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Analytical Study on Capacity and Ductility for Composite Column Under Different Areas Loading

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Abstract— **the main purpose of this research is to study analytically the CFT columns using the finite element method. ANSYS computer program is employed, in order to evaluate the behavior of the CFT short columns. 3-D finite element model is presented and calibrated successfully in order to predict the performance of the CFT columns under axial static loading. This paper presents the results of analytically study on the performance of axially loaded concrete-filled steel box columns subjected to different loading cases. The study investigates the effect of these loads on both axial capacity and ductility of CFT columns for different loading cases. The study investigates the effect of these loads on both axial capacity and ductility of CFT columns for different loading cases. This effect is studied for each type of loading individually. From the results it is obvious that in case CFT columns with load acting on total area of steel and concrete increasing both stiffness and strength can be attributed to the composite action between the steel tube and the concrete infill. Therefore, the composite action between the steel tube and the concrete not only The steel tube work as longitudinal reinforcing bars to resist the loads as ties or spirals to confine the concrete infill but also both strength and ductility of the concrete are enhanced.**

Index Terms: **composite column, ANSYS program, axial capacity, ductility, different loading.**

I. INTRODUCTION

Composite constructions include a large variety of structural systems, e.g. framed structures employing all composite members and components (composite beam-columns and joints) and sub-assemblages of steel and/or reinforced concrete (RC) elements. Such components and/or elements are employed to optimize the resistance and deformation capacity (Uchida and Tohki, 1997)[1]. Hereafter, composite columns and framed systems are discussed in details both from a design and technological standpoint. Composite steel and concrete columns are relatively recent components used in framed structures.

Analytical and experimental tests on these members have been developed in the last decades and the development of design rules is still ongoing (Elnashai et al., 1990[3]; Cosenza et al., 1998[3]). The advantages in using composite columns are, however, evident (e.g. Cosenza and Zandonini, 1997[4], among many others). For example, the Millennium Tower, which was a challenging design project due to the analyses performed along with the employed detailing. The building uses slim-floor as decks; the columns are concrete-filled and their connection with the floor deck is semi-rigid (Huber, 2001)[5]. Although CFT columns are suitable for tall buildings in high seismic regions, their use has been limited due to a lack of information about the true strength and the inelastic behavior of CFT members. There is a discrepancy in the analytical models proposed by different researchers for evaluating the strength of a CFT column and the effect of confinement [6].

Tao et al. [7] mentioned from earlier studies on CFT columns that the behavior of rectangular CFT columns differs from that of circular and square CFT columns owing to the confinement of core concrete by steel hollow section. It is shown that the performance of a concrete-filled square or rectangular steel tube is not as good as its circular counterpart. This is due to the fact that a square or rectangular steel tube cannot provide as much confining pressure to the concrete core, and that local buckling is more likely to occur. With a large aspect ratio of section, the maximum axial strength of stub columns is even less than the combination of the steel and concrete components due to the effects of local buckling.

The rolled lip in fact acted as a longitudinal stiffener for the columns, and experimental research by Zhang [8] has shown that this kind of CFTST column has an excellent static mechanical performance. The longitudinal stiffeners can not only delay the local buckling of the steel plate, but also improve the lateral confinement on the concrete core [9].

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Liang and Uy[10] studied the post-local buckling behavior and strength of steel plates in thin walled CFT welded box short columns using the finite element method. Clamped square plates with various B/t ratios (where B width of steel plate and t thickness of steel tube), geometric imperfections and residual stresses were studied Also. Previous research indicates that increasing the B/t ratio of a steel plate under a predefined stress gradient reduces its lateral stiffness, critical local buckling stress and ultimate strength (Liang et al.[11]). To improve the performance of thin-walled square or rectangular concrete filled steel tube columns, longitudinal stiffeners can be welded on the surfaces of the steel tubes.

The stiffening effects have been demonstrated by test results as in Ge and Usami[12] and Tao et. al. [13].

Dabaon et al.[14], [15] presented a test program of concrete-filled normal-strength stainless steel stiffened tubular stub columns. Results for five concentrically loaded slender stainless steel stiffened columns and ten concrete-filled stainless steel stiffened columns have been presented. The results of the experimental study showed that the design rules specified in European specifications as well as the American one are highly conservative for concrete-filled stainless steel stiffened stub columns. Also, he conducted a comparative numerical study between stiffened and unstiffened concrete-filled stainless steel hollow tubular stub columns. His results showed that the stiffened concrete-filled columns offered an average of 43% increase in the column strength over that of the unstiffened concrete filled columns.

