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ParametricInvestigations on Behaviour of Square CFST Columns

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Abstract-A three-dimensional non-linear finite element model using ANSYS code has been used to conduct a parametric study presented in this paper. Theaim of this parametric study is to study the load carrying capacity and post-yield characteristics of axially loaded Concrete Filled Steel Tube (CFST) columns with square cross section. The verified computational model has beenused for predicting the ultimate axial load carrying capacity of CFST columnshaving different sizes filled with normal compressive strength concrete. The specimens were selected to simulate the cross-section sizes in actual construction practice. All specimens hadlength equal to three times the cross-section width to behave as short columns and neglect the effect of slenderness.The parameters of this study were cross-section width and thickness of steel tube. Effects of these parameters on enhancement the properties of concrete core, load carrying capacity and post-yield behaviour have been numerically investigated.

Index Terms— ANSYS, Axial Load, Confined Concrete, CFST, Concrete Filled Tube, Ductility, Post Yield Behaviour.

1INTRODUCTION

DUE to the composite action between steel and concrete in the member, concrete filled steel tube (CFST) columns has good structural performances, such as high ductility, high load carrying capacity, high stiffness, high shear resistance and more energy dissipation ability[1]. CFST has been generally used as columns or piers in buildings or bridges because of its superior structural behavior. CFST columns can be constructed with different cross sections such as circular, square, rectangular, octagonal, elliptical, etc. The structural behavior of CFST columns is affected by many factors, such as the geometry of steel section, column slenderness and member material properties[2]. Knowles and Park[3]investigated experimentally the behaviour of circular and square CFST columns. The results of this study showed that in circular columns the confinement effect increased the load carrying capacity of short columns while no increasing in the load carrying capacity due to confinement effectat failure load was observed forsquare columns [3]. In the study conducted by Schneider[4]a total of fourteen specimens have been prepared with different grades of concrete.The results showed thatthe axial load behaviour of the specimens was significantly affected by the shape of cross section and the ratio between breadth and thickness of the steel wall (B/t). He concluded that the circular tubes offer more confinement and much more post-yield axial ductility than the square or rectangular tube sections[4]. The effects of slenderness ratio and load eccentricity on four square specimens and eight rectangular specimens have been investigated by Liu[5]. The specimens were fabricated from high strength steel filled with two grades of high strength concrete. The results showed favorable ductility performance for all specimens during the test [5]. Fujimoto[6] tested sixty five eccentrically loaded specimens (thirty three circular and thirty two square). Analytical studies for predicting the behavior of the square and box CFST have been reported in the literature. Lakshmi and Shanmugam[7] proposed a semi analytical method for predicting the behaviour of box CFST columns. Liang et al. [8]presented a nonlinear fiber element analysis method for predicting the ultimate strength and behaviour of short concrete-filled thin walled steel box columns with local buckling effects. Hu et al. [9]performed nonlinear finite element analyses of CFST columns with circular and square with stiffened and unstiffened cross-sections using finite element code ABAQUS. Gupta, Khaudhair, and Ahuja[10] proposed a three- dimensional non-linear finite element model for predicting the ultimate load and behaviour of circular CFST under axial loadings using finite element code ANSYS[10] and square CFST under axial loading using same software [11].In the present study, a parametric study was conducted using the ANSYS model developed and verified by Gupta, Khaudhair, and Ahuja[11]to investigate the effects of cross-section geometry on the load carrying capacity and post-yield behaviour of such columns. The detailed approach for modeling and verification of the proposed model are given elsewhere[11].

