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EVALUATION OF RECTANGULAR CONCRETE-FILLED STEEL-HOLLOW SECTION BEAM-COLUMNS

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ABSTRACT

Despite the excellent engineering properties of concrete filled tubs (CFT), they are not as widely used as traditional structural steel and reinforced concrete members. The aim of this study was to predict the buckling behavior of concrete-filled steel hollow structural section beam columns with advanced finite element methods and compare the predictions with experimental results and optimize findings and represent a finite element model for further studies. A total of 2 different specimens from the experimental study were investigated with eccentric loading and ABAQUS software is used for modeling and non-linear analysis. The specimens have square section with overall depth of 120 mm and 140 mm respectively and the thickness for all sections was 3.84 mm. The tests were performed on pin-ended Beam-columns. It is found that load could carried by concrete filled steel tube with size of 120 mm, increased about %44 in compression of steel tube section also, it increased about %108 in compression of reinforced concrete section with %3 of longitudinal rebar.

Keywords: CFT, Beam-columns, Steel hollow section, Buckling behavior, Composite action, ABAQUS.

Contribution/ Originality

This study uses new estimation methodology in non-liner FEM analysis to investigate buckling behavior of different model and mesh sizes of concrete filled steel tubes, Steel tube, and reinforced concrete under eccentric loading to find the failure load and critical buckling load of them. Modeling accuracy is established by comparing results of the experimental test conducted on beam-columns that the axial load was applied through a very stiff top platen with an offset triangle hinge.

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1. INTRODUCTION

One of the earliest research projects on concrete filled steel hollow section columns by Furlong [1] showed that the stability of steel hollow sections could be significantly enhanced but not the strength of columns. Schneider [2] concluded from his test results that the concentrically loaded circular concrete filled steel hollow section columns could have better post-yield behavior and larger stiffness than rectangular concrete filled steel hollow section columns. For circular concrete filled steel hollow section columns with large diameter-to-thickness ratios, O'Shea and Bridge [3] confirmed that the load conditions could significantly influence the behavior. On the other hand, Uy [4] provided a set of experimental results for square concrete filled steel hollow section columns with high strength steel and concluded that the EC4 approach overestimated the capacity of columns under pure compression and pure bending as it was based on a rigid plastic analysis. It should be noted that the behavior of rectangular concrete filled steel hollow section beam-columns differs from that of circular and square concrete filled steel hollow section beam-columns owing to the confinement of core concrete by steel hollow section. Besides, concrete filled steel hollow section beam-columns with different strength materials would have different structural behaviors. High strength steel tends to have higher yield-to-ultimate stress ratio but lower strain ductility than mild steel [5]. Many studies have been carried out to investigate the behavior of concrete filled steel hollow section beam columns subjected to concentric, eccentric and seismic loadings. However, most of the tested specimens are circular and square concrete filled steel hollow section columns [6].

Concrete-filled tubes (CFT) are composite structural elements comprised of a rectangular or circular steel tube with concrete infill [7]. CFT, structural members efficiently combine the tensile strength and ductility of steel with the compressive strength of concrete. Lighter and more slender CFT columns can replace traditional steel or reinforced columns with equivalent resistance. The tube provides large buckling and bending capacity by placing the steel at the outer perimeter of the section where the moment of inertia and radius of gyration are greatest. There, the steel can perform most effectively in tension with the minimum amount of material [8]. The concrete core provides compressive strength and flexural stiffness to the section, and it delays and often prevents local buckling of the steel tube. Confinement of the concrete infill improves its strength and prevents sapling that might occur in a traditionally reinforced concrete component under lateral loading such as an earthquake. Despite the excellent engineering properties of CFT, they are not as widely used as traditional structural steel and reinforced concrete members. Current design methods for CFT component are limited and the experimental research is not sufficient to establish reliable engineering methods. Specially, although the codes have provisions for using CFT but, they are restrictive and therefore of limited practical value. The main purpose of current study is summarizes the literature review on the behavior of concrete-filled tube members, develop an analytical model for CFT, evaluation of code specifications, and recommendations for design and evaluates the design specifications used to design them. Concrete filled tubes are effective structural components due to their strength-to-size efficiency and facilitation of rapid construction. The flexural stiffness of the steel is maximized by placing it along the perimeter of the crosssection resulting in a large moment of inertia relative to the area of steel [9]. As material costs continue to rise, the need for structural efficiency becomes paramount making CFT components more attractive to design.

