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Finite Element Study on Shear Performances of In-filled Bolt Joint of Assembled GRC Wall with Light Steel Skeleton Frame

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Abstract. A new in-filled wall is used in assembled steel structure buildings, which consists of two layers of glass fiber reinforced concrete (GRC) panels and a built-in light steel skeleton frame. To make this new wall fill in the main steel structure, a new in-filled bolt joint is used. In order to obtain the mechanical properties and failure modes under shear load, the shear performances of this joint were studied with the finite element (FE) software ABAQUS. The results show that before reaching the fracture failure strain, the in-filled bolt joint shows good elastic-plastic behaviour. When the strain of the in-filled bolt joint reaches the failure strain, the shear load reaches the peak value. Subsequently, due to the shear fracture of the bolt, the shear load drops rapidly. Throughout the loading process, the stress of steel beam and rectangular steel tube is always very small and the stress of the joint yields in a large area in the later stage.

1. Introduction

In recent years, with the development of assembled architecture, different types of assembled wall are applied in construction projects. The assembled wall, which is also known as precast concrete wall, can be prefabricated in plant and assembled on site rapidly. The assembled wall has two methods for connecting to the main body steel frames, including out-hung method and in-filled method. As shown in Figure 1 and Figure 2, a new assembled wall consists of two layers of glass fiber reinforced concrete (GRC) panels and a built-in light steel skeleton frame, which are connected with self-tapping screws. In order to keep the wall insulated and saving energy, a layer of insulated core materials such as foam concrete, rock wool and glass wool and so on always be filled between two layers of GRC panels. This new wall has lots of advantages such as rapid installation, good thermal insulation, anti-cracking, fire resisting performance and so on.



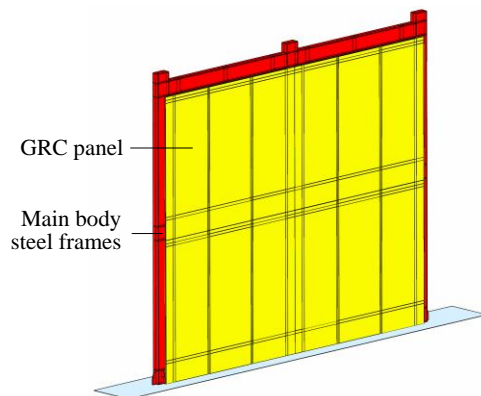


Figure 1. Assembled GRC wall.

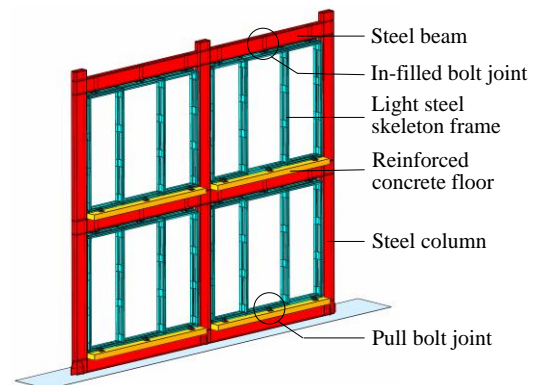


Figure 2. Main body steel frame and light steel skeleton frame.

This new wall is placed on the reinforced concrete floor and the wall is filled in the main body steel frame. At the top of the wall, the wall is fixed to the main body steel frame by a new in-filled bolt joint which play an important role in fixing and pulling the wall and preventing the wall collapse. At the bottom of the wall, the wall is fixed by the pull bolt joint which only plays a role in pulling the wall in the vertical direction of the wall.

As shown in Figure 3, to fix this new wall to the main steel structure, a new in-filled bolt joint made of steel are used. As shown from Figure 4 to Figure 7, the in-filled bolt joint consists of lower and upper L-shaped angle steel, bolt and gaskets. The upper L-shaped angle steel is welded on the steel beam of main steel frame. The lower L-shaped angle steel is welded on the rectangular steel tube of the light steel skeleton frame of the wall. In order to make the installation and positioning of bolt be more convenient, the upper L-shaped angle steel have bigger long round bolt holes than that of the lower L-shaped angle steel. The bolt is fastened through the lower and upper L-shaped angle steel with gaskets. Finally, this new external wall is fixed to the main steel structure by the in-filled bolt joint.

