CHAPTER 2

REVIEW OF LITERATURE

2.1 GENERAL

A brief review of the research carried out during the last decade related to the behaviour of light gauge steel hollow and in-filled columns and beams subjected to axial load and eccentric loads is presented in this chapter. Literature pertaining to experimental and theoretical investigations is presented in the first part and literature pertaining to numerical investigation is presented in the second part.

2.2 STUDIES ON EXPERIMENTAL AND THEORETICAL INVESTIGATION

Rangan and Matthew (1992) tested 9 steel tubular columns filled with concrete. The length of the steel tube was varied. A method for calculating the strength of eccentrically loaded slender steel tubular concrete in filled column was presented. Based on the assumption that the failure load is said to have reached when the maximum moment at mid height of the column is equal to ultimate bending strength of cross section at location.

Bradford (1996) presented the behaviour of slender concrete filled RHS columns using the RC column approach. The strength of the section was established with load moment interaction curves and intersection of the load line for an eccentrically loaded column (the ultimate load was calculated from
the strength envelope of the section by setting resistance factors equal to unity) and compared with independent test results.

Wang and Moore (1997) suggested a design procedure for concrete filled composite columns suitable for manual calculations based on the recommendations given in BS 5950 for bare steel columns. The proposed method compared with the design codes such as BS5400 and EC4. The proposed method predicted the behaviour of composite columns reasonably well and it was much easier to use than the methods given in BS 5400 and EC4.

Local and post local buckling of concrete filled steel welded box columns were studied experimentally by Uy (1998). In this study, the concept of local buckling was described and this effects on the strength of concrete-filled steel column were illustrated. A semi-analytical finite strip method was developed including the beneficial effect of concrete and incorporating the true stress strain behaviour and the residual compressive and tensile stress produced by welding. Slenderness limits derived from the analysis were compared with existing Australian and British standards. It was observed that the local buckling results were similar to each other in the elastic range and differ from the model in the inelastic range. The residual stresses for heavily welded box columns were similar when calculated using Australian and British standards. In the finite strip method it was over estimated by 50% when compared with test results.

Schneider (1998) presented experimental and analytical studies on the behavior of short, concrete in filled steel tubular columns under concentric loads. Fourteen specimens were tested to study the effects of the shape of the steel tube and the wall thickness on the ultimate strength of the composite columns. The columns having depth to tube wall thickness ratio between 17 <
D/t < 50 and length to tube depth ratio between 4<l/D<5 were also investigated. Experimental results suggested that the circular tubes offered substantial post-yield strength and stiffness. All the circular tubes were classified as strain-hardening for small D/t ratios.

Brauns (1999) studied the basis of constitutive relationship of material components and the state of stress in composite columns. The factors taken into account were the dependence of modulus of elasticity and poison’s ratio on the stress levels in concrete. It was stated that the effect of confinement exist at high strength level, tension acts on structural steel and compression acts on concrete. In order to optimize the working conditions of composite columns and to prevent the possibility of failure of the columns in the case of small thickness and large eccentricities, appropriate strength classes of concrete and steel have to be used.

Natraja et al. (1999) formulated the stress strain curves for SFRC under compression. The compressive strength of concrete, volume fraction of fibers and aspect ratio of the fibers were the test parameters. An analytical model was also proposed to generate both the ascending and the descending portion of the stress-strain curves. It was found that the addition of crimped steel fibers increased the toughness and it was directly proportional to the reinforcing index. From the analytical investigation, an expression was derived which had good correlation with the experimental results. The toughness ratio calculated from the stress-strain curves based on the predicted equation matches with the experimental curves.

Zhang and Shahrooz (1999) examined the available data from the experimental results with the provisions in the two widely used ACI and AISC codes. Experimental data was collected for the specimens tested under combined axial load, shear force and bending moment. Each specimen
consisted of cold formed steel tube filled with normal concrete. When the impact of cold work on steel properties were taken into account, an additional capacity of 10% or less for reasonably sized steel tubes and for reasonable levels of axial loads were achieved. The capacities of the columns were also calculated by detailed analytical techniques involving cross section fiber analysis and numerical integration of the moment-curvature relationship along the length. The numerical investigation captured the behaviour of Concrete Filled steel Tube (CFT) columns reasonably well.

