CALCULATION METHOD OF LATERAL STIFFNESS OF PVC CAVITY PARTITION WALL WITH DIFFERENT CONNECTION FORMS

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To explore the difference in seismic performance of walls with different connections, this paper designs a pseudo-static test of three groups of steel frames infilled with walls and a group of empty steel frame as a control. The test phenomena and the datum are used to evaluate the performance of structures. The results show that: (I) the initial stiffness and the peak load of the cast-in-place wall are large. The main failure modes are cracking at the joint between the wall and the frame, crushing at the corner, and internal splitting as well as curving outwards under large displacement. (II) The wall with L-shaped connectors dissipates energy by bolt slip and the yield deformation of connectors, which has the lowest contribution to the frame in stiffness and strength. The main failure is the cracking of cement mortar at the joint. (III) The connection mode of U-shaped and L-shaped connectors is relatively safe and reliable, which could make the steel frame and wall panel work better together under the action of earthquake. It could be recommended to use according to the bearing capacity requirements; Walls connected by reinforcement are not recommended because of brittleness failure, poor ductility, ordinary bearing capacity and energy dissipation capacity. Based on the principle of equivalent tension and compression bar, a simplified formula for calculating the lateral stiffness of polyvinyl chloride (PVC) cavity wall panel embedded in fabricated steel frame is proposed, and the accuracy of the calculation results is verified.

Keywords: Prefabricated steel frame, Cement mortar, Seismic performance, Formula of reduction.

1 INTRODUCTION

As an important partition and stress component in architecture, interior wall has attracted much attention from scholars at home and abroad. At present, the mainstream internal wall forms include aerated concrete block wall, autoclaved aerated concrete slab, light steel keel wall, etc. These walls have the characteristics of environmental protection, excellent sound insulation performance, but also have high construction requirements, slow speed, high cost. In recent years, Wenling (2021). Proposed foamed concrete composite wall with light steel keel with square steel tube as connecting parts, and pointed out through tests that steel mesh has better performance than high-strength cement pressure plate, and foamed concrete has obvious advantages in improving the overall ductility and bearing capacity of wall plate. Yao (2012) proposed a new type of concrete drywall system, which has higher strength and better sound insulation and anti-theft effect than ordinary walls.
The internal structure of PVC cavity partition wall is shown in Figure 1. Although the construction of PVC cavity partition wall is faster, less labor and lower cost than that of ordinary aerated concrete block wall, it is still mainly constructed on site, with many processes and wet operations, which affect its large-scale popularization. The PVC cavity partition wall for factory prefabrication, site assembly construction, will be the future mainstream development trend. However, there are few reports on the connection between precast PVC cavity partition wall and main structure. Therefore, this paper takes the connection mode as the parameter, carries out the pseudo-static test of the steel frame for installing PVC cavity partition board and deduces the relevant formula, which provides the basis for the subsequent popularization, application, and theoretical research of PVC cavity partition board.

![Figure 1. PVC cavity partition.](image)

### 2 SPECIMEN PROFILE

#### 2.1 Specimen Design

The three walls are designed with the width, height and thickness of 2170mm, 2505mm and 100mm respectively. Where SJ1 is a steel frame with beam and column joints hinged and column pin connected, and SJ2, SJ3 and SJ4 are installed with PVC cavity partition walls of different connection forms on the basis of SJ1. The facade of steel frame and wall panel structure is shown in Figure 2.

![Figure 2. Frame plan.](image)
2.2 Material Properties

The mean compressive strength of mortar cube is 18.00N /mm², and the mean elastic modulus is 1.22MPa. The mechanical properties of steel are shown in Table1.

Table 1. Mechanical properties of steel.

