube shape and plate thickness of the steel tube on the column strength. It was found that circular steel tubes offer much post-yield axial ductility than square and rectangular tube sections. For this analytical study, three codes such as American Institute of Steel construction (AISC), American Concrete Institute (ACI) and Eurocode (EC4) are used and comparison was made between them. Main purpose of this study is to study the influence of D/t ratio and L/D ratio of steel tube on the compressive behaviour.

2. Literature Review

There are many researchers have been carried out on CFST section for investigating its behavior with considering parameters like grade of concrete, cross-sectional shape, Diameter to thickness (D/t) ratio and length to width (L/D) ratio. This section summarizes various studies carried out on CFST section.

Lia-Hai Han et al. (2011), have investigated the tensile behaviour of CFST section considering parameters such as steel ratio and type of concrete. Tensile behaviour of CFST section was examined by experimentally as well as developing a finite element model. The study found that the tensile strength of CFST section is more than the hollow steel tube and it was further increased by filling SFRC concrete into steel tube. Researchers had also proposed a simplified formula for calculating tensile strength of CFST section and it gives good agreement between calculated and tested results.

Jingfeng Wang, Na Zhang (2017), This paper investigated performance of circular concrete filled steel tubular (CFST) column to steel beam joints with blind bolts. Four monotonic loading tests were conducted on the flush or extended end plate joints to circular CFST columns with blind bolts. A nonlinear finite element (FE) modeling study on the circular CFST column joints under static loading was developed, in considering contact interaction, material model and analysis steps etc. The accuracy of the FE models was examined by the experimental results in the field of moment rotation relationships and failure modes. Massive parametric analysis was utilized to explore the effects of axial level, bolt diameter and anchorage length ratio etc. on the ultimate moment capacity and the initial stiffness of the novel connections. The test and 3D elasto-plasticity numerical analysis results indicated that the circular CFST column joints could be regarded as semi-rigid and partial or full strength. Effective methods including anchorage and stiffening strengthening were also discussed in this paper to promote the engineering application of circular CFST column joints with blind bolts.

Jingfeng Wang, Beibei Li, Jinchao Li (2017), An experimental and numerical research on the seismic performance of semi-rigid concrete-filled steel tubular (CFST) frames with external sandwich composite wall panels (SCWPs) was reported. Four specimens of semi-rigid CFST frames with external SCWPs and one specimen of pure semi-rigid CFST frame subjected to low-cyclic loading were conducted. Failure modes, horizontal load versus displacement relation curves were analyzed. The test specimens exhibited good hysteretic behavior, energy dissipation and ductility. Finite element (FE) analysis modeling was developed and the results obtained from the FE model matched well with the experimental results. Extensive parametric studies have been carried out to investigate the effect of steel strength, column slenderness ratio and steel wire diameter of wall, etc. on the strength and stiffness of the typed composite frames. The opening ratio and location of the SCWPs were also discussed. The experimental study and numerical analysis will provide the scientific basis for design theory and application of the SCWPs in fabricated steel structure building.

Y. F. Yang, L. H. Han (2012), have examined the behavior of CFST under partial compression by considering different parameters, namely cross sectional shape, length to diameter ratio and partial compression area ratio. The study was carried out by testing twenty-six specimens of CFST by varying the above parameters and their behavior was also verified by developing a finite element model using ABAQUS software. The study shows that the behaviour of partial compressed CFST section is similar to the behaviour of fully compressed CFST section. Also, it is possible to predict strength of partial compressed CFST section using mathematical model proposed by researchers.

Chen Shiming, Zhang Huifeng (2012), studied the compressive behavior of circular CFST section with provision of the separation gap between inner concrete core and steel tube. Study is carried out with different parameters such as gap depth, strength of concrete, yield stress of steel, thickness of steel tube and eccentricity of the load. The Finite Element model is developed by using ABAQUS software and their results are compared with test results. The results indicate that the strength of CFST section decreases with increasing depth of the gap and eccentricity of the load. Also, it is observed that the thickness of steel tube helps to improve the strength of CFST section due to confinement effect.

Farid Abed et al. (2013), studied the compressive behaviour of circular CFST column filled with different concrete grades and varying D/t ratios. The experimental results of study were compared with analytical method proposed by various codes namely EC-4,ACI-318,AISC-2005and AS. From these studies researchers have concluded that for higher D/t ratio, reduction in compressive strength of CFST section occurs due to less confinement. The study also shows that for the higher D/t ratio there is less deviation observed in experimental and analytical results. Experimental results of this study were also verified using ABAQUS software and there is found to be a good agreement in-between both results.

