Comparative Study of Load Carrying Capacity of Steel Tube Columns Filled with Lightweight Concrete and Normal Concrete

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ABSTRACT

Tests on steel columns filled with normal concrete and lightweight concrete were carried out to investigate the actual behavior and the load carrying capacity of such columns. Eight full scale rectangular cross-section columns filled with lightweight aggregate concrete and normal weight aggregate concrete, four specimens each, were tested under axial loads for comparison purposes. The results showed that using lightweight concrete filling instead of normal concrete filling will reduce the weight of columns. At the same time, a high load carrying capacity is achieved.

KEYWORDS: Failure load, Lightweight aggregate concrete, Normal weight aggregate concrete, Local buckling, overall buckling, Composite action, Tubular columns.

INTRODUCTION

Composite columns may be used for low-rise and high-rise buildings. For low-rise buildings, steel sections are often encased in concrete for the sake of appearance and for protection of steel from fire, corrosion and from vehicles in garages. For high-rise buildings, composite columns are stiffer than non-composite steel columns. The size of composite columns is often considerably smaller than required for reinforced concrete columns to support the same loads.

Although composite columns (concrete in filled steel tubulars) are often considered as a new type of column, its development has been the subject of extensive research over the past few decades. Many researchers have investigated the load carrying capacity of such composite sections, but they did not focus on the squash load (Nu). Several investigations were carried out by

(Hunaiti, 1997) in order to study the behavior of short and long columns filled with foamed and lightweight aggregate concrete. Other researchers studied the slender circular columns filled with normal concrete (Johansson and Gylltoft, 2001). Furthermore, buckling of channel beam columns was studied by (Teng, Yao and Zhao, 2002). Uy (2001) studied the behavior of concrete filled high strength steel box columns.

The purpose of this study was to study the behavior of composite columns of rectangular cross-section and to compare the load carrying capacity of lightweight aggregate concrete filled steel tubular columns with that of normal weight aggregate concrete filled steel tubular columns. All columns were tested up to failure to assess their behavior.

EXPERIMENTS

Eight full scale column specimens of rectangular hollow section were tested in this study. The column

specimens were classified into two groups. The first group of specimens consisted of four specimens which were filled with lightweight aggregate concrete, and the second group consisted of four specimens that were filled with normal weight aggregate concrete. All

columns were slender with various lengths and slenderness ratios and of rectangular cross-sectional dimensions as shown in Fig.1. Types and sectional dimensions of test specimens are given in Table 1.
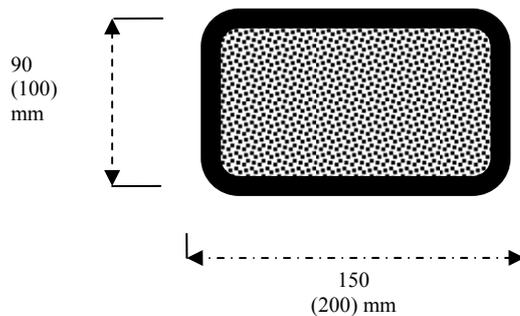
90
(100)
mm

150
(200) mm

Figure (1): Concrete-filled rectangular steel hollow section

The columns were of different sizes, shapes, lengths and slenderness ratios. From the prototype sections of 200x100x5mm and 150x90x3mm, four specimens of each section were prepared, two of them were filled with normal weight aggregate concrete, and the other two were filled with lightweight aggregate concrete .

Two different concrete mixes were used with a max. aggregate size of 10 mm. For normal concrete, a concrete mix of 1: 1.4: 2.8 with w/c=0.6 was used. Ordinary Portland cement, medium crushed limestone aggregate gravel and fine sand (2mm size) were used. For lightweight concrete, pumice of 10mm size was used with expanded perlite.

