EXPERIMENTAL STUDY FOR THE INTERACTION CURVES OF CFST COLUMNS SUBJECTED TO A STATIC CENTRIC OR ECCENTRIC LOADS

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ABSTRUCT

An experimental study on composite columns of square and circular steel hollow sections filled with normal concrete has been held in this paper. The concrete used in this study have two different compressive strength with mixing ratios of (1:2:4) and (1:1.5:3); the compressive strength of concrete were (22.9 MPa) and (31.8 MPa) respectively. Square steel hollow sections of (7.5×7.5 cm) and 2 mm thickness used with a yield stress of (352 MPa) while the circular hollow sections have (7.5 cm) diameter and 2 mm thickness with a yield strength of (327 MPa). Samples tested under the effect of concentric and eccentric axial loads with one case in which the column tested horizontally as a beam to evaluate the maximum bending resistance. The interaction curves for both shapes of columns and for two different concrete compressive strength are presented with a simple analysis for the pattern of failure in columns for each case of loading and for each type. The results show that the increase in compression strength of concrete provides more capacity for the composite columns in axial loading more than bending due to the confinement, and the failure in columns with square cross-sections are different from those which have circular cross-sectional area.

Keywords : CFST columns; Interaction curve; normal concrete; centric load; eccentric load; Failure Patterns.

الخلاصة.

تم اجراء دراسة عملية على الاعمدة المركبة ذات المقاطع المربعة والدائرية المجوفة والمملوءة بالخرسانة الاعتيادية. تم استخدام خرسانة الاعتيادية ذات مقاومتي انضغاط مختلفة وبنسب خلط (١:٢:٤) و (١:٥:١,٣) حيث كانت مقاومة الانضغاط للخرسانة هي (٢٢,٩ نت/ مم^{٢}) و (٨.٣١ نت/ مم^{٢}) على التوالي. تم استخدام مقاطع حديد مجوفة مربعة بأبعاد (٧,٥× ٧,٥ سم) بسمك ٢ ملم ذات اجهاد خضوع (٣٥٢ نت/ مم^{٢}) ودائرية الشكل بقطر (٧,٥ سم) وبسمك ٢ ملم ايضا ذات اجهاد خضوع (٣٢٧ نت/ مم^{٢}). تم اختبار النماذج تحت تأثير الحمل المحوري وغير المحوري مع حالة واحدة تم وضع العمود فيها بشكل افقي وفحصه كعتب لغرض ايجاد التحمل الاقصى له في حالة الانحناء. وتم تعيين ال (interaction curve) للأعمدة بنوعيها ولمقاومتين مختلفتين مع تحليل نمط الفشل الحاصل في الاعمدة. اظهرت النتائج بأن الزيادة في مقاومة الانضغاط للخرسانة تزيد من قابلية تحمل الاعمدة تحت تأثير الحمل المحوري بنسبة اكبر من تلك التي تكون تحت تأثير الحمل الغير محوري كما ان الفشل الحاصل في الاعمدة المركبة ذات المقاطع المربعة يختلف نوعا ما عن الفشل الذي يحصل في نظيرتها ذات المقاطع الدائرية.

1. Introduction

A concrete-steel composite column is a structural member could be made from a hot-rolled steel section encased by concrete or a concrete filled tubular section of hot-rolled steel. Figure (1) shows the typical cross-sections of concrete filled tubular sections. The external load on composite columns resisted by both steel and concrete through interacting; this depends on the bond and friction between them. Using of composite columns in structures like multistory buildings, bridges, towers, piles, …etc. has been increased during last decades due to their high capacity, easy construction, fire resistance, and ductility.

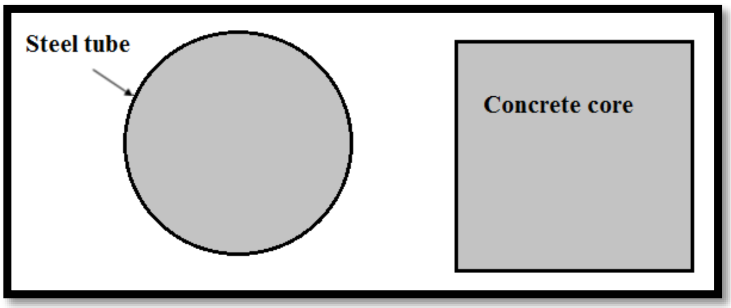

Fig. (1) Typical cross-sections of concrete filled steel tube columns.

