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Modeling of circular concrete-filled steel tubes subjected to cyclic lateral loading☆

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ABSTRACT

In this paper, a simple and efficient yet fairly accurate analytical model for the cyclic behavior and strength capacity of circular concrete-filled steel tubes (CFT) under axial load and cyclically varying flexural loading is developed. Firstly, an accurate nonlinear finite element model is created using the ATENA software. The validity of this model is established by comparing its analyses results with those of experimental data published in the pertinent literature. Then, using this finite element model, an extensive parametric study is conducted to create a fairly broad databank of hysteretic behavior of circular CFTs, involving numerous circular CFT columns with different diameter to thickness ratios, steel tube yield stress and concrete strength. On the basis of this databank, empirical expressions are developed to evaluate the phenomenological parameters of the well-known Ramberg-Osgood hysteretic model. Additionally, empirical analytical relations providing a direct and efficient representation of the ultimate strength of circular CFT columns are constructed and validated. Comparisons between analytical and experimental results demonstrate that the proposed analytical model can describe efficiently and reliably the behavior of circular CFT columns under cyclic lateral loading.

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1. Introduction

Concrete-filled steel tube (CFT) columns have been increasingly used in many modern structures due to the respective advantages of both steel and concrete, i.e. high strength, high ductility, high stiffness and large energy- dissipation. Steel offers high tensile strength and ductility, while the concrete core provides high compressive strength and stiffness [1]. CFT columns are widely used in heavy constructions because they provide all the aforementioned advantages. Furthermore, the steel tube eliminates the permanent formwork for concrete, reducing construction time and cost, while the concrete core takes the axial load and prevents or delays local buckling of the steel tube [1–3].

In the last decade, experimental and analytical investigation on CFT columns has been ongoing worldwide having succeeded in significant contributions. Most of the analytical methods are based on beam theory in conjunction with concentrated or distributed plasticity modeling [4–12], with fiber models included on the distributed plasticity ones. One can mention here, amongst others, the works of Hajjar et al. [9] and Aval et al. [10] who developed fiber-based distributed plasticity finite element formulations for CFT beam-column members representing the effects of geometric and material nonlinearities, including slip between the steel and concrete surfaces, steel yielding, concrete strength and stiffness degradation as well as the effect of confinement and cyclic loading on the concrete core. Furthermore, Varma et al. [4] developed also a fiber-based model for finite element analysis of CFT members under bending and axial load. Tort and Hajjar [11] reported a beam finite-element formulation which analyzes composite square CFT beam-column members with interlayer slip subjected to monotonic, cyclic, transient dynamic loads in the framework of a mixed finite element method of the distributed plasticity type. Han and Yang [13] developed a model for concrete-filled steel CHS (circular hollow section) columns subjected to constant axial load and cyclically increasing flexural loading extending their models that had been proposed for monotonic loading condition [14,15]. Skalomenos et al. [8] investigated numerically the nonlinear response of square CFT columns subjected to constant axial load and cyclically varying flexural loading taking into account all the parameters affecting the response of CFT members. By using this model, extensive parametric studies were conducted and three hysteretic models associated with concentrated plasticity were developed including strength and stiffness degradation. Leon et al. [16] presented an experimental and computational work in which they developed not only accurate nonlinear models for the behavior of steel and concrete composite frame systems subjected seismic and non-seismic loading but also they proposed new interaction equations. Chacón [17] focused his research on the structural behavior of CFT columns under seismic

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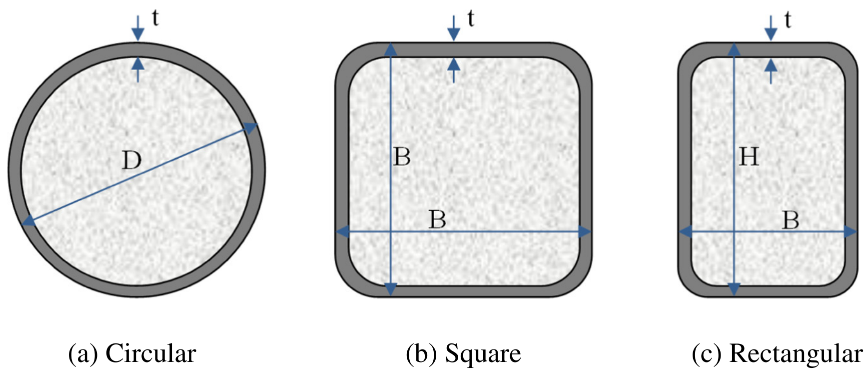

Fig. 1. Concrete-filled steel tubular (CFT) columns.

