ISSN 2706-655X Vol.5, Issue 10: 53-58, DOI: 10.25236/IJFET.2023.051009

Calculation and analysis of full plasticity of lateral force resisting member connection of industrial steel structure bracket

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Abstract: *Steel structure belongs to the engineering structure formed by welding or connecting, and is generally made of section steel and steel plate by welding, or by connecting or riveting bolts. Compared with other types of construction, it has the characteristics of low cost and good activity, so it has more advantages in design, construction, use process and economy. Theoretically, steel structure members or connecting members have arbitrary machinability, but in each specific project. Structural members and connecting members are always restricted by realistic conditions. Based on the test results, this paper deeply analyzes the combined performance of the lateral force resisting members of industrial steel structure support, and puts forward the full plastic calculation method of the lateral force resisting member connection of industrial steel structure support. It has a good enlightenment and reference for the research of light steel multi-storey residential system which is being vigorously promoted in China. The results show that the performance coefficient under uniformly distributed load is larger than that under inverted triangular load, and the overall super-strength coefficient increases from 5.09 to 6.96, an increase of 36.74%, which shows that the performance of the structure under uniformly distributed load is better than that under inverted triangular load distribution.*

Keywords: *Rigid connection of beams and columns, rigid connection of column bases, and full plastic bearing capacity*

1. Introduction

In recent years, China's construction industry has developed vigorously, and large-scale steel structure buildings have also emerged. Steel structure buildings (including structures) are usually composed of structural members and connecting members. The purpose of connection design is the continuation of structural members and the transmission of force. According to the definition of material mechanics, when the dimension of one dimension of a member is much larger than the other two dimensions, this member is defined as a linear member [1]. Splicing and connection of components is a very important link in seismic performance-based design, and its leading idea is that the bearing capacity of connections should be greater than that of components. In order to improve the overall seismic performance of buildings and avoid continuous collapse of buildings in earthquake areas, strengthening the splicing and connection of nodes and components is one of the very important measures [2-3].

Although the vast majority of light steel connection components are completed by manufacturers, engineers and technicians must have a clear understanding of the connection methods, control principles and leading factors of light steel structure building components. Based on the test results, this paper deeply analyzes the combined performance of the lateral force resisting members of industrial steel structure support, and puts forward the full plastic calculation method of the lateral force resisting member connection of industrial steel structure support. It has a good enlightenment and reference for the study of light steel multi-storey residential system.

2. Lateral force resisting member of industrial steel structure support and its characteristics

The lateral force resisting members of industrial steel structure support are characterized by the diversity of cross sections: on the one hand, the isotropic homogeneity of steel makes it possible to be processed into various shapes, and the connecting members in the member structure are almost all steel; On the other hand, the cross-sectional shape of the lateral force resisting members of industrial steel

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structure supports also has a great influence on the connection design. Steel structure belongs to the engineering structure formed by welding or connecting, and is generally made of section steel and steel plate by welding, or by connecting or riveting bolts. Compared with other types of construction, it has the characteristics of low cost and good activity, so it has more advantages in design, construction, use process and economy [4]. The area with large stress and strain values is near the bearing, and the area with small stress and strain values and regular distribution is the middle of the member. The internal area of the specimen is deformed by hydrothermal action, and it is constrained by the external area. Under the action of these two forces, the internal stress value becomes lower and the external stress value becomes larger accordingly.

There is a complex and logical hierarchical relationship between the structural systems of steel buildings. At the connection level, this hierarchical relationship is reflected in the difference of component size and installation order. The purpose of connection is to realize hierarchical transformation, and it is also the key to realize the transformation of force from three-dimensional to two-dimensional and finally to one-dimensional components [5-6]. Complex connection is usually completed by the combination of three-dimensional connection members and plane connection members. For example, the welding tabs of steel pipes and cables are always in the plane formed by them. In the case of connection of multiple members, the combined plane members can correspond to the three-dimensional stress situation.

The structural construction of steel structure buildings includes two basic types: bar and cable, and the resulting connection modes can be divided into cable-to-cable connection, bar-to-bar connection and cable-to-bar connection. No matter the plane structure or the spatial structure [7]. Due to the linear characteristics of the single component, the complexity of the structural system will not lead to more types of connections, and complex connections can be regarded as a combination of these three basic types.

3. Full plastic calculation of lateral force resisting member connection of steel structure support

Theoretically, steel structure members or connecting members have arbitrary machinability, but in each specific project. Structural members and connecting members are always restricted by realistic conditions [8-9]. Experienced designers usually choose section steel which is easy to obtain and install, and design simple and effective connection methods and components. The main substructure can be made of reinforced concrete as the frame structure, while the roof is made of steel structure. Welded steel is used for the intersection of roof beams and columns, and the free grid division technology is a part of the program unit divider. This technology is used to divide the grid, so that the density of the grid is determined by the actual shape of the calculation model. The material adopts the reinforced two-fold line model, and the strengthening stiffness is 1%~3% of the initial elastic modulus.

