Journal of Constructional Steel Research 129 (2017) 301–314

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Direct analysis of high-strength concrete-filled-tubular columns with circular & octagonal sections

Si-Wei Liu [a], Tak-Ming Chan [a], Siu-Lai Chan [a],*, Derek Kwok-Leung So [b]

[a] Department of Civil and Environmental Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong, China
[b] Hip Hing Construction Co. Ltd, Hong Kong, China

ARTICLE INFO

Article history:
Received 19 July 2016
Received in revised form 24 November 2016
Accepted 24 November 2016
Available online xxxx

Keywords:
Direct analysis
Element
High-strength concrete
Nonlinear
Octagonal
Steel

ABSTRACT

High-strength-concrete (HSC) is brittle, but its ductility can be dramatically increased when confined by steel tubes. However, the size of hot-rolled tubular sections is commonly limited to 600 mm, its capacity as mega columns in many high-rise buildings is inadequate. This paper details the use of fabricated and rolled sections as mega-columns by the direct analysis of design (DAM) which is further presented for application with high-strength-concrete-filled-tubular (HCFT) columns of circular and octagonal sections allowing for confinement effects in concrete. To capture the material yielding behaviors and to allow for an explicit simulation on the member initial curvatures, a curved-piecewise-Hermite (CPH) element is especially developed for simulating the behaviors of HCFT columns under extreme loading conditions. A plastic-fiber-hinge-model using the sectional strength-iteration surfaces is proposed for capturing the yielding behavior at the hinge locations and the analytical method for generating the yield surfaces is elaborated. To this, one-element-per-member is sufficient for numerical simulation; and the savings in computer time are considerable, making the proposed theory practical. The material model for the HSC in steel tubes is essential for a successful design. To this, an experiment on two groups of confined specimens, e.g. circular and octagonal, is established for investigating the properties of HSC, and an approximated calculation method is proposed and validated with the experiments. Consequently, the corresponding stress vs. strain relations of the confined HSC can be determined for use in analysis. Finally, examples are given for verifying and validating the proposed method for HCFT columns with circular and octagonal sections.

1. Introduction

Direct analysis, which is also sometimes called as second-order plastic analysis with geometric and material imperfections, is advocated to investigate the true and ultimate structural behavior of members and frames over the past decades. This method is widely adopted in conventional structural design under static loads, performance-based seismic design, progressive collapse analysis and structural fire analysis. In order to reflect the actual structural performance and stability, the vital effects inherent to the members are needed to be considered and they include the large deflection effect, material yielding and initial member curvatures.

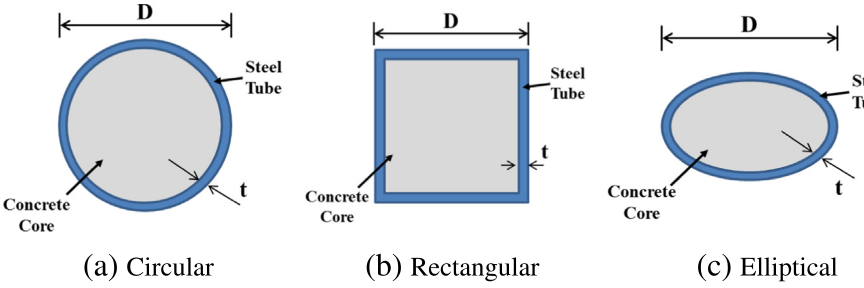
Concrete-filled tubular (CFT) columns are among the most economical and structurally efficient among reinforced and composite members in terms of resistance to high compressive loads. In addition to the steel tube being used as a load-carrying component, it also provides the confinement to the concrete core, thereby increases the compressive strength and improves ductility of the concrete. Further, the steel sections can be used as temporary works for fresh concrete so the cost of fabricating formworks can be saved. All these advantages are well-recognized and supported by experiments and reported (see, for example, Knowles and Park [1], Wardenier et al. [2] and Han et al. [3]). Extensive research and experiments have been conducted in the past decades to investigate the behaviors of CFT columns including Tomii et al. [4], Tanaka et al. [5], Schneider [6], Huang et al. [7], Mursi and Uy [8], Hu et al. [9], Dai and Lam [10], Sheehan et al. [11], Ellobody [12], Han et al. [3] and Dai et al. [13].

When using the structural form, a considerable increase in load bearing capacity due to concrete confinement effect is achieved and column size can be reduced with an increase in the usable floor area. Additionally, the concrete core restricts the local buckling of surrounding steel tubes and increases the column stiffness. Susantha et al. [14] investigated the Hyogoken-Nanbu earthquake in Japan and noted another advantage of CFT columns as having more ductility and larger energy absorbing capacity than the bare steel or reinforced concrete columns. Summarizing all these observations, CFT columns are thus favorable

---

* Corresponding author.
E-mail addresses: siwei.liu@connect.polyu.hk (S.-W. Liu), tak-ming.chan@polyu.edu.hk (T.-M. Chan), ceslchan@polyu.edu.hk (S.-L. Chan), derek_so@hiphing.com.hk (D.K.-L. So).

http://dx.doi.org/10.1016/j.jcsr.2016.11.023



(a) Circular (b) Rectangular (c) Elliptical

Fig. 1. Typical concrete-filled-tubular (CFT) columns with normal-size sections.

structural components for tall buildings constructed in high-density urban areas and earthquake-active regions.

