

Effect of the concrete compressive strength on the structural behaviour of the steel concrete composite cloumn

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KEYWORDS

Concrete-filled hollow steel sections
Structural behavior
Concrete compressive strength
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Load capacity

ABSTRACT

Composite column has been popularly used in buildings, which are mainly subjected to forces and end moments. There are two types of the steel concrete composite columns: open sections partially or fully encased in concrete, and concrete-filled hollow steel sections. The first type of section has used for fireproof and the slender structural steel can be protected buckling by the exterior concrete, while the remaining type can prevent the transverse deformation of the concrete inside and enhance the load capacity. The steel tube serves as a formwork for casting the concrete, which reduces the construction cost. In this study, four the steel concrete composite columns with concrete-filled hollow steel sections were tested to investigate the effect of the concrete compressive strength on the structural behaviour of the steel concrete composite columns. The parameters observed are load capacity, longitudinal and transverse deformation of the tube steel and the concrete, and the column failure.

1. Introduction

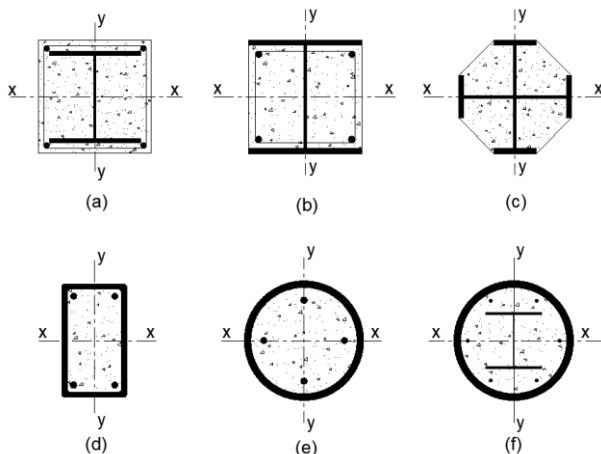


Figure 1. Some sections of steel-concrete composite columns.

The section of steel-concrete composite columns can be classified into two types: concrete-encased steel sections and concrete-filled steel tubes, as shown in Figure 1.

The first section is created by a structural steel section (like a I, H or box shape) with concrete surrounded, while the remand section is a steel tube that is filled up by concrete. The concrete-encased steel section may be partial or fully encased open section. The fully encased open section (Fig. 1a), protect the steel from fire, prevents the local buckling the structural steel and enhances the ductility and tensile strength of steel. The partial encased open section (Figure 1b, and 1c), leaving some portions of the flanges exposed, is easy to connect to other

structural elements. The concrete-filled hollow sections (Figures 1d to 1f) may be circular or rectangular. For the concrete fills the section, the steel tube acts as a formwork, and the concrete infill prevents the inward local buckling of the steel tube, while the steel tube provides confinement to the concrete core, results in providing additional compressive strength and stiffness.

Many researchers have studied the behavior of the steel-concrete composite columns. Artiomas Kuranovas and Audronis Kazimieras Kvedaras conducted to analyse behavior of hollow concrete-filled steel tubular composite elements [1]. This study analysed the complex stress state appearance and behaviour of hollow CFST element components in different load stages of compressed stub structural member. Artiomas Kuranovas¹, Audronis Kazimieras Kvedaras et al. analysed 1303 specimens of CFST experimental data and compared the load capacity with that determining from EC4 [2]. There was the good agreement between the test results and the results calculating from EC4. N. Jamaluddin, D. Lam, X. H. Dai. I. Ye carried out on twenty-six elliptical CFT specimens to study the effect of member geometry and constituent material properties on the structural behaviour of elliptical CFT columns [3]. Mr. K. Suresh Kumar, Sri. O. Suresh, Dr. E. V. Raghava Rao studied the buckling CFST with different cross section using Ansys Workbench and Sap software [4]. Circle cross sections are investigated to study the effect of L/D and D/t on the behaviour of the CFST composite columns. Piotr Lacki, Anna Derlatka, and Przemysław Kasza performed to compare the behaviour of the steel-concrete composite column and steel column by the finite element method [5]. This study was considered the stress and displacement in the steel column, and the stress in steel and concrete, the stress distribution in the reinforcement

