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Finite Element Study on Bearing Capacities of Hook-Bolt Joint of Assembled GRC Wall with Light Steel Skeleton Frame

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Abstract. A new assembled external wall is composed of two glass fiber reinforced concrete (GRC) panels and built-in light steel skeleton frames and a layer of filled insulated core materials. To connect this new wall to the main steel structure, the new hook-bolt joint is used. The finite element (FE) software ABAQUS was used to study the bearing capacities of hook-bolt joint under horizontal force and vertical force. The FE results show that under horizontal and vertical force, the hook-bolt joint shows good elastic-plastic behaviour. In the initial stage of displacement loading, there is slip displacement stage and the load is very small. After this initial stage, with the gradual increase of displacement, the load increases gradually. Larger stresses are mainly distributed at the intersection of the hook-shaped connector and the U-shaped connector. The vertical bearing capacity of the hook-bolt joint is about two times larger than that of horizontal one. These studies can provide referential basis for the design and application of the hook-bolt joint of the assembled wall with light steel skeleton frame.

1. Introduction

Precast concrete walls can be prefabricated in the factory and assembled on site rapidly. The wall panels are either out-hung or in-filled connected to the main body steel frames. A new assembled external wall is composed of two glass fiber reinforced concrete (GRC) panels and a built-in light steel skeleton frame and a layer of filled insulated core materials such as foam concrete, rock wool and glass wool and so on, as shown in Figure 1 and Figure 2. This new wall has the advantages of quick installation, heat insulation, cracking resistance, fire resistance and so on.



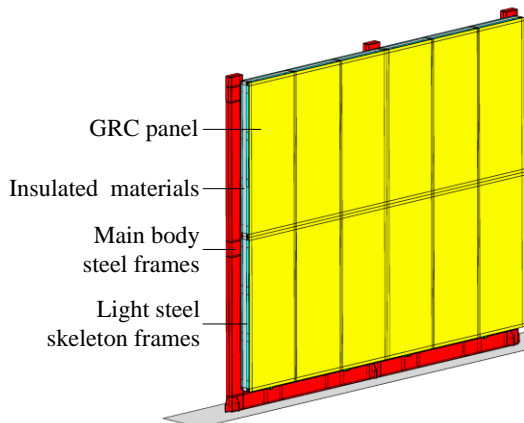


Figure 1. Assembled GRC external wall.

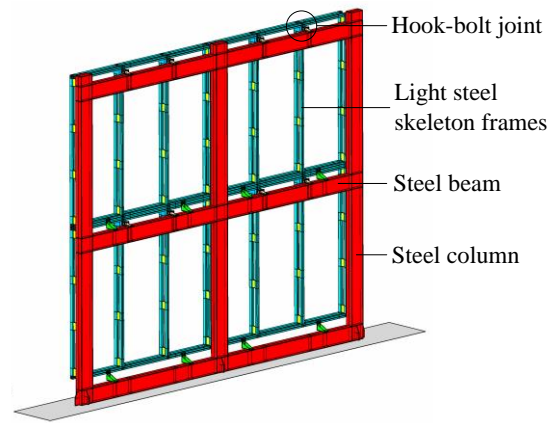


Figure 2. Main body steel frame and light steel skeleton frames.

To connect this new external wall to the main steel structure, the new hook-bolt joints made of steel are used. As shown in Figure 3 and Figure 4, the hook-bolt joint consists of hook-shaped connector, U-shaped connector, L-shaped connector, bolts and gaskets. The triangular connector is firstly fixed to the steel beam of main steel frame by bolts and gaskets. Then the U-shaped connector is fixed to the L-shaped connector by bolts and gaskets. In order to make the installation and positioning of bolt be more convenient, the U-shaped connector and L-shaped connector have long round bolt holes. One end of hook-shaped connector is fixed to light steel skeleton frame by bolts and the other end of hook-shaped connector hooks on the U-shaped connector. The hook-shaped connector can slip horizontally relative to U-shaped connector.