Ibtisam and Zuhiar et.al [16] studied the effect of length on the CFT columns analytical using the finite element FE method. ANSYS software was employed to evaluate the CFT columns behavior. The test results showed that increasing the slenderness ratio L/B has a negligible effect on the load capacity of the column but is accompanied by a large reduction of its ductility.

The aim of this work is to employ the nonlinear finite element (FE) program ANSYS [17] to perform numerical simulations of CFT columns subjected to axial loads. The parametric study is conducted using SIX specimens under concentric compression for short square CFT columns. The primary parameters considered in this study include for the load-strain relationship for CFT columns with different loading cases on column..

II. FINITE ELEMENT MODEL

The FE method has been extensively used to study the structural behaviors of steel-concrete composite section. The well-known commercial finite element package, (ANSYS V10) is employed in the present study. 3-D FE model is developed in order to predict the performance of the CFT columns under static loading. The issue concerning in modeling a problem using the FEM is described. Several factors must be considered in modeling a problem using the finite element method. These include the dimensional of the problem, the element type, material properties, mesh generation, boundary condition, and types of loading. In this section, these issues concerning the present study are described in detail.

A. *Concrete Element (Solid 65)*

To be able to account for the failure modes of concrete cracking in tension and crushing in compression a special brittle finite element material model should be used. Solid 65 three dimensional solid element is the only one concrete material model available in the finite element program ANSYS. Consequently, it is used to model the concrete in the present analysis. The crack modeling adopted by ANSYS program is the smeared crack representation where shear transfer coefficient (β_t) is introduced to represent the shear strength reduction factor for the subsequent loads which induce sliding (shear) across the crack face. If the crack closes, then all compressive stresses normal to the crack plane are transmitted and only a shear reduction factor (β_c) for a closed crack is introduced. Typical shear transfer coefficients ranges from zero, representing a smooth crack, to one, representing a rough crack. In the present analysis, as mentioned earlier, (β_t) is assumed 0.1 and (β_c) is assumed 0.8 (Ghoniem (1990)[18] and Ibrahim (2006)[19]).

B. *Steel Plate Element (Shell 181)*

A four node element, (shell 181), is used to model the steel plates. Shell 181 element is suitable for analyzing thin to moderately-thick shell structures. It is a 4-node with six degrees of freedom at each node: translations in the x, y, and z directions, and rotations about the x, y, and z-axes. Shell 181 element is well-suited for linear, large rotation, and/or large strain nonlinear applications. The geometry, node locations, and the coordinate system for this element are shown in Figures. (3.4). In the present analysis, the shell 181 element is used to model both of the steel tube and the stiffeners.

C. *Contact between Steel and Concrete (Targe 170 and Conta 173):*

(3-D point-point contact element): is used to model the connection between concrete core and steel tube or stiffeners. Both target and contact elements are paired via a shared real constant. When the two surfaces are in contact, a frictional force is resulted. A friction coefficient between steel tube and concrete core is used as 0.25 (Hu et al.[20]).

Meshing is one of the most important issues in modeling since the accuracy of the results largely depends on it. The technique of FE lies in the development of a suitable mesh arrangement. The meshing process must balance the need for a fine mesh to give an accurate stress distribution and reasonable analysis time. The optimal solution is to use a fine mesh in areas of high stress and a coarser mesh in the remaining areas. The mesh has to be relatively coarse based on the studies of Hu et al.[21] who recognized that the mesh refinement has very little influence.

Due to symmetry, symmetric boundary conditions are enforced on the symmetric planes, for which *u*=0 and *w*=0 on the planes normal to the *x* and *z*-axis respectively. According to the mechanism of loading and test setup, the boundary conditions of the analyzed columns are both ends allow rotations in the whole directions. Column upper end allows a displacement in y-direction (direction of the column axis) only while the lower end does not allow any displacements.

III. MATERIAL MODELING

The stress strain relationships for concrete core and steel plates were idealized for the finite element model as described below:

A. *Steel Tube*:

The uniaxial behavior of the steel tube can be simulated by an elastic-perfectly plastic model as shown in Figure. 2. When the stress points fall inside the yield surface, the behavior of the steel tube is linearly elastic. If the stresses of the steel tube reach the yield surface, the behavior of the steel tube becomes perfectly plastic. Consequently, the steel tube is assumed to fail and cannot resist any further load (Hu et al.[21]). The modulus of elasticity for steel (E_c) is taken as 200000 MPa, poisson's ratio is assumed to be v_s= 0.3 (Hu et al.[21]).