2. EXPERIMENTAL MODELS

For verification of this study the experimental results conducted by Han [10] are used. Eight tests on concentrically loaded composite columns were carried out. A total of 21 specimens were tested with eccentric loading. Tow beam-columns, selected as reference for verifying the ABAQUS model .A summary of the these tow specimens is presented in Table 1 where the section sizes, slenderness ratios (λ), load eccentricities (e), material properties (f_{sy} and f_{ck}) are given. These values are also used in the following FE analyses. The desired eccentricity was achieved by accurately machining grooves 6 mm deep into the stiff end plate that was welded together with the steel tubes. The endplate was very stiff with a thickness of 30 mm. The axial load was applied through a very stiff top platen with an offset triangle hinge which also allowed specimen rotation. A typical set up is shown in Figure 1. Typical failure mode was overall buckling failure. The maximum loads obtained in the test are summarized in Table 1. Experiment and predicted load versus mid-span lateral deflection curves are shown in Figure 2.

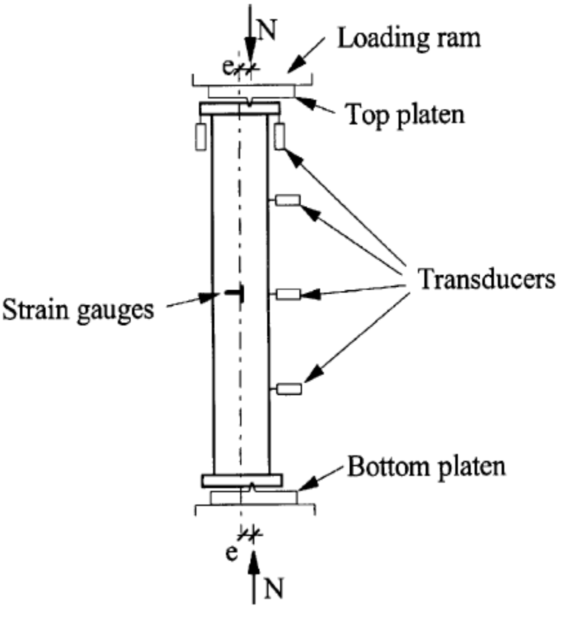
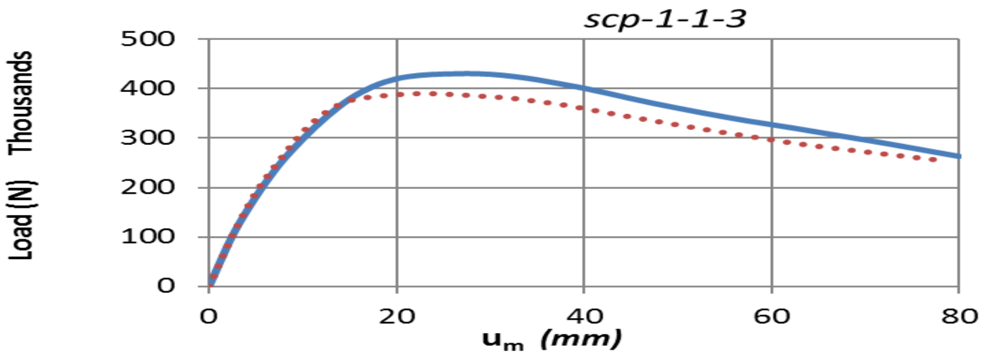


Fig-1. Test set up of the columns and beam-columns

Table-1. Specimen labels, material properties and member capacities

specimen label	B (mm)	H (mm)	t (mm)	λ	e (mm)	fsy (MPa)	fck (MPa)	Nu,e (KN)
scp1-1-3	120	120	3.84	75	40	330	26	421
scp1-2-4	140	140	3.84	64	40	330	26	559



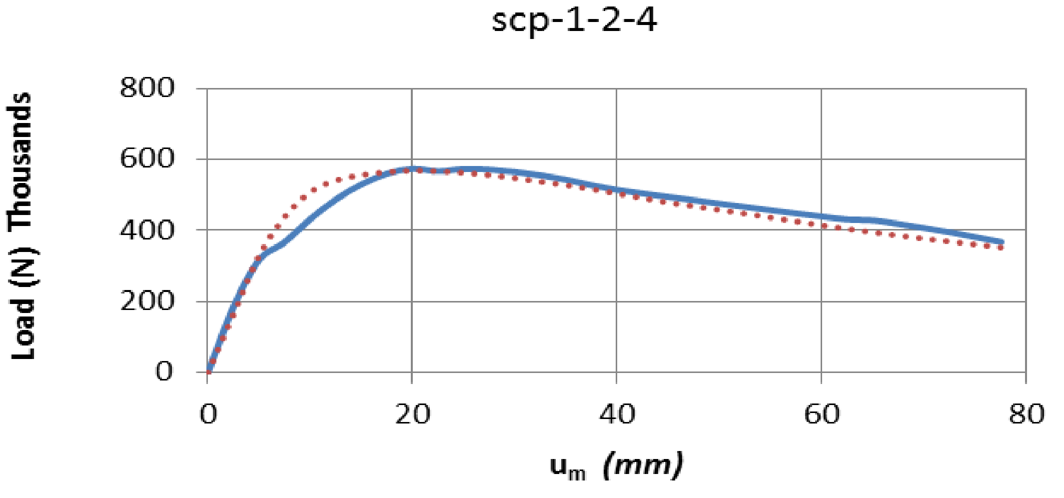


Fig-2. Load versus mid-span lateral deflection curves (Experimental curves are shown in solid lines; Predicted curves are shown in dashed lines)