Uy (2000) investigated the strength and behavior of short columns under the combined action of compression and bending moment. An extensive set of experiments and numerical models where developed to calibrate the test results. The model was based on rigid plastic method of analysis considering the interaction of local buckling effect. It was observed that there was significant effect on thin-walled column due to local buckling and it was included in the modified rigid plastic analysis based on the methods of existing codes of practice where the plate slenderness limits were very large. In the conclusion, suggestions where made to allow for the inclusion of slender plated columns in design.

O’Shea et al. (2000) developed several design methods to estimate the strength of circular thin-walled concrete filled steel tubes under different loading conditions. The examined load condition included axial loading on steel tube only, concrete core only, simultaneous loading on steel and concrete core. Experimental results were compared with the proposed design methods. The test parameters were length to diameter ratio and diameter to thickness ratio and in-filled concrete strength. EC4 was used to verify the experimental values. The design methods given only un-conservative strength if used out side the calibrated range, but EC4 given correct values for the experimental results.
Uy (2001) conducted series of experiments to ascertain the long term properties of creep and shrinkage in concrete in filled steel columns. The test results revealed that the creep and shrinkage of concrete in side the steel columns are significantly lower than those of the exposed concrete. A predictive model based on ACI provision for both the service and ultimate load behaviour of the specimens was developed. The composite column was calibrated with the experimental results and the recommendations were made for the design.

Uy (2001) experimentally and analytically studied the behaviour of short concrete filled high strength box column. A comparison with EC4 was also presented. A mixed analysis technique, which treated the concrete as rigid plastic and the steel as linear elastic was described in this paper. While the numerical model gave fairly accurate results compared to the experimental results where as EC4 results were higher than the experimental results. Hence the mixed analysis approach was found to be conservative but reasonably estimated the column strengths and is suitable for design applications.

Han (2002) studied the behaviour of 24 concrete-filled steel rectangular stub columns subjected to axial load. The test parameters were constraining factor, strength index and the tube width to thickness ratios. Higher the constraining factor the bigger was the strength index and the ductility index was also higher. For higher width to thickness ratios, the strength index and ductility were found to be on the lower side. The experimental results were compared with the design provisions given in LRFD, AIJ, EC4, and GJB4142-2000. The GJB4142-2000 method gave a closer prediction of the test results than that of LRFD, EC4 and AIJ methods.

Huang et al. (2002) investigated the axial load behaviour of CFT columns with width to thickness ratios between 40 and 150 and proposed an
effective stiffening scheme to improve the mechanical properties of square CFT columns. Seventeen specimens were tested to examine the effects of shape of the cross section, width to thickness ratios and stiffening arrangements on the ultimate strength, stiffness and ductility of CFT columns. Non-linear FEA was also conducted to investigate the stress distribution across the section at the ultimate loads. Compared with the measured ultimate strengths, the estimated strength using the current specifications considerably underestimated the ultimate strength of circular CFT columns, particularly for columns with small width to thickness ratios. The stiffening scheme significantly enhanced the ultimate strength and ductility of the columns.

The mechanical behaviour of circular steel-concrete composite stub columns was studied experimentally and analytically by Johansson and Gylltoft (2002). A total of 13 stub columns were tested under axial loading. The concrete core exhibited greater compressive resistance than predicted due to the confinement of the steel tube. This effect was most pronounced for the stub column with no bond strength between the concrete core and the steel tube when the load was applied only to the concrete sections. The stiffness was also influenced by the increase in the bond strength for this loading condition. The increased bond strength resulted in the greater contribution from the steel tube i.e. the stiffness of the column was found to have increased. The force was applied on the entire section so that it undergoes the same deformation to ensure strain compatibility.

Liu et al. (2003) presented the ultimate capacity of the high strength rectangular concrete filled steel hollow section stub columns. Twenty two specimens with cross sectional aspect ratio of 1.00, 1.50 and 2.00 were tested under the axial compressive loading. The ultimate strengths obtained from the tests were compared with the values obtained from the design codes such as EC4, AISC and ACI. In the experimental results the circular and square
columns were taken more load before failure than the rectangular columns
due to the material yielding occurred first on the broader faces of the
rectangular steel sections. It was concluded that the rectangular steel hollow
sections provide lesser confinement to the core concrete than the square
hollow sections. In the theoretical comparison, EC4 closely predicted the
critical loads with a difference of 6%, while AISC and ACI under estimated
the critical loads by 16% and 14% respectively. It was noticed that the
strength of specimens decreased with the increase in the aspect ratio of the
cross section.