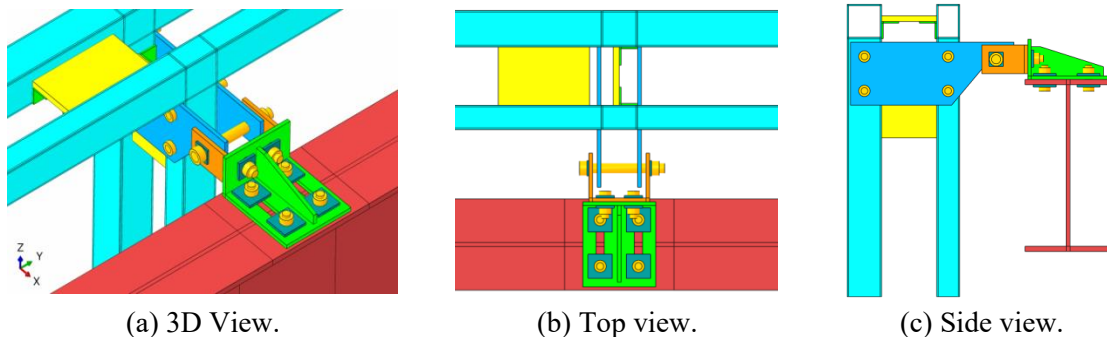
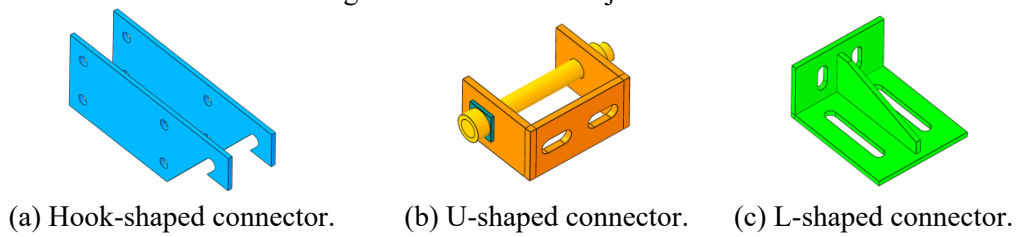
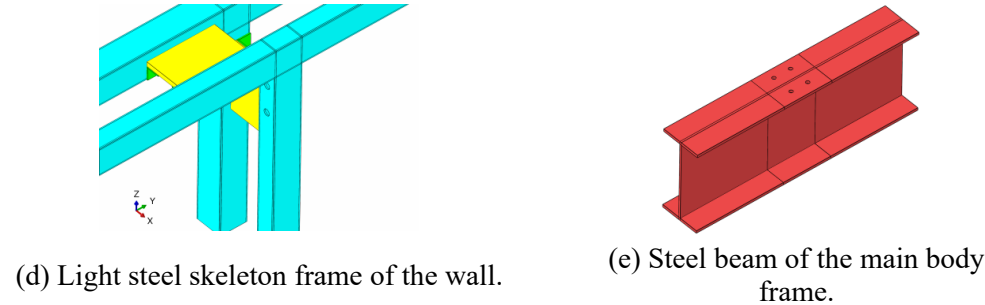


Figure 3. The hook-bolt joint.



(a) Hook-shaped connector. (b) U-shaped connector. (c) L-shaped connector.



(d) Light steel skeleton frame of the wall. (e) Steel beam of the main body frame.

Figure 4. Assembled parts of the hook-bolt joint.

As a key force transmission joint, its mechanical properties are very important for wall systems in the building. Under the self-weight or earthquake action, the wall and the main structure will be relatively deformed and it causes the force between the two. The mechanical properties of the hook-bolt joint determine whether the wall can avoid being damaged or detached, which can cause significant economic losses and casualties.

