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Behavior of concrete filled steel tubular (CFST) members under lateral impact: Experiment and FEA model

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ABSTRACT

This paper reports an investigation into the impact performance of concrete filled steel tubular (CFST) members. A series of tests were carried out to obtain the failure modes and the time history of the impact forces for the composite components under lateral impact. The testing parameters include the axial load level on CFST specimens, constraining factor and the impact energy. A finite element analysis (FEA) model was developed, in which the strain rate effects of steel and concrete materials, interaction between the steel tube and the core concrete, as well as the confinement effect of the outer steel tube provided to the core concrete were considered. The test data were then used to verify the accuracy of the FEA model and generally a good agreement was achieved. A full-range analysis on the impact behavior of CFST member was performed by using the FEA model.

1. Introduction

Concrete filled steel tubes (CFST) have been used more and more popularly as bridges piers and as building columns due to their excellent structural and constructional performance. During the whole life cycle, bridge piers and building columns may inevitably suffer from various impact loads. For example, they may be laterally crashed by vehicles or vessels. A sketch map for a ship-bridge collision was shown in Fig. 1. It is evident that bridge piers and building columns always bear axial load induced by live load and dead load of slab or deck simultaneously when the impact accidents happen. There are different types of impacting [1], and the elastic–plastic behavior of structural members under high impact is very important.

In the past, a large number of studies have been carried out on CFST members under both static and cyclic loads, and several design codes have also been published (ASCCS, 1997 [2]; Gourley et al., 2008 [3]; Han and Li, 2011 [4]; Tao et al., 2008 [5]).

Research has seldom been conducted on the impact performance of CFST members, however. Previously, axial impact experiments on twenty-one circular CFST columns were reported by Chen et al. (1986) [6]. Bambach (2011) [7] and Bambach et al. (2008) [8] investigated the performance of square CFST members subjected to lateral impacts at the beam mid-span and a design procedure was also developed. Impact resistances of small-size micro-concrete-filled steel tubes under axial impact loads at elevated temperatures up to 400 °C were experimentally studied by Huo et al. (2009) [9].

The research mentioned above indicates that CFST members have excellent impact resistances generally. However, there is a lack of investigation into the performance of CFST members with axial load under lateral impact loads. It is expected that the axial load will have a notable effect on the impact behavior of the structures, so it is necessary to take research on this issue further.

Thus this paper is an attempt to study the performance of CFST members subjected to lateral impact, in which the effect of axial load is also considered. The purposes of the current research were threefold. First, to report a series of new experimental results on twenty-two circular CFST members under lateral impact, the testing parameters include the axial load level on the specimen, constraining factor as well as the impact energy. Second, to study the typical failure modes and the time history of the impact forces for the composite members based on the testing results. And third, to develop a finite element analysis (FEA) model for further study on the mechanism of the CFST members under impact loads.

2. Experimental program

2.1. Specimen preparation

Twenty-two circular CFST members were tested. The outer sectional diameter (D) and the length of the composite specimens are

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Nomenclature

A_c	area of core concrete
A_s	area of steel tube
D	outer section dimension
E_s	modulus of elasticity
E_p	plastic strain energy dissipation
f_{ck}	characteristic static compressive strength of concrete
f_{cu}	characteristic 28-day concrete cube strength
f_d	dynamic compressive strength of concrete
f_t	static tensile strength of concrete
f_{td}	dynamic tensile strength of concrete
f_y	yield strength of steel
f_y^d	yield strength of steel under strain rate
F	impact force
F_{max}	peak value of the impact force
F_{stab}	plateau value of the impact force
H	impact height
n	axial load level ($n = N_o/N_u$)
N_o	axial load applied on the specimen
N_u	ultimate axial strength of column
t	load duration of impact
t_s	wall thickness of steel tube
V	lateral velocity at the mid-span section of CFST member
V_i	velocity of the indentor
V_o	initiation impact velocity
W	impact energy
W_{frac}	critical fracture energy
α	steel ratio
Δ	lateral deflection of the specimen at mid-span
δ	standard deviation
ε	strain
$\dot{\varepsilon}_d$	strain rate
$\dot{\varepsilon}_s$	static strain rate
ξ	constraining factor ($\xi = A_s f_y / A_c f_{ck}$)

114 mm and 1200 mm, respectively. Fixed-sliding boundary conditions were applied at the ends of the specimens.