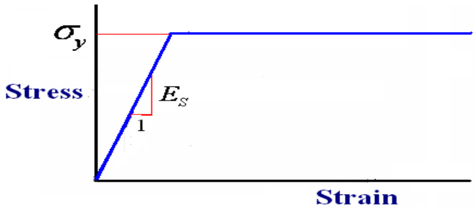

Figure 1. Elastic-perfectly plastic model for steel tube (Hu et al.[21])

B. *Concrete Material*

The Poisson's ratio of concrete is assumed to be v_c=0.2, according to Dalin Liu [22], suggested the following equations to model the stress-strain curve of the concrete as shown in Figure. (2):

$$\sigma_C = E_C\,\varepsilon \quad \text{for} \quad \varepsilon \le \varepsilon_1 \qquad (1)$$

$$\sigma_C = f_0 \quad \text{for} \quad \varepsilon_1 \le \varepsilon \le \varepsilon_2 \qquad (2)$$

$$\sigma_C = f_0(\varepsilon_2/\varepsilon_1)^{0.24+0.45/\zeta} \quad \text{for} \quad \varepsilon \ge \varepsilon_2 \qquad (3)$$

In which, $f_0 = 0.85 f_c^{\eta}$ (4)

$$\eta = 1 + \frac{(1-0.65(H/B-1)^3)(0.37\zeta^{0.82}-0.19\zeta)}{1+0.05(f_C'/50)^{5.65}} \qquad (5)$$

$$\zeta = \frac{A_S\, f_y}{0.85 A_C f'_C} \qquad (6)$$

$$\varepsilon_1 = f_0/E_C \qquad (7)$$

$$\varepsilon_2 = 2\varepsilon_1 \qquad (8)$$

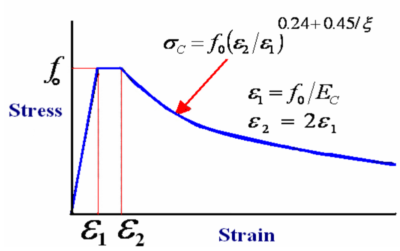

Figure. 2. Relationship for confined concrete.

The initial modulus of elasticity of concrete E_C is highly correlated to its compressive strength and can be calculated with reasonable accuracy from the equation given in ACI code [23] as:

$$.\,E_C = 4700\sqrt{f'_{cc}} \quad \text{MPa} \qquad (9)$$

IV. VERIFICATION OF THE MODEL

Before the parametric study could be carried out, it was necessary to prove that the established finite element model is capable of simulating the structural behavior of unstiffened and stiffened CFT steel columns in order to give the coming parametric study intensity and reliability. The proposed finite element model is examined through comparisons with experimental work available in the literature. Comparing the results from ANSYS models with the published papers showed an accepted difference for the compared values up to 5%. The details of the verifications are briefly discussed in Rabie and Ibtisam [24] and El-Hifnawy et al.[25].

V. PARAMETRIC STUDY

A finite element models were constructed to simulate and compare between CFT columns. In this paper, the proposed model is extended to invest six CFT box columns are examined for the study. where in this paper, two CFT columns models are compared. These models are shown in figure 3:

1- CFT columns with load acting on total area of steel and concrete.

2- CFT columns with load acting on area of steel.

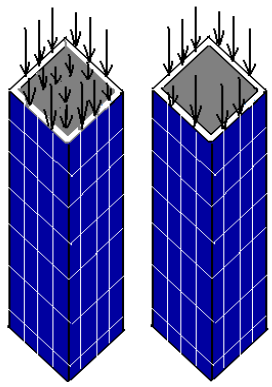

Figure 3. different loading cases.

Table 1. Dimensions and material properties of model for different loading areas

CFT columns	Column dimensions (mm)			Ratio B/t	Area loaded	Material properties (MPa)	
	L	B	t				f_y
C1	1800	200	4	50	Total	25	240
C2					Steel only		
C3			3	67	total		
C4					Steel only		
C5			2	100	total		
C6					Steel only		

The parametric study is conducted using six CFT box columns including three CFT columns with load acting on total area of steel and concrete and three CFT columns with load acting on area of steel.

The test specimens were short and all the columns were square have the same width (B) of 200 mm and also have the same length (L) of 1800mm as shown in figure 4. The dimensions of steel plate tube and cases of loading are the parameters to be examined.

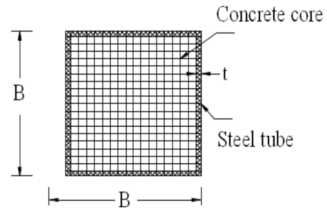

Figure 4. Column cross-section model.