2. Review of Prior Work

In 2009, Ghannam[1] Studied the behavior of the composite columns of rectangular cross section using eight full scale column specimens. In this study, the author compared the load carrying capacity of lightweight aggregate concrete filled steel tubular columns with normal weight aggregate concrete. All columns were tested up to failure to assess their behavior. Based on the experimental results and design calculation the light weight aggregate concrete used in composite columns showed acceptable resistance in comparison with design calculation and the behavior of concrete filled steel tube (CFST) columns with normal concrete was similar to those with light weight concrete.

In 2010, Perea[2] carried out an experimental study on eighteen CFST full-scale slender columns. During the test program, the rectangular and circular CFST specimens were subjected to a different types of loading (axial compression, uniaxial, biaxial, torsion, and torsion combined with compression). The best benefit of the research is clarification of the interaction between stability and strength in slender CFST columns and beam-columns.

In 2011, Fei-Yu et al.[3] studied the effect of gap between concrete core and steel tube on the capacity and behavior of CFST columns. A twenty one specimens were tested and divided into two groups: (fourteen short columns subjected to axial load only, and seven beams subjected to bending). The parameters investigated in the study were the gap-type (circumferential or spherical-cap), and gap-ratio.

In 2012, Hafes et al.[4] presented a theoretical and experimental study for short composite columns behavior under static concentric and eccentric loads, the experimental program contained test of six square CFST columns. One of the experimental variables in the study is the load position. The experimental and theoretical study concluded that the concentric loading improved the ultimate capacity to about 250 – 275% while the eccentric loading increased the ultimate capacity to about 307 – 341%. The concrete confinement action and the increase in total cross-sectional area were the main source for the improvement in the ultimate capacity.

In 2012, Nie et al. [5] presented an experimental study on the concrete filled steel tube columns behavior under pure torsion and compression – torsion cyclic load.
Eight CFST columns tested in the study, the parameters investigated in the study were section type, steel ratio and axial load level. Based on results from the test, The torsional capacity of CFST columns subjected to a compression – torsion load increased by low compressive load. But, the torsional capacity of CFST columns decreased under high compressive load.

In 2013, Xiushu et al.[6] studied the concrete filled steel tube columns behavior of rectangular CFST columns subjected to eccentric loading. During the study a seventeen rectangular CFST columns were tested under uniaxial and biaxial bending load. The parameters studied were; compressive strength of concrete, steel strength, cross-sectional proportion.

3. Experimental Work

A twenty specimens have been tested in this study, divided into two groups one for square CFST columns and the other for circular CFST columns. The sections used in the study are shown in Fig. (2).

Fig.(2) Square and circular columns used.

Each group also divided into two small groups of five specimens according to concrete mixture. Ordinary Portland cement (type I) manufactured according to ASTM-C150, fine aggregate conformed to the requirements of ASTM-C330, and coarse aggregate with a maximum size of 1/2 in (12.7 mm) used in this study with water/cement ratio of 0.5, The details of concrete mixes are summarized in table (1).

Table (1) Concrete Mixing properties

Mixing ratio	W/C	Compressive strength f_{cu} (MPa)	Density (kg/m3)
1:2:4	0.5	22.9	2017
1:1.5:3	0.5	31.8	2108

The hollow steel columns (square or circular) tested according to ASTM A6 to find the yield strength of steel; the details of sectional properties of steel columns are summarized in table (2).

Table (2) Sectional properties of hollow steel columns

Steel section	Dimensions (mm)	Yield strength (MPa)
Rectangular section	75×75×2	352
Circular section	75×2	327

The column specimens were tested by a special mechanical testing frame as shown in Fig. (3). The frame consisted of fixed part made from steel fastened to a bearing plate to support the column specimens. The frame can be used to test columns under axial and uniaxial loads by applying the load at a small distance (e) from the center of the section in the direction needed.

Fig.(3) Testing machine.