<table>
<thead>
<tr>
<th>Material property</th>
<th>Beam flange, web</th>
<th>Column flange, web</th>
<th>Beam and column stiffeners, end plates</th>
<th>Column bottom ear plate</th>
<th>L-shaped connection</th>
<th>Hitch reinforcement</th>
<th>Reinforcement connection</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yield strength (MPa)</td>
<td>266.05</td>
<td>300.90</td>
<td>353.60</td>
<td>304.02</td>
<td>299.31</td>
<td>443.21</td>
<td>457.34</td>
</tr>
<tr>
<td>Ultimate strength (MPa)</td>
<td>428.20</td>
<td>487.35</td>
<td>519.93</td>
<td>448.71</td>
<td>411.72</td>
<td>561.02</td>
<td>616.46</td>
</tr>
<tr>
<td>Elongation (%)</td>
<td>28.00</td>
<td>32.05</td>
<td>28.73</td>
<td>38.20</td>
<td>28.41</td>
<td>28.20</td>
<td>28.31</td>
</tr>
</tbody>
</table>

3 TESTING PROGRAM

3.1 Loading Method

In this test, MTS hydraulic servo control system is used for pseudo-static loading, and displacement control loading scheme is adopted.

4 ANALYSIS OF TEST RESULTS

4.1 Experimental Phenomenon

![Figure 3. SJ2 failure.](image)

![Figure 4. SJ3 failure.](image)

![Figure 5. SJ4 failure.](image)

SJ1 deforms harmoniously at the initial loading stage of the test, and the frame has no out-of-plane deformation and maintains in-plane stability. SJ2 showed no obvious out-of-plane deformation at the initial stage of test loading. When the displacement angle between layers is
4%, the PVC hollow inner wall panel has completely separated from the upper and lower keels. The final failure phenomenon is shown in Figure 3.

When SJ3 is loaded to 0.75% of the displacement angle between layers, the first 1mm wide crack appears in the inner wire sleeve at the lower left corner of the wall. The displacement angle between layers is 2%, the test is stopped. After disassembly, it is found that the bending part of the upper L-shaped connector has damage and deformation. The failure is shown in Figure 4.

At the initial stage of SJ4 loading, the specimen deformation is small. When the displacement angle between loading layers is 0.375%, a wide gap of 0.1mm is formed between the wall and the contact surface of the horizontal steel plate of the lower connector. Finally, a 0.3mm wide crack is formed between the reinforcement connector and the upper wall, as shown in Figure 5.

### 4.2 Hysteresis Curve

In order to further study the hysteretic performance of PVC cavity partition wall, the overall hysteretic curves SJ2, SJ3 and SJ4 of each specimen are subtracted from the pure frame SJ1 respectively, and the corresponding hysteretic curves of the corresponding walls are obtained, as shown in Figure 6. SJ2 has the largest residual deformation, and its hysteretic curve is between S-type and Z-type. The hysteretic curve of failure stage is full and the energy dissipation capacity is optimal. Due to reinforcement fracture, the bearing capacity decreases significantly under negative loading, SJ4 hysteretic curve keeps S shape.

![Figure 6. Hysteretic curve of specimen.](image)

### 5 SIMPLIFIED CALCULATION METHOD FOR LATERAL STIFFNESS

Based on the principle of equivalent baroclinic bar, this paper makes a simplified calculation of the anti-side stiffness of the structure installed with partition plate. Taking SJ3 as the research object and referring to the relevant studies of Xie (2021) Yang (2017) and Qiao (2020), a simplified calculation formula for the lateral stiffness of PVC cavity partition wall-steel frame was proposed.

#### 5.1 Lateral Stiffness of PVC Cavity Partition Wall

The PVC cavity partition wall can be identified that the steel column and the upper and lower steel beam are hinged, and it is equivalent to the diagonal bar with the stiffness of $EA$, ignoring the axial deformation of the wall. The simplified model is shown in Figure 7, and the calculation diagram is shown in Figure 8.
It is stipulated that the bending moment is positive clockwise, and the shear force is positive in the same direction as \( P \). The derivation process of the formula is as shown in Eq. (1-6):

