Finite Element Analysis of Circular Concrete Filled Steel Tube: A review

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Abstract - *This paper presents a review on research performed on performance of concrete filled steel tube (CFST). This paper begins with the effect of confining effect of concrete in steel tubes of different shapes. Then the focus of the discussion turns to the performance of CFST under eccentric load done experimentally. Due to the need of high strength members, research on reinforced CFST is also seen. Analytical constitutive models have proven to be very effective for analysis of its performance and effects of different parameters. Then the paper concludes with the use of CFST in different areas of construction like truss members. With proper design and planning, CFST can be used very effectively for excellent performance of the structure both efficiently and effectively.*

Key Words: review, concrete filled steel tube, passive confinement, composite, confined concrete.

1. INTRODUCTION

In the current era, there is less availability of space due to which the structural members are reduced to the least possible dimensions and self-weight thanks to the high strength concrete (HPC). But the brittleness of concrete increases with the strength of the same. To overcome this drawback, the ductility of concrete is increased by two methods i.e. passive confinement and active confinement. Active confinement is done by providing lateral pre-stressing creating initial confining stress in the structural member. In this the confining stress is effective from the start. Passive confinement is done by restraining the lateral strain which increases from zero with the magnitude of the lateral strain. In the latter case, confining stress depends upon the lateral strain and lateral strain which in turn is dependent on confining stress, which makes it complicated to calculate the confining stress. In previous studies and as recommended by IS 456:2000 lateral confinement is done by providing transverse reinforcement or shear reinforcement. The arching action in transverse reinforcement develops the confining stress in RCC member. But there are limitations to it like:

i. Closely spaced transverse reinforcement creates congestion creating difficulty while concreting.
ii. Confining stress decreases with the increase in distance from the bends in transverse reinforcement.

Another method of providing passive confinement is to confine the concrete in steel tubes also known as concrete filled steel tubes (CFST) or steel encased concrete. This technique removes both the above limitations, no requirement of framework, increased ductility of structure and decreasing danger of falling of cracked concrete in case of its failure. This technique also prevents the concrete from carbonation of concrete from the carbon dioxide in air. Due to the above stated reasons it is better to prefer latter method over the first one. This passive confinement increases the ductility of the concrete but on the other decreases the strength of steel resulting in overall increase of strength of the composite.

The Poisson's ratio of concrete is less than Poisson's ratio of steel (0.2 and 0.3) at the beginning of elastic stage resulting in delamination of the concrete occurs at the beginning. After the commencement of the splitting cracks in the confined concrete, dilatency of concrete starts increasing resulting in variation of hoop stress of CFST quite complicated.

The steel tube in concrete filled steel tube composite provides the passive confinement to the concrete. This confining stress and lateral strain in the composite are inter-related which makes it difficult to calculate the same. To avoid this hurdle stresses and lateral strain are considered to be uniform along the lateral directions in the cross section. This assumption is preferred in CFST with circular cross section. In case of other shapes like rectangle the cross section is not uniform. There is extra confinement at the corners due to arching action provided by the tube and bending stresses at the middle part of edges.

2. LITERATURE REVIEW

There has been a lot of research done in this field regarding its compressive strength, bond behaviour, flexural strength, tensile strength and a lot more. Along with the experimental research, analytical research like FEM modelling on commercially available softwares ABAQUS and ANSYS has been done. CFST have proven to be very effective under various loadings.

Stephen P. Schneider (1998) presented a paper on the experimental and analytical study on behaviour of short CFST columns. The main focus of the research was on the effect of thickness and depth to wall thickness ratio of the steel tube on the ultimate strength of the composite column. Non-linear finite element models were also developed using ABAQUS 1994 using 20 node brick element for the concrete core and an 8 node shell element for the steel tube. 15 finite-element models were studied for large diameter tubes.
Susantha et al. (2001) investigated to predict the stress-strain curve for the concrete that is subjected to tri-axial

compression caused by axial load and lateral compression due to confinement in steel tubes of different shapes (circular, box and octagonal). Finite element models were created to propose an empirical formula for the calculation of confining pressure in the tube. It was found that the predicted post-peak behavior and confined concrete strength were comparable to the obtained test results within acceptable limits. It was also observed that the highest confinement of concrete was present in circular followed by octagonal and least in box type shape Fujimoto et al. (2004) investigated the effects of depth to thickness ratio, different shapes of cross section and the combinations of different strengths of steel tube and concrete using 65 eccentric compression tests. It was concluded that the use of high strength concrete in CFST decreases the ductility of CFST and at small depth-to-thickness ratio, the ductility of sample is generally improved due to confining of concrete.