Three types of loading used in this study: axial, uniaxial, and pure bending; controlled by placing the specimen under the applied load with high accuracy. For uniaxial test, the loading point shifted a distance (e) as an eccentricity for the required direction. The properties of tested CFST columns (square and circular) are summarized in table (3) and table (4) respectively.

Table (3) Properties of tested square CFST columns

Column	Mixing ratio	Comp. strength f_{cu} (MPa)	Dimensions (mm)	Yield strength f_y (MPa)	Eccentricity (mm)
S1	1:2:4	22.9	75×75×2	352	0
S2	1:2:4	22.9	75×75×2	352	12.5
S3	1:2:4	22.9	75×75×2	352	25
S4	1:2:4	22.9	75×75×2	352	37.5
S5	1:2:4	22.9	75×75×2	352	∞
S6	1:1.5:3	31.8	75×75×2	352	0
S7	1:1.5:3	31.8	75×75×2	352	12.5
S8	1:1.5:3	31.8	75×75×2	352	25
S9	1:1.5:3	31.8	75×75×2	352	37.5
S10	1:1.5:3	31.8	75×75×2	352	∞

Table (4) Properties of tested circular CFST columns

Column	Mixing ratio	Comp. strength f_{cu} (MPa)	Dimensions (mm)	Yield strength (MPa)	Eccentricity (mm)
C1	1:2:4	22.9	75×2	327	0
C2	1:2:4	22.9	75×2	327	12.5
C3	1:2:4	22.9	75×2	327	25
C4	1:2:4	22.9	75×2	327	37.5
C5	1:2:4	22.9	75×2	327	∞
C6	1:1.5:3	31.8	75×2	327	0
C7	1:1.5:3	31.8	75×2	327	12.5
C8	1:1.5:3	31.8	75×2	327	25
C9	1:1.5:3	31.8	75×2	327	37.5
C10	1:1.5:3	31.8	75×2	327	∞

4. Results

Based on experimental work explained in section 3. The results can be summarized in table (5) and table (6).

Table (5) Loads and failure pattern for square CFST columns

Col.	Load (kN)	Mom. (kN.m)	Failure Pattern
S1	134	0	Concrete crushing
S2	91	1.14	Local buckling due to concrete gap or failure
S3	77	1.93	Local buckling due to concrete gap or failure
S4	61	2.29	Local buckling due to concrete gap or failure
S5	0	2.22	Concrete failure and steel yielding at
S6	159	0	Concrete crushing and steel yielding
S7	109	1.36	Local buckling due to concrete gap or failure
S8	96	2.4	Local buckling due to concrete gap or failure
S9	76	2.85	Local buckling due to concrete gap or failure
S10	0	2.56	Concrete failure and steel yielding at

Table (6) Loads and failure pattern for circular CFST columns

Col.	Load (kN)	Mom. (kN.m)	Failure Pattern
C1	108	0	Buckling
C2	70	0.88	Buckling
C3	58	1.45	Local buckling due to concrete gap or failure
C4	45	1.68	Buckling
C5	0	1.57	Concrete failure and steel yielding at
C6	126	0	Buckling
C7	83	1.04	Buckling
C8	72	1.8	Buckling
C9	55	2.06	Buckling
C10	0	1.79	Concrete failure and steel yielding at

4.1. Interaction Curves

The interaction curves for square concrete filled steel tube columns are shown in Fig. (4), while the interaction curves for circular concrete filled steel tube columns are shown in Fig. (5).

