Experimental study on the behaviour of concrete filled steel tubular (CFST) members under lateral impact

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Abstract

This paper presents an experimental investigation into concrete filled steel tubular (CFST) members under lateral impact at mid span using a dropped weight moving with low velocity. A series of tests were carried out to obtain the residual deformation mode and the time histories of impact loads. The testing parameters include, impact energy and the axial level on CFST. Based on the testing data, stability value of impact force, time of duration impact, as well as the maximal deformation at mid span of the composite members under different axial load level and impact energy are analyzed and discussed.
Keywords: concrete filled steel tube (CFST), hollow tube, concrete, lateral impact, axial load level, energy, failure mode.

1 Introduction

Concrete filled steel tubes (CFST) have been more and more applied in bridges, high-rise buildings, viaducts and electricity transmission towers. In the past, a large number of studies have been carried out on traditional straight CFST columns, and some design codes have been developed worldwide [1–4].

During the whole life cycle, structures may inevitably suffer from various impact loads. For example as the bridge pier, they may be laterally crashed by vehicles or vessels. It is evident that bridge piers always bear axial loads simultaneously when impact accidents occur.

Research has seldom been conducted on the impact performance of CFST members, however. Previously, axial impact experiments on twenty-one circular

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CFST columns were reported in paper [5]. Bambach investigated the performance of square CFST members subjected to lateral impacts at the beam mid-span, a design procedure was also developed in papers [6] and [7]. Impact resistances of small-size micro-concrete-filled steel tubes under axial impact loads at elevated temperatures up to 400°C were experimentally studied in paper [8].

The abovementioned research demonstrated that CFST members have excellent impact resistance. However, there is a lack of investigation on the performance of CFST members with an axial load under lateral impact loads so it is necessary to undertake further research on this issue. This paper is thus an attempt to study the performance of CFST members with a different axial load level subjected to lateral impact. The typical failure modes and the time history of the impact forces for the composite members were reported.

2 Experimental program

2.1 Specimen preparation

Twelve circular CFST members were tested. The outer sectional diameter (D) and the length of the composite specimens are 114 mm and 1200 mm, respectively. Fixed-sliding boundary conditions were applied at the ends of the specimens. The detail information of each member is presented in Table 1, where t_s is the wall thickness of the steel tube; n= N_o/ N_u is axial load level, where N_o is

Table 1: Information of the test specimens.

No.	Specimen Label	$D \times t_S$ (mm× mm)	ξ	n	H (m)	W (J)	F_{max} (kN)	F_{stab} (kN)	t (ms)	Δ (mm)
1	DZF32	114×3.5	1.23	0	1.0	2252	281.0	102.0	16.8	17.00
2	DZF22	114×3.5	1.23	0	3.0	6756	317.5	112.8	18.2	39.42
3	DZF23	114×3.5	1.23	0	5.0	11260	352.6	112.4	18.8	63.78
4	DZF24	114×3.5	1.23	0	5.3	11935	346.8	112.2	18.8	65.40
5	DZF25	114×3.5	1.23	0	6.0	13512	380.8	125.2	25.0	72.42
6	DZF27	114×3.5	1.23	0	6.5	14638	414.8	120.8	25.8	74.02
7	DZF28	114×3.5	1.23	0	6.8	15313	420.0	122.6	26.2	79.42
8	DZF29	114×3.5	1.23	0	6.9	15539	428.2	122.8	26.8	82.30
9	DZF26	114×3.5	1.23	0	7.0	15764	440.8	123.2	27	87.20
10	DZF34	114×3.5	1.23	0.3	1.0	2252	320.2	127.6	12.3	15.90
11	DZF31	114×3.5	1.23	0.3	7.0	15764	458.4	125.7	38.2	101.70
12	DZF33	114×3.5	1.23	0.6	7.0	15764	332.1	——	18.6	109.38

the axial load applied on the specimen; N_u is the axial compressive capacity of the CFST specimen; $W=mg\times H$ is impact energy, where m=229.8 kg is the mass of the drop hammer, g is the acceleration of gravity, and H is the height of the drop hammer.

2.2 Material properties

Standard tensile coupon test were conducted to measure the material properties of the steel tube. The average yield strength of steel (f_y) is 298 N/mm^2 and the modulus of elasticity (E_s) is 2.01×10^5 N/mm^2 for specimens. The average measured cube strength of concrete at the day of testing is f_{cu}=48.7 N/mm^2.

2.3 Testing method

The specimens were tested under a combination of static axial load and dynamic lateral impact. A schematic view of the testing setup is shown in Fig. 1. The rig could provide one fixed and one sliding support for the specimen. The hammer has a 30mm×80mm square rigid flat indentor.

