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Circular concrete filled steel tubular (CFST) columns under cyclic load and acid rain attack: Test simulation

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ABSTRACT

Concrete filled steel tubular (CFST) structure attracts increasing engineering applications in earthquake prone regions due to its high section modulus, high strength, and good seismic performance. However, the seismic resistance of CFST columns may be affected by the environmental corrosions, such as acid rain attack. This paper makes an attempt to investigate the performance of CSFT columns with circular sections under both a cyclic load and an acid rain attack. First, the tensile mechanical properties of steel plates with various corrosion rates were tested. Second, a total of 12 columns with different corrosion rates were tested subjected to a reversed cyclic load. It was found that the corrosion leads to not only a loss in wall thickness but also an evident decrease in yield strength, elastic modulus, and tensile strain capacity of the steel coupons, and also to a significant deterioration in the load carrying capacity, ductility, and energy dissipation of the CFST columns. The larger the axial force ratio, the severer deterioration of deformation capacity of the columns.

1. Introduction

Concrete filled steel tube (CFST) has an increasing utilization in the earthquake prone regions in China due to its high strength, good ductility, and excellent energy dissipation capacity [1]. The outer steel tube of CFST member is exposed to external environment and is prone to suffer environmental corrosions during the service life span, such as acid rain attack. Worldwide acid rain problems have been worsened by industrial and urban developments and acid rainfall has been reported to cover at least one third of Chinese territory [2–5]. Thus, it is essential to evaluate the seismic behaviors of CFST members that have suffered acid rain corrosion.

In the past few decades, a great number of studies have been carried out on the seismic behaviors of CFST members [6–13]. Some literature reviews had been conducted by Nakanishi et al. [12] and Elremaily and Azizinamini [13]. It made a consensus that the CFST members exhibit much higher ductility compared with the hollow steel tubes owing to the composite effect between the core concrete and outer steel tube. Han et al. [14] also tested the cyclic behaviors of concrete filled double skin steel tubular (CFDST) members under combined axial and flexural load. It was reported that the CFDST members show good ductility and excellent energy dissipation capacity even under high levels of axial force ratio above 0.6.

Experimental studies on steel structures and CFST members under corrosive environment have also been conducted in recent years. For example, Almusallam [15] studied the effect of sodium chloride corrosion on the properties of reinforcing steel bars and found that reinforcing steel bars with more than 12% corrosion indicates a brittle failure. Qin and Cui [16] studied the effect of corrosion models on the time-dependent reliability of steel plate elements and the advantages and the flexibility of the proposed corrosion model were demonstrated. Melchers [17] studied the influential factors on the corrosion rate of steel in seawater environments. Saad-Eldeen et al. [18] tested the load carrying capacity of a corroded steel box girder. Sultana et al. [19] studied the compressive strength of stiffened panels under pitted corrosion. Karagah et al. [20] tested the steel columns under corrosion and axial compression. Han et al. [21,22] and Hou et al. [23] carried out the experimental studies on 22 beams and 34 stub columns under sustained load and chloride corrosion. The test results showed that the chloride corrosion has great effects on the load carrying capacity of construction steel and CFST members. Simplified calculation methods for the load carrying capacity of CFST beams and stub columns were also proposed based on parametric studies [24].

Previous studies have focused on the static behaviors of corroded CFST members. Few experimental works have been studied the seismic behaviors of corroded CFST members, especially under acid rain attack. This gives rise to the need for more studies of the problem.

This paper aims to investigate the seismic behaviors of circular CFST members subjected to acid rain corrosion. The effect of corrosion on the mechanical behaviors of steel tubes is firstly tested and discussed. After

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Nomenclature

The following symbols are used in this paper

A_c	cross-sectional area of core concrete
A_s	cross-sectional area of steel tube after corrosion
D	column diameter
E_s	elastic modulus of corroded steel
E_{s0}	elastic modulus of uncorroded steel
f_{ck}	characteristic compressive strength of concrete
f_{cu}	compressive strength of cube concrete
f_y	yield strength of corroded steel
f_{y0}	yield strength of uncorroded steel
f_u	ultimate strength of corroded steel
f_{u0}	ultimate strength of uncorroded steel
n	axial force ratio
L	column length
N_0	axial force applied on the columns
N_u	axial compressive capacity of the columns
P	lateral load of column
P_m	peak load of column
P_u	ultimate load of column
P_y	yield load of column
t_s	wall thickness of steel tube after corrosion
t_{s0}	initial wall thickness of steel tube
η	corrosion rate
ξ	confinement factor
μ	ductility coefficient
ε_{u0}	ultimate elongation of corroded steel
ε_u	ultimate elongation of corroded steel
Δ	lateral displacement of column
Δ_y	yield displacement of column
Δ_m	displacement of column at peak load
Δ_u	ultimate displacement of column

that, the effects of the corrosion rate and axial force ratio on the seismic behaviors of CFST columns, such as ultimate strength, ductility, energy dissipation ability, et al., are experimentally studied and systematically evaluated.