3. MATERIAL PROPERTIES

Concrete-filled tubes (CFT) are composite structural members that consist of a steel tube and filled with concrete. In this research the square and rectangular shaped section were investigated. The yield strength of steel (f_{sy}) was found to be 330 MPa and the modulus of elasticity was about 200 GPa. The compression strength (f_{ck}) of concrete at the age of 28 days was 25.46 MPa based on experimental results for investigated specimens. The modulus of elasticity (E_c) of concrete was measured in accordance with the ACI 318-05 code of practice specifications, the average value was taken as 26GPa. To realize this aim, two series of tests were extracted from the experimental results conducted by Han [10]. A total of 2 different specimens from the experimental study were investigated with eccentric loading .the specimens have square section with overall depth of 120 and 140 respectively. The steel tube section thickness for both sections was 3.84 mm. Two different models were established, to investigate behavior of rectangular sections with overall depth of 120 by140 and the thickness of 3.84mm. The tests were performed on pin-ended Beam-columns. To further study the structural behavior of the beam columns thoroughly, finite element analyses were performed to simulate the geometric and material nonlinear behavior of the beam columns. Each analytical model includes 10 modules: Part, Property, Assembly, Step, Interaction, Load, Mesh, Job, Visualization, and Sketch. To create a complete analysis model, it is usually necessary to go through most of these modules such as build up the geometry of the structure under a set of parts, create element sections, create steps and choose analysis method, and Introduce load and boundary conditions. Therefore, another quantity must be used to measure the progress of the solution; ABAQUS/Standard uses the "arc length" along the static equilibrium path in load-displacement space. This approach provides solutions regardless of whether the response is stable or unstable. Table 2 shows the basic material properties used for the concrete, the reinforcement and the steel tube. The values for the mass density, E-Moduli and Poisson ratios are taken from Euro code and ACI-318 specifications.

Table-2. Basic material properties used for analyses

Material	Mass density ρ (kg/m3)	E-Modulus (MPa)	Poisson ratio ν	Yield stress compression (MPa)	Yield stress tension (MPa)
Concrete	2400	26000	0.2	25.46	2.4
Steel	7850	200000	0.3	330	330

4. FINITE ELEMENT MODELS

4.1. Concrete Filled Steel Tubes

An established FE model should be able to simulate the beam-columns in a realistic way. The non-linear finite element analyses were made with ABAQUS/Standard 6.11. Three symmetry planes were used and full scaled model of the beam column was modeled since the same concentric load was applied in the same way at both ends; see Figure 3. The steel tube, the concrete core and the loading plates modeled separated from each other.

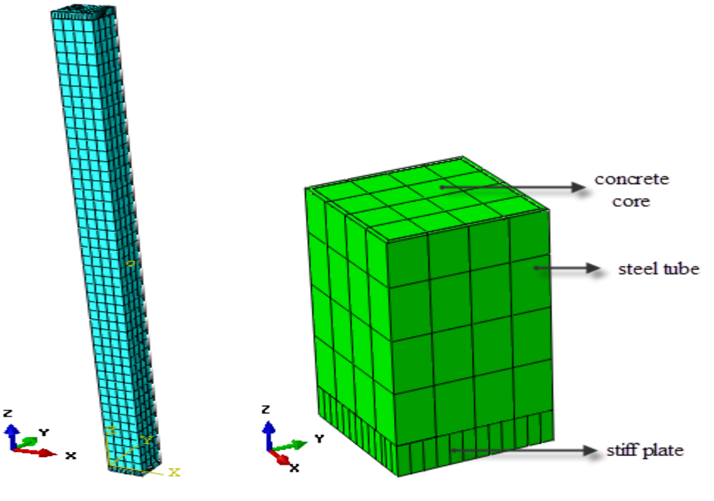


Fig-3. The FE model of CFT

Tow specimen with different size and same property were modeled and the results were compared with experimental results. Tow rectangular section beam-columns were simulated with the same size and property but different direction of load eccentricity. The specimens' data are presented in Table 3 and Table 4.