The parameters are put in a non-dimensional form as follows: B/t. To get practical results, the values of non-dimensional parameters are taken in the range of previous experimental work mentioned in the literature, where; B/t varies between 50 and 100. The yield strength of steel, f_y = 240 MPa and concrete compressive strength, $f_{c=}$25 MPa (in the range of previous experimental work mentioned in the literature) as listed in Table 1.

VI. DUCTILITY FACTOR (μ_{95})

The ductility definition proposed by Ge and Usami [26] is considered herein;

$$\mu_{95} = \partial_{95} / \partial_y \quad (10)$$

Where ∂_{95} =deformation corresponding to a load of 95% of the ultimate load at the side of descending part which is larger than the deformation corresponding to the ultimate load, and ∂_y is the yield displacement as shown in Figure. 4.

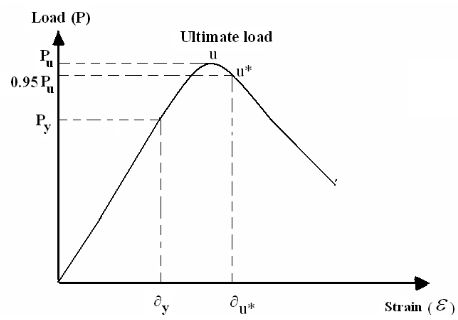

Figure 4. Describe of ductility factor.

VII. RESULTS AND DISCUSSION

Table 2 list the ultimate load capacities and the ductility factor (μ_{95}) of the analyzed CFT columns for different B/t ratios under different loading cases. Figures. (5 to 11) represent the results curves of the analyzed CFT columns for different ratios of studied parameters under different loading cases.

Figures. (5 to 7) shows a comparison between different loading area for different B/t. It can be noticed that the loading case leads to increasing both stiffness and strength. It is obvious that The effect of the area of loading appears in the ductility, stiffness and load capacity of the columns. Figs. indicate that in case of CFT columns with load acting on total area of steel and concrete increasing both stiffness and strength by 280% and 320%, respectively; on the other hand, the ductility decreased by 113% comparing with CFT columns with load acting on area of steel.

Figures. (8 to 11) indicate that increasing the B/t ratio results in an decrease of the load capacity as well as ductility of the column decreases.

According to Table 2, when B/t ratios increased by 34% and 100%, the ultimate axial load for a column is decreased by 11% and 23%, respectively. On the other hand, the ductility factor for a column decreased by 3% and 14% respectively.

Table 2. Ultimate load and Ducility factor of CFT Colimns for different loading areas

CFT columns	Ratio B/t	Area loaded	Ultimate capacity load (KN)	Ductility factor
C1	4	Total	2080	1.59
C2		Steel only	770	1.33
C3	3	total	1844	1.54
C4		Steel only	670	1.3
C5	2	total	1600	1.36
C6		Steel only	512	1.13

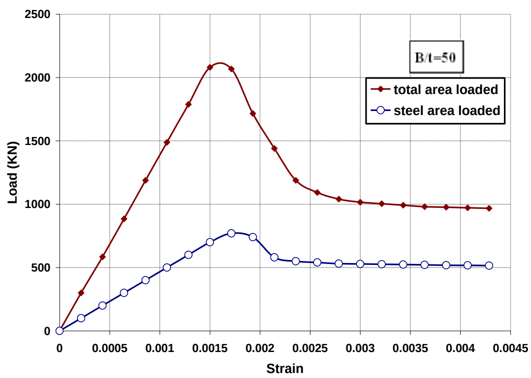

Figure 5. Load-strain relationship for B/t=50 under various loading.

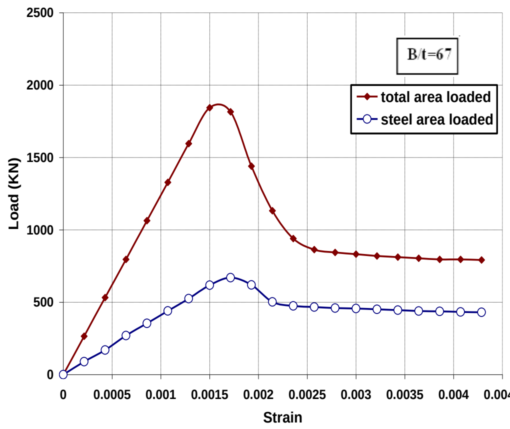

Figure 6. Load-strain relationship for B/t=67 under various loading.