The design seismic capacity of a structure is usually less than its actual seismic capacity, which is called structural super strength and measured by super strength coefficient. In earthquake engineering, the overall super-strength coefficient of the structure is defined as the ratio of the actual seismic capacity of the structure to its design seismic force [10]:

$$\Omega = \frac{V_u}{V_d} \tag{1}$$

Where: Ω ——Super coefficient;

V_d ——Design seismic force of the structure;

V_u ——Ultimate strength of intact structure.

Butt weld forms a part of the cross section of the connected component, and its stress distribution is the same as the original basic situation of the weldment. The compressive strength of weld can be considered as the parent metal, but its tensile strength must be determined by calculation. According to the different stress conditions of the weld, the calculation formula of the weld is as follows:

$$\delta = \frac{N}{l_w t} \tag{2}$$

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Where: N ——Axial tension or pressure;

l_w ——Calculated length of weld; Take the actual length minus 10mm when arc striking plate is not used, and take the actual length when arc striking plate is used.

Shear of butt weld refers to the force passing through the centroid of weld and parallel to the length direction of weld, and its calculation formula is:

$$\tau = \frac{VS_w}{I_w t} \tag{3}$$

Where: V ——Shear force borne by weld;

I_w ——Calculate the inertia distance of the cross section to the neutral axis of the weld;

S_w ——Calculate the welding seam above the shear stress and calculate the area distance between the cross section and the neutralization axis.

The design of column foot connection will directly affect the safety and economy of steel structure. The bottom foundation of column foot is reinforced concrete structure and the upper part is steel structure. The damage of column foot will lead to the damage of the whole upper structure. Therefore, column foot is one of the key factors to determine the bearing capacity of the structure. A large number of steel structures have been destroyed due to the brittle failure of column foot joints. However, the stability of structures and members is also related to the connection stiffness of column foot joints, which has an important impact on the internal force and displacement of structures.

At present, there are two traditional calculation methods for the thickness of the sole plate of the rigid-connected column of light steel structure: one is based on the foundation reaction of concrete under the sole plate of the column and the supporting conditions of the bottom plate, and the other is calculated by checking the thickness of the bottom plate of the anchor bolt on the tension side, and the result is often that the latter is much larger than the former, resulting in a certain amount of waste.

The formula for calculating the effective area of anchor bolt in tension area is as follows:

$$A_e \geq \frac{M - N_a}{f_t^a x} \tag{4}$$

Where: A_e ——Effective area of anchor bolt in tension area;

M ——Bending moment at the bottom of the column when the anchor bolt bears the maximum bearing capacity;

N ——Axial force at the bottom of the column when the anchor bolt bears the maximum bearing capacity;

a ——The distance from the mandrel of column section to the resultant line of pressure in the compression area of column sole;

f_t^a ——Design value of tensile strength of anchor bolt;

x ——Distance from the axis of anchor bolt to the resultant force line of the compression zone on the bottom of column foot.

If the diameter of anchor bolt calculated by formula (4) is greater than 60mm, elastic deformation between anchor bolt and bottom plate should be considered.

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$$\begin{cases} \dfrac{\sigma_1}{\sigma_2} \geq \dfrac{\eta(l-y)}{y} \\ \dfrac{1}{2}\sigma_2 By = \sigma_1 A_e + n \\ \sigma_1 A_e\left(l - \dfrac{y}{3}\right) - M - Na \end{cases} \tag{5}$$

Where: σ_1 ——Stress of anchor bolt in tension zone;

σ_2 ——Maximum stress at the edge of compression zone of concrete foundation;

η ——The ratio of elastic modulus of steel and concrete;

l ——Distance from the axis of tension anchor bolt to the edge of maximum compressive stress of concrete foundation;

y ——Length of compression zone of concrete foundation or pile cap;

B ——Width of bottom plate.

The axial force acting on the skeleton bar at the boundary of composite wall can be calculated according to the following formula:

$$N = k_m \frac{M}{L} \tag{6}$$

Where: N ——Tension or pressure on the skeleton bar at the boundary of the wall;

M ——Bending moment generated by lateral load in the plane of the wall;

L ——The center distance of the square steel pipe of the boundary skeleton on both sides of the wall;

k_m ——Considering the adjustment coefficient of flange wall participating in the work;

In the cold-formed thin-walled steel residential structure system, because the emphasis is on the overall production of component walls, the walls are installed on site after they are in place, and the connection between vertical and horizontal walls is weak, and the participation of flange walls is limited.