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bars and displacements of the steel-concrete composite column. A. A. Galatage and Hasan Abdul Rashid Parkar conducted testing on rectangular and square hollow structural steel with and without infill under compression and flexure to study the behavior of hollow and composite specimens under compression and flexure, normal concrete and no-fines concrete under composite action, the effect of chemical and mechanical bond with composite section under compression and flexure, and then, conducted finite element modeling and analyzing composite section by ANSYS under numerical method using ANSYS [6]. Deividas Martinavicius, Mindaugas Augonis tested on three columns with difference of dimensions and then evaluated the influence of imperfections on behaviour of thin-walled steel-concrete composite columns based on finite element (FE) models using Abaqus [7]. Thunga Kartheek and T. Venkat Das used ABAQUS to simulate fully encased composite (FEC) columns and determined Axial load capacity deformation, stress and strain patterns are determined for reinforced concrete columns and composite columns with I-section steel confinement [8]. These results are compared with that of reinforced concrete columns of different strengths. The results also showed that the reinforced concrete column has less resistance to ultimate axial load compared to fully encased composite columns. Vincent Kvocak et al. analysed a numerical and experimental of global stability of axially compressed columns [9]. This steel-concrete composite columns were used thin-walled rectangular concrete-filled steel tubes (CFSTs), with the consideration of initial geometric imperfections. Besides, the results obtained from 3D model using the ABAQUS software was also compared with the test results. Shaghayegh Ameri, Rudolf Roß, Jochen Zehfuß, and Martin Mensinger conducted testing on specimens to examine the thermo-mechanical performance of bar-bundle columns with concrete-filled hollow section [10]. Authors described an advanced nonlinear finite element model to estimate the fire behavior of bar-bundle columns.

Concrete filled steel tubes have been popularly used for columns, caissons, piers because of their significant load capacity and stiffness. This study was carried out on four steel-concrete composite columns to investigate the behaviour of concrete-filled steel tube columns. The load capacity, longitudinal displacement of steel tube and concrete core are studied in this test.

2. Test program

2.1. Incremental loading models

There are two incremental loading models, as shown in Figure 2.

Model 1: The steel-concrete composite was placed on the load frame, the column base rests on the hydraulic jack, the column head contacted the bearing shoe through a 150 mm diameter and 25 mm thickness steel plate.

Model 2: The steel-concrete composite was also placed on the load frame. However, the column base and head contacted the bearing shoe and the hydraulic jack through a 150 mm diameter and 25 mm thickness.

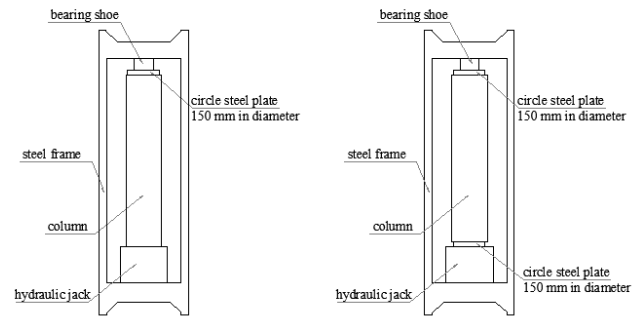


Figure 2. Incremental loading models.

2.2. Specimens

The test program was carried out on four specimens with different concrete grades. The length of column C1 and C2 was 1200 mm, and that of columns C3 and C4 was 1500 mm. The sections of columns were the concrete-filled hollow steel sections, as shown in Figure 3 and the gridding process is shown in Figure 4. The steel tube was cut and ground the surfaces at the ends, as shown in Figure 3. The steel bar was fed into the milling machine to drill two holes measuring 7 mm × 14 mm at a distance of ± 250 mm from the center point of the column to measure the longitudinal deformation of the concrete. Concrete was poured directly into steel tubes without using formwork. The parameters of specimens are listed in Table 1.