For different type of walls, the corresponding joints have different mechanical properties and failure modes. The various research works in the related field are described as follows. Tian and Chen [1] studied the autoclaved lightweight concrete (ALC) spliced-connection wallboard system which links steel frame with hooked bolt connection method is composed of finished product boards with mortar cementing the seam by full-scale tests. Contact finite element (FE) method analysis with normal penalty stiffness factor simulating spliced-connection interface was performed. Li and Wang [2] studied the hysteretic behaviour of steel frames with ALC out-hung and in-filled walls by test. The test prove that the connections between ALC wall panels and steel frames behave very well and ALC in-filled wall panels can play an important role in the mutual work of in-filled walls and steel frames. Hou and Qiu et al. [3] studied the hysteretic behaviour of steel frames filled with sandwich composite panels by low cyclic loading tests. Test results show that the success of connection between panel and steel frame is especially important to guarantee the mutual work of the two parts. Hou and Zhou et al. [4] studied on seismic test of connections of steel frames and sandwich composite panels and investigated the failure modes and force mechanisms of the connections. The results show that the connections have sufficient bearing capacity and provide effective connection to the steel frames and panels. Zha and Tang [5] studied on the tensile bearing capacity of self-drilling screw (SDS) joints furnished with C-saddle washers and M-saddle washers for sandwich insulated panels were studied by test and FE method with ANSYS/LS-DYNA software. Based on mechanical analysis, a new theoretically computational formula for tensile bearing capacity of SDS joints is proposed. Zhao and Chen et al. [6] used the finite element simulation program ANSYS to study the hysteretic behavior analysis of Steel frame structure with ALC walls. The results show that the two modes of connection between ALC panels and steel frames work quite well and the in-filled ALC wall panels can play an important role in the interaction between walls and steel frames. Guo and Sun [7] studied the seismic performance of flexible steel frame with recycled concrete external wall by test under low cyclic load. The results show that the external wall can increase the bearing capacity of the structure. The flexible steel frame with recycled concrete external wall has good ductility. Xu and Wang et al. [8] studied the mechanical performance of prefabricated external wall panel under lateral displacement by experiment and FE method. It is found that with the gradual increase in tangential contact stiffness of joint interfaces, the overall lateral stiffness of wall panels will approach complete joint consolidation conditions before the peak load.

Although some studies have been done on other different types of joints, few researches were done on this new hook-bolt joint at present. In this paper, the bearing capacities of the new hook-bolt joint under horizontal force and vertical force are studied by FE method. The results of these studies can provide referential basis for the design and application of the hook-bolt joint of the assembled wall with light steel skeleton frame.

2. Finite Element Method

The geometric sizes and materials of the hook-bolt joint were determined by the actual sizes and materials in the actual engineering project. The model had been simplified as necessary. In the light steel skeleton frame, the geometric sizes of cross sections of rectangular steel pipes are 60mm×60mm×2.5mm and 60mm×40mm×2.5mm. The geometric size of cross sections of H-shaped steel beam is 300mm×150mm×6.5mm. The length of square steel pipes and H-shaped steel beam is 840mm. The geometric size of angle steel is 150mm×30mm×3mm. The geometric size of bakelite is 150mm×96mm×10mm. The bolt type between hook-shaped connector and U-shaped connector is M16 and the other bolt type is M14. The detailed geometric sizes of the assembled parts of the hook-bolt joint are shown in the Figure 5.

The FE model of hook-bolt joint of assembled wall with light steel skeleton frame was built with the ABAQUS software. In the FE model, all components were modeled with solid elements of type C3D8R. In order to get more accurate results, the finite element meshes of the assembled parts of joint were refined. The FE model of hook-bolt joint of assembled wall with light steel skeleton frame is shown in Figure 6.