Table-3. Details of square concrete filled steel tube model

FEM Label	B (mm)	H (mm)	t (mm)	λ	e (mm)	fsy (MPa)	fck (MPa)
CFT-120	120	120	3.84	75	40	330	26
CFT-140	140	140	3.84	64	40	330	26

Table-4. Details of rectangular concrete filled steel tube model

FEM Label	B (mm)	H (mm)	t (mm)	L mm	e (mm)	fsy (MPa)	fck (MPa)
CFT-120_140	120	140	3.84	2500	40	330	26
CFT-140_120	140	120	3.84	2500	40	330	26

4.2. Steel Tube Model

Furthermore an empty steel tube beam-column and a conventional reinforced concrete beam-column were modeled with the same material property of experimental specimens. For the steel tube an elastic, perfectly plastic material was used with an equal behavior in tension and compression see Figure 4. A summary of steel tube beam column presented in Table 5.

Table-5. Details of steel tube models

B(mm)	H(mm)	t(mm)	L(mm)	e(mm)	fsy(MPa)
120	120	3.84	2500	40	330

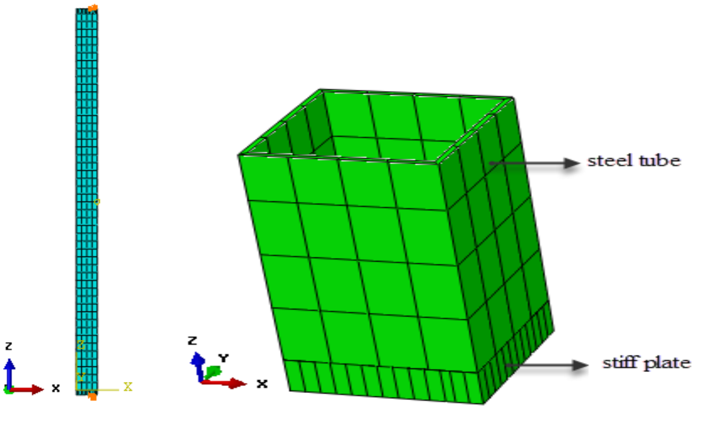


Fig-4. The FE model of steel tube

4.3. Reinforced Concrete Model

For the reinforced concrete column the minimum reinforcement calculated according to ACI-318 code of practice. An elastic, perfectly plastic material was used for the steel bar with an equal behavior in tension and compression. The steel bars used in the reinforced concrete beam were assumed to have the yielding stress: σy=460 MPa; While its elastic modulus was assumed to be: Es=200 GPa. Details of material and FE model of reinforced concrete are shown in Table 6 and Figure 5 respectively.

Table-6. Details of reinforced concrete model

B (mm)	H (mm)	L (mm)	e (mm)	fck (MPa)	fsy (MPa)	main bar	stirrup
120	120	2500	40	26	460	4T12	T8@50

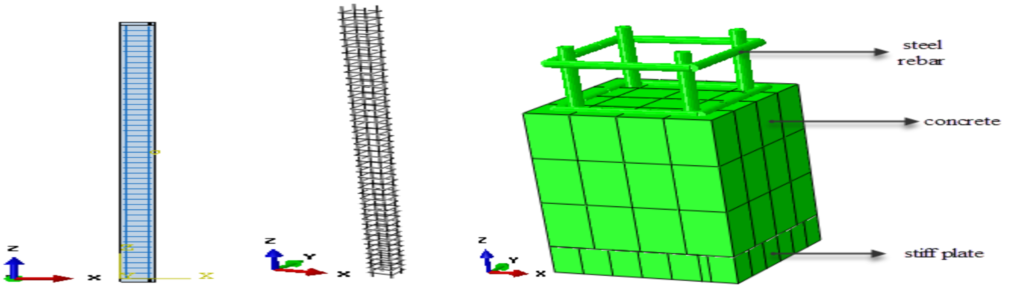


Fig-5. The FE model of reinforced concrete

4.4. Boundary Condition

The translations of the nodes at bottom of the beam-column have been completely constrained in the width of 6mm at desired eccentricity, see Figure6. At the top of beam-column in the width of 6mm at the position of bottom boundary condition, the translation along x and y direction have been completely constrained. The other nodes are unconstrained, which means that the beam-column can deform in all directions.

