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Load Carrying Capacity of Square and Circular Composite Columns under Axial Loading

(Comparative Study)

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Abstract **- Load carrying capacity of composite columns under axial loading is the main goal of this research. For that purpose, some tests on steel columns of square and circular section filled with normal and lightweight concrete were tested to investigate the load capacity of such columns under axial loadings. Comparisons between Normal and lightweight concrete filled steel columns for different columns cross sections using Euro Code 4 were carried out. The test results appeared that both types of concrete filled columns failed due to overall buckling, while hollow steel columns failed due to local buckling. The circular columns show greater load carrying capacity than other sections regarding to its confinement for the same modulus of elasticity. According to the said results, the further interest should be taken onto the replacement of the normal concrete by any type of lightweight concrete due to its low specific gravity.**

Keywords: Load carrying capacity, Steel Columns, Lightweight Concrete, Normal Concrete, Local Buckling, Overall Buckling.

I. INTRODUCTION

In slender columns, where buckling will occur, the steel shell will add significantly to the strength. When the concrete-filled steel tubular columns are employed under favorable conditions, the steel casing confines the core and the filled concrete inhibits local buckling of the shell. However, thermal conductivity of lightweight concrete, as well as the low specific gravity that produces lighter structures, seems to be good reasons for using lightweight concrete in composite construction. The purpose of the present study was to study the load carrying capacity and the buckling behavior of different types and sections of filled concrete columns and to do a comparison between the tests and the existing design Euro Code 4.

II. LITERATURE REVIEW

Composite columns have become the preferred type for many seismic resistance structures all over the word. In slender columns, where buckling will occur, the outer skin of steel section as a confinement will add new strength to the load carrying capacity. However, thermal conductivity of lightweight concrete, as well as the low specific gravity that produces lighter structures, seems to be good reasons for using lightweight concrete as a good replacement of normal concrete in composite construction.

Hajjar, J.F. and Gourly (1996), developed a polynomial equation to represent three dimensional cross section strength of square or rectangular filled steel tube beam column. This expression is verified against the results of a detailed fiber analysis formulation. Representation of concrete filled steel tube cross section.

Hunaiti (1997), conducted an experimental study on steel hollow tubes of square and circular section filled with foamed and lightweight aggregate concrete, and he concluded that the foamed concrete-filled column specimens were incapable of reaching the predicted values of the squash load, while column specimens filled with lightweight aggregate concrete developed the ultimate axial capacity and the lightweight concrete enhances the strength of the steel section. Braun's (1998) conducted a stress analysis for concrete-filled steel tubular column.

Tests were conducted by Wang (1999) on concrete filled rectangular hollow steel slender columns. They were loaded with end eccentricities producing moments other than single curvature bending.

Hunaiti, Y. M. 2003. Aging effect on bond strength in composite sections. The tests were focused on determination of Aging effect on bond strength in composite sections.

The purpose of this research was to study the buckling behavior of different types of filled concrete columns and to do a comparison between the tests using ***Euro Code 4***.

III. EXPERIMENTAL TESTS

Six column specimens of square, and circular steel hollow sections, designated S for square, and C for circular, were

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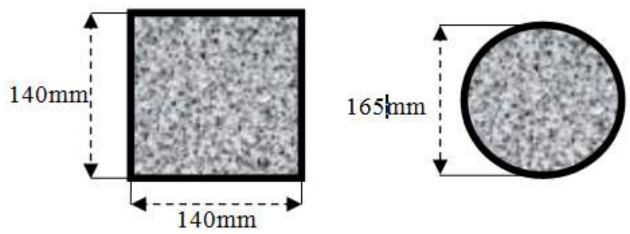
tested in this study. All columns were slender with various lengths and slenderness ratios and of cross-sectional dimensions as shown in Fig.1, and Table 1.