Ho et al. (2010) studied the effectiveness of confinement on the flexural ductility of high strength concrete (HSC). This study used the nonlinear moment-curvature analysis considering stress-path dependence of stress reinforcement. Using analytical results, it was concluded that the confinement enhances the flexural ductility of the CFST member through increased balanced steel ratio and balanced axial load. It was also concluded that as the concrete strength and axial load level increases, the effectiveness of the confinement on flexural ductility on CFST decreases.

Qu et al. (2013) demonstrated the behavior of rectangular CFST columns subjected to eccentric loading. A series of 17 rectangular CFST specimens were tested under uniaxial and biaxial bending load. The main variables in the research were eccentricity, concrete strength, cross-sectional area and steel strength. The effect of eccentric ratio and constraining factor in relation to the strength were examined. Finite element method was used to find the necessary concrete contribution ratio for rectangular CFST columns to resist the eccentric loading. The load versus lateral displacement and load versus vertical displacement graphs were plotted and analyzed. It was concluded that with increasing constraining index, the strength index increases while the ductility index decreases. It was concluded that the circular CFST sample shows more post-yield axial ductility in comparison to their square and rectangular counterparts. It was also seen that after reaching 92%of yield strength of column, only then substantial confinement of concrete takes its course.

Chen et al. (2014) presented the experimental behavior of reinforced concrete-filled steel tubes embedded with steel angles and reinforcing bars subjected to eccentric tension. A total of 8 specimens were designed and cast for the purpose of experiment. The main parameters of the research were the load eccentricity, connection pattern and the cross section of the sample. As there was no direct contact between steel tube and reinforcement, tensile stresses were transferred through the infilled concrete. Height versus lateral displacement were drawn using the recorded data from results. This paper proposed design equations to predict the stiffness and tension-moment interaction relationship of reinforced CFST under eccentric tension.
Dong et al. (2015) studied the lateral strain of confined concrete from elastic stage and pre-crack to inelastic state and post-crack state. It was hypothesized that elastic strain depends on three parameters are the concrete strength, axial strain in the longitudinal direction (or the axial strain) and the confining stress in that lateral direction. Regression analysis was done using previously available experimental data to generate the equation for calculating total strain in the lateral direction. It was found that the proposed model could be a very useful tool in predicting the lateral strain of CFST
Zhan et al. (2016) demonstrated the behavior of pre-stressed concrete filled steel tube beam under flexural loading. In this paper 8 pre-stressed CFST beams of 300 X 450 mm size were cast with two different concrete strengths (C50 and C60) and prestressing ratio (0.26 and 0.40). To improve the performance of samples full vibration and grouting techniques were used. A model was proposed considering the confinement effect and was compared with the experimental data. It was concluded that the cracking moment capacity was increased up to 400% in case of pre-stressed than that of non-prestressed CFST sample when derived using plastic stress distribution method. It was also found that width-to-thickness ratio has considerable effect on the ultimate moment capacity and loading pattern has an impact on local buckling.

Talha Ekmekyapar (2016) investigated the performance of the laterally and longitudinally welded CFST column members. Results of 18 test results with different D/t ratios, L/D ratios and lateral weld locations were presented. It was found that seam weld failures have a little effect on capacity and failure mode but reduce ductility. It was also deduced that lateral weld joints have great potential in transmitting the bending effects and compression.

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Tao et al. (2016) presented the bond behavior between steel tube and concrete in the CFST sample using a number of push-out tests on square and circular CFST samples. This studies main parameters were:

i. Steel (carbon and stainless steel.
ii. Concrete (recycled aggregate, conventional and expansive concrete).
iii. Dimensions of cross-section.
iv. Interface (normal interface, interface with an internal ring and interface with shear studs).
v. Age of concrete

It was concluded that the bond between stainless steel tube and concrete is 32% to 69% is less than that of carbon steel tube and concrete due to the smoothness of stainless steel. With increasing age and dimensions of CFST, the bond between the tube and concrete core becomes less. It was also found that the bond strength between tube and concrete can be significantly improved by using welded internal ring onto the inside surface of tube followed by the welded shear studs onto the same.