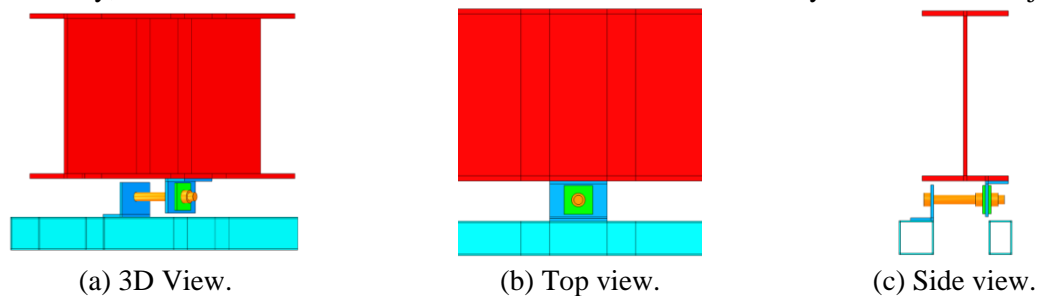


Figure 3. The in-filled bolt joint in assembled GRC wall.

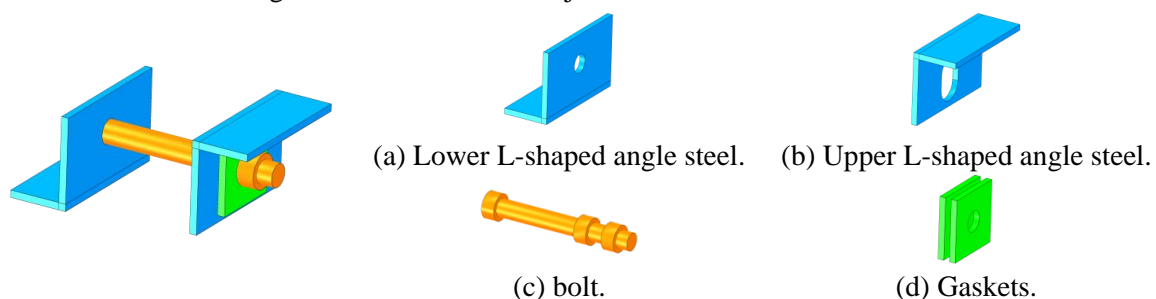


Figure 4. In-filled bolt joint.

Figure 5. Assembled parts of the in-filled bolt joint.

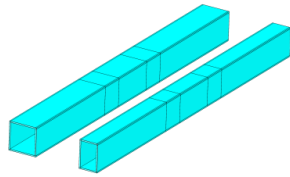


Figure 6. Rectangular steel tube of the light steel skeleton frame.

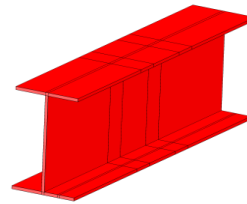


Figure 7. Steel beam of the main body frame.

As a key force transfer joint, the mechanical performances of the in-filled bolt joint is very important for the wall subjected to the load. Under the horizontal earthquake or wind action, the inconsistency of deformation between the wall and the main body steel frame will lead to relative deformation and force between them. Especially under strong earthquake or strong wind action, the in-filled bolt joint can play an important role in fixing and supporting the wall and preventing it being serious damaged or collapsed.