Liu (2004) examined the behaviour of 12 high strength rectangular
concrete filled steel columns subjected to eccentric loading. This study has
included the computation of their ductility performance, failure modes and
slenderness effects. The experimental results were compared with design
strengths predicted by the codes of practice EC4, ACI and AISC. The results
showed favorable ductility performance for the in-filled columns when the
slenderness ratio was around 20. Local buckling occurred at the ends and the
failure loads were reached with the local buckling at the mid heights when the
slenderness ratio was 50. For this case, EC4 was found to be slightly unsafe
whereas the ACI and AISC conservatively predicted the failure loads.

Lam and Williams (2004) conducted series of tests on short
composite columns and axial compressive loadings. The test parameters
considered were the grade of steel section and variation in the concrete
strength. Eighteen specimens were tested to derive the interaction between
steel and the concrete component. The steel concrete composite columns were
tested with and without applying grease inside the steel sections. The test
results exhibited that peak load was achieved at small shortening for columns
with low constrains factor and for high constraining factored column, the
ultimate load was obtained with large displacement. The test strength
exhibited that the effort of applying grease had no effect on low strength concrete and variation was 14% for high strength concrete in-filled columns. Comparing the test strength with theoretical values from the codes, EC4 over estimated by 20% where as ACI-3/8 under estimated the values marginally.

The strength and deformation of the short and slender concrete in filled steel tubular columns under the combined action of axial compression and bending moment was experimentally studied by Ramanagopal and Manoharan (2004). Sixteen circular columns were tested to study the influence of SFRC on their strength under axial and eccentric loads. The fiber reinforced concrete in-fill had moderate improvement on the load carrying capacity of columns under eccentric loading. At large slenderness ratios and eccentricity ratios FRC filled specimens showed 5 to 8% increase in the ultimate loads than the PCC in-filled specimen. The ductility of the SFRC in-filled columns had been slightly better than PCC in-filled specimens. PCC in-filled columns showed increased load carrying capacity than the hollow columns and sustained large strains and deformations.

Sakino et al. (2004) made extensive experimental studies on the performance of CFT columns with square and circular sections. The Japanese, “Recommendations for design and construction of concrete filled steel tubular structures” (Architectural Institute of Japan (AIJ) 1997) have been edited base on these investigations. A total of 114 specimens were tested in the experimental investigation on centrally loaded hollow and CFT short columns. The main experimental parameters were tube shape, tube tensile strength, tube diameter to thickness ratio and design concrete strength. A capacity reductions factor due to local buckling of the square steel tube walls were empirically derived in this research work. A stress strain model for a square steel tube was also formulated based on the experimental results.
The studies on the behaviour of thin walled Hollow Structural Steel (HSS) columns filled with self consolidated concrete were performed by Han and Yao (2004). Thirty eight HSS columns were tested with varying compaction methods, diameter to thickness ratios and load eccentricity ratios and compared with the column strengths obtained by using the codes of practice such as AISC-LRFD-1999, AIJ-1997, BS5400-1979, EC4-1994, DL5085 / T-1999 and GJB 4142-2000. In the experimental investigations, it was found that the entire specimen behaves in similar way irrespective of the vibration methods. The test strength of SCC columns was slightly lesser than the columns compacted by other means. The results also revealed that the ultimate strength of the columns compacted with poker vibrator were 1.4 to 6.8% and 8.3 to 14% higher than those columns compacted by hand and no compaction respectively. The design codes AISC-LRFD, AIJ, BS5400, EC4 and GJB 4142-2000 were conservative in predicting the strengths of the specimens.