The column specimens comprised three different groups. First group specimens consisting of two specimens were filled with lightweight concrete (designated LWC), and the second group specimens also consisting of two specimens, were filled with normal weight concrete (designated NC). The rest of the column specimens were tested as hollow sections for comparisons (HS).Designation and sectional properties of the specimens are given in Table 2.



(a) (b)

Figure 1: Cross-Sectional Dimensions of Specimens: (a) Concrete-Filled SHS; (b) Concrete-Filled CHS

The sections of 140x140x5 mm, 165x4.7 mm. Three specimens of each section were prepared, one of them was filled with normal concrete and another was filled with lightweight concrete, and the last one was tested as a hollow steel section. End plates, 10mm thick were welded to the column ends.

TABLE 1
Sectional Dimensions of Tested Columns

Column Types	Section Dim. (mm)	Eff. Length (mm)	Depth (mm)	Width (mm)	Thick. (mm)	Diameter (mm)	Slend. Ratio
C-N.C.	140x140x5 Square	2100	140	140	5	--	15
C-LWC	140x140x5 Square	2100	140	140	5	--	15
C-H.S.	140x140x5 Square	2100	140	140	5	--	15
C-N.C.	165x4.7 Circle	2475	...	...	4.7	165	15
C-LWC	165x4.7 Circle	2475	...	...	4.7	165	15
C-H.S.	165x4.7 Circle	2475	...	...	4.7	165	15

Concrete mixes were used with a size of aggregate of 10mm. For normal concrete, concrete mixes of proportions were: 1: 1.5: 2.7 / 0.6 were used. Ordinary Portland cement, fine sand (2mm size) were used. For the lightweight aggregate concrete, pumice of 6mm size was used with expanded perlite. Concrete mixes and material properties of the columns are explained in Table 2 and Table 3. The columns were tested by universal test machine - loading 2,000-kN capacity, **see Fig.2.**

TABLE 2
Concrete Mixes

Type of Concrete	f_{cu} (MPa)	ρ (Kg/m³)	Concrete Mix
Normal Weight Concrete	30.4	2020	C : S : A 1 : 1.5: 2.7 w/c = 0.6
Lightweight Concrete	8.9	1300	C : P 1 :1.6 P : 0.95 L/kg of P , w/c = 0.90

TABLE 3
Section Properties of Columns

Steel Section	Sec. Dim. (mm)	Area of steel (mm²)	Area of concrete (mm²)	Yield Strength (Mpa)	Ec (Mpa)
Square	140x140x5	2700	16900	362	231600
Circular	165x4.7	2267	19016	355	227000

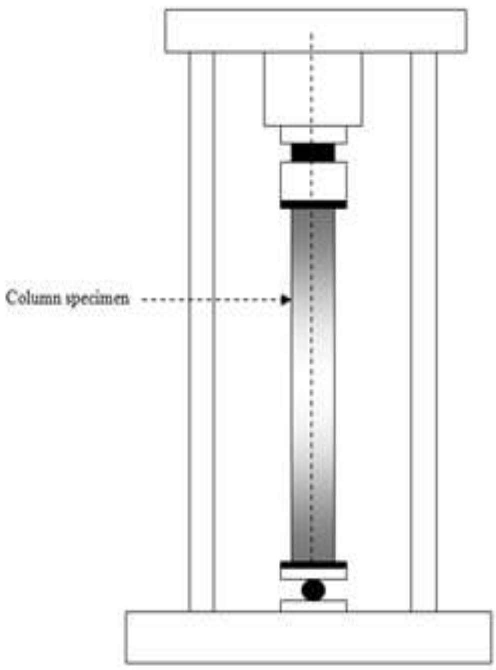


Figure 2: General View of the Test Rig

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IV. DESIGN FORMULATION

The load-carrying capacity of a composite column can be calculated by different methods, which exist in codes of practice. The ***Eurocode4,*** 1985 contain rules of the design of composite columns. These rules are applicable only to concrete-filled steel tubes and to concrete-encased steel sections.