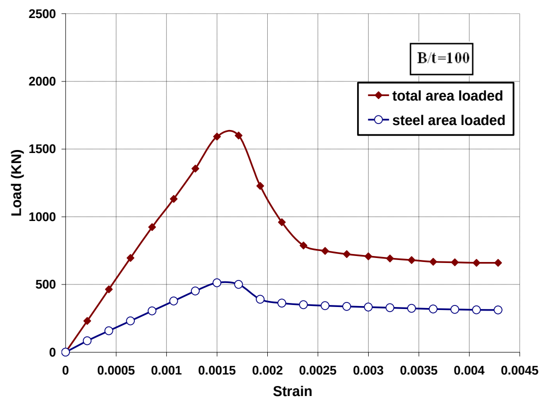

Figure 7. Load-strain relationship for B/t=100 under various loading.

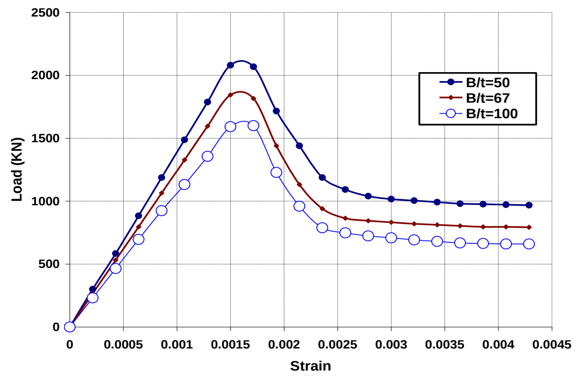

Figure 8. Load-strain relationship for various B/t under total area loaded.

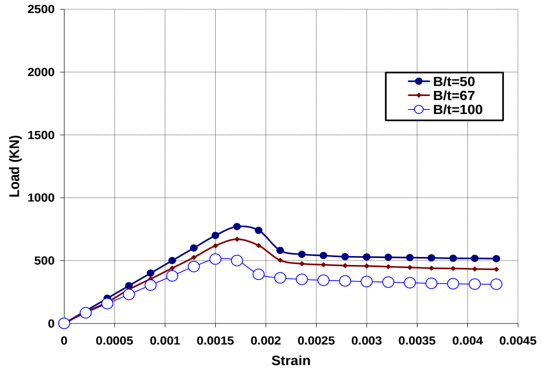

Figure 9. Load-strain relationship for different B/t under steel area loaded

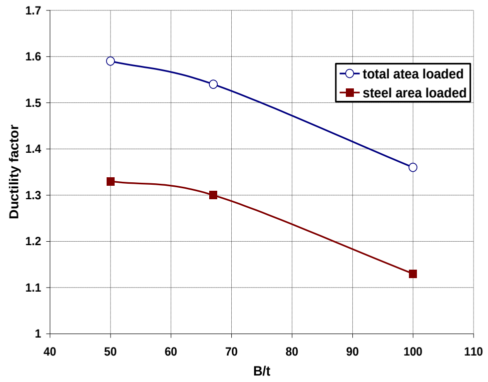

Figure 10. Load-B/t relationship for various areas loaded

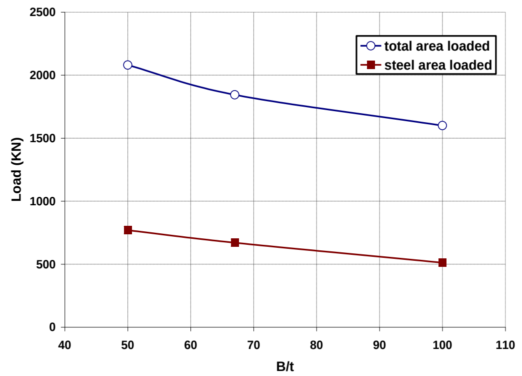

Figure 11. ductility factor-B/t relationship for various areas loaded

VIII. CONCLUSIONS

Intensive parametric study is carried out to investigate the behavior of stiffened CFT columns considering different geometric parameters such as the B/t under different loading cases. From the analyses performed on different sets of CFT columns under axial loading, the following conclusions are drawn:

Increasing B/t ratio leads to decreasing both the axial capacity and the ductility of CFT columns. Such conclusion reflects the little contribution of the steel tube to the confinement when its thickness decreases.

Increasing both stiffness and strength and decreasing the ductility in case CFT columns with load acting on total area of steel and concrete comparing with CFT columns with load acting on area of steel.

IX. RECOMMENDATIONS FOR FUTURE WORK

More research has to be carried out on the rectangular and circular composite column whether experimental or analytical. Also, effect of cyclic loading on CFT columns performance should be studied.

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