Mursi and Uy (2004) presented the strength of short and slender concrete in filled high strength steel box columns. A numerical model was also developed to study the behaviour of column incorporating material and geometrical non-linearity. The local buckling effects depend on the slenderness of the component plates of the column and this plays larger role in considering the confinement effect of the concrete core. The full load deflection response of the columns before and after the peak were in extremely good agreement with the experimental results. In the theoretical approach EC4 has not provided any recommendations for the design of slender columns with the slender cross section. Hence a modified approach for the analysis has been provided in this paper for slender sections.

Ghannann et al. (2004) examined the failure modes of steel tubular columns of square, rectangular and circular section filled with normal and
light weight aggregate concrete. Thirty six full scale columns were tested under axial loads. The test results were illustrated with load-deflection and axial deformation curves. The hollow column failed by local buckling and in-filled columns failure by overall buckling. The columns with normal concrete in fill exhibited over all buckling with no signs of local buckling prior to failures. The columns with light weight aggregate concrete in fill showed more lateral and axial deformations than the hollow steel columns. Due to low specific gravity and thermal conductivity of light weight aggregate, it was found to be worth to replace the normal aggregate concrete by light weight concrete.

Motto et al. (2004) studied the behaviour of 33 circular and 32 square CFT columns under the eccentric loading. The test parameters for the circular section were D/t ratio, concrete strength and yield strength of steel, where as in the square specimens, the test parameters were B/t ratio, in-filled concrete strength and yield strength of steel. It was found that the high strength concrete filling caused reduction in the ductility of the circular CFT columns. A fiber analysis was also conducted to calculate the scale effect and confinement effect of concrete. By the fiber analysis it was reported that the bending behaviour of eccentrically loaded CFT columns had reasonable level of accuracy compared to the experiment results and the estimated ultimate strengths from the analysis coincided with the experimental results.

An experimental program on high strength rectangular concrete-filled steel hollow sections has been reported by Liu (2005). Twenty two specimens were tested keeping the in-fill material strength, cross sectional aspect ratio and volumetric steel to concrete ratio as the test variables. The results were compared with design specifications given in EC4, ACI and AISC. The test results manifested favorable ductility performance of the high strength composite columns. The strength improvement was adversely
affected by the aspect ratio of the cross section. Comparing the design codes, EC4, ACI and AISC conservatively estimated the ultimate capacities of the specimens by 1%, 9% and 11% respectively.

Liu and Gho (2005) conducted experimental investigations on 26 high-strength rectangular CFT columns subjected to axial compression. The test parameters were the material strength and the aspect ratios of the cross section. The authors also examined the test results with the design code provisions for ACI, AISC and EC4. A fiber model was also constructed to evaluate the non-linear axial load behaviour of the specimens. The studies showed that EC4 is not safe to predict the ultimate capacity, where as, ACI, AISC and the proposed fiber model conservatively estimated the failure loads by 7, 8 and 2% respectively.

Hatzigeorgiou and Beskos (2005) studied the optimum design of Fiber Reinforced Concrete filled (FRC) steel tubular columns. The study has taken into account the effects of confinement of concrete and steel fiber (micro) reinforcements. The design variables of the problem were the dimensions of the column and percentage of steel fibers and the constraints prescribed by the strength and stability requirements. An optimum methodology was prescribed for the economical and effective design of FRC filled steel tubular columns.

Hyun-Sik et al. (2005) studied the behaviour of circular and square stub columns filled with high strength concrete and Polymer Cement Concrete (PCC) under concentric loads. Twenty four specimens were tested to investigate the effects of variations in the tube shape, wall shape and concrete strength. The strength of normal concrete-filled stub columns were 2.00 to 3.05 times more than the reference hollow column and PCC in-filled columns having 1.48 to 2.22 more than the hollow column. The experimental values
were compared with the values calculated using KSSC, AISC, LRFD, CISC and EC4. It was observed that the ratio of the test results to calculated results were lower for PCC than for normal concrete. Circular steel tubular specimens filled with high strength polymer concrete did not show a sudden decline in load carrying capacity beyond ultimate load.

