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Seismic performance of concrete-encased column base for hexagonal concrete-filled steel tube: experimental study

Wu Xu, Lin-Hai Han *, Wei Li

Department of Civil Engineering, Tsinghua University, Beijing 100084, China

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ABSTRACT

The concrete-encased column base investigated in this paper is composed of an inner base plate column base partially encased by an outer reinforced concrete (RC) component. The seismic behavior of the column base for hexagonal concrete-filled steel tube (CFST) along the strong axis is studied experimentally. Twelve composite specimens are tested under constant axial loading and cyclic lateral loading applied on the hexagonal CFST columns. The test parameters are the height of the outer RC component, with or without shear studs outside the tube and the axial load level on the hexagonal CFST column. Two typical failure modes are observed in the test, and the experimental results show that the concrete-encased column bases exhibit a high strength with good ductility and high energy dissipation capacity. The damage modes of the outer RC component are investigated, and the load transfer mechanism of the concrete-encased column base is analyzed. The load versus displacement relation, strain development, lateral deflection distribution and bottom rotation are compared for specimens under different failure modes. Further analysis is conducted to investigate the effects of parameters on various seismic performance indexes, such as the elastic stiffness, the maximum strength, the ductility coefficient, the strength and stiffness degradation, and the equivalent viscous damping ratio. Finally, a simplified strength model of the concrete-encased column base for hexagonal CFST is also proposed.

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1. Introduction

In a real building, the column base bears loads from the column and transfers them to the foundation, the behavior of which significantly affects the overall behavior of the structure. In recent decades, the concrete-filled steel tube (CFST) has achieved a large number of applications as columns for its excellent mechanical performance and constructional efficiency [1]. The application of CFST columns requires column bases with high stiffness and strength. There are mainly three types of column bases, i.e., the base plate column base, the embedded column base and the concrete-encased column base, as shown in Fig. 1. The base plate column base composed of a base plate and anchor bolts in Fig. 1(a) is the most widely used column base in low-rise and medium-rise buildings. Fig. 1(b) shows the embedded column base where the column is embedded into the foundation. The concrete-encased column base, as shown in Fig. 1(c), is composed of an inner base plate column base partially encased by an outer reinforced concrete (RC) component. Compared with other types of column bases, the concrete-encased column base provides high stiffness and strength with moderate constructional complexity, which indicates its application potential as CFST column base.

The concrete-encased column base has already been used in both China [2] and Japan [3]. Fig. 2(a), (b) and (c) show the application of concrete-encased column bases in high-rise building, multi-story steel building and industrial plant, respectively. Compared with the base plate column base, the concrete-encased column base provides larger stiffness and strength because of the support provided by the outer RC component. Under seismic loading, the pinching effect of the load-deformation curve caused by the elongation of anchor bolts might also be weakened. For the embedded column base, the thickness of the foundation needs to be larger to avoid punching shear failure, and the foundation reinforcement needs to be cut off when it intersects with the embedded column, resulting in a more complex construction process. The construction of concrete-encased column base is more convenient and follows the process below. The anchor bolts and the longitudinal bars of the outer RC component are installed first and the foundation concrete is poured. After that, the steel column with base plate is then erected and the formwork of outer RC component is installed. Then the core concrete in the CFST and the outer concrete in the outer RC component is poured.

Up to now, extensive studies on the base plate column base [4–6] and the embedded column base [7–9] have been carried out. As for concrete-encased column base, some experimental work was reported. Akiyama et al. [10] conducted a series of tests on concrete-encased column bases for H-shaped steel columns, where the parameters included the height of the outer RC component, the stirrup layout and the axial

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* Corresponding author.
E-mail addresses: lhhan@tsinghua.edu.cn, lhhanqw@gmail.com (L.-H. Han).

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load level. Nakashima [11] reported seismic tests on concrete-encased column bases for square tubular steel columns. The experimental behavior of concrete-encased column bases was also studied by Wang [2] and Guo [12]. However, previous experiments are mainly on concrete-encased column bases for steel columns, and tests on concrete-encased column bases for CFST are rather limited. In addition, detailed numerical work for the seismic behavior of the composite column base is not reported yet.

There is also lack of concern for the design specifications on the concrete-encased column base for CFST. The Japanese code AIJ-2008 [13] and the Chinese specification CECS-230-2008 [14] provide some conservative design methods, while the American code ANSI/AISC360-10 [15] and European code EC3 [16] are lack of guidelines for the composite column base. Meanwhile, the load transfer mechanism of the column base is unclear, such as the load distribution in different sections along height, as well as the interaction among the CFST column, the outer RC component and the base plate. More experimental and analytical work is needed to enhance the understanding of the column base.