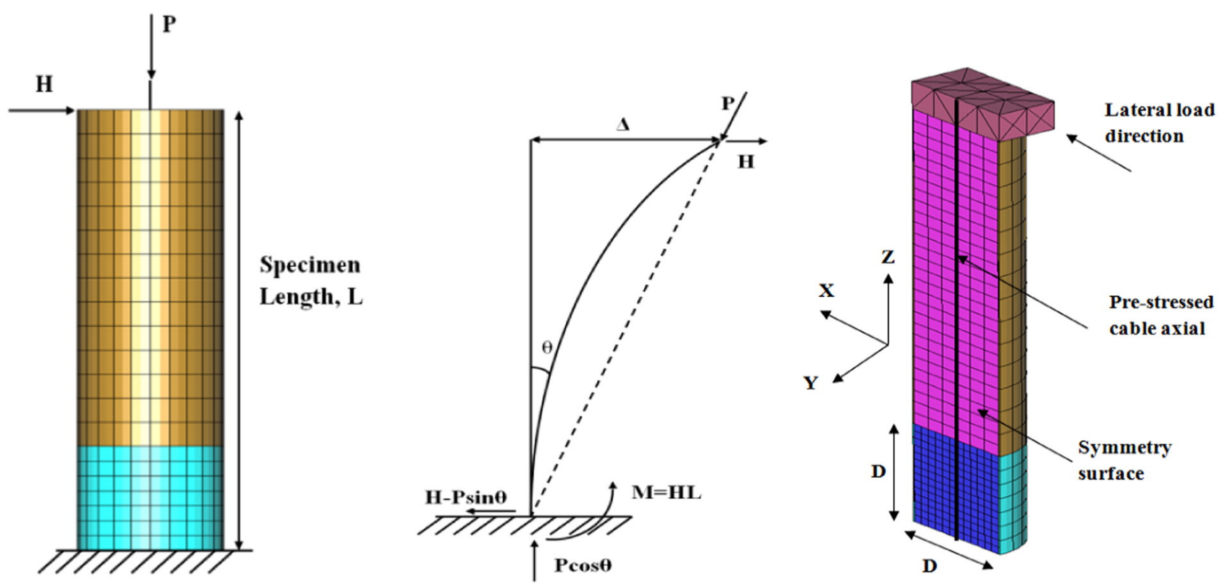

Fig. 2. Columns specimen and its finite element model.

events, fire or impact loading on the basis of experimental and numerical studies. The main aspects that have been investigated in the seismic response of circular CFT are related to seismic behavior of beam to column connections, local buckling, tensile fracture and cracking under cyclic loading. Numerical models dealing with the hysteretic behavior of CFT beam-columns with large sections have been provided [18] where the material modeling is based upon damage plasticity with additional implementation of a crack opening formulation. There are many types of CFT columns, as illustrated in Fig. 1.

This study focuses on circular CFT columns (Fig. 1a), which have advantages over other types (Fig. 1b,c), such as their greater moment enhancement ratios due to the larger confinement of the concrete core, their higher flexural strength and ductility and their ability of restraining local buckling and limiting the deterioration phenomena [12].

Aim of this paper is to simulate the nonlinear response of circular CFT columns subjected to constant axial load (assuming the 20% of the axial load carrying capacity, i.e., $N/N_{\max} = 0.2$) and cyclically varying flexural loading. Following the methodology developed by Skalomenos et al. [8], the Ramberg-Osgood (R-O) hysteretic model is adopted for simulating the cyclic response of circular CFT beam-columns. This model is based on concentrated plasticity theory and it is already available in Ruaumoko software [19] or other similar nonlinear structural analysis programs. One of the objectives of this study is the determination of the R-O hysteretic model parameters, which are evaluated

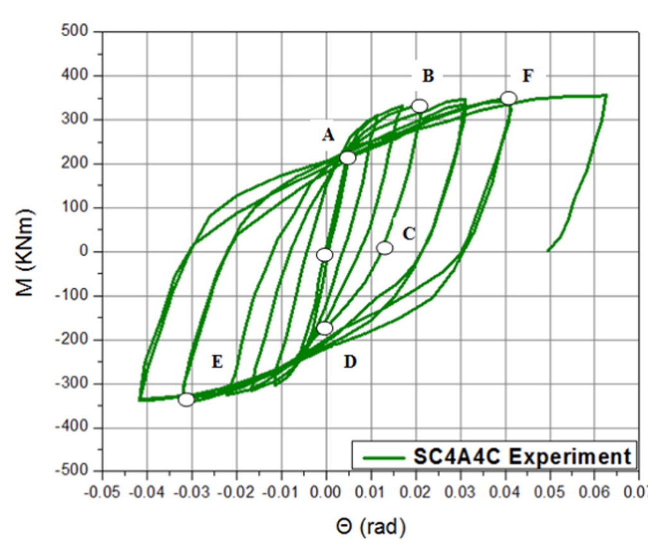

Fig. 3. Typical moment (M) versus rotation angle (Θ) relationship [12].

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