Research on the Application of Fabricated Steel Structures to the 220kV Indoor Substations

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Abstract: The significant development of fabricated steel structure is helpful to solve the issue of excessive productivity in steel industry and promote the greenization, informatization and industrialization in construction industry. This paper takes a 220kV indoor substation for example to compare the stress ratio, displacement, types of joints and steel quantity of the steel pipe column frame with those of the mixed one. The result demonstrates that the employment of steel pipe columns for indoor substation structures can generate certain economic and social benefits.

1. Introduction

Sufficient electric power supply is crucial to the rapid expansion of economy. As an indispensable role in city construction, the construction of substations also has to keep the pace. At present, our country has launched the projects of standard distribution-mode intelligent substations and strongly popularized standard design, industrialized manufacture, and fabricated construction.

Fabricated steel structures refer to high-rise or multi-story buildings using industrialized steel columns and beams for their structure skeleton with light, adiabatic, insulated and high-strength materials for wall. A consensus to promote the employment and development of high-rise or multi-story buildings and accelerate the revolution of production modes in construction industry has formed from enterprises to administrations.

This paper introduces the employment of fabricated steel structures for indoor substations and its advantages on technique and cost in a contrast fashion with an example of a power transmission project.

2. Profile

The design parameters of this substation are as following: first-class safety rank, 50-year design working life, earthquake fortification intensify for seven degrees, design basic acceleration of ground motion of 0.1g, second earthquake group, wind pressure at 0.55kN/m² and snow pressure at 0.20kN/m² of 50-year frequency.

According to the traits of constructing an indoor substation, as well as considering the environmental pollution, wasting of resource, unrecyclable building materials, long construction period and some other issues of concrete structures, it’s decided to employ a fabricated steel structure for the building. With the engineering characteristics, it’s suitable to use the assembly type. According to the volume of components, two schemes are mapped out to contrast and analyse— one is a steel
pipe column frame and another is a mixed column frame consisting of H shaped steel, cross shaped and rectangular steel pipe columns. To analyse the substation, an integral space model is established as picture 1 and the hierarchical model as picture 2 by PKPM.

![Figure 1. The integral space model of substation](image1)

![Figure 2. The hierarchical model of substation](image2)

3. Schema design

3.1 Steel pipe column frame

Rectangular steel pipe columns have good feasibility for buildings with constant strength in all directions, huge torsion stiffness, high bearing capacity, good corrosion resistance after closing the heads of tubes and the regular shape suitable to make up light and beautiful structures. Formworks are unnecessary when pouring concrete, and after pouring, columns can obtain good fire resistance, as well as overall and local stability. At abroad, particularly in Japan, rectangular steel tubes and concrete-filled steel tubes have been universally employed for high-rise or multi-story buildings and started to popularize at home as well.

However, hot rolled section H shaped steel beams are used for frame beams. This steel has excellent mechanical properties and usability, because its aspect ratio of section is distributed by purpose. Compared with I shaped steel, its section modulus is bigger, and for this, the consumption steel can be reduced by 10% to 15% under the same loading. Furthermore, the hot rolled section H shaped steel, compared with the welded one, is superior for its lower cost of raw materials, energy and manpower, as well as low residual stress and qualified appearance. And the high industrialization of steel structures—mainly the H shaped ones—facilitates the machine manufacturing, intensive production and installation, as well as improves the precision and quality.

In factory, workers primarily weld angle hoops on the four corners of columns, and then weld collar flanges on the two ends of lateral beams. There is a certain inclination in these hoops and flanges. After arriving at the construction site, workers put columns on the ground at first, next lift the lateral beams with collar flanges and then slowly lay them down to the gap between two angle hoops until the beams settle. After that, beams in the other directions could be lifted successively. Finally, after these beams taking their places, workers only need to tighten the bolts. The practical process of node assembly is described as Picture 3.
3.2 Mixed column frame

Meeting the requirements of construction and craft is too difficult to completely employ H shaped steel columns for this project. On the floor with a full-height gap, due to the lack of constraint in some direction and the excessive slender proportion even with a large section, steel columns cost needless materials, space, and money, as well as uglify the whole building. To avoid this, a plan that is to use H shaped steel columns in the sections with small slenderness ratio while cross shaped steel (X-type) columns in those with big slenderness ratio is adopted. However, the computed result shows that six side columns’ slenderness ratio still cannot fit the bill. But after changing them to the concrete-filled square steel tubular ones, the result passes all checking calculations.

