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# Large diameter concrete-filled high strength steel tubular stub columns under compression

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ABSTRACT

Experimental and numerical investigations on three large diameter concrete-filled high strength steel tubular (CFHSST) stub columns under axial compression were performed. The three large size steel tubes had the same dimension in the test. The outer diameter was approximately 550 mm, the length was approximately 1000 mm, and the thickness was approximately 16 mm. The steel tubes were made of high strength steel Q550 and filled with C30 concrete. A 40,000 kN press machine was adopted to apply the required axial compression to the three specimens. It was found that the load-displacement curves of the three concrete-filled high strength circular steel tubular stub columns were notably close to each other, and the ultimate capacities were approximately 30,000 kN. Finite element analysis (FEA) was performed to analyze the stub columns, and the FEA results are consistent with the experimental results. The formulas from three types of design codes were used to calculate the column loading capacity, and the calculation results were compared with the experimental results. The results were close to the experimental results. The EC4 design code gives the most accurate estimations, with discrepancy less than 4% being observed.



## 1. Introduction

Concrete-filled steel tubes (CFSTs) are advantageous because of their high bearing capacity, good seismic performance and easy construction. CFSTs are widely used in engineering all over the world and have been analyzed by many researchers [1]. Han [2,3] carried out a series of tests on curved concrete filled steel tubular (CCFST) built-up members subjected to axial compression, and investigated the influence of variations in the tube shape (circular and square) on the performance of such composite built-up members. Bai [4–8] conducted tests on stirrup-confined concrete-filled steel tubular columns in order to understand the contribution made by loop or spiral stirrup confinement to the improvement of overall mechanical performance, and investigated the connection system of the steel tube concrete composite column and the reinforced concrete beam. With the development of steel products, the application of high strength steel has received considerable attention worldwide. However, research on concrete-filled steel tubular stub columns with high strength steel is still limited.

Yao [9] summarized the research results of CFHSST members, then numerical methods were applied in the analyses of load-deformation curves of concrete filled high strength steel tubes beam-columns, and calculated results agree well with tested results. Gardner and Jacobson [10] investigated 12 CFHSSTs under axial compression, and the steel strength was 451–633 MPa. Knowles and Park [11] conducted an analysis and experiment on 6 CFHSSTs under axial compression, and the steel strength was 482 MPa. Task Group [12] carried out a series of tests on 20 CFHSSTs under axial compression, and the strength of the steel tubes were 452–682 MPa. Masuo [13] conducted tests on 10 CFHSSTs under axial compression, and the steel strengths were 461–505 MPa. Kato [14] carried out a series of tests on 5 concrete-filled high strength square steel tubes under axial compression, and the strengths of the high strength steel were 477–767 MPa. Schneider [15] carried out a test on a CFHSST under axial compression, and the strength of the high strength steel was 537 MPa. Uy [16] analyzed the mechanical properties of 14 concrete filled

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**Nomenclature**

| | |
|---|---|
| $A_c$ | cross-sectional area of core concrete |
| $A_s$ | cross-sectional area of steel tube |
| $A_{sc}$ | cross-sectional area of short column |
| CFHSST | concrete-filled high strength steel tube |
| CFST | concrete-filled steel tube |
| $D$ | overall dimension of a circular tube |
| $E_c$ | elastic modulus of concrete |
| $E_s$ | elastic modulus of steel |
| $f_{sy}$ | yield strength of steel |
| $f_{ck}$ | characteristic strength of the concrete, equal to 0.67 $f_{cu}$ for normal strength concrete |
| $f_{cu}$ | concrete cube strength |
| $f_{sc}$ | design value of compressive strength of concrete-filled steel tube |
| $L$ | height of specimen |
| $N$ | axial load |
| $N_u$ | axial compressive capacity |
| $t$ | wall thickness of the steel tube |
| $\sigma$ | stress |
| $\varepsilon$ | strain |
| $\theta$ | confinement index of concrete-filled steel tube |
| $[\theta]$ | the boundary value of confinement index related to the strength grade of concrete |
| $\alpha$ | coefficient related to the concrete strength grade |
| $\eta_a$ $\eta_{ao}$ | factors related to the confinement of concrete |
| $\eta_c$ $\eta_{co}$ | factors related to the confinement of concrete |
| $\bar{\lambda}$ | relative slenderness |
| $\varphi_l$ | bearing capacity reduction factor considering the influence of the ratio of length and width |
| $\alpha_{sc}$ | steel ratio |
| $B$ $C$ | influence coefficient of cross section shape on confinement index |

high strength box-type steel tube columns through the experimental study and numerical simulation. Vrcelj and Uy [17] carried out tests on 2 concrete-filled high strength square steel tube long columns under axial compression, and the strength of the steel was 450 MPa. Gho and Liu [18] carried out tests on five concrete-filled high strength rectangular steel tubes subjected to pure bending and the strengths of the steel tubes were 495 MPa.