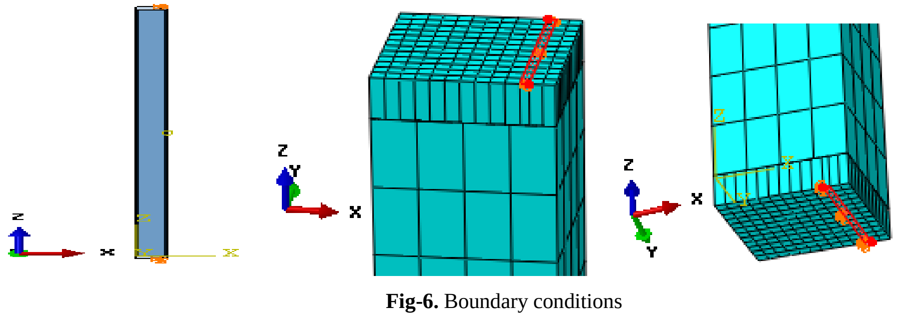


Fig-6. Boundary conditions

4.5. Loading

A vertical load with eccentricity was supposed to be acting on the structure to simulating the beam-column. This loading have been equally contributed on the nodes of the frame that they act and correspond to the initial load that are used by the Arc Length Method in order to define the critical buckling load of the beam-column. The load is applied in the width of 6mm with desired eccentricity, see Figure 7.

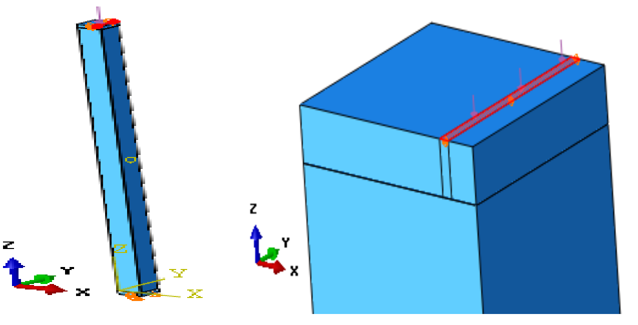


Fig-7. Vertical load with eccentricity

4.6. Mesh Size

One of the important factors that influence the accuracy of a finite element analysis is mesh size. A finer mesh generally leads to more accurate analysis, but also requires larger computational resources and time. Table 7 shows different mesh sizes which used for convergence mesh size.

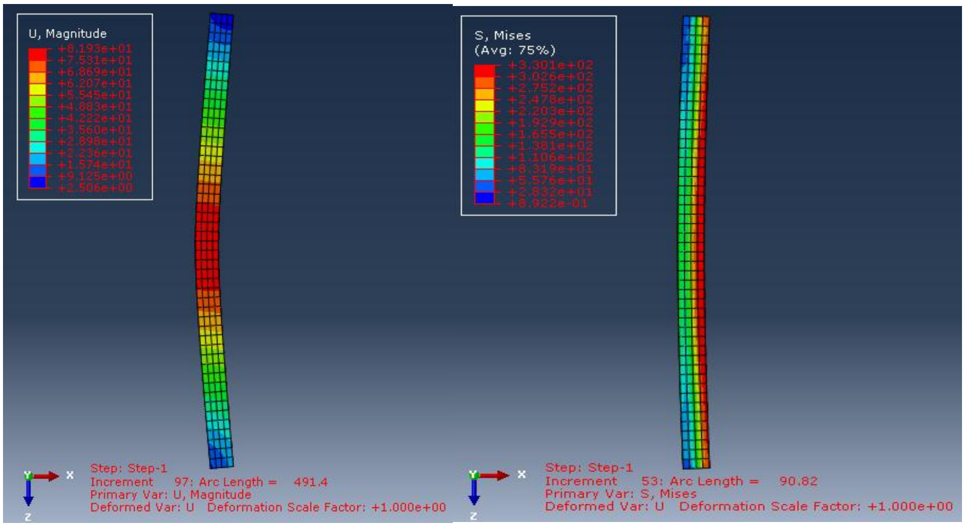
Table 7. CFT120 different mesh size

CFT 120	Nodes	Elements	mesh distance (mm)	
			x&y axis	z axis
CFT-30_30	4953	2728	30	30
CFT-30_50	3521	1848	30	50
CFT-50_50	1345	616	50	50
CFT-30_300	1241	568	30	300
CFT-40_50	2040	1032	40	50
CFT-40_100	1080	528	40	100
CFT-40_300	440	192	40	300

5. SIMULATION OF CONCRETE FILLED STEEL TUBES

5.1. Cft120

The specimen CFT120 is selected at random through the experimental specimens. Figure 8 (a) shows the deformed shape of CFT120 and Figure 8 (b) shows the misses stress at the critical load.