Hooke's law:

\[
\delta = \Delta \cos \alpha = \frac{N_{AD} L_{AD}}{EA} \quad (1)
\]

\[
L_{AD} = \sqrt{L^2 + H^2} \quad (2)
\]

\[
\cos \alpha = \frac{L}{\sqrt{L^2 + H^2}} \quad (3)
\]

where, \( \delta \) is the deformation of the equivalent pressure bar; \( \Delta \) is the lateral shift at the top of the wall; \( \alpha \) is the included angle between the equivalent pressure bar and the lower beam; \( N_{AD} \) is the axial force of \( AD \) rod; \( L_{AD} \) is the length of the \( AD \) rod; \( E \) is the elastic modulus of the equivalent pressure bar; \( A \) is the cross-sectional area of the equivalent pressure bar; \( L \) is the distance between steel columns; \( H \) is the wall height.

Substitute equation (2) and (3) into equation (1):

\[
N_{AD} = \frac{\Delta L E A}{L^2 + H^2} \quad (4)
\]

Static balance analysis was carried out on the upper part of the simplified model of PVC cavity partition wall.

\[
P - N_{AD}\cos \alpha = 0 \quad (5)
\]

To sum up, the steel frame adopts L-shaped connectors to install the side stiffness of PVC cavity partition wall:

\[
K = \frac{L^2 E A}{(L^2 + H^2)^{\frac{3}{2}}} \quad (6)
\]

In order to calculate the stiffness of U-section steel keel connection forms and reinforcement connection forms, stiffness adjustment coefficients \( \eta \) were introduced, and the adjustment values of SJ2, SJ3 and SJ4 were calculated as 11.13, 1.00 and 4.67 respectively based on the existing test data. Finally, the simplified calculation formula for the lateral stiffness of PVC cavity partition wall was obtained in Eq. (7).
\[ K = \frac{\eta L^2 EA}{(L^2 + H^2)^{1.5}} \]  

(7)

### 5.2 Comparison of Results

The comparison between the lateral stiffness of the wall plate calculated according to Eq. (7) and the test results is shown in Table 2. As can be seen from Table 2, the average error between the calculated results of the theoretical formula and the experimental results is 8%.

<table>
<thead>
<tr>
<th>number</th>
<th>Actual measured value(K)(kN/mm)</th>
<th>Calculated value(K)(kN/mm)</th>
<th>Actual measured value/Calculated value</th>
</tr>
</thead>
<tbody>
<tr>
<td>SJ2 positive</td>
<td>8.75</td>
<td>8.74</td>
<td>1.04</td>
</tr>
<tr>
<td>SJ2 negative</td>
<td>8.03</td>
<td>8.74</td>
<td>1.04</td>
</tr>
<tr>
<td>SJ3 positive</td>
<td>0.74</td>
<td>0.79</td>
<td>1.07</td>
</tr>
<tr>
<td>SJ3 negative</td>
<td>0.75</td>
<td>0.79</td>
<td>1.07</td>
</tr>
<tr>
<td>SJ4 positive</td>
<td>4.50</td>
<td>3.69</td>
<td>0.87</td>
</tr>
<tr>
<td>SJ4 negative</td>
<td>4.02</td>
<td>3.69</td>
<td>0.87</td>
</tr>
</tbody>
</table>

### 6 CONCLUSION

In this paper, pseudo-static tests are carried out on PVC cavity partition wall and steel frame with different connection modes, and the lateral stiffness of the wall is simplified. The main conclusions are as follows:

- The overall PVC cavity partition wall of the steel keel connecting specimen was cracked at the joint and crushed at the corner; the cement mortar cracking at the joint of the wall panel with L-shaped steel connectors; the wall plate connected by reinforcement will fracture under small displacement, making the wall and the frame lose connection.
- The connection mode of U-shaped and L-shaped connectors is relatively safe and reliable, which can make the steel frame and wall panel work together better under the earthquake action. Can be recommended according to the bearing capacity demand.
- Based on the principle of equivalent baroclinic bar, a simplified formula for calculating the lateral stiffness of steel frames with PVC cavity partition walls is proposed in this paper. The calculated results are basically consistent with the experimental results.

### References