Concrete mixes and material properties of the columns are summarized in Tables 2 and 3. The column specimens were tested under axial monotonic loading in a 2000 kN capacity compression hydraulic jack (M 1000/RD), with a deformation rate of 0.01 mm/sec. All specimens were prepared and placed axially with a high degree of accuracy to ensure that the load application is in the required position as shown in Fig. 2 and Fig. 3 (1&2).

DESIGN CONSIDERATIONS

The ultimate load carrying capacity of a composite column can be calculated by several methods, which exist in codes of practice. The Bridge Code (BS 5400,2000), (The Eurocode 4, 2000) and the American Standard (AISC-LRFD Methods, 1993) contain rules of the design of composite columns.

In calculating the squash load, N_u, (According to the Bridge Code) for rectangular cross section, the following formulae can be used:

$$N_u = A_s f_{sk} / \gamma_{ms} + A_c f_{ck} / \gamma_{mc} \qquad\qquad Eq.\ (1)$$

The material partial safety factors for steel and concrete, γ_{ms} and γ_{mc}, were taken as unity. Moreover, the value of the characteristic concrete strength f_{ck} was taken as $\qquad\qquad f_{ck} = 0.83\, f_{cu} \qquad\qquad Eq.\ (2a)$
instead of $\qquad\qquad f_{ck} = 0.67\ f_{cu} \qquad\qquad Eq.\ (2b)$
where f_{cu} is the 28 day cube strength of concrete. The value of $0.83\ f_{cu}$ is recommended by ECCS for experimental work. Furthermore, the ratio between

A_c f_{ck} / γ_{mc} and N_u is called the concrete contribution factor α_c, and for a filled composite section it varies between 0.1 and 0.8 which is considered in this paper. f_{sk} was taken as $f_{sk} = 0.91 f_y$.
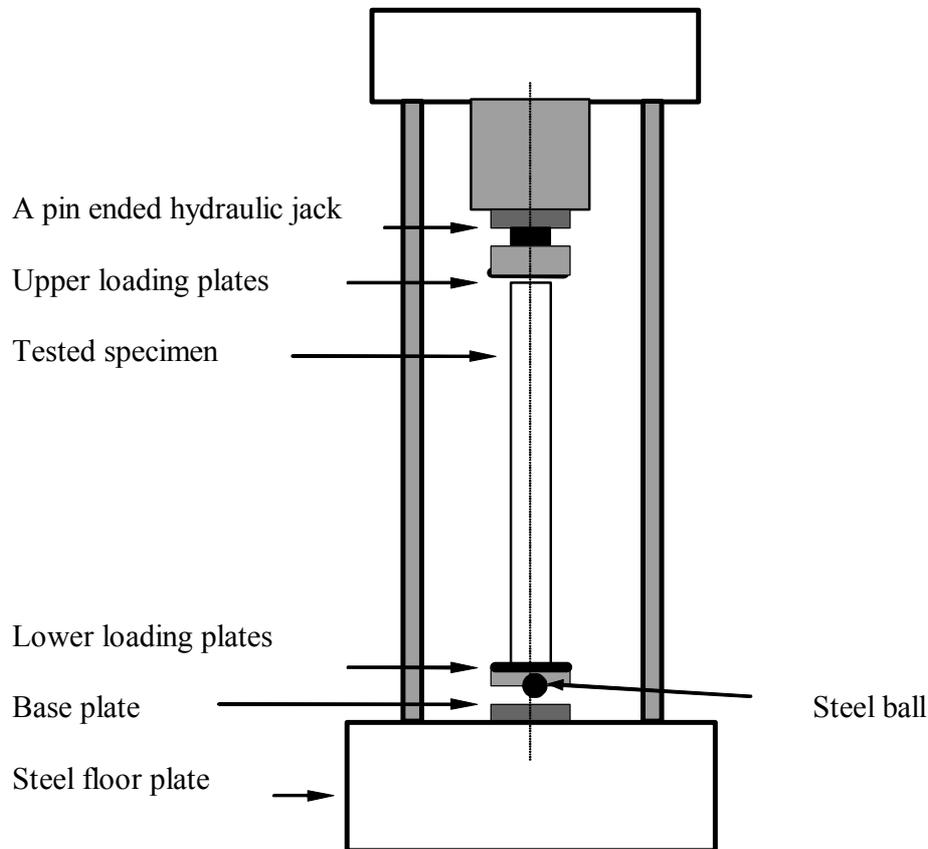
Figure (2): General scheme of the test rig

