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Analysis of steel-reinforced concrete-filled steel tubular (SRCFST) columns under cyclic loading

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ABSTRACT

A new form of composite column, steel reinforced-concrete filled-steel tubular column (SRCFST) has been proposed to undertake higher loads. This contribution presents a numerical study of cyclically loaded SRCFST columns based on the ABAQUS standard solver. The feasibility and accuracy of the numerical method was verified by comparing the calculated results with the experimental observations. The lateral displacement–load curves and sectional stress distributions were analyzed. The results indicate that the SRCFST columns have higher specimen stiffness, peak lateral load and deformability than common concrete filled steel tubular (CFST) columns due to the presence of the section steel. A parametric study, including influence of axial load levels, ratio of section steel, yield strength of section steel, concrete strength and thickness of steel tube on peak lateral load was also carried out.

1. Introduction

Over the last several decades, the concrete-filled steel tubular (CFST) structure is widely used in the construction of modern buildings and bridges [1–3], even in regions of high seismic risk. This composite construction ideally combines the advantages of both steel tube and concrete, namely the speed of construction and high strength. Moreover, they have lighter weight, higher bending stiffness, and better cyclic performance than the reinforced concrete construction. In recent years, a large structure or group of structures arises in China and some other place. With the increase of span-length and height, the cross area of a column is often designed bigger to provide higher bearing capacity. For example, the diameter of CFST columns in first story of ShenZhen Saibo Plaza Building reaches 1600 mm. Such a large cross area of a column results in a reduced useful indoor area.

Steel reinforced concrete (SRC) structural members are composed of a concrete, a section steel, longitudinal steel bars and transverse steel bars. They are widely used due to their advantages in term of high sectional strength. However, it is a very complicated process for construction.

A new form of composite column, steel reinforced-concrete filled-steel tubular column (SRCFST), has been proposed recently [4,5]. The new column consists of a steel reinforced concrete inside and a steel tube outside, as shown in Fig. 1. No steel bars are used in this composite column and the outside steel tube can provide confining effect to keep the concrete and section steel work together. The new column is an attempt to combine the advantages of the SRC column and the concrete filled steel tubular column, so as to achieve a high performance structural member.

Most of existing studies focused on mechanical performances of SRCFST columns under axial load or bending both in theoretical analyses and tests [4–7]. Compared with the studies made in the fields mentioned above, fewer experimental studies have been carried out on the behaviors of SRCFST columns under cyclic loading [8].

In order to give a further understanding of such a new column, in this contribution, the ABAQUS/standard solver is employed to investigate and predict the resistances of SRCFST columns under cyclic loading. Validation of this numerical method is carried out by comparing the computed results with the experimental observation of five tested specimens. A parametric study, including the thickness of steel tube, steel ratio of section steel, yield strength of section steel and strength of concrete, is also carried out.

2. Numerical modeling

2.1. Materials properties

The steel is assumed to behave as an elastic–plastic material with strain hardening after yield strength. The Mises yield surface is used to define isotropic yielding for steel material and the model assumes associated plastic flow. To describe the behaviors of steel under cyclic loading, linear kinematic hardening model is adopted to ease the modeling of the composite columns. Steel properties

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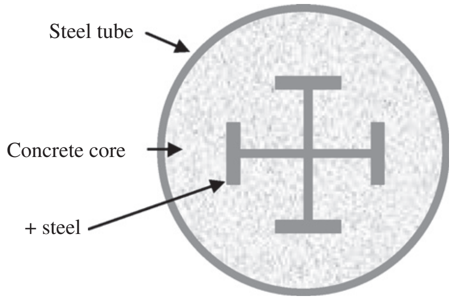

Fig. 1. Cross section for SRCFST column.

specified in ABAQUS include a Young's modulus of steel (E_s), a Poisson's ratio μ_s and a yield strength. A hardening rigidity of 1% E_s after yield has been adopted.

The damaged plasticity model defined in Standard ABAQUS [9] is used in the analysis. By using the finite element method, strength improvement at the state of triaxial loading can be achieved by the definition of the yielding surface, and the description of the plastic behavior comes from the equivalent stress–strain relationship of concrete core. Many stress–strain models have been proposed [10–13]. The widely accepted equivalent stress–strain model proposed by Han et al. [14] is used in this paper, which is based on a large amount test results. As the model has been fully documented by Han et al. [14], so we only briefly describes as following:

$$y = \begin{cases} 2x - x^2 & (x \leqslant 1) \\ \frac{x}{\beta_0 (x-1)^{\eta} + x} & (x > 1) \end{cases} \tag{1}$$

where $x = \varepsilon/\varepsilon_0$, $y = \sigma/\sigma_0$. σ_0 is the compressive strength of concrete core and ε_0 is the corresponding strain. β_0 and η are parameters for controlling the shape of the curve. More details about the definition of parameters can be found in reference [14].