2. Experimental program

2.1. Preparation of specimens

In total, 12 circular column specimens were tested in the present work. All tested specimens have a sectional size of $D \times t_s = 1500 \times 114 \times 4$ mm and a length (L) of 1500 mm, where D is the diameter of outer steel tube sand t_s is the wall thickness of steel tube. The CFST specimens were fabricated through the following steps. The steel tubes were segmented from an industrial steel tube. A steel plate was welded into one end of the steel tube. Then, the steel tubes were placed upright for casting. The concrete was cast into the steel tube and vibrated by a poker at the same time. After curing, a small gap between concrete surface and top steel tube was observed due to concrete shrinkage. The longitudinal gap was filled with a high strength epoxy in order to make the concrete surface flush with the top steel tube. Another steel plate was welded onto the top end of the steel tube before testing. The main design parameters were an axial force ratio (n) from 0 to 0.5 and a corrosion rate (η) from 0% to 30%. The axial force ratio herein is defined as:

$$n = \frac{N_0}{N_u} \tag{1}$$

where N_0 is the applied axial force on the specimens, and N_u is the axial load carrying capacity of the columns, which is calculated by the simplified formulas described in [25]. The corrosion rate is defined as:

$$\eta = \frac{t_{s0} - t_s}{t_{s0}} \times 100\% \tag{2}$$

where t_{s0} is the initial thickness of the steel plate; t_s is the remaining thickness after corrosion. The designed corrosion rates are 0, 10%, 20% and 30% respectively.

Table 1 shows a summary of the tested specimens, where ξ represents the confinement factor to account for the 'composite action' between the steel tube and core concrete, and was defined as follows [26]:

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

where A_s is the cross-sectional area of steel tube after corrosion, f_y is the yield strength of steel, A_c is the cross-sectional area of the core concrete, f_{ck} is the characteristic compressive strength of concrete. The value of f_{ck} is calculated to be 67% of the cube strength of concrete (f_{cu}). The following naming rules are employed to distinguish specimens: 1) the two initial characters 'CC' represents the circular column section; 2) the Arabic numerals before hyphen stand for the axial force ratio; 3) the Arabic numerals after hyphen represent the corrosion rate. For example, the specimen 'CC0.2-10' stands for the circular column with designed axial force ratio of 0.2 and corrosion rate of 10%.

Table 1
Information of column specimens.

No.	Specimen ID	D (mm)	t_s (mm)	L (mm)	f_{cu} (MPa)	n	η (%)	ξ	Yield		Peak		Ultimate	
									P_y (kN)	Δ_y (mm)	P_m (kN)	Δ_m (mm)	P_u (kN)	Δ_u (mm)
1	CC0.2-0	114	4.00	1500	60	0.2	0	1.49	56.4	16.18	73.55	35.85	62.69	–
2	CC0.2-10	114	3.62	1500	60	0.2	9.48	1.18	52.3	15.78	69.40	33.25	58.99	44.21
3	CC0.2-20	114	3.23	1500	60	0.2	19.25	0.95	45.8	15.67	58.80	29.85	51.00	37.10
4	CC0.2-30	114	2.84	1500	60	0.2	29.00	0.85	40.7	14.89	51.50	29.50	44.12	34.04
5	CC0.4-0	114	4.00	1500	60	0.4	0	1.49	53.1	12.82	73.75	33.95	62.69	60.75
6	CC0.4-10	114	3.63	1500	60	0.4	9.25	1.19	46.3	11.15	65.80	33.55	56.49	36.64
7	CC0.4-20	114	3.21	1500	60	0.4	19.75	0.94	40.2	10.37	56.85	23.55	48.33	33.23
8	CC0.4-30	114	2.81	1500	60	0.4	29.75	0.84	34.8	8.85	46.70	17.90	39.70	21.60
9	CC0.5-0	114	4.00	1500	60	0.5	0	1.49	52.6	11.44	70.35	31.50	58.36	39.42
10	CC0.5-10	114	3.60	1500	60	0.5	10.00	1.18	49.3	12.42	62.65	27.50	53.25	38.66
11	CC0.5-20	114	3.19	1500	60	0.5	20.25	0.94	46.1	11.60	57.70	24.40	49.05	34.48
12	CC0.5-30	114	2.78	1500	60	0.5	30.50	0.83	39.3	10.11	48.85	23.45	41.52	25.73