2PARAMETRIC INVESTIGATIONS

There is no doubt that the full scale physical testing is more reliable. As the engineering systems get complicated day by day, a better understanding of

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Tables 1 Details of Simulated Columns

B (mm)	t (mm)	B/t	A_s/A_t	P_n (kN)	P_u (kN)	EL	HI
300	6	50	0.078	5476	5559	1.50	0.87
300	8	37.5	0.104	6318	6390	1.13	0.97
300	10	30	0.129	7148	7213	0.90	1.00
300	12	25	0.154	7967	9064	13.77	1.14
300	14	21.43	0.178	8773	10961	24.93	1.18
400	6	66.67	0.059	8599	8737	1.60	0.74
400	8	50	0.078	9736	9864	1.31	0.83
400	10	40	0.098	10860	10976	1.06	0.91
400	12	33.33	0.116	11973	12083	0.91	0.94
400	14	28.57	0.135	13074	13421	2.65	1.03
400	16	25	0.154	14163	16094	13.63	1.16
400	18	22.22	0.172	15241	18620	22.17	1.18
500	6	83.33	0.047	12363	12461	0.80	0.66
500	8	62.5	0.063	13793	13898	0.76	0.64
500	10	50	0.078	15212	15319	0.70	0.71
500	12	41.67	0.094	16620	16725	0.63	0.77
500	14	35.71	0.109	18015	18121	0.59	0.85
500	16	31.25	0.124	19399	19505	0.55	0.92
500	18	27.78	0.139	20771	21974	5.79	1.06
500	20	25	0.154	22131	25133	13.57	1.15
500	22	22.73	0.168	23479	28174	19.99	1.18
500	24	20.83	0.183	24816	30896	24.50	1.19

such systems is pivotal to their correct design and fabrication. However, in such cases the experimental approach suffers from various drawbacks such as limited capacity of instrumentations, significance increase in the cost of materials and data acquisition systems etc. For example, due to their high load capacity, the capacity of loading machine can become a major issue in testing of CFST columns. Therefore, most of the researchers have performed tests on limited scale for such columns, due to which there is lack of knowledge regarding behaviour of CFST columns. With simulations, engineers are able to overcome most of these problems, as these are time and cost-friendly, and need no special instrumentations. Hence, the aim of present parametric study is to simulate CFST columns with controlled increased sizes of steel tube to clarify the effect of such increase on the load carrying capacity and on the post-yield behaviour of CFST columns. The increase in sizes has been achieved by increasing cross-sectional area of steel tube and/or wall thicknesses. Three cross-sectional sizes have been used which are 300 mm square cross-section, 400 mm and 500 mm square cross-section. A Wide range of thicknesses have been adopted for each size. A total of twentytwo CFST columns have been simulated using the ANSYS model. Same grade of concrete (150 dia. cylinder compressive strength, f'_c equals 32 MPa) and same yield strength of steel (f_y equals 400 MPa) have been used in all columns to investigate the change in the behaviour of CFST columns due to changing the area of steel tube only. All specimens have been simulated with L/D equal to three, to assure there will not be any effect of slenderness. The details of the simulated columns are listed in Table 1, where B is width of cross-section, t is thickness of steel tube, A_s is cross-sectional area of steel tube, A_t is total cross-sectional area of composite column, P_n is nominal capacity of cross-section calculated as given in Eq. 2, P_u is ultimate axial capacity of CFST column from ANSYS model. The numerical results of the proposed model for these specimens are presented in Fig.1, Fig. 2 and Fig. 3.Two parameters were used in this investigation, namely, Enhanced Load (EL) and Hardening Index (HI).

