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Experimental study of large-sized concrete filled steel tube columns under blast load

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HIGHLIGHTS

- Concrete-filled steel tube (CFST) columns are tested under close-range blasts.
- The influence from charge weight, tube thickness and cross section geometry was analyzed.
- Failure modes of CFST columns under blast loads were studied.
- Residual strength of blast-damaged CFST columns was analyzed.

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ABSTRACT

This paper investigates blast resistance and residual strength of concrete-filled steel tube (CFST) columns under close-range blast loads. A total of 8 CFST columns, including 4 with circular cross sections and 4 with square cross sections, were tested under close-range blasts. LVDTs were used to record displacement histories and pressure sensors were used to measure pressure histories. The influence of explosive charge weight, steel tube thickness and cross section geometry on dynamic response of CFST columns was analyzed and failure modes of CFST columns were also investigated. Following the blast tests, an experimental study was conducted to investigate residual strength of blast-damaged CFST columns. It was found that the CFST columns were still able to retain a large portion of their axial load capacities even after close-range blast events.

1. Introduction

Over the past few decades, due to the increasing threat of terrorist attacks, more attentions have been drawn to the evaluation of the vulnerability of structural members against blast loads [1–6]. Conventional structures are not designed to resist blast load, and the magnitude of design loads are significantly lower than those caused by blast, making them more vulnerable to blast scenarios such as bomb attacks. Engineers and architects are endeavored to seek a solution to protect structures and their occupants against potential blast situations.

A concrete filled steel tube (CFST) column consists of a thin-walled hollow steel tube filled with concrete inside. On one hand, the tubing can effectively restrain the lateral expansion of concrete, resulting in a confining pressure which can greatly enhance the strength and ductility of concrete. On the other hand, the concrete filler improves the geometric stability of steel tube so that the local buckling of steel is prolonged, if not prevented at all. In recent years, CFST columns have been more and more commonly used in the construction industry due to their attractive properties such as high strength, advanced plasticity, fatigue resistance, high temperature resistance and impact resistance [7,8]. Hence, it is of great significance to investigate the behaviors of a CFST column under blast loads as well as its residual strength afterwards.

A number of studies showed that the overall axial load capacity of a CFST column is considerably greater than the sum of the individual components acting independently, and the ductility of a CFST column under axial load as well as flexural load can also be significantly enhanced [9–11].

Apart from studies on the axial behaviors of CFST columns, the knowledge of their structural behaviors under lateral impact and

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blast loads is still relatively inadequate. Wang et al. [12] experimentally studied the behaviors of CFST columns subjected to lateral impact loads. It was observed there were generally two types of failure modes: specimens with large constraining factors (i.e. area of steel/area of concrete) showed behavior in a ductile manner whilst those specimens with low constraining factors were found to behave in a brittle manner. Deng [13] studied the use of post-tensioned and steel-fiber reinforced CFST columns to alleviate lateral impact loads. It was reported that pre-stressing strands and steel-fiber concrete filled steel tube column delayed concrete tension cracks, hence effectively reducing the column deflection under transverse impact load.

Numerical simulation is widely used to study CFST members under different loading conditions due to its efficiency and cost-effectiveness over laboratory tests. Liang [14] investigated the local buckling of steel plates in CFST beam-columns using a finite element approach. It was found that increasing the width to thickness ratio of a steel plate greatly reduced the lateral stiffness and critical load buckling stress, and the ultimate strength of steel plates under edge compression decreased with an increased stress gradient coefficient.

The existing studies have clearly shown the outstanding performance of CFST members under different loading conditions. However, the knowledge of CFST members under blast load still remains relatively limited [15,16]. Whether a structure can survive a blast event primarily depends on 1) whether the structure can withstand the incoming blast load without being severely damaged and 2) whether its columns are still able to retain enough residual strength afterwards. Although there are numerous studies on CFST columns, little effort is put on the residual strength of CFST columns after blast loads. This paper thus presents an experimental study on CFST columns under blast loads along with their residual axial capacities afterwards.