Kalingarani et al. (2014), investigated the compressive behavior of slender CFST columns by analytically using various available codes, namely EC4, ACI-318 and AISC- 2005.The study was carried out by varying diameter to thickness (D/t) and length to width (L/D) ratio. Analytical results obtained by using codal method indicates that for an increased D/t ratio keeping diameter constant, compressive strength of CFST section was decreased due to less confinements also reduction in compressive strength occurs for increased L/D ratio due to slenderness effect.

B. R. Niranjan, Eramma H.(2014), studied the compressive behavior of triangular and rectangular fluted reinforced circular CFST column with varying length to width (L/D) ratio. The compressive strength of CFST columns were obtained by experimentally and analytically. Analytical results of CFST column calculated using codes EC-4, ACI- 318 and AISC. In this study the experimental strength results of CFST columns were founds higher than the analytical strength results calculated from methods given in above codes; hence the researchers had suggested that the equations given in above codes cannot be directly used to calculate the compressive strength of the fluted CFST column.

Burak Evirgen et al. (2014), they investigated the compressive behavior of CFST section considering various cross-sectional shapes like circular, hexagonal, rectangular and square. Experimental study was carried out by varying B/t (Breadth to thickness) ratio and grades of concrete. The obtained results of experimental study were compared with software results calculated by developing a finite element model using ABAQUS software. In this study, researchers observed that the concrete core of CFST resists the inward buckling of steel tube and steel tube provides better confinement to concrete core which results increase in the strength of CFST section. The study also shows that the ductility of the circular CSFT section is more than hexagonal, rectangular and square CFST sections.

M. F. Hassanein, O. F. Kharoob (2014), studied the compressive behaviour of double skin concrete filled steel tube circular short columns with varying diameter to thickness (D/t) ratio. In this study many previously developed equations were referred to calculate the strength of Concrete Filled Double Skin Tube (CFDST). Obtained results of these equations were compared with test results and by developing a finite element model using ABAQUS software. After comparison, it was found to be a less agreement in-between both analytical and experimental result values, hence researchers had derived new equation for finding strength of the CFDST short column.

X. H. Dai et al. (2014), investigated the compressive behavior of elliptical slender CFST section. A Complete behavioral study carried out by developing a finite element model using ABAQUS software and these software results of elliptical CFST sections compared with several test results for validation and accuracy. The researchers have also calculated the buckling load of elliptical section according to the specification given in Euro Code – 4 for rectangular and circular CFST section and it is concluded that the design method given in EC-4 for finding the axial compression behavior of circular and rectangular CFST section may be used for the elliptical CFST section.

Qing-Xin Ren et. al. (2014), examined the compressive behavior of CFST stub column considering special-shaped cross section, namely triangular, fan shaped, D-shaped, ¼ circular and semicircular for constant outer perimeter. This study mainly focused on the effect of thickness of steel tube and infill concrete on the behavior of composite column. There were about 44 specimens tested of special-shaped cross section including a hollow steel tube section. Test results are also compared with the results of Eurocode-4 and DBJ/T13-51-2010 and found reasonable variations. It is shown in this study that the failure of special sections was also occurred due to outward buckling in the middle of section. This study also shows that the strength of special cross sections was increased in the order of triangular, semicircular, fan shaped, D-shaped, ¼ circular and circular sections.

3. Conclusion

With the advent of steel and reinforced concrete, the concepts in construction has changed from one of securing stability to that of stressing the materials to the optimum values. This has resulted in very light structures compared to the pre-19th century constructions. This has been made possible by eliminating in the newer materials, the short comings of poor tensile strength of the traditional materials. In order to critically evaluate the research works done in the area of concrete filled steel tubular composite columns, a detailed review of literature in the field of CFST column has been undertaken. The state-of-the-art research on CFST column has been critically reviewed and grouped under various categories. They are presented in the following sections. The history of the first application of composite columns in construction industry dates back to the 1940's. The year 1970 marked the evolution of concrete filled steel tubes in Japan and this practice was followed by many countries around the world. On the basis of the research results, many countries have developed their design codes for use by their engineers. The current design standards and specifications have originated either from the steel or concrete design approach of that time.

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