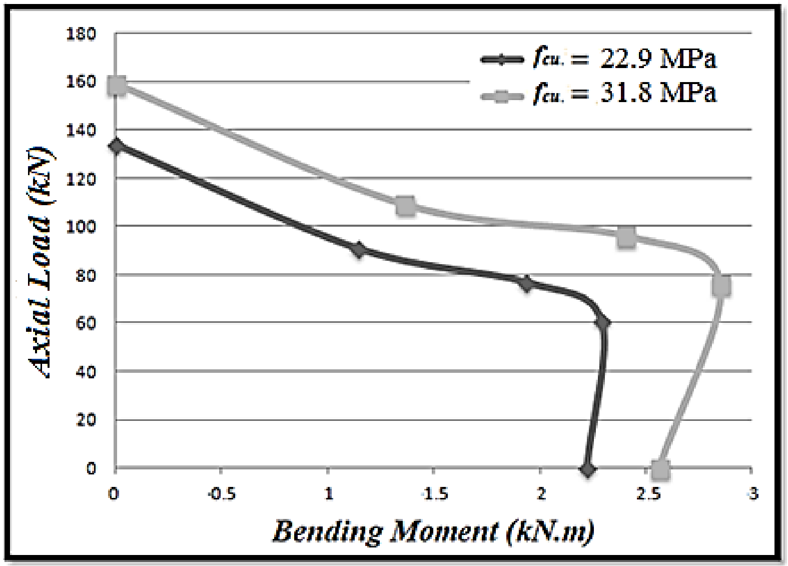

Fig.(4) Interaction curves for square CFT columns.

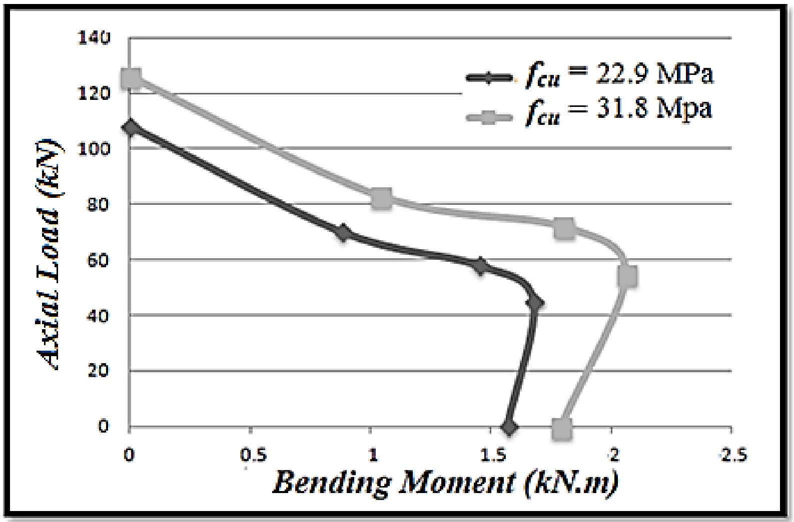

Fig.(5) Interaction curves for circular CFT columns.

4.2. Failure Patterns

For square CFST columns subjected to axial load, the failure happened due to concrete crushing or concrete crushing and steel yielding with a relatively ductile behavior as shown if Fig.(6) .

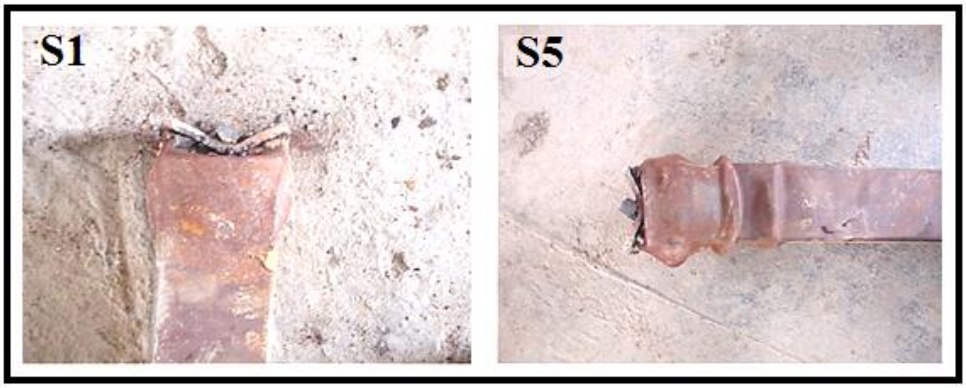

Fig.(6) Failure patterns for columns S_1 and S_5.

For square CFST columns subjected to uniaxial load, the failure happened due to buckling or local buckling because of a concrete gap or failure, the failure behavior was relatively ductile as shown in Fig.(7).