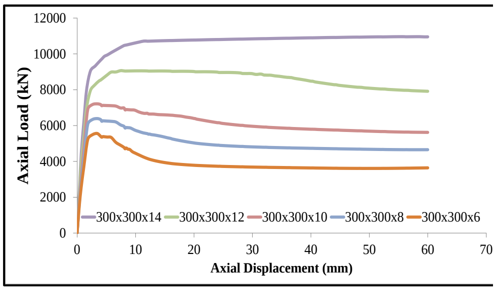

Fig. 1. Load-Displacement Relationship for 300x300 mm cross-section

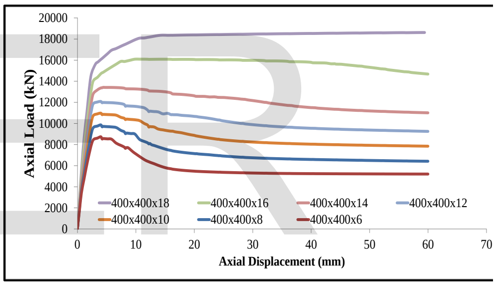

Fig. 2. Load-Displacement Relationship for 400x400 mm cross-section

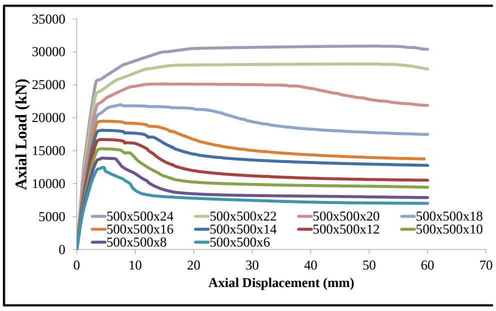

Fig. 3. Load-Displacement Relationship for 500x500 mm cross-section

2.1 Enhanced Load, (*EL*)

Enhancement in axial load capacity was measured in the present study as given in Eq.1.

$$EL = \frac{P_u - P_n}{P_n} * 100 \qquad (1)$$

Where, P_u is the ultimate axial capacity of CFST from proposed model, P_n is the nominal cross-sectional axial capacity of CFST calculated as the summation of axial capacity of steel and concrete independently, as given in Eq.2:

$$P_n = A_s f_y + A_c f'_c \qquad (2)$$

In which A_s and A_c are the cross-sectional area of steel tube and concrete core, respectively. Effect of the ratio of area of steel to total area of composite section (A_t)was investigated to define the optimum ratio of area of steel. The relationships are presented in Fig.4 and 5.

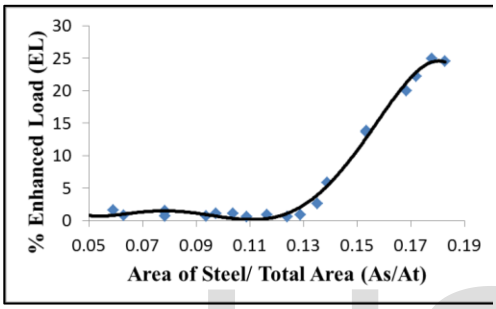

Fig. 4. Effect of increasing area of steel on enhance load parameter of CFST columns

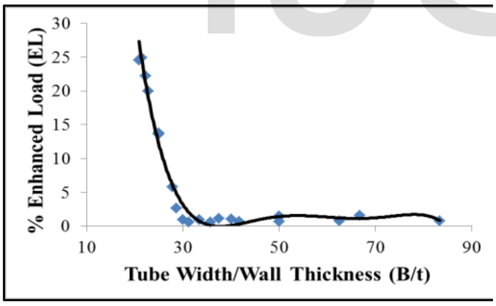

Fig. 4. Effect of wall width to wall thickness on enhanced load parameter of CFST columns

From Fig.4, It can be noticed that there was no enhancement in axial load capacity for CFST columns having area of steel less than or equal to 13% of total area of composite section (i.e. no confinement effect). For specimens having area of steel more than 13% of total area, an increase was observed in axial load capacity of the composite columns due to confinement provided by steel tube to concrete.Fig.5 shows the relationship between B/t ratio, which indicates the cross-sectional stability, and the percentage enhancement in load. It can be noticed that increasing the B/t ratio significantly reduces the enhancement in load carrying capacity; for specimens having B/t morethan 30, percentage enhancement is negligiable.It is thus concluded from Fig. 4 and Fig.5 that for better enhancement in axial load carrying capacity of CFST columns with square cross-sections,two limitations can be proposed:

$A_s/A_t > 13\%$

$B/t \leq 30$

2.2 Hardening Index, (*HI*)

The main advantages of CFST is the enhanced ductility because such columns are prefered in high-rise buildings and/or high seismic activity zones. It is also commonly prefered by engineers that the structure sholud be able to sustain the gravity load imposed on it, even at high deformation levels. Therefore, to evaluate post-yield behaviour of CFST columns, Hardening Index (*HI*) proposed by Johansson (2002) [12]has been adopted. Hardening index is defined as “the load at five times the yield strain, $P_{5\varepsilon y}$,divided by the yielding load,P_y.”

$$HI = \frac{P_{5\varepsilon y}}{P_y} \qquad (3)$$

Physically, this means that the specimens having *HI* less than one will behave as strain softening behavior for post yield behavior, while the specimens having *HI* equal to 1 will behave as elastic-perfectly-plastic and specimens having *HI* more than one will behave as strain hardeing. In the present study analysis was conducted until an elastic-perfectly-plastic behaviour was obtained in CFST columns (i.e. until no signifcant degradation were observed in load carried after the peak-axial capacity).*HI* for all the simulated specimens is calculated and presented in Table 1. Effect of increasing area of steel on this index, *HI*, has been investigated through Fig.6 and Fig.7.

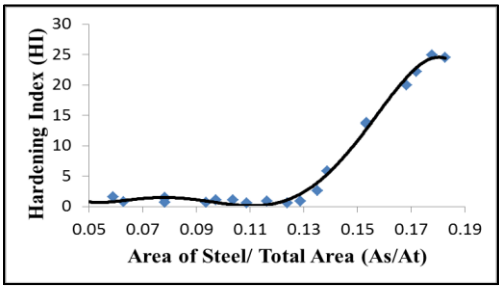

Fig. 6. Effect of increasing area of steel on hardening index parameter

Fig. 6shows that increasing the ratio A_s/A_t will increase the hardening index significantly. Hence, it can be concluded from Fig. 6 that the *HI* will be one for CFST specimens having A_s/A_tratio 14% at least and formaximum *B*/*t* ratio 33 (see Fig.7).

$A_s/A_t > 14\%$

$B/t \leq 33$

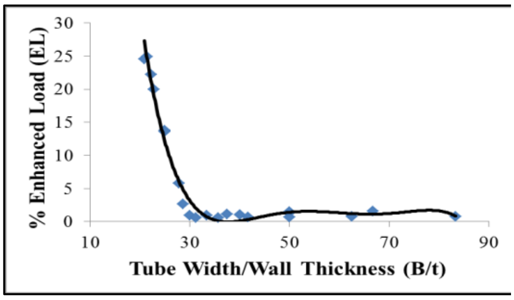

Fig. 7. Effect of wall width to wall thickness on hardening index parameter

3 CONCLUSIONS

A total of twenty two finite element CFST columns have been simulated to investigate the optimum ratio of area of steel in the composite section of such columns.A three-dimensional non-linear finite element model has been used for conducting a parametric studt to investigate the effect of controlled increase in area of steel tube in the composite section on the load carrying capacity and ductility of CFST. It is concluded that the area of steel should be at least 13 % of the total area of composite section with cross-section to thickness ratio (B/t) ≤30 to enhance the load carrying capacity and ductility of CFST. No significance enhancement in load carrying capacity was observed for columns having area of steel lower than 13% or B/t higher than 30. Further, to achieve an Elastic-Perfectly-Plastic or strain hardening characteristics as it is desired for design purposes and sustain ductility, the area of steel should be at least 14 % of the total area of composite section.This ratio is also be governed by the parameter B/t which should be less than 33. Strain softening behaviour was observed for columns having unsaftisfied limit for this purpose. Eventually, using superposition principle, it is recommended to use such composite columns with minimum area of steel 14% of total area of cross-section and maximum B/t ratio as 30 to efficiently utilize the distinct composite features of CFST columns.

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