2.3. Material properties

2.3.1. Concrete

The concrete used for the specimens are grades of B35 and B50. The aggregate gradation is shown in Table 2. The concrete was cured in 28 days and tested in compliance with TCVN 3118-1993 [11]. The concrete compressive strength test was carried out simultaneously with the test of the steel concrete composite columns. The test results of concrete compressive strength are shown in Table 3.

2.3.2. Tube steel

The technical specification of the tube steel was taken from the manufacturer's specification given in the Table 4.

2.4. Test setup

2.4.1. Test models

Incremental loading frame withstand 300 tons was used to test the steel concrete composite columns. Linear Variable Differential Transformer (LVDT) and strain gauges (SG) were attached to the column to measure the displacement and strain of the steel-concrete composite column. LVDT and strain gauges were attached to the steel tube as shown in Figure 5. They have the following roles:

LVDT1: measures the longitudinal deformation of concrete core
 LVDT2, LVDT3, and LVDT4: measure the longitudinal deformation of steel tube

SG1, SG2, and SG3: measure longitudinal strain of steel tube

SG4, SG5, and SG6: measure lateral strain of concrete

2.4.2. Incremental loading process

The incremental loading process was performed in two stages:

Stage 1: load up to 40 % of the maximum load P_{max} (the expected failure load of the column) and keeping this value in 20 seconds, then reducing load to zero. This process is performed twice.

Stage 2: After the second load is reduced to zero, increasing load until failure. The deformation in stage 1 is eliminated, the force-deformation curve is obtained from stage 2.

The load control system used during the test is a manual force-controlled system. The measured data during the test are automatically recorded by the system every second.

3. Test results and discuss

3.1. Test results

The test results of the displacements of steel tubes and concrete cores are presented in Table 5. The longitudinal and lateral strains of steel tubes are shown in Table 6. These values of displacements and strains were recorded corresponding to the ultimate load of columns.

3.2. Effect of the concrete compressive strength on load capacity of column

Table 7 shows the difference of the load capacity of columns with different concrete compressive strength. When the concrete compressive strength increased from 36.07 MPa to 49.94 MPa, the failure load of column in model 1 and model 2 increased about 11.3 % and 14.2 % respectively. Obviously, the higher the compressive strength of concrete, the more it increases the bearing capacity of the steel concrete composite column.

3.3. Effect of the concrete compressive strength on the longitudinal displacement of steel tube

The longitudinal displacements of steel tubes were recorded by LVDT2 attached at middle length of columns, and LVDT4 attached at L/4 from the end of columns. The values measured at LVDT2 are often higher than that at LVDT4, as illustrated in Table 5. The results show that the columns with higher concrete compressive strength reduce the longitudinal displacement of steel tubes. At the failure load, the longitudinal displacement of columns C2 and C4 are smaller than that of columns C1 and C3 although the failure load of columns C2 and C4 are higher than the failure load of columns C1 and C3. Even, at the failure load of columns C1 the longitudinal displacement of columns C2

is 0.265 %, just about 27.01 % in comparison with that of column C1. Similar, at the failure load of columns C3 the longitudinal displacement of columns C4 is 0.291 %, just about 31.66 % in comparison with that of column C3, as shown in Figure 6. This proves the concrete compressive strength significantly effects on the longitudinal displacement of the steel tubes.

3.4. Effect of the concrete compressive strength on the longitudinal displacement of concrete core

The longitudinal displacements of concrete cores were recorded by LVDT1 attached at middle length of columns and these values are shown in Table 5. The column C2 with higher failure load gave the longitudinal displacement of the concrete core of higher than that of column C1 with smaller failure load. However, at the failure load of column C1, the longitudinal displacement of the concrete core of C2 is 0.29 %, about 87.9 % in comparison with that of column C1, as shown in Figure 7. This shows the concrete compressive strength reduces the longitudinal displacement of concrete core.