Helena and Knight (2005) conducted series of tests on hollow and in-filled cold formed steel sections subjected to axial and bending forces. Forty eight Medium sized concrete in filled columns were tested to study their strengths and the effects of the eccentric ratio. The experimental results showed that the provision of infill increases the load carrying capacity by 1.5 to 2 times and increase in the strength of in-fill from M20 and M30 increased the load carrying capacity by 1.5 times. The experimental results were compared with the existing design codes IS 801-1975, BS 5950, AISC-LRFD and EC4. For hollow columns the loads predicted by IS 801-1975 was on un-conservative, where as BS 5950-1987 and AISC-LRFD methods gave conservative results. For in-filled columns the theoretical load predicted by EC4 agreed well with the experimental results.

Han et al. (2005) investigated the behaviour of self consolidated concrete (SCC) filled hollow structural steel (HSS) stub columns subjected to axial loads. Fifty specimens were tested with the variation of test parameters such as section type, steel yield strength and the tube width to wall thickness ratio. An analytical model was also developed to study the section capacity and load-deformation characteristics. These results were compared with the experimental results obtained for both circular and square stub columns. The results showed that the results obtained from the mechanical model matched the experimental values. Comparisons were also made with the predicted section capacities using codes such as ACI-1999, AIJ-1997, AISC-LRFD-1999, BS 5400-1979 and EC4-1994. The design codes developed for normal
Concrete filled HSS stub columns were found to be valid for SCC-filled HSS stub columns.

Concrete in filled steel tubular bridge girders were studied by Mossahebi et al. (2005). This study described the new bridge system using the steel tubular in filled concrete as a replacement for the conventional girder. The CFT girder was the main load carrying element of the bridge. In the experimental results, it was found that the CFT exhibited good behaviour up to the ultimate load level. The in-fill precluded the local buckling of steel while the closed shape of the tube provided the torsional rigidly. The failure of the specimen was due to yielding of the steel tube followed by crushing of the slab deck. It was concluded that the proposed bridge system is suitable for shorter spans of less than 30m.

Zhang et al. (2005) examined the behaviour of steel tube and confined high strength concrete for concrete-filled RHS tubes. Fifty specimens were tested to study the steel ratio, the section height to breadth ratio and the concrete strength on the ultimate strength of the columns. A numerical separation method was used to separate the compressive load carried by the steel tube and the core concrete. To determine the overall behaviour of the high strength concrete-filled RHS tubes an equivalent one dimensional non-linear stress strain model of the steel and the confined concrete were developed. In these tests, the concrete strength influenced the failure pattern of concrete-filled RHS columns. The core concrete with lower strength failed by splitting, while the concrete with higher strength failed by shrinking. Ductility had increased with the increase in height to breadth ratio. It was also noted that, the load bearing capacity of high strength concrete-filled RHS tubes under axial loads was greater than the sum of the load bearing capacities of the steel tube and the core concrete. The models
developed to analyse the behaviour of high strength concrete filled RHS tubes were in agreement with the experimental results.

Twenty seven concrete-filled steel tubular columns were tested by Zeghiche and Chaoui (2005). The test parameters were slenderness of the columns, eccentricity of the loads and the compressive strength of the concrete core. The results were compared with the method described in EC4. The test results showed that the increase in column slenderness decreased the load carrying capacity of the columns. The load-slenderness ratio decreased at a higher rate for the high strength concrete in-fill compared to the column with normal strength concrete in-fill. The EC4 code predicted the strength on the safer side for columns with single curvature bending. For columns with double curvature bending EC4 predictions were not found to be safe.

The behaviour of stiffened concrete-filled thin walled hollow steel structural (HSS) stub column under axial compression was presented by Tao et al. (2005). Nineteen specimens were tested. Four types of steel tubes were fabricated; stiffened square tubes, inner stiffened square tubes, outer stiffened square tubes and inner stiffened rectangular tubes. In the experimental results it was observed that the sectional capacities increased when stiffeners were provided. The longitudinal stiffeners, not only delayed the local buckling of the plate, but also improved the lateral confinement on the concrete core. It was also observed that there was no improvement in the ductility for the stiffened CFT columns. The outer stiffened columns showed almost the same behaviour as that of the inner stiffened columns. The experimental results were compared with the existing design codes such as ACI, AIJ, AISC, BS5400, EC4 and PBJ1351-2003. Among these codes EC4 and DBJ 1351-2003 gave best results.
Young and Ellobody (2006) investigated the behaviour of high strength concrete filled high strength stainless cold formed steel tubular columns under the effects of shape of the stainless steel tube, plate thickness and concrete strength. The strengths obtained were compared with the design strengths calculated using the American, Australian, New Zealand standards. The strength to the axial strain relationship showed that the ductility of the columns decreases with the increase in the strength of concrete. Slender sections failed by local buckling. Compared to the strengths obtained experimentally, the strengths predicted by the codes were conservative. Based on the test results, recommendations were proposed for the design of concrete in filled high strength stain less steel tubular columns.