RESULTS

The column specimens behaved very well under load, and as shown in Table 4, the experimental failure loads of all columns were mostly well in excess of design values estimated by most composite codes. According to the visual observations and due to the experimental failure loads shown in Table 4, The failure modes of the tested columns are summarized as follows:

a. Sections filled with lightweight aggregate concrete failed due to local as well as overall buckling, and they supported more than 92% of the squash load.

b. Sections filled with normal weight aggregate concrete failed due to overall buckling at mid height, and they supported more than 87% of the squash load.

It can obviously be seen that columns with lightweight aggregate concrete filled steel tubulars support similar loads as columns filled with normal weight aggregate concrete. On the other hand, the weight of the column with lightweight concrete was 30% less than that of the column with normal concrete of the same cross-section.

Figure (3.1): Data acquisition system

Figure (3.2): General view of the test rig

Table (1): Types and sectional dimensions of test specimens

Column type	Section dimensions(mm)	Effective length (mm)	Slenderness ratio Kl_e/r
C1-N	200x100x5	2000	20
C2-N	200x100x5	2000	20
C3-LW	200x100x5	2000	20
C4-LW	200x100x5	2000	20
C5-N	150x90x3	2250	25
C6-N	150x90x3	2250	25
C7-LW	150x90x3	2250	25
C8-LW	150x90x3	2250	25

Table (2): Concrete mixes

Type of concrete	Cube strength (fcu MPa)	Density, ρ (kg/m^3)	Concrete mix proportions
Normal weight aggregate concrete	33.4	2081	Cement : sand : medium aggregate 1 : 1.4 : 2.8 w/c = 0.6
Light weight aggregate concrete	10	1390	Cement : pumice 1 : 1.53 Exp. Perlite 0.92 L/kg of pumice w/c = 0.85

Table (3): Details of sectional properties of columns

Steel section	Dimension of section (mm)	Area of steel As (mm^2)	Area of concrete Ac (mm^2)	Yield strength Fy (MPa)	Steel modulus of elasticity Est (MPa)
Rectangular cross section	200x100x5	2900	17100	360	229300
	150x90x3	1404	12096	320	201000

Table (4): Column properties and results

Col. No. and type	Concrete contribution factor (α_c) (Bridge Code)	Squash load N_u (kN) Bridge Code	Experimental load N_e (kN)
C1-N	0.303	1356	1242
C2-N	0.333	1417	1242
C3-LW	0.139	1103	1062
C4-LW	0.116	1048	1022

CONCLUSIONS

The steel tubes filled with lightweight aggregate concrete showed acceptable strength under the applied loads when compared to design calculations. According to the experimental and design code calculations, the behaviours of both lightweight concrete –filled steel tubular columns and normal concrete-filled steel tubular columns were very similar.

Column specimens filled with lightweight aggregate concrete developed the ultimate axial capacity and significantly enhanced the strength of steel sections. The load carrying capacity of the column was increased in the view of the fact that the concrete core, in addition to its own strength contribution, also helped prevent the effect of local buckling of the steel tube. This increased the strength contribution of the tube portion over the hollow section.

Notation

The following symbols are used in this paper:

A_c = concrete cross section;

A_s = steel cross section;

E_c = modulus of elasticity of concrete;

E_s = modulus of elasticity of steel;

f_{ck} = characteristic strength of concrete;

f_{sk} = characteristic strength of steel;

K = restraint column factor;

L_e = effective length of a column;

N_u = squash load of a column;

r = radius of gyration of the column cross-section;

α_c = concrete contribution factor;

γ_m = partial coefficient of material.

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