3.5. Effect of the concrete compressive strength on longitudinal strain of steel tube

The longitudinal strain of steel tubes was measured at the middle length (SG2) and the two ends (SG1, SG3) of columns, as shown in Table 6. The result shows that the longitudinal strain at the middle length of columns are almost larger than that at the two ends. This is consistent with experimental practice where the column deforms more at the middle than at the two ends. Figure 8 points out the difference of the longitudinal strain of steel tube at middle-length of column with different compressive strength of concrete. Columns with higher concrete compressive strength considerably reduces the longitudinal strain of steel tubes. Even when the failure load is greater the longitudinal strain of column with higher concrete compressive strength is also smaller than that of column with lower concrete compressive strength. At the failure load of column C1, the longitudinal strain at middle-length of column C2 is 0.105 %, just about 55.56 % in comparison with that of column C1. Similar, At the failure load of column C3, the longitudinal strain at middle-length of column C4 is 0.072 %, just about 31.44 % in comparison with that of column C4. This can be explained that the higher compressive strength of concrete reduces the longitudinal displacement of concrete core results in reduce the longitudinal strain of steel tube.

3.6. Effect of the concrete compressive strength on lateral strain of steel tube

The lateral strain of steel tubes was measured by strain gauges SG1 and SG3 at the two ends of columns, and SG2 at the middle-length of column. The test results show that the lateral strain of steel tubes at the two ends of columns are smaller than that at the middle-length of

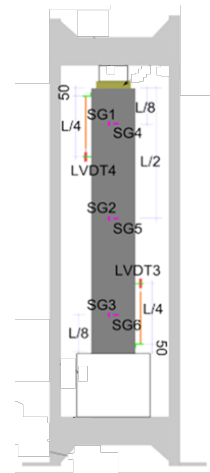
columns, as shown in Table 6. Figure 9 plots the applied load - lateral strain curves of columns to compare the lateral strain between columns C1 and C2, C3 and C4. At the failure loads of columns C1 and C3 (lower than the failure load of columns C2 and C4), the lateral strain of steel tubes of columns C2 and C4 are 0.053 % and 0.02 %, respectively. These values equal 73.61 % and 23.53 % in comparison with the lateral strain of steel tubes of columns C1 and C2, respectively. This is supposed that the longitudinal displacement of concrete core in higher concrete compressive strength is smaller than that in lower concrete compressive strength, so the longitudinal and lateral strain of steel tubes of columns with higher concrete compressive strength (C2 and C4) are smaller than that of columns with lower concrete compressive strength (C1 and C3).

3.7. Failure mode

During the failure process, the steel pipe does not crack. When the failure load is reached, the top and bottom of the concrete do not crack. When columns reach the failure load, most of the steel tubes will deform slowly, which is believed to be due to the anti-expansion effect of the steel tubes.



a. Steel-concrete composite columns



b. Positions of LVDT and strain gauges

Figure 3. Configuration of steel-concrete composite column and positions of LVDT and strain gauges.



a. Steel tube cutting



b. Surface grinding



c. Hole drilling

Figure 4. Steel tube processing.

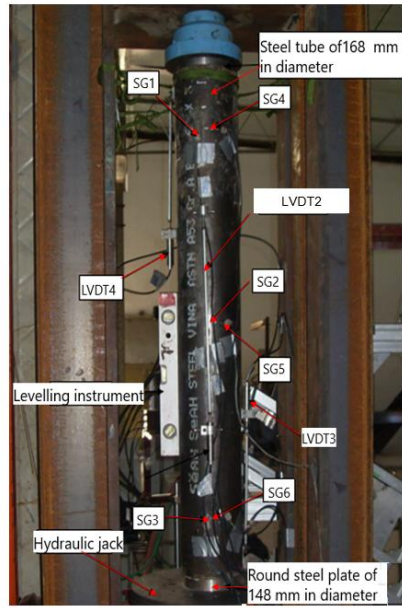


Figure 5. Install composite column into the test frame.

Table 1. The geometric parameters of steel-concrete composite columns.

Column	Concrete compression strength (MPa)	Diameter of steel tubes (mm)	Thickness of steel tubes (mm)	Length of columns (mm)	Test model
C1	B35	168	4.78	1200	1
C2	B50	168	4.78	1200	1
C3	B35	168	4.78	1500	2
C4	B50	168	4.78	1500	2

Table 2. The aggregate gradation for 1 m³ concrete.