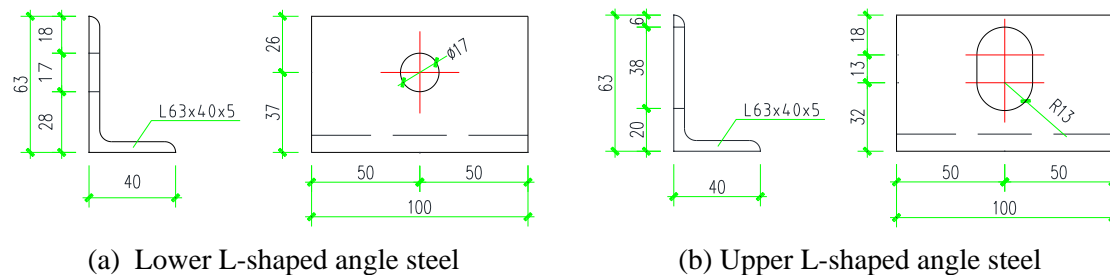
For different types of walls, the mechanical performances and failure modes of the corresponding joints are different. In the past, there have been some related studies on different types of joints. Li and Wang [1] studied the hysteretic behaviour of steel frames with the autoclaved lightweight concrete (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. Tian and Chen [2] studied lateral shearing behavior of the autoclaved lightweight concrete (ALC) spliced-connection wallboard system which links steel frame with hooked bolt connection by experimental research and finite element (FE) method. Zhao and Chen et al. [3] studied hysteretic behavior analysis of steel frame structure with ALC walls by the FE program ANSYS. 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. Hou and Qiu et al. [4] studied on steel frames with energy-saving sandwich composite panels by low cyclic tests. The 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. [5] studied connections of steel frames and sandwich composite panels and investigated the failure modes and force mechanisms of the connections by seismic test. Zha and Tang [6] studied the tensile bearing capacity of self-drilling screw joints for sandwich insulated panels by test and FE method with software ANSYS/LS-DYNA. Zhou and Li et al. [7] studied on seismic behavior of flexible connection masonry infilled frame structure by the low-cyclic reversed loading test. The results show that flexible connection specimens have lower bearing capacity than rigid connection specimens, but the other performance indexes are better. As a result, flexible connection scheme can improve the seismic performance of infilled frame structure. Guo and Sun [8] 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. Liao and Li et al.[9] studied the seismic performance of RC frames filled with shale hollow bricks and lightweight wallboards by tests. The study shows that the co-work ability of lightweight wallboards and frames is better than hollow bricks. The L shaped connector can play a certain role in restraining the deflection of lightweight wallboards.

For other different types of joints in wall, there have been some studies on their mechanical properties. However, for this new type of in-filled bolt joint, there are few researches on its mechanical properties at present. Although there have been some studies on other different types of joints in the past, there is a lack of study on mechanical performances of this new in-filled bolt joint at present. So this paper studies on the shear performances of this new joint under shear load by FE method. The results can provide related reference for the design and application of this new in-filled bolt joint of the assembled GRC wall with light steel skeleton frame.

2. Finite Element Method

2.1 Geometric sizes

The geometric actual sizes and materials of this joint, which were used in the actual engineering project, were used in this FE analysis. The detailed geometric sizes of the lower and the upper L-shaped angle steel of the in-filled bolt joint are shown in the Figure 8.



(a) Lower L-shaped angle steel (b) Upper L-shaped angle steel
Figure 8. The detailed geometric sizes of the lower and the upper L-shaped angle steel of the in-filled bolt joint.

The cross section geometric sizes of rectangular steel pipes are 60mm×60mm×2.5mm and 60mm×40mm×2.5mm. The cross section geometric size 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 the lower and the upper L-shaped angle steel is 63mm×40mm×5mm. The bolt type of this joint is M16.

2.2 FE model and boundary conditions

The FE model of in-filled bolt joint of assembled wall with square steel pipes and steel beam was built with the ABAQUS software. According to the actual situation, some assembled parts were simplified when they were built in FE model. All assembled parts of the joint were modeled with 3D solid elements of type C3D8R. To get more accurate analysis results, the FE mesh parts of this joint were refined with relatively smaller sizes. The FE model of in-filled bolt joint with square steel pipes and steel beam is shown in Figure 9.

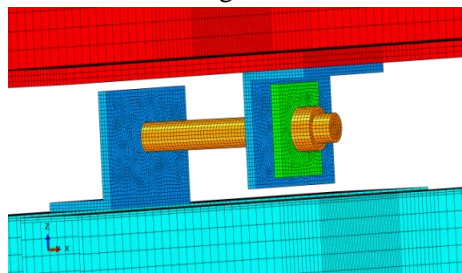


Figure 9. The FE model of in-filled bolt joint.

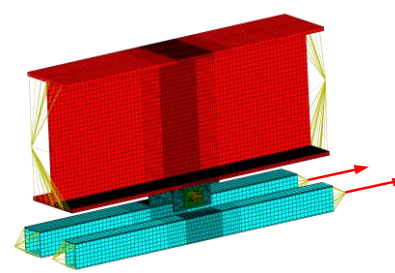


Figure 10. Applied shear load conditions.