Meanwhile, CFST columns with special cross-sectional shapes, such as hexagonal shape, have been used in several high-rise buildings in China, as shown in Fig. 2(a). The hexagonal section makes the column easier to be connected with other structural members, and also achieves good esthetic performance. In this study, twelve concrete-encased column bases for hexagonal CFST subjected to constant axial load and cyclic lateral load are tested. As the hexagonal column has strong and weak axes, the seismic behavior along the strong axis is studied. The failure modes, load versus displacement relations, strain and displacement developments of typical specimens are displayed. Based on the test results, the effect of parameters on various indexes, such as the stiffness, maximum strength, ductility, stiffness and strength degradation, and energy dissipation ability, are discussed. The specimens are also classified by stiffness and strength according to EC3 [16]. A simplified strength method is also suggested for the column base.

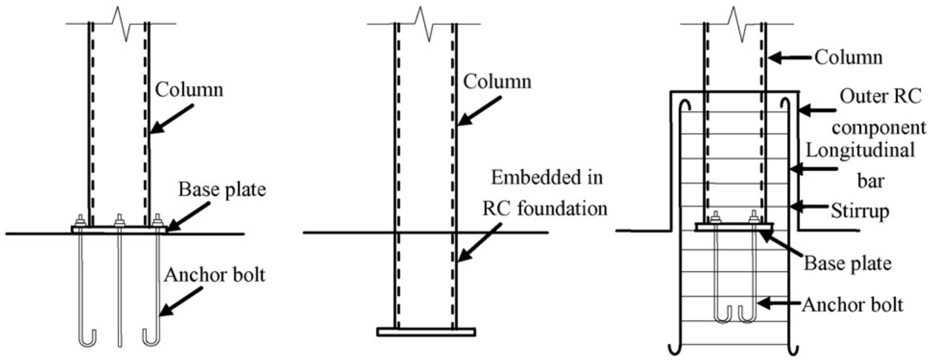
2. Experimental program

2.1. Specimens design

The specimens were designed as the substructure of a frame, which consisted of the bottom column (below the inflection point), the foundation and the concrete-encased connection, as shown in Fig. 3(a). A schematic view of the column base is shown in Fig. 3(b), where L represents the effective length of the column; H and w_r represent the height and thickness of the outer RC component, respectively. The specimens were subjected to constant axial load (N_0) and cyclic lateral load (P). The axial load level ($n = N_0/N_u$) was used to quantify the axial load. N_u represents the ultimate compressive strength of the hexagonal

Nomenclature

A_a	Cross-sectional area of anchor bolts
A_c	Cross-sectional area of core concrete in CFST
A_l	Cross-sectional area of longitudinal bars
A_s	Cross-sectional area of steel tube in CFST
B	Section width of hexagonal CFST
E_s	Elastic modulus of steel
E_{total}	Accumulated energy dissipation
f_c'	Cylinder compressive strength of concrete
f_{cu}	Cube compressive strength of concrete
f_u	Tensile strength of steel
f_y	Yield strength of steel
h_e	Equivalent viscous damping ratio
H	Height of the outer RC component
K_e	Elastic stiffness of column base
K_i	Equivalent stiffness at peak displacement $i\Delta_y$ of column base
K_s	Serviceability-level stiffness of column base
L	Effective length of CFST column
M_{max}	Maximum moment
M_u	Predicted flexural strength of column base
M_{uc}	Predicted flexural strength of CFST section
M_{upc}	Predicted flexural strength of inner base plate connection
M_{ur}	Predicted flexural strength of outer RC component in bottom section
n	Axial load level of CFST column ($=N_0/N_u$)
N_0	Axial load applied on CFST column
N_u	Ultimate compressive strength of CFST column
P	Lateral load
P_{max}	Maximum lateral load
P_y	Yield lateral load
S_{je}	Elastic rotation stiffness of column base
S_{js}	Serviceability-level rotation stiffness of column base
t_s	Thickness of steel tube
w_r	Thickness of outer RC component
Δ_{max}	Displacement corresponding to maximum lateral load
Δ_{total}	Accumulated displacement
Δ_u	Displacement corresponding to lateral load of $0.85P_{max}$
Δ_y	Displacement corresponding to yield lateral load
λ_i	Strength degradation coefficient at peak displacement $i\Delta_y$
ρ_l	Longitudinal bar ratio
ρ_v	Volumetric stirrup ratio
μ	Ductility coefficient ($=\Delta_u/\Delta_y$)



(a) Base plate type (b) Embedded type (c) Concrete-encased type

Fig. 1. A schematic view of three types of column bases.

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