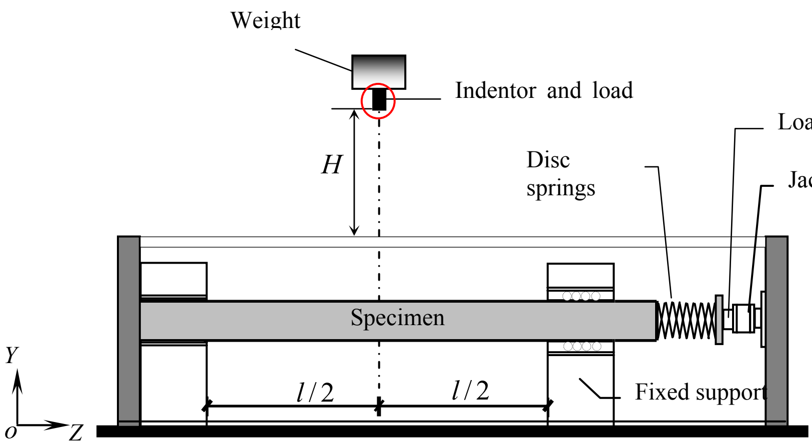


Figure 1: Schematic view of testing setup.

In the testing, the specimen was placed in the impact rig, and then the axial load (N_o) was applied at the end of the specimen by a set of self-reacting system of disc springs. The drop hammer was lifted to the design height and then released to impose the impact load at the mid-span of the specimen.

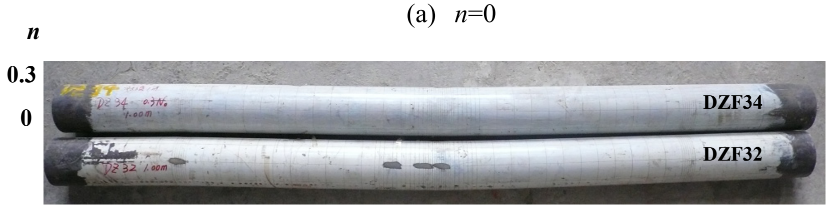
3 Experimental results and discussions

3.1 Failure modes

Fig. 3 shows the observed failure modes of the tested specimens. In Fig. 3(a), it can be seen that with the increase of the impact height (H), the residual mid-span lateral deflection (Δ) of the specimen increased. Local buckling of steel tube occurred at the top of the section in the mid-span for specimen DZF23 when H=5 m. When the impact height (H) increased to 6m (DZF25), local buckling of steel tube also appeared at the top of the section in the support ends. Crack of the steel tube was observed at the bottom of the mid-span section in specimen DZF26 (H=7 m, n=0), and the corresponding impact energy W_{frac}=15764 J.

The failure modes of specimens with different axial load level (n) under the same impact height (H=1m) are given in Fig. 3(b). It can be found that the lateral deflection (Δ) at the mid-span of specimen DZF32 (H=1 m, n=0) was 17 mm. However, for specimens DZF34 (H=1 m, n=0.3), the measured lateral deflections (Δ) was 15.9 mm. This means that the axial load on CFST could decrease the residual lateral deflection of the specimens. The failure modes of the composite specimens behaved in a ductile manner.

(a) n=0



(b) with different axial load leval

Figure 3: Failure modes of the tested specimens.

After the testing, the outer steel tubes of the specimens were removed to observe the failure mechanism of the core concrete, as shown in Fig. 4 (a). It can be seen that tensile cracks occur at the bottom of the mid-span section, as well as the top of the sections in the support ends. The integrity of concrete in other areas is fairly good in view. No obvious shear failure mode is observed in the core concrete due to the effective confinement provided by its outer steel tube.

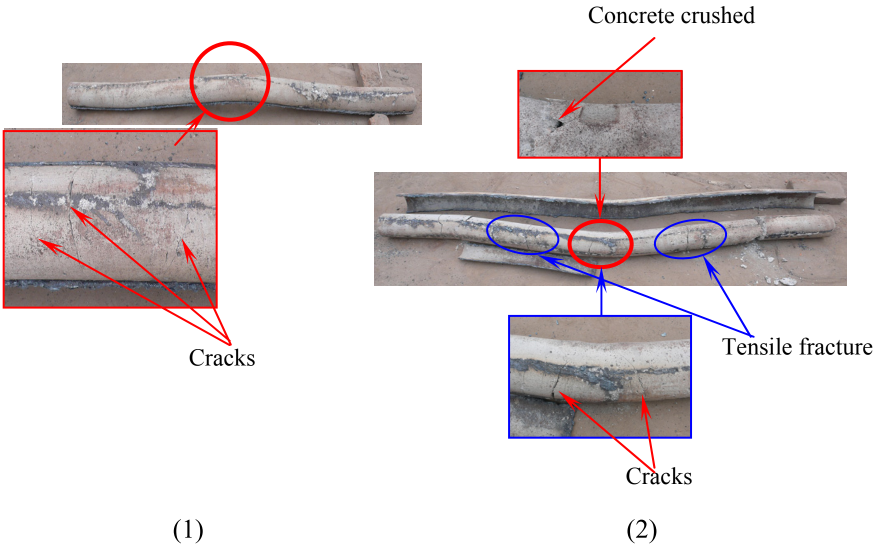


Figure 4: Typical failure modes of the core concrete.