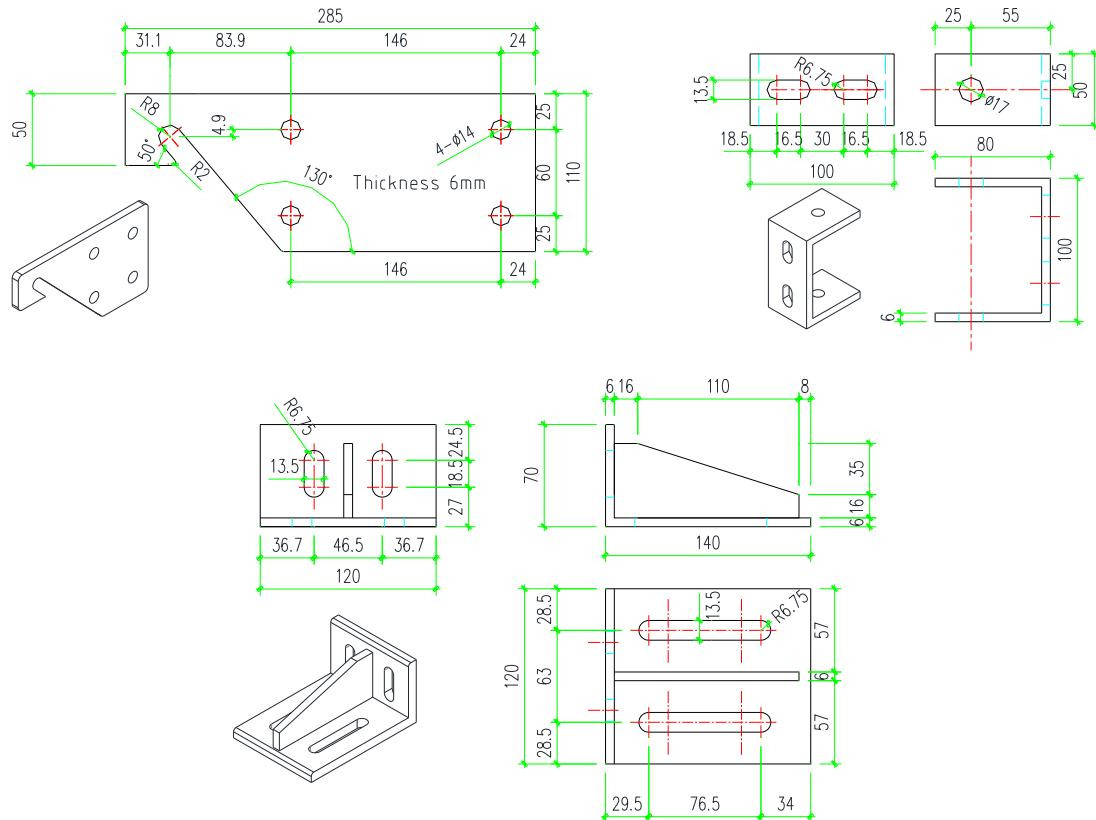


Figure 5. The detailed geometric sizes of the hook-bolt joint.

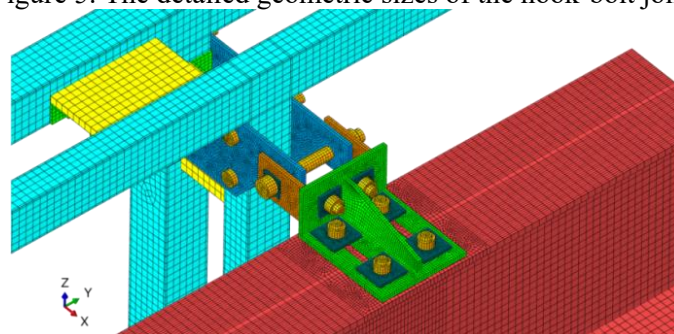


Figure 6. The FE model of hook-bolt joint of assembled wall with light steel skeleton frame.

The all parts of the hook-bolt joint were assumed to be isotropic linear elastic-plastic material. The steel type of H-shaped steel beam is Q345. Another steel type of the light steel skeleton frame and hook-bolt joint is Q235. The material properties of Q345 and Q235 refer as *the Standard for Design of Steel Structures* [9]. The material properties of both steels used for FE analysis are shown in Table 1.