The behaviour of eccentrically loaded high strength rectangular concrete in filled steel tubular columns was presented by Liu (2006). In this study an analytical and experimental investigations were made on 16 slender columns. The test parameters were the strength of steel, cross sectional aspect ratio, slenderness ratio and the eccentricity of loads. The failure loads were compared with the values obtained using the codes of practice EC4, ACI and AISC. The ultimate load carrying capacity of CFT columns was found to be adversely affected by the load eccentricity ratio. Favourable ductility performance was observed for all columns during the tests. By comparing the test results with the theoretical values, the ACI and AISC conservatively predicted the failure loads where as the EC4 provided an un-safe estimate. The proposed numerical model closely predicted the design strength of the columns; hence this model was suggested for the design of high strength rectangular CFT columns subjected to eccentric loadings.

Ellobody et al. (2006) presented the experimental behaviour and design of axially loaded circular concrete-filled steel tube stub columns. The test parameters were the strength of in-filled concrete and the external
diameter of the steel tube-to-plate thickness ratio. The column strength and axial load shortening values were evaluated for the various concrete strengths and aspect ratios. The experimental results were validated by the design strengths calculated using the American, Australian and European specifications. From these experimental investigations, following conclusions were drawn. The strength of the columns increases when the D/t ratio decreases up to 55 and increases for the D/t ratio between 55 and 70. Also, the strength of the concrete columns was found to have a linear relationship with the cube strength of concrete. It was also described that the ductility of the columns decreases as the concrete strength increases. Comparing the theoretical ultimate values of column, the American and Australian standards were found to be conservative unlike the European code. In this paper reliability analysis was also performed to evaluate the current composite column design rules.

The axial load behaviour of square concrete-filled steel tubular (S-CFT) stub columns with binding bars were tested by CAI and He (2006). Ten specimens with the binding wires and 5 specimens without binding bars were tested to examine the effects of width to thickness ratio and binding bars on ultimate strength, stiffness and ductility of S-CFT columns. The spacing and diameter of binding bars were found to have an important influence on the ultimate strengths and the plastic deformability of square CFT columns with binding bars. When spacing of binding bars were decreased and the diameter of binding bars were increased, the ultimate strength and the corresponding strain of specimens with binding bars were increased remarkably and the post load-strain curve increased slowly. With the thickness of steel tube increasing, the D/t ratio decreasing, the ultimate strength and the corresponding strain increase and the columns became more ductile.
An experimental and computational study of the behaviour of concentrically loaded circular concrete-filled steel tube columns were presented by Gupta et al. (2007). The test parameters were the diameter of the tube and D/t ratio of steel tube, grade of concrete and effect of addition of fly ash to concrete. In the CFT columns, as the concrete strength increases the confinement effect of the concrete core decreased. For smaller D/t ratio, the steel tube provided effective confinement of concrete. The energy absorption capacity was found to decrease with the increase in the fly ash up to 20% but at 25% fly ash it again increased.

Lu et al. (2007) investigated the bending moment-axial force-curvature (M-N-Φ) relation of eccentrically compressed, square, concrete in filled steel tubular columns. A simplified analytical method for predicting the ultimate strength of eccentrically compressed square concrete in filled steel tubular columns based on a collapse theory was presented. This method was also used to calculate the ultimate strength of axially compressed columns with initial imperfections. The results of the proposed method were compared with the experimental results obtained from the works of Furlong, Knowles and Park and Zuo. From the comparisons, it was found that the proposed formula predicted the ultimate strength of the square CFT columns fairly well.