Poisson's ratio μ_c in the elastic part of concrete under uniaxial compression stress ranges from 0.15 to 0.22, with a representative value of 0.19, according to ASCE [15]. In this numerical modeling, Poisson's ratio of concrete is taken as 0.19. The other parameters, such as dilation angle, eccentricity, ratio of the biaxial compression strength to uniaxial compression strength of concrete, the ratio of the second stress invariant on the tensile meridian to that on the compressive meridian and viscosity parameter are default by ABAQUS [9].

For the concrete under cyclic loading, it is also necessary to define the tensile behavior in the damaged plasticity model of concrete. The equivalent stress–strain relationship of concrete core under tension proposed by Guo [16] is used:

$$y = \begin{cases} 1.2 \cdot x - 0.2 \cdot x^6 & (x \leqslant 1) \\ \frac{x}{0.31 \cdot \sigma_p^2 \cdot (x-1) + x} & (x > 1) \end{cases} \tag{2}$$

where $x = \varepsilon/\varepsilon_p$, $y = \sigma/\sigma_p$. σ_p and ε_p σ_p are the tensile strength of concrete and the corresponding strain, which can be calculated as follows:

$$\sigma_p = 0.26 \cdot (1.25 \cdot f_c)^{2/3}\ (\text{MPa}) \tag{3}$$

$$\varepsilon_p = 43.1 \cdot \sigma_p(\mu\varepsilon) \tag{4}$$

where f_c is the compressive strength of concrete.

2.2. Finite element mesh and boundary conditions

Three-dimensional eight-node linear brick and reduced integration with hourglass control solid element (C3D8R) has been proved to be used for concrete the most effective element type for concrete [17–19] For steel tube, both shell elements and solid elements were

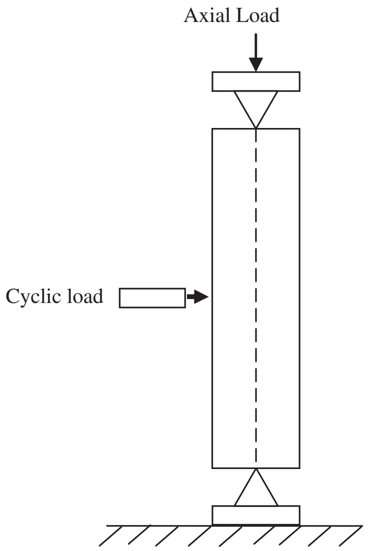

Fig. 2. Sketch of test arrangement for cyclic loaded SRCFST column.

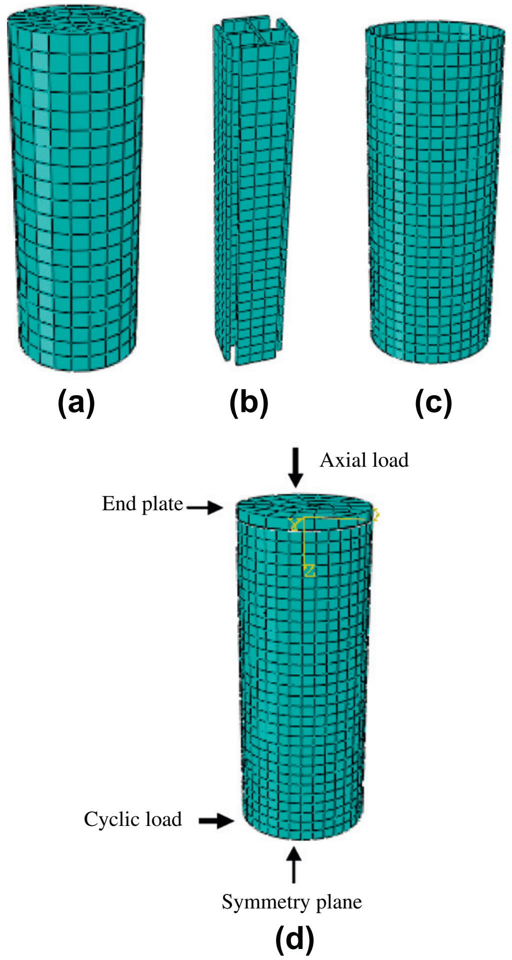

Fig. 3. Element divisions and boundary conditions. (a–c) are element divisions for concrete core, section steel and steel tube, respectively, (d) is for boundary conditions. Axial load applied through elastic end plate and lateral load applied on symmetry plane at mid-height of column.