Table 1. Material properties in FE model.

| Type | Density (kg/m ³) | Yield Strength (MPa) | Elastic Modulus (MPa) | Poisson's ratio |
|------|------------------------------|----------------------|-----------------------|-----------------|
| Q235 | 7850 | 235 | 2.06×10 ⁵ | 0.30 |
| Q345 | 7850 | 345 | 2.06×10 ⁵ | 0.30 |

| | | | | |
|----------|------|-----|--------------------|------|
| Bakelite | 1200 | 182 | 1.29×10^4 | 0.36 |
|----------|------|-----|--------------------|------|

It has been assumed that the rectangular steel pipes in the light steel skeleton frame are perfectly welded together. So the nodes of elements at the interfaces were meshed to keep compatible and coincident with each other in FE analysis, which just was the same as welding. The constrained type of the interaction among bakelite, angle steel and rectangular steel pipes was set to “tie contact”, and the interfaces have no slippage occurs relative to each other. The constrained type of the other interaction among light steel skeleton frame, hook-shaped connector, U-shaped connector, L-shaped connector, steel bolts, gaskets and steel beam was set to “general contact”. The tangential behaviour used penalty function with friction coefficient 0.3 and the normal behaviour used hard contact.

Each end of rectangular steel pipes and H-shaped steel was coupled by a reference point. The DOFs (degrees of freedom) of the reference point were constrained. To make steel pipe slide horizontally, only the horizontal DOF of rectangular steel pipes were released and the horizontal displacement loads were applied to the reference point at one end of horizontal pipes, as shown in Figure 7. Considering the complex nonlinearity of analysis, the nonlinear explicit dynamic analysis of FE software ABAQUS, which replaced general nonlinear implicit static analysis method, was used to simulate the mechanical behaviour under earthquake action.

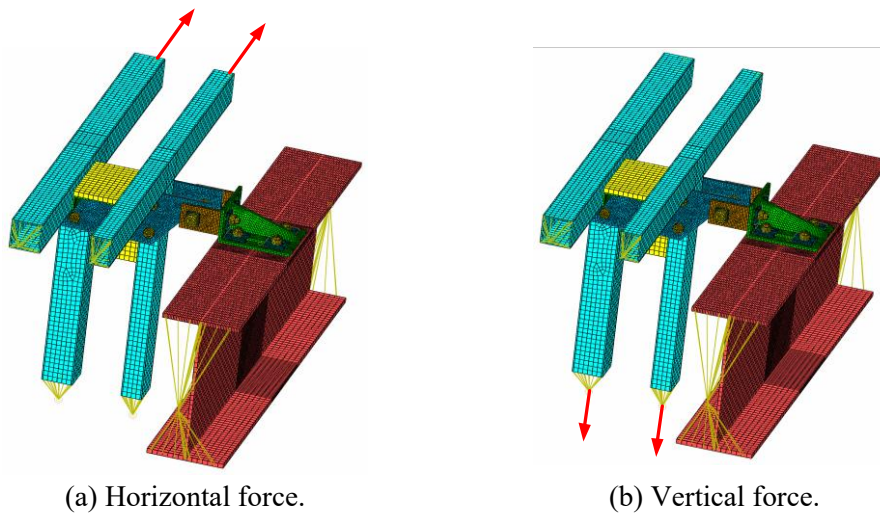
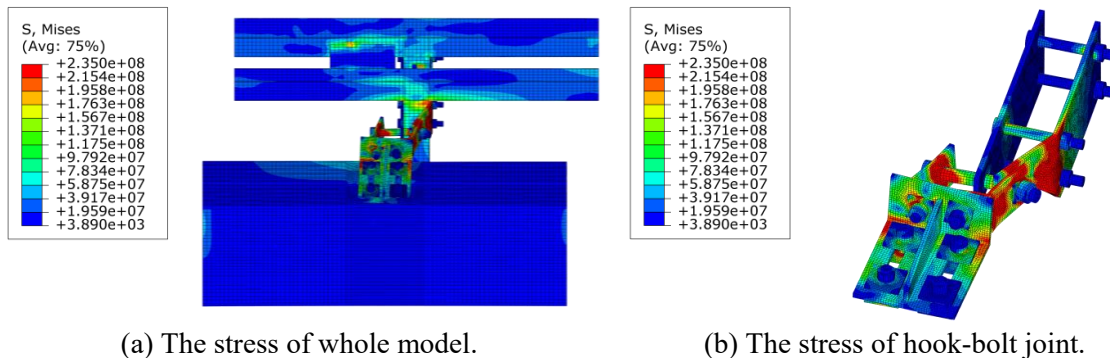


Figure 7. Applied load conditions.