However, the above research on CFHSSTs still has a number of deficiencies. Several researchers used different high strength steels to carry out experiments and could not guarantee the reliability of the experiment because every specimen was unique. In addition, the specimen dimension was small, meaning that the bearing capacity was relatively low. However, in reality, large size tubes are applied. Therefore, the above experiments cannot represent the mechanical behavior of large diameter CFHSSTs.

Therefore, this paper presents an axial compressive experiment on three CFHSSTs with an outer diameter of 550 mm and a wall thickness of 16 mm, which comes from the concept design of an 800 m steel wind power tower. Three specimens are identically designed and fabricated; thus, the three repeating specimens improve data reliability. The steel tubes are made from Q550 high strength steel which has the nominal yield strength of 550 MPa. Since the tube diameter is large and the steel strength is high, the loading capacities of the three CFHSSTs are very high so that a compression machine with 40,000 kN capacity is required to finish the experiment. Actually, such experiments are very rare since a 40,000 kN capacity machine is not easy to find. Then the finite element analysis is carried out and the numerical results are verified by the experiment. The results from three design codes are also given and compared with the experiments. All of them show good agreement with the experiment.

## 2. Experimental program

### 2.1. Specimen details

Three test specimens with identical sizes were designed in this experiment. Table 1 lists the section properties of the CFHSST stub columns. The cylindrical steel pipes are welded from steel plates, with a thickness of approximate 16 mm. The steel plates are produced by Anshan Iron and Steel Group Corporation, with a nominal strength level of 550 MPa. After being welded in Anshan steel pressure vessel Co., Ltd., the specimens were transported to the Structural Laboratory of the Beijing University of Civil Engineering and Architecture.

**Table 1**
Section parameter.

| Specimen | Material | $D \times t$ (mm) | $L$ (mm) | Section area (mm$^2$) | Section moment of inertia (mm$^4$) |
|---|---|---|---|---|---|
| Z3 | Steel tube | $558.10 \times 16.53$ | 997.50 | $2.813 \times 10^4$ | $1.032 \times 10^9$ |
| | Concrete | | | $2.165 \times 10^5$ | $3.728 \times 10^9$ |
| Z4 | Steel tube | $557.65 \times 16.52$ | 994.90 | $2.809 \times 10^4$ | $1.028 \times 10^9$ |
| | Concrete | | | $2.161 \times 10^5$ | $3.716 \times 10^9$ |
| Z5 | Steel tube | $559.40 \times 16.54$ | 994.85 | $2.820 \times 10^4$ | $1.040 \times 10^9$ |
| | Concrete | | | $2.176 \times 10^5$ | $3.765 \times 10^9$ |

The concrete was mixed and cast into cylindrical steel tubes at the laboratory. At the same time, two cubic specimens (size: 150 mm × 150 mm × 150 mm) were prepared for each test specimen and cured under the same condition as the test specimens. After concrete curing, because of the shrinkage of the concrete, the top surface of the concrete and the top of the steel tube was not in one horizontal plane, with a difference of several millimeters being observed. During the test, a layer of fine sand was paved on top of the concrete to ensure the steel tube and the concrete worked together under loading.

### 2.2. Strain gauge arrangement

In the middle cross-section of each specimen, along the outer wall of the cross-sectional circumference, strain gauges were arranged in both axial and hoop directions at typical positions as shown in Fig. 1. Four displacement transducers were set at the top of the column and two at the bottom of the column symmetrically. The relative displacements of the two symmetrical positions were measured separately. The average was recorded as the axial deformation of the specimen (Fig. 2).

### 2.3. Material properties

Immediately after the CFHSST axial compression test was completed, the cube specimens were tested according to the compressive cube strength test standards. The average measured cube strength ($f_{cu}$) and the elastic modulus ($E_c$) of the concrete were 31.7 MPa and 30.35 GPa, respectively. The standard tensile coupon tests were conducted to measure the material properties of the steel plates and steel tubes. The yield strength ($f_{sy}$), modulus of elasticity ($E_s$) of the steel plates and steel tubes are listed in