Components	Unit	Grade B35	Grade B50
Cement Fico PC50	kg	385	410
Bank sand	kg	760	740
Stone 10×20	kg	1040	1220
Water	litter	200	140

Table 3. Test results of compressive strength of concrete.

Specimen	Dimensions (mm)	Compression strength of B35 (MPa)	Compression strength of B50 (MPa)
M1	150×150×150	35.76	49.25
M2	150×150×150	36.53	50.58
M3	150×150×150	35.91	49.67
Average value	150×150×150	36.07	49.92

Table 4. The technical parameters of the tube steel.

Technical parameters	Quantity
Yield strength f_y (MPa)	304
Ultimate strength f_u (MPa)	406
Elastic modulus E (MPa)	200×10^3
Plastic strain ϵ (%)	1.80

Table 5. The longitudinal deformation of steel tube and concrete.

Column	Concrete grade	L (mm)	P _{max} (kN)	LVDT1 (%)	LVDT2 (%)	LVDT4 (%)
C1	B35	1200	1744	0.330	0.981	0.006
C2	B50	1200	1941	0.503	0.559	0.541
C3	B35	1500	1574	-	0.919	0.010
C4	B50	1500	1798	-	0.857	0.968

Table 6. The longitudinal strain of steel tube and lateral strain of concrete.

Column	Concrete grade	L (mm)	P _{max} (kN)	SG1 (%)	SG2 (%)	SG3 (%)	SG4 (%)	SG5 (%)	SG6 (%)
C1	B35	1200	1744	-0.057	-0.189	-0.076	0.060	0.072	0.064
C2	B50	1200	1941	-0.150	-0.142	-0.032	0.087	0.140	0.056
C3	B35	1500	1574	-0.102	-0.229	-0.154	0.085	0.092	0.045
C4	B50	1500	1798	-0.090	-0.093	-0.088	0.058	0.074	0.067

Table 7. Load capacity of the steel concrete composite columns.

Column	Concrete grade	L (mm)	P _{max} (kN)	Increment (%)
C1	B35	1200	1744	-
C2	B50	1200	1941	11.3
C3	B35	1500	1574	-
C4	B50	1500	1798	14.2

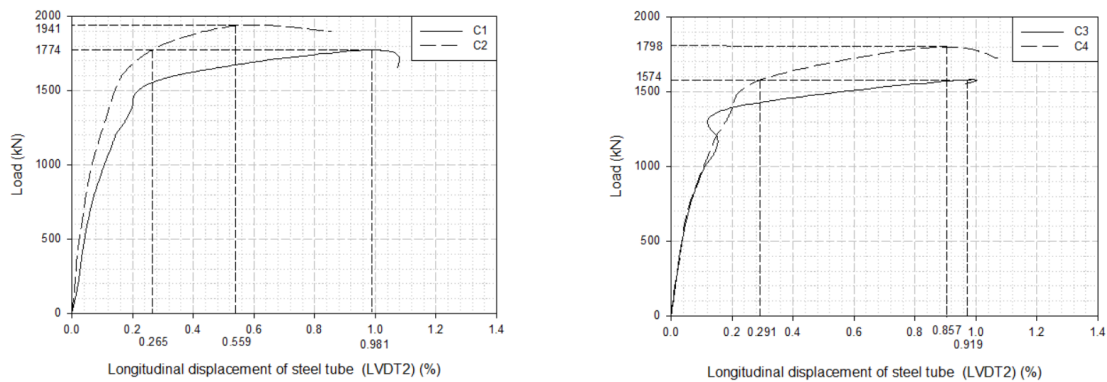


Figure 6. Longitudinal displacement of steel tubes recorded by LVDT2 at middle length of columns.

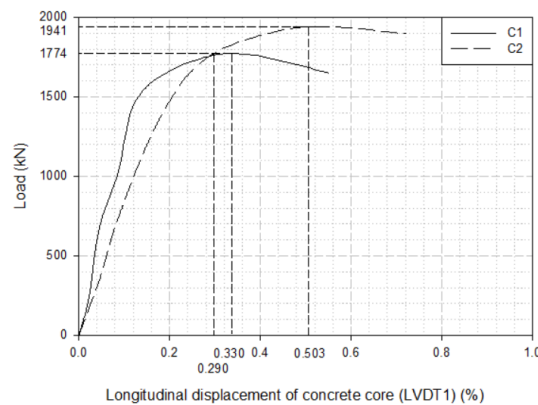


Figure 7. Longitudinal displacement of concrete core recorded by LVDT1 at middle length of columns.