The all parts of in-filled bolt joint were assumed to be isotropic liner elastic-plastic material. The steel type of the light steel skeleton frames and the in-filled bolt joint is Q235. Another the steel type of H-shaped steel beam is Q345. The basic material properties of Q235 and Q345 refer as Chinese national standards for design of steel structures [10]. It is assumed that when the strain of steel material reaches the corresponding fracture strain, the element will become invalid and be removed. The material properties of two types of steel used in the FE model are shown in Table 1.

Table 1. Material properties in the FE model.

Type	Density (kg/m ³)	Elastic Modulus (MPa)	Poisson's ratio	Yield Strength (MPa)	Fracture Strain
Q235	7850	2.06×10^5	0.30	235	0.26
Q345	7850	2.06×10^5	0.30	345	0.30

It has been assumed that the upper and lower L-shaped angle steel are welded perfectly on the steel beam of the main body steel frame and the rectangular steel pipes of the light steel skeleton frames,

respectively. The interaction constrained type between the upper L-shaped angle steel and steel beam and that between the lower L-shaped angle steel and rectangular steel pipes was set to “tie contact”. In FE analysis, the tied interfaces have no slippage occurs relative to each other, which just was the same as welding. The other interaction constrained type among angle steel, steel bolts, gaskets, rectangular steel pipes and steel beam was set to “general contact”. The normal behaviour used “hard contact” and the tangential behaviour used “penalty function” with friction coefficient 0.3 which refer as Chinese national standards for design of steel structures [10].

Each end of steel beam and rectangular steel pipes was coupled by a reference point (RP). The all translational and rotational DOFs (degrees of freedom) of the RP of the steel beam were constrained and they can't move and rotate. However, to make the steel pipe can slide horizontally, only the horizontal translational DOFs of the RP of the rectangular steel pipes were released and the other DOFs of the RP were constrained. As shown in Figure 10, the horizontal displacement loads were applied to the RP at one end of steel pipes, so the relative shear displacement can be produced between the steel beam and the steel pipe. Considering that the simulation analysis involves complex nonlinearity including material nonlinearity, geometric nonlinearity and boundary nonlinearity, the nonlinear explicit dynamic analysis of FE software ABAQUS/Explicit was used to simulate the shear performances of the in-filled bolt joint.

3. Results and Discussion

3.1 Stress variation

Under shear load, the stress variation of the in-filled bolt joint by FE analysis method is shown in Figure 11. As the shear displacement increases, the stress of the joint increases. Before reaching the fracture failure strain, the angle steels and the bolt of the joint appear obvious shear deformation and torsional deformation. After that, one end of the bolt near the lower angle steel is cracked rapidly and the joint become destroyed. To a certain extent, some larger stress of the joint element is released at the same time. However, the stress of steel beam and rectangular steel tube is always very small. The whole loading process undergoes large horizontal elastic-plastic deformation and the stress of the joint yields in a large area.