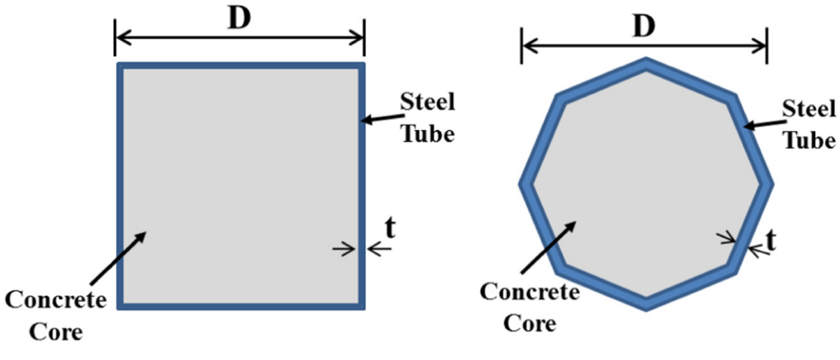
However, the commercial off-the-shelf tubular columns are limited to rectangular, circular and elliptical cross-section (see Fig. 1a to c). Their maximum outer diameter, *D* and thickness, *t* are normally <500 mm and 50 mm, respectively. For high-rise buildings <100 m, tubular columns are normally fabricated as welded sections (see Fig. 2a) to increase the load-carrying capacity. In recent years, mega-size cross-sections as shown in Fig. 3 have been adopted to further increase the load-carrying capacity for super high-rise buildings with height over 100 m. As the maximum diameter of tubular sections is generally limited to 600 mm, the size of using them as columns cannot satisfy the need for a column in a high rise building under high axial compression due to accumulative loads from floors above.

In addition to the load-carrying capacity, steel tube can also confine the concrete in-fill, and hence increases the compressive strength and significantly improves the ductility of the concrete. Research from Susantha et al. [15] indicated that this influence would be dramatically affected by the cross-section shape of the tube. The strength and ductility of the confined concrete core can be increased in circular CFT columns [1], while only the ductility of the concrete in CFT members with rectangular sections can be improved [16]. However, manufacturing challenges would be encountered while fabricating a large-sized circular steel tube. Therefore, an optimal and practical solution can be achieved by using the alternative – octagonal shaped section, as illustrated in Fig. 2b. It is crucial to investigate the corresponding confinement behavior on the concrete core in this octagonal shaped section.

In this research, high strength concrete (HSC) refers to concrete with the characteristic concrete cube strength >60 MPa (~8.7 ksi). HSC offers greater stiffness and strength than normal strength concrete. To date, the readily-mixed product of HSC can be easily sourced in the market and is being extensively used [17]. However, HSC is an extremely brittle material as schematically shown in Fig. 4. Nevertheless, when it is confined by circular steel tubes, both the ductility and strength of HSC can be improved (see Fig. 5, Liew et al. [18]).

High-strength concrete-filled-tubular (HCFT) columns are usually slender and their stability problems are dominant and therefore the P-δ-Δ effects are important in design. To achieve an acceptable level of accuracy, the member local imperfection should be taken into account otherwise the structural stability cannot be assessed reliably. The curved high-order beam-column element developed by Chan and Zhou [19] and the curved stability function element proposed by Chan and Gu [20] are suitable candidates for analysis of slender axially-loaded members and also have been widely used in the design practice. However, the current theories mainly use the conventional refined plastic hinge method and it assumes the plastic hinges are formed only at the element ends. Therefore, two and more elements are required for accurate modeling of a member to capture the plastic hinge location. This not only increases the computational time, but also causes difficulties in modeling the member imperfections. In this paper, a curved-piecewise-Hermite (CPH) element is developed for simulating the HCFT columns with circular and octagonal sections, which is derived on the basis of the arbitrarily-located-hinge (ALH) element developed by Liu et al. [21,22] and the work originally conducted by Chen and Chan [23].

To reflect the inelastic behavior of HCFT columns, an approach using the plastic fiber hinge model [24] is adopted in the present study. Material yielding on hinge locations is reflected by a gradually softening spring. Contrary to the traditional or refined plastic hinge model, where the simplified linear interaction equations are adopted to examine yielding on sections, the accurate and rigorous criterion described by the sectional yield surfaces are utilized in the proposed plastic fiber hinge model. To generate the sectional yield surfaces, the numerical method based on quasi-Newton interactive scheme [25] is employed, where the steel and concrete components are divided into several fibers and parallel layers, respectively, in calculating the stress resultants of a cross section.



(a) Rectangular (b) Octagonal

Fig. 2. Concrete-filled-tubular (CFT) columns with large-size sections.