In calculating the squash load [defined as the ultimate short term axial load for short column], ***Nu***, according to (Eurocode4, 1985) is given as:

A. Square Sections:

$$Nu = As\, fs\, k / \gamma\, m\, s + Ac\, f\, ck / \gamma\, m\, c \quad (1)$$

The material partial safety factors for steel and concrete $\gamma\, m\, s$ and $\gamma\, m\, c$ were taken as unity.

B. Circular Sections:

$$Nu = 0.91 As\, fy` + 0.45\, Ac\, f\, cc \quad (2)$$

V. RESULTS AND DISCUSSION

The column specimens very well supported the axial load, as shown in Table 4 , the experimental loads of all column specimens were acceptable in excess of design values calculated by *Euro code 4*. Design values and experimental results are shown in Table 4**.** The results of the tested columns are as follow:

a. Hollow steel sections failed due to yielding resulted in local buckling at the ends of the column sections, and they supported in the range of 91% -96% of the squash load. The ratios between the experimental loads and the design loads ranged from 99% to 102%.
b. Sections filled with lightweight aggregate concrete failed due to local as well as overall buckling, and they were strong enough to support about 99% of the squash load. The ratio between experimental and design values ranges from 95% to 97%.
c. Sections filled with normal concrete failed due to overall buckling, and they supported about 90% of the squash load. Design code values of failure loads, according to *Eurocode 4*, are also compared with the experimental results. The ratios between the experimental loads to the design loads vary between almost 92% and 98%.

TABLE 4
Results of Column Specimens by Eurocode 4

Column Type	Con. Cont. Factor (α)	Squash Lod (KN)	Exp. Load (KN) (Load Carrying Capacity)	Design Load (KN)
CNC 140x140x5	0.358	**1386**	**1248**	**1275**
CLWC 140x140x5	0.124	**1016**	**1005**	**954**
CHS 140x140x5	....	**996**	**953**	**936**
CNC 165x4.7	0.406	**1287**	**1058**	**1149**
CLWC 165x4.7	0.143	**895**	**800**	**824**
CHS 165x4.7	...	**836**	**763**	**771**

It can be clearly seen that normal concrete-filled columns support higher loads than those filled with lightweight aggregate concrete. Moreover, in terms of the cube strength, columns of more than three times stronger normal concrete compared to the lightweight concrete (cube strength of normal concrete is 30.4MPa, while it is 8.9MPa for lightweight concrete, about 3.4 times greater, while concrete contribution factor ratio, is 2. 9) showed enhancement of the loads of only about 30%, but the weight of the column with lightweight concrete is lighter than that with normal concrete of the same cross section by about 36%. This leads to reduce the column sections.

VI. CONCLUSION

The composite column sections that were tested under axial load show good strength when compared to design calculations. According to the experimental and design results, the buckling behavior of both lightweight concrete steel column and normal concrete steel column is very similar.

It is very important to mention the following:

a. For comparison purposes, the load carrying capacity between the square hollow section and the circular hollow sections, from table 4, it is clearly seen that: The experimental load of circular section comparing with square section is about 80% due to low steel cross sectional area of circular section, comparing with steel cross sectional area of square section which is about 84%, that means the circular column seems to have load carrying capacity approximately close to the square sections, this due to the circular confinement.
b. Columns filled with lightweight concrete failed due to local buckling. Also, such negative effect did not largely reduce the load carrying capacity of the column. However columns with normal concrete failed due to overall buckling with no signs of local buckling. It can be seen from the results of comparisons between different types of columns with different dimensions and different sections (square and circular sections). Moreover, sections with larger dimensions exhibited higher load carrying-capacity.
c. The circular columns show greater load carrying capacity than other sections regarding its confinement for the same modulus of elasticity. But the square section steel composite columns are more applicable in steel connections than circular due to using square plates.

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