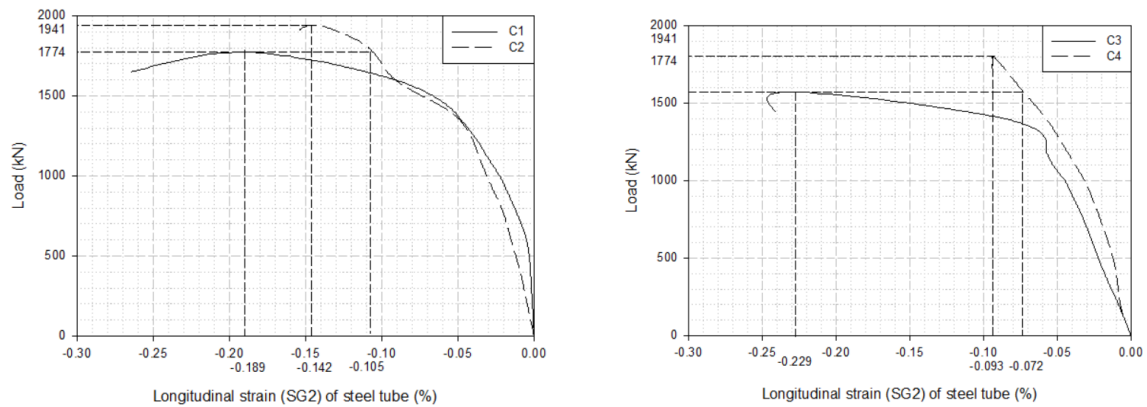


Figure 8. Longitudinal strain of steel tubes recorded by strain gauge SG2 at middle length of column.

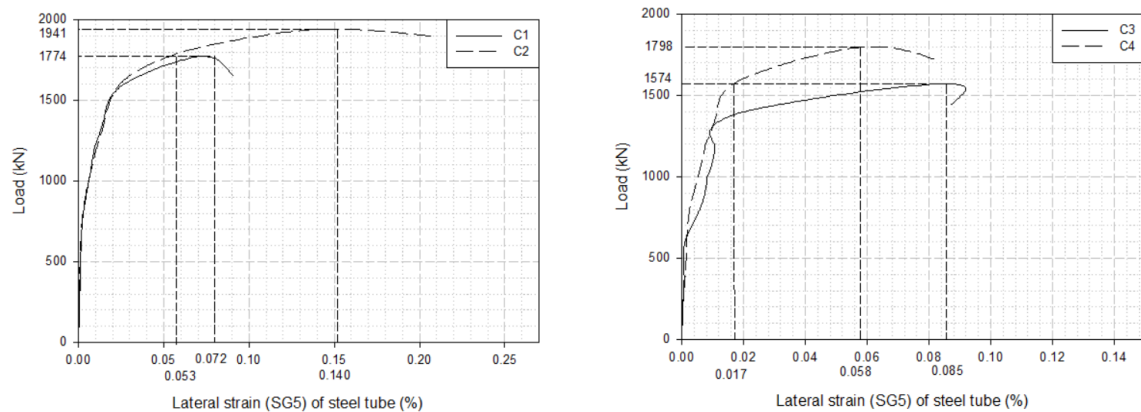


Figure 9. Lateral strain of steel tubes recording by strain gauge SG5 at middle length of column.

4. Conclusions

Testing 4 steel concrete composite columns with concrete-filled hollow steel sections to study the effect of concrete compressive strength on their behavior. Some conclusions drawn from the research results:

The bearing capacity of steel-concrete composite columns increases with the compressive strength of the concrete.

The longitudinal displacement of the steel tube and concrete core decreases with the compressive strength of the concrete.

The lateral strain of the steel tube decreases with the compressive strength of the concrete.

Acknowledgment

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