In order to consider the inelastic deformation ability of the structure under the action of large earthquakes, the elastic seismic force is reduced by the structural reflection correction coefficient to obtain the design seismic force, so it is necessary to use the displacement amplification coefficient to amplify the elastic displacement of small earthquakes, so as to obtain the elastic-plastic displacement of the structure under the action of medium earthquakes and large earthquakes. The amplification factor of structural displacement is the ratio of the maximum displacement of the structure to the design displacement of the structure:

$$C_d = \frac{\Delta_{\max}}{\Delta_d} \tag{7}$$

Where: $\Delta_{\max}$ ——Maximum displacement of structure;

Δ_d ——Displacement corresponding to structural design earthquake force.

4. Computational analysis

In the test, when the wall has a considerable lateral deformation, the diagonal braces are tensioned to bear the force. Therefore, attention should be paid to properly straightening the diagonal braces before

ISSN 2706-655X Vol.5, Issue 10: 53-58, DOI: 10.25236/IJFET.2023.051009

installing the connection, and a pre-tightening device can be set up if necessary to ensure the effective bearing capacity of the diagonal braces. The lateral bearing capacity of each test wall is calculated by formula and compared with the test results (see Table 1). The adjustment coefficient is not considered. The value of material strength is obtained according to the test report of the materials used in the test.

Table 1: Comparison between calculated bearing capacity and experimental value of composite wall of specime

number	Lateral bearing capacity of brace	Lateral load-bearing capacity of cladding plate	Shear force borne by weld	experimental value
#102	30.18	0	30.783	33.82
#103	39.444	39.699	89.52	59.146
#104	32.34	74.22	121.113	81.111
#105	36.418	71.163	142.885	133.158
#106	24.292	46.151	66.732	64.825

It can be seen that due to the serious pressure concentration of the boundary skeleton bars and columns in some composite walls, the square steel tubes of the columns are buckled prematurely, which leads to the excessive deformation of the walls, and the test is suspended. In order to avoid excessive deformation caused by local buckling of the composite wall, the composite wall was strengthened locally, and the calculated results of lateral bearing capacity were in good agreement with the experimental values.

In this study, the static elastic-plastic analysis of the displacement control of the structure is carried out by using the inverted triangle lateral distributed load and the uniformly distributed lateral load, respectively. The development of plastic hinges in both loading modes occurs at both ends of the beam, and no plastic hinges are found at the end of the column, thus realizing the design of "strong column and weak beam". See Table 2 for the seismic performance coefficient under two kinds of loads.

Table 2: Seismic performance coefficient

Seismic performance coefficient	Inverted triangular load distribution	Uniform load distribution
Super strong structure	5.09	6.96
ductility factor	1.53	1.81
Ductility reduction factor	1.48	1.94
Reaction correction coefficient	7.74	10.23
Displacement amplification factor	5.31	8.99

The performance coefficient under uniformly distributed load is larger than that under inverted triangular load, the overall super-strength coefficient increases from 5.09 to 6.96, with an increase of 36.74%, the overall ductility coefficient increases from 1.53 to 1.81, with an increase of 18.3%, the ductility reduction coefficient increases from 1.48 to 1.94, with an increase of 31.08%, and the response correction coefficient increases from 7.74 to 10.23. It is increased by 32.17%, and the displacement amplification factor is increased from 5.31 to 8.99, an increase of 69.30%, which shows that the performance of the structure under uniformly distributed load is better than that under inverted triangular load distribution.

5. Conclusions

There is a complex and logical hierarchical relationship between the structural systems of steel buildings. At the connection level, this hierarchical relationship is reflected in the difference of component size and installation order. The purpose of connection is to realize hierarchical transformation, and it is also the key to realize the transformation of force from three-dimensional to two-dimensional and finally to one-dimensional components. The calculation and analysis of the full plasticity of the connection of the lateral force resisting members of the industrial steel structure support show that some composite walls are subjected to excessive deformation due to the serious pressure concentration of the boundary skeleton bars and columns in the compression foot area, resulting in premature buckling of the square steel tubes of the columns, and the test is suspended. In order to avoid excessive deformation caused by local buckling of the composite wall, the composite wall was strengthened locally, and the calculated results of lateral bearing capacity were in good agreement with the experimental values. The performance coefficient under uniformly distributed load is larger than that under inverted triangular load, and the overall super-strength coefficient is increased from 5.09 to 6.96, an increase of 36.74%,

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which shows that the performance of the structure under uniformly distributed load is better than that under inverted triangular load distribution.

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