Yu et al. (2007) presented an experimental study on the behaviour of circular Concrete-Filled steel Tube (CFT) stub columns with Self Compacting Concrete (SCC) and Normal Concrete (NC) under concentric loads. Seventeen tests were conducted to investigate the effects of concrete strength, notched holes or slots made at the mid height of the steel tubes under different loading conditions on the ultimate capacity and the load deformation behaviour of the columns. From the experimental results, it was observed that the increase in the compressive strength of concrete resulted in a significant increase in load carrying capacities, but maintained a constant value in
residual capacity after failure. For the columns notched with small holes, the confinement effect enhanced but the axial compressive stiffness was reduced. When the steel tube was notched with a full perimeter slot, the concrete behaviour with three dimensional compressive stress was changed and axial compressive stiffness were also reduced. The theoretical treatment showed that the EC4 provide good prediction on the ultimate capacities of the un-notched CFT stub columns with SCC.

2.3 STUDIES ON NUMERICAL INVESTIGATIONS

Shanmugam et al. (2002) presented an analytical model for thin-walled box columns with concrete in-fill. A method using an effective width principle has been proposed in this paper to predict the behavior and also load carrying capacity of thin-walled steel tubes with concrete in-fill, the present investigation addresses column pinned at their ends and subjected to biaxial loading. Column tested by other researchers have been analyzed using the proposed method and the predicted resulted were compared with the corresponding test results. The proposed model was also verified against Euro code4 which shows that the method could predict the ultimate load with sufficient accuracy.

Hu et al. (2003) studied the proper material constitutive models for concrete-filled tube (CFT) columns and verified by the nonlinear finite element program ABAQUS against the available experimental data. The cross sections of the CFT columns in the numerical analysis were categorized into three groups, i.e., circular section, Square section, and square section stiffened by reinforcing ties. Through the numerical analysis, it has been showed that for circular CFT columns, the tubes can provide a good confining effect to the concrete, especially, when the width-to-thickness ratio D/t are small (D/t < 40). For square CFT columns, the tubes do not provide large confining effects
to the concrete, especially, when the width-to-thickness ratio $B/t$ is large (say $B/t > 30$). The confining effect of square CFT columns with reinforcing ties were enhanced by the use of reinforcing ties, especially, when the spacing of the ties were small and the number of ties (or diameter of the ties) are large.

Spacone and El-Tawil (2004) presented the current state of the art of nonlinear analysis of steel-concrete composite structures. The focus was on frame elements, which are computationally faster then continuum finite element models. First, section models were presented, with a review of resultant and fiber models and a discussion on possible practical applications. The presentation of frame elements followed. Models with lumped and distributed inelasticity, as well as models with perfect and partial connections were covered. Rigid and partially restrained joints were then reviewed and discussed at length. A discussion of the analysis of structural walls completed the presentation of the models. Modeling applications to the analysis of composite frames were also presented.

Hu et al. (2005) presented a non linear finite element analysis (ABAQUS) for CFT columns with circular and square section with and without stiffeners subjected to axial force and bending moment in combination and compared with the experimental data. In the numerical analysis, the cross section of CFT columns were categorized into three groups, i.e., one with circular section, one with Square section, and one with square section stiffened by reinforcing ties. It was shown that the steel tubes can provide a good confining effect to the concrete core when the axial compressive force is large. The confining effect of a square CFT stiffened by reinforcing ties was stronger than that of the same square CFT columns without stiffening ties but weaker than that of circular CFT columns. When the spacing of reinforcing ties is small, a CFT with a square section might possibly achieve the same confining effect as one with a circular section.
De Sousa Jr. and Caldas (2005) presented a numerical formulation for the nonlinear analysis of slender steel-concrete composite columns of generic cross-sectional shape, subjected to axial force and biaxial bending. The cross sections were defined in terms of a number of closed polygonal loops of a specific material each one with its own stress-stain relation, with displacement-based stress resultant of the beam-column elements. The proposed scheme is possible, with a unified treatment, to perform analysis of concrete-filled steel tubes, fully or partially encased steel profiles, or less usual cross sections present on composite constructions. The robustness and accuracy of the formulation was verified against numerical and experimental results available in the literature.

From the above literature survey, it is clear that the SFRC in-filled light gauge steel box section columns and beams under axial and eccentric loadings need further studies.