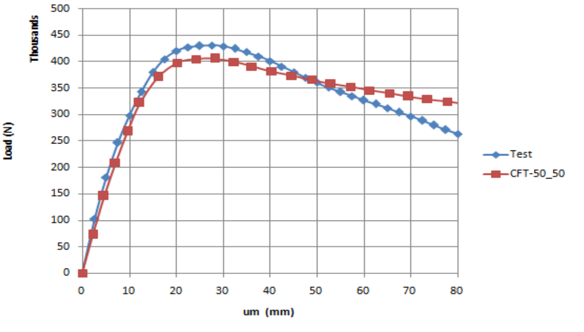


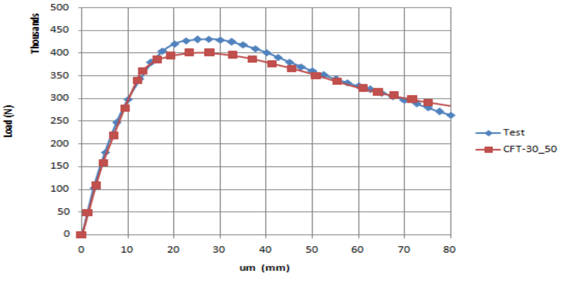
(a) (b)

Fig-8. Deformed shapes of CFT120 and misses stresses

5.1.1. Comparison of Different Mesh Size

Results for different mesh size for CFT120 are shown in Figure 9. This figure shows the load-deflection response computed by FE software using different mesh refinements. As can be see, the accuracy of the ABAQUS model was highly dependent on mesh size for this problem, and that a very fine mesh was needed to achieve good agreement with the theoretical solution. Predicted curve and experimental results [8] are shown in Figure 10.





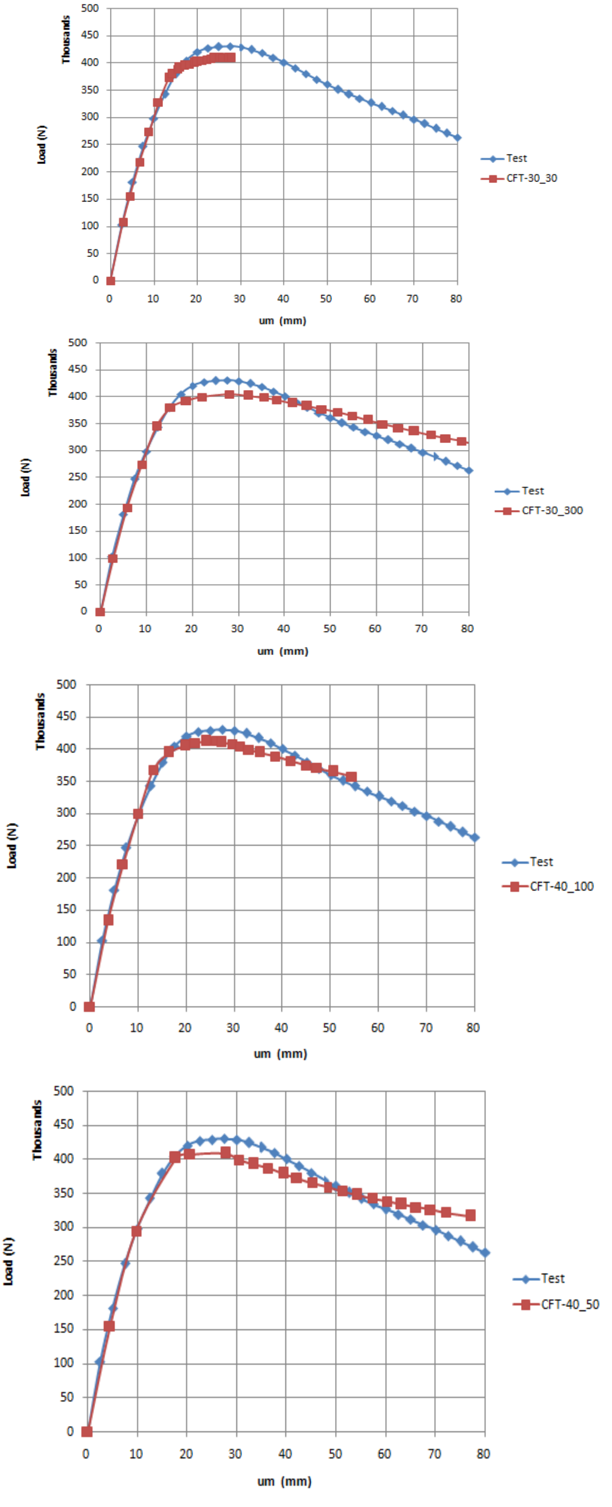


Fig-9. Load-mid span lateral deflection curve for different mesh sizes of CFT120

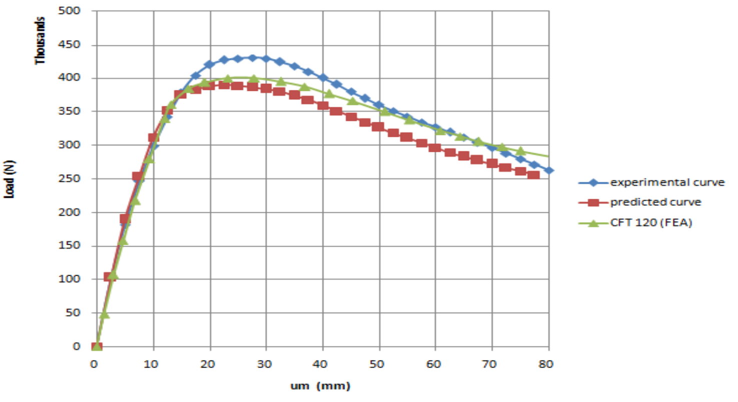


Fig-10. Load-mid span lateral deflection curve of CFT120 compared with Zhong Tao' experimental results [9].