For I shaped section frame columns, the rigid joints on major axis of H shaped section columns have three common types as following. Among them, (a) is the fully welded, (b) is the fully bolted and (c) is the mixed.

Among the three types of connections, the fully welded and the mixed need to be done at site so that the quality of construction, as well as the speed, is by no means guaranteed well. And the employment
of fully bolted structures is restricted for their demand of massive bolts and obviously different stiffness on the two axes of columns.

4. Schemes comparison
As following, the construction periods, mechanical properties and steel consumption of the two schemes are compared to analyse their advantages and disadvantages.

4.1 Construction period
To demonstrate the superiority of fabricated steel structures in construction, a comprehensive comparison among reinforced concrete frames, concrete-filled steel tubular frames and the mixed ones are made and the result is shown in Table 1.

| Construction order                              | Steel tubular frames | Mixed frames | Reinforced concrete frames |
|------------------------------------------------|----------------------|--------------|----------------------------|
| Lifting columns                                | 1                    | 1            |                            |
| Lifting main girders and secondary beams on the ground floor | 1                    | 5            |                            |
| Lifting steel truss formworks on the ground floor | 1                    | 1            | Usually, the whole process is divided into two stages and the construction of each floor spends 12 to 15 days. |
| Pouring and curing concrete of the support plate on the ground floor | 1                    | 1            | This structure is computed as three floors. |
| Lifting main girders and secondary beams on the second floor | 1                    | 5            |                            |
| Lifting steel truss formworks on the second floor | 1                    | 1            |                            |
| Pouring and curing concrete of the support plate on the ground floor | 1                    | 1            |                            |
| Lifting main girders and secondary beams on the second floor | 1                    | 5            |                            |
| Lifting roof components                        | 1                    | 1            |                            |
| Lifting roof panels                            | 1                    | 1            |                            |
| Totalday                                       | 10                   | 22           | 45                         |

By comparison, fabricated steel structures spend obviously less time on construction than reinforced concrete frames, which highlights the superiority of steel structures. Meanwhile, through comparing steel tubular frames with the mixed ones, it could be easily found that the former has an outstanding advantage on construction period for the employment of fully fabricated node connections rather than vast welding connections for the latter.
4.2 The arrangement and construction of structures
Through modeling, computing and comparing the two schemes, steel pipe columns and mixed columns are both able to meet the demands of stress ratio, structural displacement and bearing capacity. However, square tubular columns with same geometrical and mechanical properties at two axes are more proper to the structural arrangement of frames\(^4\). While for the mixed columns with \(H\) shaped steel columns in the parts of small slenderness ratio and cross-section columns in those of big slenderness ratio, the failure to meet the requirement of slenderness ratio still happens to six side columns. But after replacing them with concrete-filled steel square tubular columns, the checking calculation succeeds.

4.3 The consumption of steel
By comparison, the steel pipe columns use 764.96t steel while the mixed ones use 966.38t steel, 26.3% more than the former. That demonstrates the employment of steel pipe columns can reduce the consumption of steel.

5. Conclusions
By introducing the application of fabricated steel structures to indoor substations, with comprehensively comparing the advantages and disadvantages of different frame columns, several conclusions can be drawn as following.

(1) Steel pipe column frame is prior to be used for indoor substations with large span and high floor load.

(2) The construction period of steel pipe column frames is shorter than that of the mixed ones, not to mention that of the reinforced concrete frames.

(3) The small consumption of steel well demonstrates the advantages of square tubular columns such as constant strength in all directions, large torsional stiffness and good bearing capacity.

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