The detailed information of each member is presented in Table 1, where t_s is the wall thickness of the steel tube. The following naming rules are used to characterize each specimen: the first letter "D" denotes that the member is under dynamic test; the second letter "B" or "Z" denotes that the constraining factor (ξ) is 0.44 (series I) or 1.23 (series II), respectively; the last letter "F" denotes the fixed-sliding boundary condition; and the last numeric value denotes the different specimens in the same group.

The influences of CFST under lateral impact mainly include the load condition and the carrying capacity of CFST member.

To impact, the load condition was the impact energy and the location of impact. The carrying capacity of CFST members was decided by their section physical dimension and the mechanical property of material in the section. It is well known that the columns in the bridges or buildings would carry the axial load, which was induced by live load and dead load of slab or deck. The axial load would affect the flexure carrying capacity of CFST members under lateral load.

As mentioned above, the main parameters varied in the tests in this paper include:

- Impact energy (W): 1801 J–15,764 J
  The impact energy (W) is defined as:

$$W = \frac{1}{2} m V_o^2 \tag{1}$$

  where $m = 229.8$ kg is the mass of the drop hammer, V_o is the imitation velocity of drop hammer as shown in Table 1. In the test, the initial impact velocity was determined from the time interval of the drop hammer passing two sets of photoelectric sensors immediately before collision with the CFST members as shown in Fig. 2(a).
- Axial load level (n): 0–0.6
  The axial load level (n) in this paper is defined as follow:

$$n = \frac{N_o}{N_u} \tag{2}$$

  where N_o is the axial load applied on the specimen; N_u is the axial compressive capacity of the CFST specimen. The value of N_u was determined by using the finite element analysis (FEA) model presented in Section 4 of this paper. The measured material properties of steel and concrete for the specimens were used in the calculations.
- Constraining factor (ξ): 0.44 and 1.23
  The confinement factor ξ to quantify the "composite action" of CFST was introduced by Han et al. (2001) [10] as follows,

$$\xi = \frac{A_s f_y}{A_c f_{ck}} = \alpha \frac{f_y}{f_{ck}} \tag{3}$$

  where A_s is the cross-sectional area of the steel tube, A_c is the cross-sectional area of the core concrete, α ($= A_s/A_c$) is the steel ratio of CFST members, f_{ck} is the characteristic concrete strength, which is taken as 0.67 of the cube strength of concrete for normal strength concrete, and f_y is the yield strength of steel.

2.2. Material properties

In preparing the testing specimens, cold-formed hollow circular steel tubes were used. The concrete was poured into the tube in layers with vibration.

A standard tensile coupon test was conducted to measure the material properties of the steel tube. The average yield strength of steel

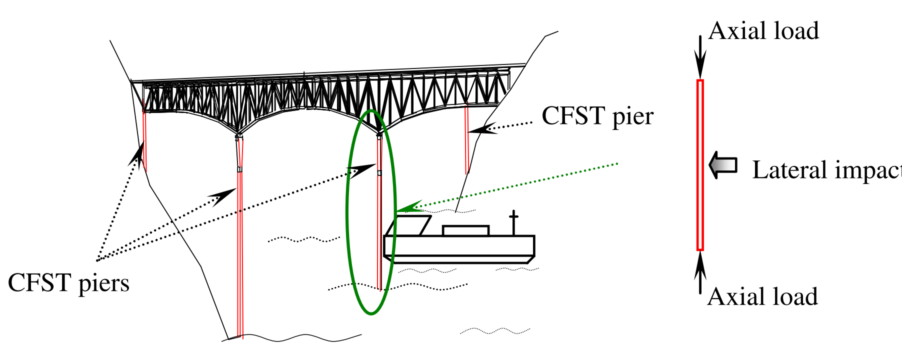

Fig. 1. A schematic view of ship-bridge collision.