5.1.2. Linear Geometry and Non-Linear Geometry Analyses

The effect of using linear versus nonlinear geometry analysis on a CFT120 beam-column is illustrated in Figure 11. The theoretical load-deflection curve shown in this figure is based on a simple plastic analysis and an assumption of linear geometry. Also shown are the results of two FE analyses; one using linear geometry analysis and another using nonlinear geometry analysis. Both FE analyses included inelasticity using an elastic perfectly plastic material model.

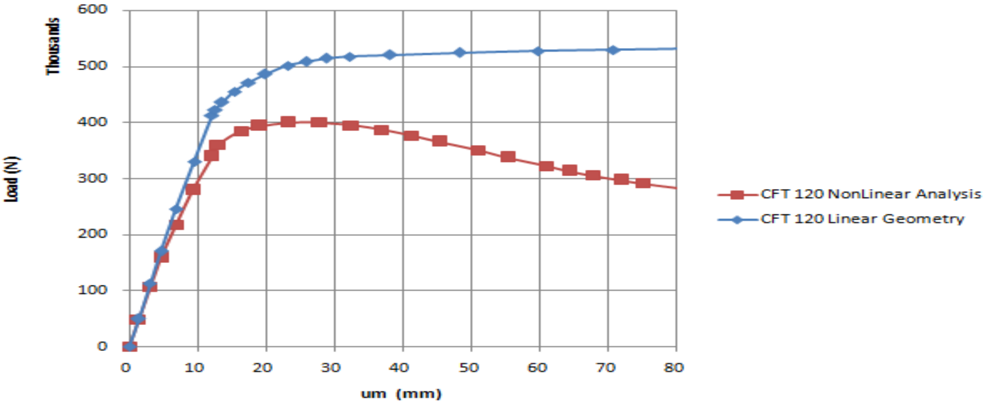


Fig-11. Load-mid span lateral deflection curve using nonlinear analysis and linear geometry analysis

5.2. Reinforced Concrete Model

In Figure 12 the load-mid span horizontal displacement curve for reinforced concrete is compared with CFT120 results.

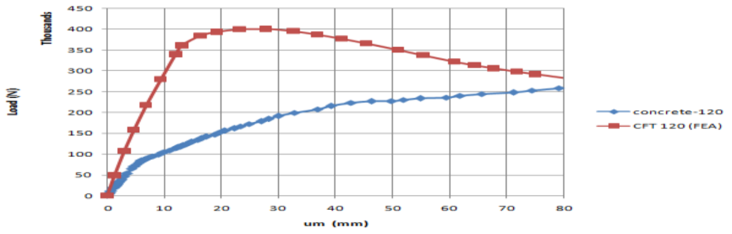
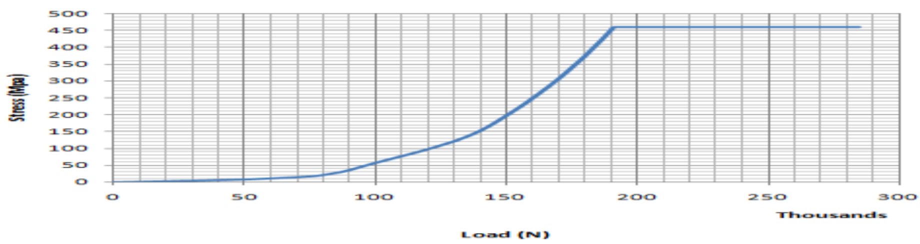


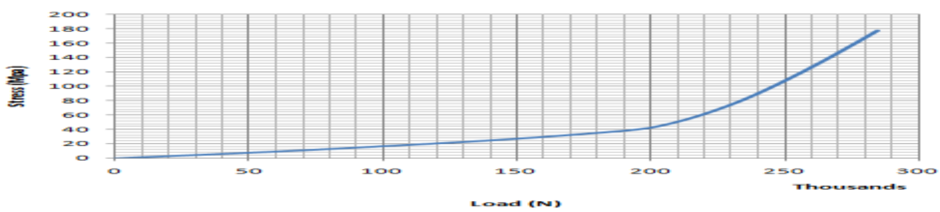
Fig-12. Load-mid span lateral deflection curve of reinforced concrete