3.2 Impact force

The recorded impact force (*F*) versus time (*t*) curves of specimens are shown in Fig. 5. The curves could be generally divided into three stages, i.e. (1) Peak value stage; (2) Platform stage, in which the impact force retains a steady value. Most of the impact energy is dissipated at this stage; (3) Unloading stage. The impact force (*F*) would decreases rapidly to zero during this stage. From Fig. 5 (1), (2), (3) and (4), it can be found that with the increase of the impact height (*H*), the peak values (F_{max}), the plateau values (F_{stab}), as well as the durations (*t*) of the impact forces increase. For specimen DZF26 (*H*=7 m, *n*=0), the trend of unloading becomes more slowly than that of specimens DZF32 (*H*=1 m, *n*=0), DZF22 (*H*=3 m, *n*=0) and DZF25 (*H*=6 m, *n*=0), which is due to the fracture of the outer steel tube. Fig. 5 (1) and (5) show the impact force curves of specimens DZF32 (*n*=0) and DZF34 (*n*=0.3) under the same impact height (*H*=1 m). It can be found that the plateau values (F_{stab}) and the duration (*t*) of the impact force of specimen DZF34 (*H*=1 m, *n*=0.3) are larger than that of specimen DZF32 (*H*=1 m, *n*=0). The same phenomena can be found in Fig. 5 (4) and (6). Whereas in contrast, the plateau value (F_{stab}) and load duration (*t*) of specimen DZF33 (*H*=7 m, *n*=0.6) in Fig. 5 (7) is smaller than that of specimen DZF26 (*H*=7 m, *n*=0).

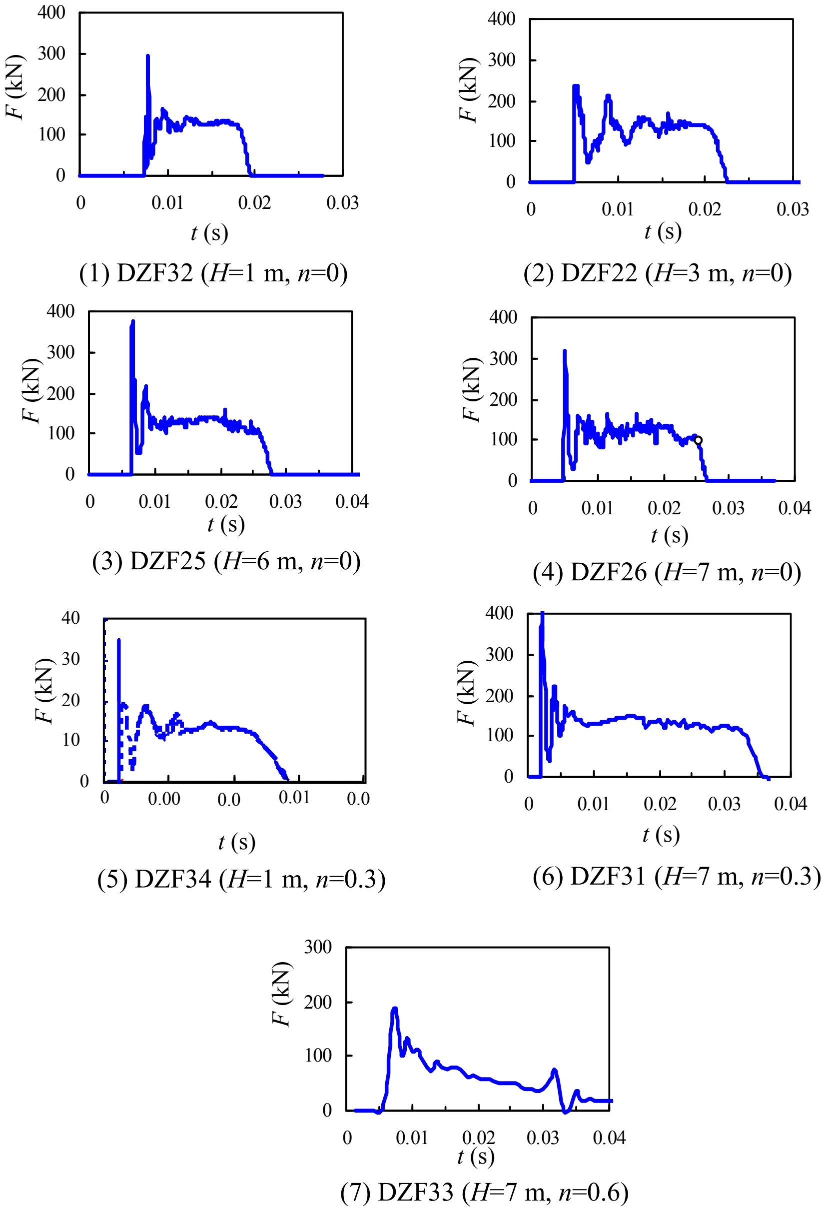


Figure 5: Impact force (F) versus time (t) history curves.

4 Conclusions

The following conclusions can be drawn within the limitation of the current study presented in this paper.

(1) The CFST specimens behaved in a very ductile manner under lateral impact.

(2) The impact force (F) curves can be generally divided into three stages, peak value stage, platform stage and unloading stage.

(3) The axial load level (n) on the CFST has a significant effect on the impact force (F) curves and the residual lateral deflection.

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