2. Specimen preparation

All specimens were made 2500 mm long and the steel tubes were either 2.8 mm or 3.8 mm thick. Prior to concrete pouring, one steel plate (400 mm × 500 mm × 16 mm) was firstly welded to one end of the empty steel tube. The tube was then set up straight followed by pouring concrete from the top. For consolidation purposes, concrete vibrator was also used. Each specimen was cured at room temperature for 28 days. At last, each specimen was leveled and polished before welding the other steel plate to the end.

C40 grade concrete was used to manufacture all specimens. Compressive tests were carried out on a number of 100 mm × 100 mm × 100 mm cubic specimens to determine the compressive strength. The average cubic compressive strength obtained from the tests was 47.4 MPa with the Elastic modulus being 34 GPa and the concrete tensile strength being 2.6 MPa.

The strengths of steel tubes were determined by direct tensile test using a high capacity hydraulic machine. The average strengths of the steel tubes obtained from the direct tensile test are listed in Table 1.

3. Three points bending test

Three point bending tests were carried out to investigate the static behaviors of CFST columns subjected to combined axial and lateral loads. As shown in Fig. 1, the test specimen was simply supported during the test.

In total, 3 CFST columns were tested including 1 square CFST column and 2 circular CFST columns. Table 2 summarizes the experimental results of three point bending tests as well as their corresponding theoretical values calculated from theoretical equations as given below [17]:

If $N/A_{sc} \geqslant 0.2\left[1-\left(\frac{V}{V_0}\right)^2\right]^{0.5} f_{sc}$, then

$$\left(\frac{N}{N_0}+\frac{M}{1.07M_0}\right)^{1.4}+\left(\frac{V}{V_0}\right)^2 \leqslant 1 \tag{1a}$$

Otherwise,

$$\left(\frac{N}{1.4N_0}+\frac{M}{M_0}\right)^{1.4}+\left(\frac{V}{V_0}\right)^2 \leqslant 1 \tag{1b}$$

where,

N is the applied axial load and N_0 is the designed axial load capacity

$$N_0 = A_{sc}f_{sc} \text{ and } f_{sc} = (1.212 + B\xi + C\xi^2)f_{ck} \tag{2}$$

$$B = \begin{cases} 0.1759f_y/235 + 0.974\ (\textit{circular cross section}) \\ 0.131f_y/235 + 0.723\ (\textit{square cross section}) \end{cases}$$

$$C = \begin{cases} -0.1038f_{ck}/20 + 0.0309\ (\textit{circular cross section}) \\ -0.07f_{ck}/20 + 0.0262\ (\textit{square cross section}) \end{cases}$$

M is the applied moment and M_0 is the designed moment capacity

$$M_0 = r_m W_{sc} f_{sc} \text{ and } r_m = -0.4832\xi + 1.9264\xi^{0.5}, W_{sc} = \begin{cases} \frac{\pi r^3}{4}(\textit{circular}) \\ \frac{b^3}{6}(\textit{square}) \end{cases} \tag{3}$$

V is the applied shear force and V_0 is the designed shear capacity

$$V_0 = r_v A_{sc} f_{sc} \text{ and } r_v = -0.2953\xi + 1.2981\xi^{0.5} \tag{4}$$

A_{sc} is the cross sectional area of the CFST column; A_s and A_c are the cross sectional areas of the steel tube and the concrete, respectivelyf_y and f_{ck} are the yield strength of the steel tube and the characteristic strength of the concrete, respectively.

ξ is the restraining factor and $\xi = \frac{A_s f_y}{A_c f_{ck}}$

For both axially loaded specimen TS1 and TC1, the theoretical formulae can well predict the experimental results; whereas for axial-load–free specimen TC2, the theoretical prediction was

Table 1
Material Experimental Parameter of Steel Tube.

Geometry	Thickness (mm)	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Elasticity modulus (GPa)
Circular	2.8	311.5	414.0	22.1	203.6
Square	2.8	358.1	437.7	21.3	202.6
Circular	3.8	471.9	535.4	25.4	226.3
Square	3.8	484.7	535.2	20.8	215.9