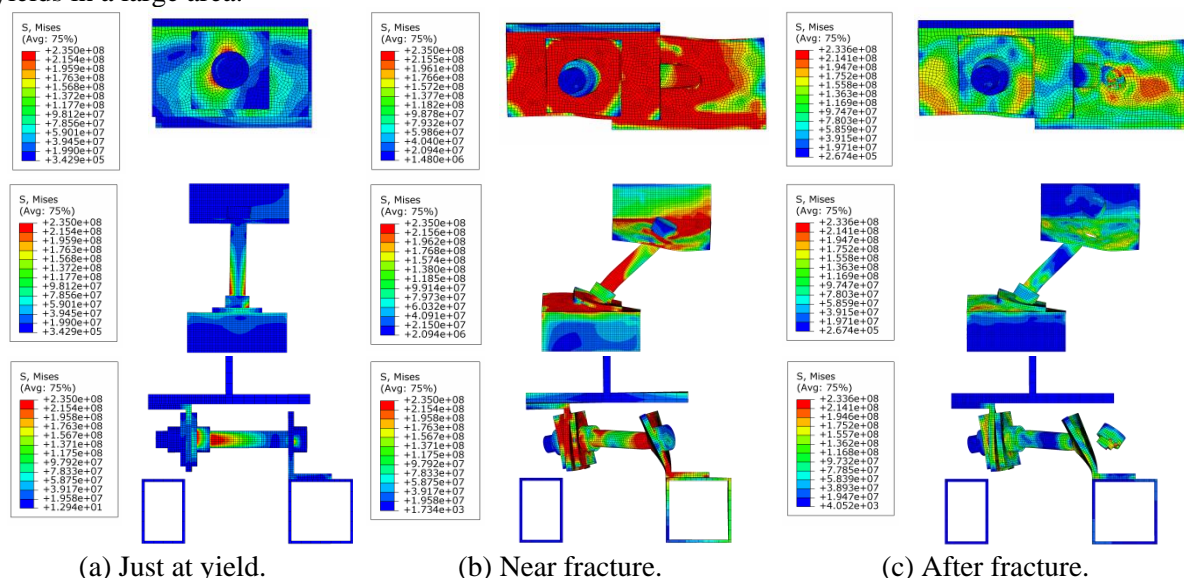


Figure 11. Stress variation of the in-filled bolt joint under shear load.

3.2 Load-displacement curve and energy curve

As shown in Figure 12, the load-displacement curve is composed of applied shear loads and relative shear displacement. Before reaching the fracture failure strain, with the gradual increase of

displacement, the load increases gradually. When the strain of the joint reaches the failure strain due to shear displacement loading, the shear load reaches the peak value. When the displacement increases to 69.06mm, the load increases to the peak load 14.62kN. Subsequently, due to the shear cracking fracture of the bolt, the load drops rapidly to 0kN, although the displacement increases. So the peak load 14.62kN can be considered to be the ultimate shear load capacity of in-filled bolt joint.

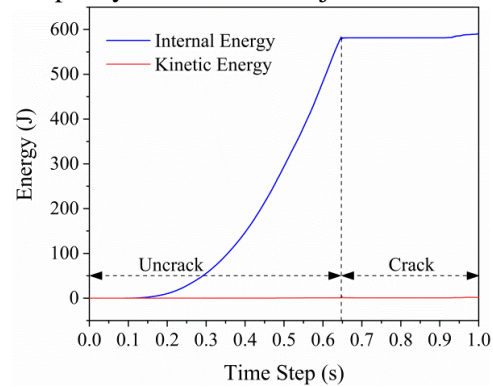
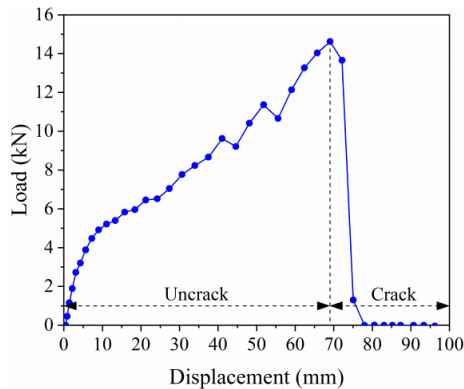


Figure 12. Load-displacement curve under shear load. Figure 13. Energy curve under shear load.

Throughout the loading process, before reaching the fracture failure strain, the bolt of the joint is not cracked. Due to the good ductility of metal materials, the joint shows good elastic-plastic behaviour. This means that the joint has good seismic performance before the bolt being cracked. However, after that, the bolt of the joint is cracked and the joint loses its bearing capacity.

As shown in Figure 13, the energy curves include the internal energy curve and the kinetic energy curve. Before the bolt being cracked, the internal energy increases with the increase of time step. The source of internal energy mainly comes from the elastic and plastic strain energy of the joint under shear forces. After that, the bolt is cracked, which causes the joint lose bearing capacity. Therefore, the plastic strain energy of the joint changes very little and the internal energy curve remains almost as a straight line. The internal energy is far greater than the kinetic energy and the kinetic energy almost can be ignored by contrast with the kinetic energy. So the dynamic influence in the explicit dynamic analysis method can be ignored in this FE simulation. Above all, the FE analysis results are reasonable.

4. Conclusions

This paper mainly studied the shear performances of the new in-filled bolt joint of the assembled GRC wall with light steel skeleton frames by FE method. The main conclusions are as follows.

- (1) Before reaching the fracture failure strain, due to the good ductility of metal materials, the in-filled bolt joint shows good elastic-plastic behaviour under shear force.
- (2) When the strain of the in-filled bolt reaches the failure strain, the shear load reaches the peak value. Subsequently, due to the shear fracture of the bolt, the shear load drops rapidly.
- (3) Throughout the loading process, the stress of steel beam and rectangular steel tube is always very small and the stress of the in-filled bolt yields in a large area in the later stage.

Acknowledgments

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