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Research on Calculation Model of Lateral Stiffness of Opening Wallboard in Steel Frame

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ABSTRACT: As a non-load bearing component in the steel frame structure system, the wallboard has an important influence on the mechanical performance of the main structure. Due to the requirements of building functions, it is often necessary to make openings in the wallboard. However, the equivalent compression rod model, which is commonly used to simulate the stiffness of the wallboard, is not suitable for the wallboard with openings. Therefore, in order to accurately calculate the lateral stiffness of the wallboard with openings, this paper equivalently puts forward the equivalent wall frame model, which can provide a reference for the design of the opening walls.

KEYWORDS: Wallboard, Openings, Calculation model, Lateral stiffness.

I. INTRODUCTION

In the development of the prefabricated building housing system, the enclosure structure is an important component to meet the requirements of residential industrialization, and the impact of the enclosure structure on the prefabricated building is crucial. As the wallboard occupies the largest part of the outer protection system, it needs to withstand horizontal wind loads and earthquakes, therefore, sufficient lateral stiffness is required [1]. However, due to the practical needs of buildings, the wallboards often need to be opened, and the open wallboards may crack or even fall off under the action of earthquakes, resulting in secondary disasters. So the calculation model of the lateral stiffness of the opening wallboard is very important for the overall stress analysis of the structure.

II. RELATED WORK

Hofmeyer et al. [2] conducted experiments on infill wall frame models with different openings, and established finite element models for comparison. It is found that the infill wall can obviously improve the bearing capacity of the structure, but the existence of the hole will reduce the initial stiffness of the structure, and the existence of the hole will also affect the crack development form of the structure. Markulak et al. [3] developed a masonry infill wall with lower stiffness and strength. Low-cycle reciprocating load tests were carried out on four different types of steel frame infill walls and a bare steel frame. The frame filled with new blocks with high ductility and low initial stiffness, this block attenuates the effects of frame-wall interactions. Yu et al. [4] proposed the slotted infill wall steel frame structure, and conducted experiments and numerical analysis on it. The structure with vertical slots weakens the contribution of infill wall to the bearing capacity and stiffness of steel frame. The energy dissipation capacity of steel frame with slotted infilled wall is higher than that of pure frame. Hashemi et al. [5] conducted a quasi-static test study on three steel frame-concrete sandwich composite wallboards with different span-to-height ratios. The analysis results show that the initial stiffness, bearing capacity, ductility and energy dissipation capacity of the steel frame-concrete sandwich composite wallboard structure are significantly improved compared with the pure steel frame structure, and different span-to-height ratios also have a greater impact on the structural performance.

The above literatures mostly study the influence of the opening of the wallboard on the bearing capacity and stiffness of the steel structure system, but the calculation model of the lateral stiffness of the perforated wallboard has not been established. Therefore, it is necessary to study the mechanical model of lateral stiffness of steel frame wallboards with openings.

III. METHODOLOGY

In this paper, a computational model is proposed based on the equivalence principle of lateral stiffness. When the opening area is larger than the overall wallboard, it can be equivalent to a wall frame model with rigid domains at both ends, as shown in Figure 1. The difference between the wall frame and the general frame is that the beam-column node of the wall frame has a rigid domain. The influence of the shear deformation of the frame beam on the lateral displacement of the structure should be considered, and the thickness of the frame is the same as that of the wall. Since the force form of the wall frame is similar to that of the frame, the D-value method can also be used in the calculation. However, when the section height of the coupling beam and the wall pier is large, the direct calculation using the D-value method is quite different from the actual situation, and a large error will occur, so it is necessary to carry out relevant corrections.

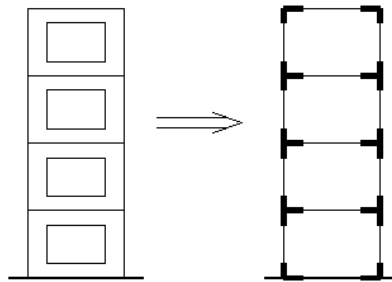


Fig.1.Equivalent wall frame model

The following is the calculation process of lateral stiffness of wall frame.

1. The length of the rigid domains

The calculation diagram of the wall frame is to linearize the wall, and use the center line of the coupling beam and the wall section as the beam-column axis of the frame. The rigid domain lengths of beams and columns are shown in Figures 2.

For beams,

$$d_{b1} = a_1 - 0.25h_b \quad (1)$$

$$d_{b2} = a_2 - 0.25h_b \quad (2)$$

For columns,

$$d_{c1} = c_1 - 0.25b_c \quad (3)$$

$$d_{c2} = c_2 - 0.25b_c \quad (4)$$

Take zero if the rigid domain length calculated by Equations 1-4 is less than zero.

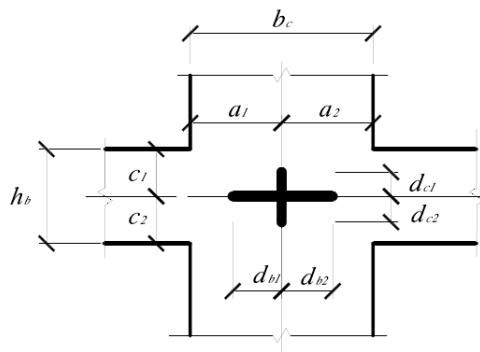


Fig.2.The length of the rigid domains

2. Displacement-force equation of rigid arm member

The relationship between the displacement and the force of the rod with rigid arms at both ends is different from that of the general rod. As shown in Figure 3, the length of the rod 1 – 2 is L , and the lengths of the rigid domains at the left and right ends are aL and bL , respectively.

