Application of Concrete Filled Steel Tube Column Structural System in Calcination Furnaces

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Abstract

The complex nature of calciner construction and its resulting height places significant structural requirements on its support system. In recent years, the concrete-filled steel tubular column (CFSTC)-steel braced frame (SBF) structural system has been applied widely in calciners due to its excellent mechanical performance and ease of construction. This paper details the development of a layout scheme for the CFSTC-SBF structural system based on the calciner's structural characteristics and loads from equipment, wind, and earthquakes. With the aid of finite element analysis software, internal stress and relevant design analyses are carried out to examine the impacts of different parameters including steel tubular column cross-sectional dimensions and concrete strength grades on the performance and cost-effectiveness of the structural system, as well as the applicability of these parameters. The results show that the CFSTC-SBF structural system offers high bearing capacity, high levels of both stiffness and ductility, and can effectively withstand horizontal loads and seismic actions, thus meeting the safety and cost-effectiveness requirements of calciners. The design results of the CFSTC-SBF structural system are detailed, which, along with practical examples, provide a reference for similar engineering projects.

Keywords: Concrete-filled steel tubular column (CFSTC), Steel bracing, Frame structure, Aluminum hydroxide calcination, Towering structure.

1. Research Background and Significance

Due to continuously rising production capacity, expanding equipment size and increasing load, traditional H-shaped or cross-shaped column-SBF structures could no longer meet the stress and cost-effectiveness requirements. As a result, CFSTCs were used in high-rise buildings as early as the mid-1980s. Fully utilizing the high tensile strength of steel and the high compressive strength of concrete, CFSTCs offer significant advantages in mechanical performance and cost-effectiveness. In terms of strength, they increase compressive strength by 30–50 % (hoop effect) because of steel tubes constraint on the core concrete [1] and raise bearing capacity by 20–40 % over pure steel columns through steel tube-concrete synergy [2]. In terms of cost-effectiveness, they reduce steel usage by 20–30 % and lower the gross cost by 15–25 % [3]. With regards to construction convenience, no formwork is needed after the hollow steel tube is hoisted and cast with self-compacting concrete, thus shortening the construction period by 30 % compared to that of concrete structures [4]. The fire resistance performance achieves a fire endurance of up to 2.5 hours and can well meet the requirement of *Code for Fire Safety of Steel Structures in Buildings* (GB51249-2017)[5], with no need for fireproof coating.

Technical Specification for Concrete Structures of Tall Building [6] lists CFSTCs as a recommended solution for high-seismicity areas. Calciners are characterized by a large single column reaction force (over 15 000 kN), high process equipment density, numerous planar openings, a high floor height, non-continuous frame beams, and a wide column grid layout (generally with a span of 10–13 m). Given these characteristics, adopting the CFSTC-SBF structural system holds great practical significance.

2. Design Theory of CFSTC

The design theories recommended in GB 50936-2014 [7] are respectively the unified theory of steel-reinforced concrete and the experiment-based limit equilibrium theory. The unified theory of steel-reinforced concrete considers it as a composite material, analysing its composite working performance based on its properties such as uniformity, continuity, and correlation. Instead of focusing on a specific critical section of the CFSTC, the limit equilibrium theory examines the entire length of the CFSTC, or the so-called unit column, taking it as the fundamental element of the structural system. By applying the broader concepts of stress and strain in the limit equilibrium theory, the broader yield conditions of the unit column under the combined action of the two broader stresses, namely axial force *N* and column end bending moment *M*, are examined based on the experimental observations.

3. Case Study

A refinery adopts CFSTC-SBF as the structural system of its calciner and uses corrugated steel plate as the floor slabs. The main structure of the calciner is 58.5 m high, with a total of 8 primary floors. The column grid, typical floor layout and elevation drawing are shown in the figures below.

Main design parameters: the site is classified as Category II, with a seismic fortification intensity of 6 degrees (0.05 g) and a reference wind pressure of 0.75 kPa.

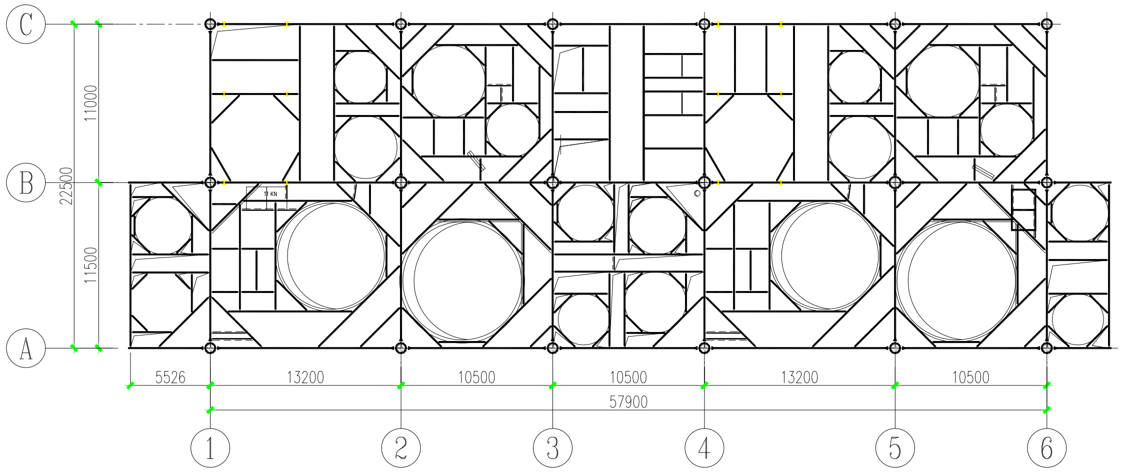

Figure 1. Typical plan layout 1.

Table 2. Displacements and displacement angles in X and Y directions under wind load conditions.

Floor No.	Maximum Displacement in X Direction (mm)	Maximum Inter-floor Displacement Angle in X Direction	Maximum Displacement in Y Direction (mm)	Maximum Inter-floor Displacement Angle in Y Direction
8	43.08	1/2553	68.44	1/970
7	42.07	1/2097	67.14	1/884
6	39.81	1/1682	64.27	1/849
5	36.55	1/928	60.51	1/513
4	27.27	1/1036	42.53	1/706
3	19.66	1/895	30.76	1/608
2	11.17	1/1104	17.69	1/679
1	5.20	1/1374	7.88	1/907

5. Conclusions

1. In the design of CFSTCs, the first step is to determine the preliminary section dimensions based on the floor height and aspect ratio. Then, the matching concrete strength should be selected according to steel strength grade, and the appropriate hoop coefficient (between 1.5 and 2.0) should be iteratively verified and adjusted to identify the optimal steel tubular section dimensions for the component;

2. Through real-world case study, this paper shows that CFSTCs can achieve favourable cost efficiency for calciners with large vertical loads and column grid spans, saving more than 40 % of steel compared to traditional H- and cross-shaped steel columns or cross shaped columns;

3. A matching bracing structural system is adopted for the steel tubular columns, which can fully leverage their compressive strength and improve the overall structural lateral resistance, thus ensuring good structural safety and economy.

6. References

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