3. Results and Discussion

3.1. Horizontal force action

Under horizontal force, the stress distribution of this joint by FE analysis is shown in Figure 8 respectively. As the horizontal displacement increases, one of the hook-shaped connector touches the U-shaped connector and its stress increases rapidly to yield stress. But the stress of the other hook-shaped connector is very small. The whole loading process undergoes large elastic-plastic deformation.



(a) The stress of whole model.

(b) The stress of hook-bolt joint.

Figure 8. Stresses distribution of the hook-bolt joint under horizontal force.

The load-displacement curve composed of applied horizontal loads and relative deformation was shown in Figure 9. The energy curves of internal energy and the kinetic energy were shown in Figure 10. As shown in Figure 9, during initial stage, before the horizontal displacement reached to 16mm, the horizontal loads are very small, which are close to 0kN. This is because there is a slip distance between the hook-shaped connector and U-shaped connector. Besides, there is a slip distance between the bolts and the long round bolt holes in U-shaped connector and L-shaped connector. When the external horizontal load is greater than the internal friction, the joint can produce relative deformation. After that, with the gradual increase of displacement, the load increases gradually. When the displacement increases to 73.85mm, the load increases to the peak load 10.96kN. Subsequently, with the increase of displacement, the load decreases and has an obvious downward trend. So the peak load 10.96kN can be considered to be the ultimate horizontal load capacity of hook-bolt joint. Throughout the loading process, the joint shows good elastic-plastic behaviour. This means that the joint has good seismic performance.

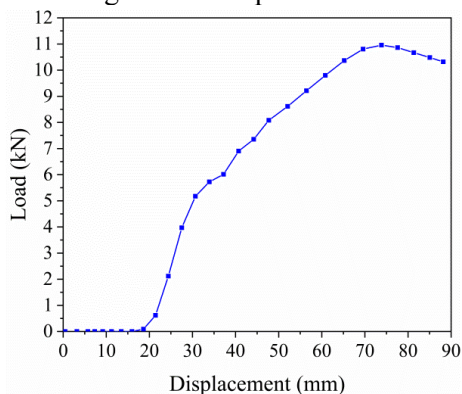


Figure 9. Load-displacement curve under horizontal force.

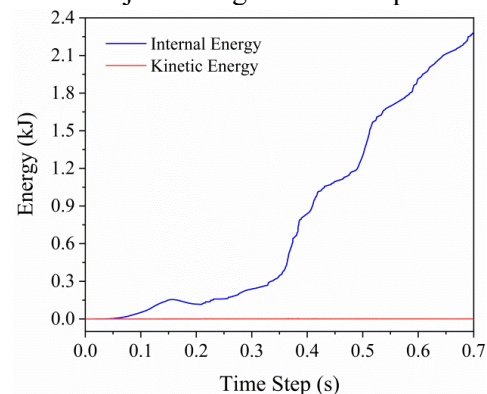
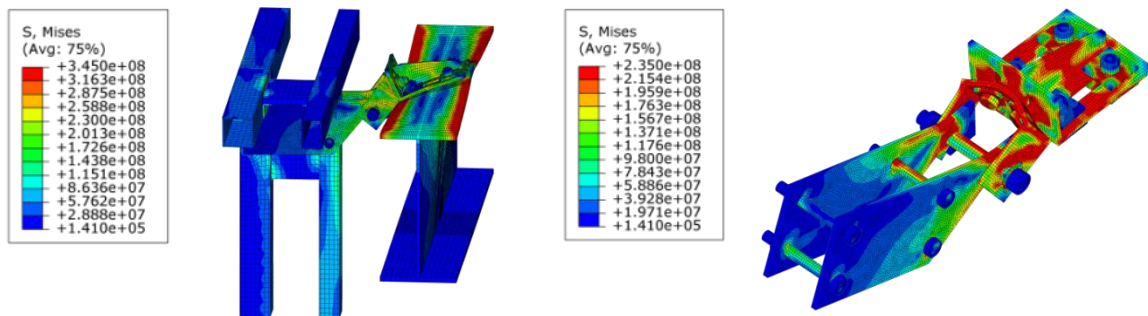


Figure 10. Energy curve under horizontal force.