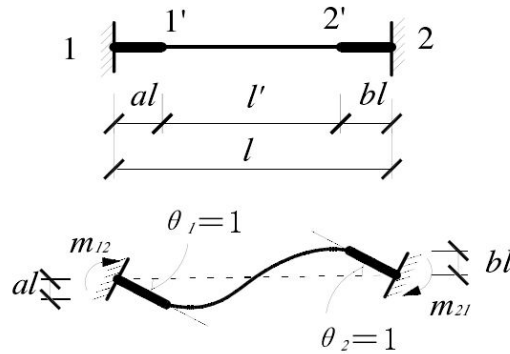


Fig.3.Deformation of beam with rigid arms

Take the middle part of the member 1'-2' as the research object. When the unit rotation angle is generated at rods 1 and 2 at both ends of the member, the unit rotation angle will also be generated at rods 1' and 2', and the linear displacements aL and bL will be generated respectively, so the relative shear displacements of rods 1' and 2' are aL plus bL . Because the height of the bar section of the wall frame is relatively large, the shear deformation of the bar section should be taken into account in the analysis. The rod end bending moment generated by rods 1' and 2' is

$$m_{1'2'} = m_{2'1'} = \frac{6EI_0}{l'^2} (al + bl) \frac{1}{1 + \frac{12\mu EI_0}{GA l'^2}} = \frac{6EI}{l'^2} (al + bl) \quad (5)$$

Where $\frac{EI_0}{1 + \frac{12\mu EI_0}{GA l'^2}} = EI$ is the equivalent stiffness considering the shear deformation of the rod section.

When the shear deformation of the rod section is not considered, $EI_0 = EI$.

The bending moment at the rod ends due to the unit rotation of rods 1' and 2' is

$$m_{1'2'} = m_{2'1'} = \frac{6EI_0}{l'} \frac{1}{1 + \frac{12\mu EI_0}{GA l'^2}} = \frac{6EI}{l'} \quad (6)$$

In the part without rigid arms, the bending moment of rods 1'-2' is the sum of equations 5 and 6, namely:

$$m_{1'2'} = m_{2'1'} = 6EI \left(\frac{al + bl}{l'^2} + \frac{1}{l'} \right) = 6EI \frac{1}{(1 - a - b)^2 l} \quad (7)$$

The shear force of 1' and 2' is

$$V_{1'2'} = V_{2'1'} = 12EI \frac{1}{(1 - a - b)^3 l^2} \quad (8)$$

Taking the rigid arm as a separate analysis object, it can be seen from the force balance equation that the internal force at the rod ends of rods 1 and 2 is

$$m_{12} = m_{1'2'} + V_{1'2'} al = 6EI \frac{1 + a - b}{(1 - a - b)^3 l} = 6ci \quad (9)$$

$$m_{21} = m_{2'1'} + V_{2'1'} bl = 6EI \frac{1 - a + b}{(1 - a - b)^3 l} = 6c'i \quad (10)$$

So the total bending moment is



$$m = m_{21} + m_{21}' = 12i \frac{c+c'}{2} \quad (11)$$

Where

$$c = \frac{1+a-b}{(1-a-b)^3} \quad (12)$$

$$c' = \frac{1-a+b}{(1-a-b)^3} \quad (13)$$

$$i = \frac{EI}{l} \quad (14)$$

If $k_{12} = ci, k_{21} = c'i$, then $m_{12} = 6k_{12}, m_{21} = 6k_{21}$. Compared with equation 2, the rod end bending moment that rod 1-2 with rigid zone and the rod 1'-2' without rigid zone have the same representations. The bending moments at the ends of rod 1'-2' without rigid zone needs to be multiplied by the corresponding coefficients C and C'.

3. Lateral stiffness of frame columns with rigid arms

The lateral stiffness of frame columns with rigid arms is D , the calculation process is shown in Table 1.

$$D = \partial \frac{12}{h^2} \frac{c+c'}{2} i_c \quad (15)$$

Where ∂ is the correction factor of column stiffness, i_c is the linear stiffness of column, h is the height of column.

Table. 1. Calculation of D value of wall frame

	Side column	Intermediate column	K	∂
General layer			Side column $K = \frac{K_2 + K_4}{2K_c}$ Intermediate column $K = \frac{K_1 + K_2 + K_3 + K_4}{2K_c}$	$\partial = \frac{K}{2+K}$
Bottom layer			Side column $K = \frac{K_2}{K_c}$ Intermediate column $K = \frac{K_1 + K_2}{K_c}$	$\partial = \frac{0.5+K}{2+K}$

According to the above derivation process, the beam-column internal force and the lateral stiffness of the wall frame can be obtained, i.e. the lateral stiffness of the perforated wallboard can be calculated.



IV. CONCLUSION

In this paper, the calculation method of lateral stiffness of opening wallboard in steel frame structure is studied. Based on the equivalent principle of lateral stiffness, an equivalent wall frame model suitable for opening wallboard is put forward. In this model, the cross sections of wall beams and columns are thin and long. The joint rigid domain and the shear deformation of member section should be considered in calculation. The location and size of the opening in the wallboard affect its own mechanical performance, failure pattern and the lateral stiffness of the steel frame structure, and the factors affecting the perforated wallboard will be further considered.

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