Kwan et al. (2016) proposed a theoretical model for evaluating the confining stress and lateral strain in CFST at various stages of loading. The proposed model was validated by comparing the analytical results with the experimental results of other researchers. After validation, this model was used to study the required thickness to diameter ratio of steel tube for various degrees of ductility.

Huang et al. (2017) investigated the effect of interfacial imperfection on the flexural behavior of CFST used as truss. A series of 4 experimental truss models with different interfacial imperfections were created in order to be tested under four-point bending. Finite element models were also developed for mechanical analysis. It was found that the ultimate loading capacity of the CFST truss models with 100% interfacial separation, 10% depth and 20% depth and are 9.2%, 18% and 37.7% respectively lower than the model with 100% bonded concrete and steel tube. Therefore, proving the significance of interfacial imperfections on the ultimate loading capacity. Results of finite element models showed that the effect of depth separation on the ultimate loading capacity is more noteworthy than the effect of interfacial imperfection and the ultimate load of models with depth separation of 10% and 20% is 13% and 33% smaller than that of model with no depth separation.

Wang et al. (2017) conducted an experimental investigation on behavior of large sized CFST under blast load. For the purpose of the same 4 samples of circular and square cross section each were cast and were tested under close-range blasts load. Three displacement gauges i.e. LVDT's and pressure sensors were used to measure displacement and pressure histories. The main parameters of the study were failure mode, steel tube thickness, cross section geometry and explosive charge weight on dynamic response of CFST columns. It was concluded that even after close-range blasts, CFST column retain most of its axial load capacity.

Zhou et al. (2017) demonstrated the behavior of concrete filled stainless steel tubular truss. A total number of three circular concrete filled stainless steel tubular truss (top chord filled, bottom chord filled and top and bottom chord filled) and one hollow circular stainless steel tubular truss were tested under static load. The overall deflections, failure modes, load carrying capacity, load-strain curves and load versus displacement curves were plotted. It was found that the ductility of truss of concrete filled in top chord has best ductility. On the other hand, truss of concrete filled in top and bottom chord has best flexural rigidity and ultimate load carrying capacity per unit truss weight.

3. CONCLUSIONS

This paper was mainly focused on the advancement in CFST type of construction system. In these previous two decades, lot of experimental analysis has been done under various loading. These experimental results can be used to validate the finite element models of specimen in commercially available software like ANSYS and ABAQUS. Currently, there are no design criteria available in INDIA for CFST type of construction system but using these experimental data and analytical models design criteria can be proposed.

Advantages and disadvantages of CFST

1. In this system (CFST), by confining the concrete core, steel tube act as the transverse reinforcement and longitudinal reinforcement both at the same time.

2.Steel tube in the CFST also acts as the permanent formwork and omission of reinforcing bars decreases the construction time and cost. Tailor et al. performed cost analysis and concluded that CFST is better than steel in terms of cost [14]. Reduction in use of wood as formwork also serves the purpose of being environmental friendly.

3.The confining stress in the concrete core produced by steel tube delays the micro cracks formation and reduces the splitting crack width [12].

4. As the Poisson's ratio of concrete is less than steel (0.18 and 0.3 respectively) at the initial elastic stage, the hoop stress in steel tube is quite small and becomes noticeable when dilatency of concrete is larger than before and becomes inelastic [11]. Due to this difference in stresses and Poisson's ratio delamination of concrete from steel becomes a permanent problem which decreases the effectiveness of confinement of concrete [8].

5.In CFST type of construction as the concrete is not exposed to surroundings the degradation of concrete due to carbonation, chlorination, moisture permeability becomes obsolete.

6.CFST columns does offer a great performance compared to normal RCC construction but as the slenderness on CFST column increases the buckling failure dominates the specimen. In RCC construction reinforcement is embedded in the concrete which prevents the reinforcing bars from buckling under compressive stresses.

7.Steel has high load carrying capacity at normal temperature but under high temperature it readily losses its load carrying capacity. As the steel in CFST is exposed to surrounding at high temperature it may not perform as well.

This does not happen in case of RCC construction as concrete prevents the embedded steel from heat.

8.In CFST system of construction steel is exposed to surrounding environment it is very much susceptible to corrosion.

In case of RCC construction the major problem is the brittle failure of concrete due to which there is high risk of life and property. But in case of CFST the concrete is confined by the steel tube due to which even if the concrete fails it will remain confined by the steel tube decreasing the risk of life and property

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BIOGRAPHIES

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