5.2.1. Reinforced Concrete Failure Load

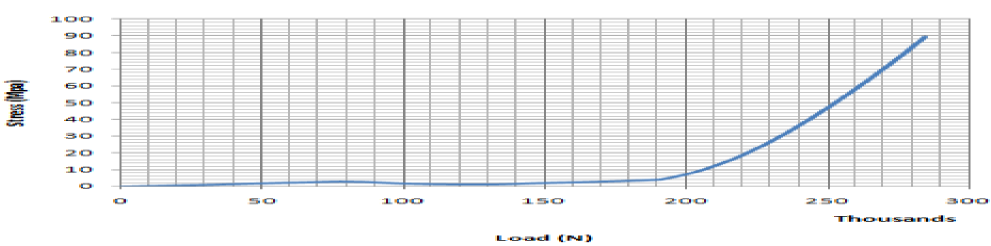
For obtain the failure load of reinforced concrete the curve of applied load versus stress for concrete in tension and concrete in compression and steel rebar in tension is plotted in Figure 13.



(a)



(b)



(c)

Fig-13. Load-stress curve for (a) steel rebar in tension (b) concrete in compression (c) concrete in tension

By regarding to Figure 13 and the failure stress of concrete in tension and compression and steel in tension, the maximum load which this reinforced concrete beam column could carry till the last component is failed will be 192.354 Kn.

5.3. Steel Model

In Figure 14 the load-mid span horizontal displacement curve for steel tube is compared with CFT120 results.

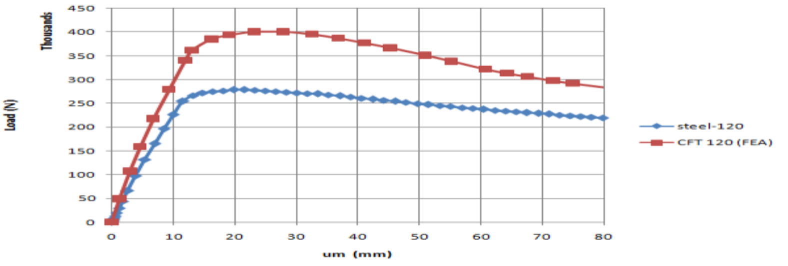


Fig-14. Load-Mid Span Lateral Deflection Curve of Steel Tube

The maximum load which this steel tube beam column could carry is obtained by load-mid span lateral deflection curve which shows in Figure 14. For steel tube the failure load is the buckling load of column.

5.4. Comparison of Models

As detailed in Table 8 and illustrated in Figure 15, the differences between the results of analysis for the CFT sections were compared with those of the different sizes.

Table-8. Maximum load for concrete filled tube sections

Name	Nu(FEA)(KN)
CFT 120	401.497
CFT 140	570.135
CFT-120_140	502.423
CFT-140_120	449.186

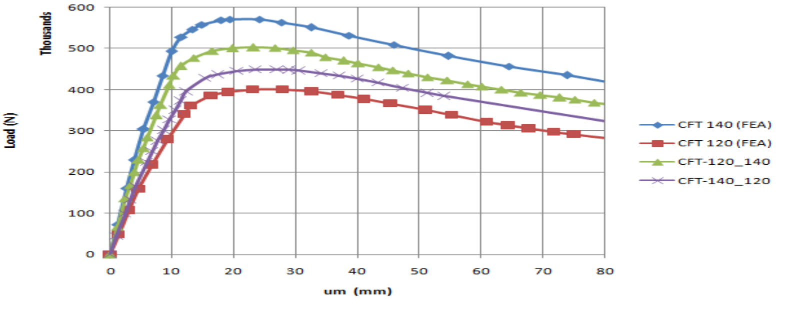


Fig-15. Load versus mid span lateral deflection curve for concrete filled tubes

It can be seen that the yield stress of the material and the buckling stress were about equal for these sections. Therefore the failure load of concrete filled tube is the critical buckling load of them.

6. CONCLUSIONS

The following conclusions were drawn based analytical models used to predict the stiffness and resistance of concrete-filled tubes.

1- The maximum load which these beam columns could carry is obtained by load-mid span lateral deflection curve.
2- Non-linear finite element analysis shows that the load could carried by concrete filled steel tube with size of 120 mm , increased compression of steel tube section and compression of reinforced concrete section about %44 and %108 respectively with %3 of longitudinal rebar.
3- The nonlinear geometry analysis gives a load capacity slightly higher than the plastic mechanism load. This increase in load capacity is the result of the effects of nonlinear geometry which models the development of tensile action in the beam column at large deformations.

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