3.2. Vertical force action

Under vertical force, the stress distribution of the hook-bolt joint by FE analysis is shown in Figure 11 respectively. As the vertical displacement increases, the hook-shaped connector forces the U-shaped connector to deform downward. The whole loading process undergoes large vertical elastic-plastic deformation and the stress yielding.



(a) The stress of whole model.

(b) The stress of hook-bolt joint.

Figure 11. Stresses distribution under vertical force.

Under vertical force, the load-displacement curve composed of applied vertical loads and relative deformation was shown in Figure 12. The energy curves of internal energy and the kinetic energy were shown in Figure 13.

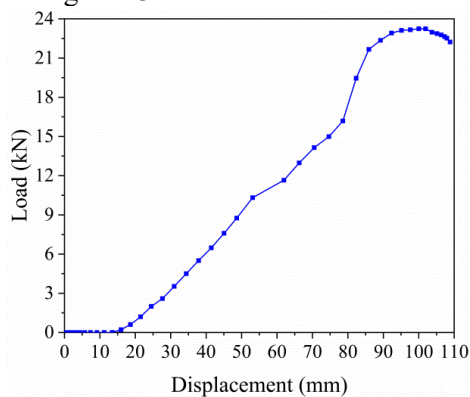


Figure 12. Load-displacement curve under vertical force.

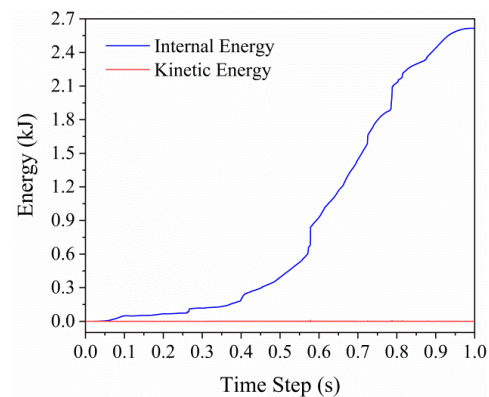


Figure 13. Energy curve under vertical force.

As shown in Figure 12, during initial stage, before the vertical displacement reached to 15mm, the vertical loads are very small, which are close to 0kN. This is because there is a slip distance between the bolts and the long round bolt holes of the U-shaped connector and L-shaped connector. When the external vertical load is greater than the internal friction, the joint can produce relative displacement. In the initial stage of displacement loading, there is slip displacement stage and the load is very small. After this initial stage, with the gradual increase of displacement, the load increases gradually. When the displacement increases to 100.01mm, the load increases to the peak load 23.24kN. Subsequently, with the increase of displacement, the load decreases and has an obvious downward trend. So the ultimate horizontal load capacity of hook-bolt joint is the peak load 23.24kN, which means that the vertical bearing capacity of the hook-bolt joint is about two times larger than that of transverse one. Throughout the vertical loading process, the joint shows good elastic-plastic behaviour. This also means that the joint has good seismic performances.

As shown in Figure 10 and Figure 13, with the increase of time step, the internal energy increases. The internal energy is much greater than the kinetic energy, so kinetic energy can be ignored, which means that in this study the FE nonlinear analysis method used dynamic analysis method to replaced static analysis method is successful and the analysis results are reliable.

4. Conclusions

This paper mainly studied the bearing capacities of the new hook-bolt joint of the assembled wall with light steel skeleton frame. The main conclusions are as follows.

(1) Under horizontal and vertical force, the hook-bolt joint shows good elastic-plastic behaviour, and this is beneficial for the wall to the seismic resistance.

(2) In the initial stage of displacement loading, there is slip displacement stage and the load is very small. After this initial stage, with the gradual increase of displacement, the load increases gradually.

(3) Larger stresses are mainly distributed at the intersection of the hook-shaped connector and the U-shaped connector.

(4) The vertical bearing capacity of this joint is about two times larger than that of horizontal one.

Acknowledgments

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