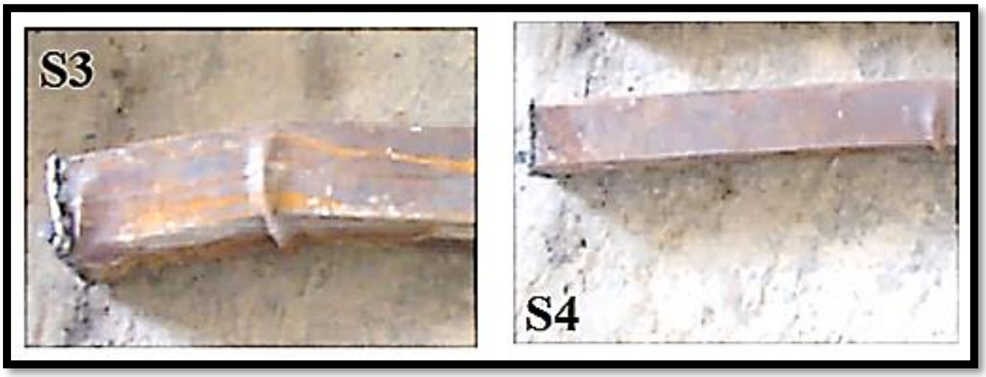

Fig.(7) Failure patterns for columns S_3 and S_4

For square CFST columns subjected to a pure bending moment, the failure happened due to concrete failure and steel yielding at midspan, the failure behavior was ductile as shown in Fig.(8).

Fig.(8) Failure patterns for columns S_5 and S_{10}

For circular CFST columns subjected to axial load, the failure happened due to buckling with a clear ductile behavior as shown in Fig.(9).

Fig.(9) Failure patterns for columns C_1 and C_5

For circular CFST columns subjected to uniaxial load, the failure happened due to buckling or local buckling because of a concrete gap or failure, the failure behavior was more ductile than square CFST columns as shown in Fig. (10).

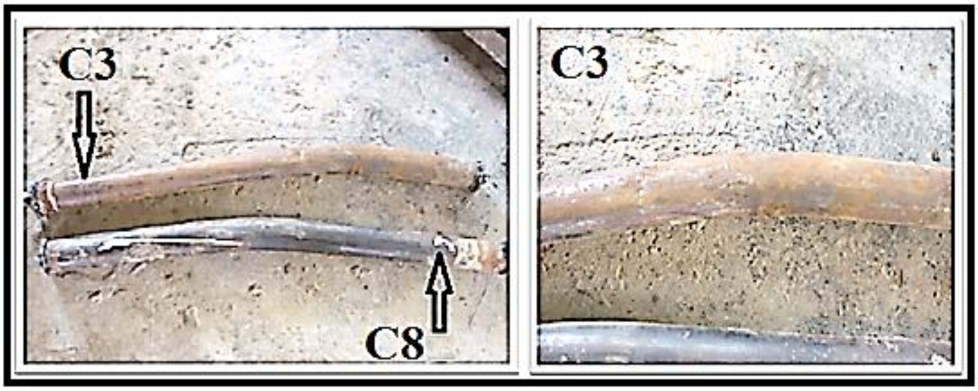

Fig.(10) Failure patterns for columns C_3 and C_8

For circular CFST columns subjected to a pure bending moment, the failure happened due to concrete failure and steel yielding at midspan, the failure behavior was more ductile than square CFST columns as shown in Fig.(11).

Fig.(11) Failure pattern for a circular CFST column subjected to pure bending load.

5. Conclusion.

Based on the experimental study, the following can be concluded:

1. The concrete filled steel tube columns have a good capacity especially in axial loading and buckling resistance with a relatively ductile failure due to concrete confinement inside steel section and the increase in moment of inertia.
2. The increase in compressive strength of concrete increased the capacity of composite columns in each loading type by about (15 – 19%) for square CFST columns and about (14 – 17%) for CFST columns with a circular cross-sectional area.

3. In axial load case, the square CFST columns failed because of steel yielding or concrete crushing or both of them while in circular CFST columns the failure happened due to buckling.
4. In uniaxial load case, the failure in both square and circular CFST columns is located at a distance from the top or the bottom of the column or in the middle point due to a gap in concrete core or concrete failure but, the effect of the gap on failure patterns in square CFST columns is clear and more effective.
5. In pure bending load case, both square and circular CFST columns have a similar failure in the midspan point, but the failure in circular CFST columns is more ductile.

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