Stress Analysis of Vertical Bar Additional Connector at the Joint of Fabricated Shear Wall

Haowen Jiang, Yueguo Zhang, Handuo Fan, Qikai Liu and Linghang Du

School of Engineering, Shenyang Jianzhu University, Shenyang 110168, China
Email: ceygzhang@sjzu.edu.cn

Abstract. Although there are many mainstream reinforcement connection methods, the realization of force transfer between reinforcement is the starting point of all connections and the most important inspection standard. Aiming at the vertical connection of the fabricated shear wall, this paper proposes a new type of additional connector connection, and two fabricated shear walls connected by new types of additional connectors and a cast-in-situ shear wall were established. The dimensions and material parameters of the fabricated shear wall connected by the new additional connector were the same as those of the cast-in-situ shear wall. The finite element software ABAQUS is used to perform static finite element analysis on fabricated shear walls and cast-in-situ shear walls connected by new additional connectors. By comparing the static finite element simulation results, the results show that the new additional connector can ensure the effective force transfer of reinforcement.

1. Introduction

Based on the advantages of high mechanization, convenient construction, energy conservation, and environmental protection, prefabricated buildings have been widely used in the continuous development of urbanization. Prefabricated building is a building construction technology with sustainable development generally recognized by society. Compared with cast-in-situ structures, there are joints between components in the prefabricated structure. To a certain extent, joint connection technology determines the quality of prefabricated building structures, so the joint connection technology is the key to researching prefabricated building structures. At present, scholars at home and abroad have made many attempts and studies on the connection technology of prefabricated shear wall structures. Among them, Yu Zhiwu and others had studied the anchorage performance of U-hoop reinforcement connections in the prefabricated shear wall structure [1]. The results show that the buried depth of U-shaped reinforcement directly affects the failure mode of the specimen. When the anchorage depth of U-shaped reinforcement is large, the specimen has good ductility and reliable performance. Chen Le et al. made the whole process static elastic-plastic analysis of the shear wall dominated by bending deformation and explained the feasibility of the calculation method [2]. Liu Liping et al. verified the effectiveness of the combined connection of longitudinal reinforcement through the quasi-static test of three shear wall specimens [3]. Brian J Smith et al. conducted an experimental study on the feasibility of vertical connection of precast concrete shear wall through unbonded prestressed reinforcement and gave the calculation formula of bearing capacity and deformation according to the test results [4]. James F. et al. studied the dynamic performance of bolted connections of fabricated structures [5]. Ertas et al. conducted experimental research on several ductile connection forms of prefabricated frame structures, such as welding, bolt connection, composite chain connection, etc [6]. Although the existing joint connection methods of the fabricated shear wall have their characteristics, there are also various
deficiencies. For example, sleeve grouting connection can obtain a good force transfer effect, but the construction accuracy is high, and the construction quality is not easy to detect. The mechanical performance of the connection at the horizontal joint of the fabricated shear wall mainly depends on the reliability of the vertical reinforcement connection. Reliable force transmission, easy construction, and controllable quality are the key points of assembled shear wall joint connection. Based on the existing connection, a reinforced U-shaped connection with additional connectors is studied in this paper. The new joint connection is numerically simulated by using ABAQUS finite element software to study its force transmission reliability.

2. Connection of Additional Connectors For Horizontal Joint And Vertical Reinforcement of The Fabricated Shear Wall

The U-shaped reinforcement connection form of the additional connector is shown in Figure 1. After the U-shaped reinforcement is overlapped, the H-shaped connector is supported on the horizontal section of the U-shaped reinforcement. When the reinforcement is in tension, the reinforcement tension at the butt joint is transmitted through the H-shaped connector. When the reinforcement is compressed, the force is transmitted through the concrete anchorage in the overlapping range. To understand the feasibility of this connection mode, the solid modeling analysis of the additional connector with 50mm U-lap reinforcement was carried out. The results show that the stress of the H-shaped connector is 47.2MPa when the reinforcement yields in tension, while the stress of the H-shaped connector is 25.01MPa when the reinforcement yields in compression, both of which are in an elastic working state. It can be seen that this connection method can ensure the tensile and compressive yield of reinforcement with a small lap length, and the stress of the connector is small. The local analysis results of the additional connector reinforcement connection are shown in figure 1.

(a) Solid model.
(b) Stress program of reinforcement and connector under compression.
(c) Stress program of concrete under compression.
3. Integral Model of Fabricated Shear Wall

3.1. Basic Parameters of The Model

To study the mechanical performance of the reinforcement connection form at the joint of the shear wall proposed in this paper, three analysis models of the reinforced concrete shear wall were designed, including one integral shear wall XW-1 and two assembled shear walls ZW-1 and ZW-2. The change of joint width was considered in the fabricated shear wall, and the reinforcement amount of the integral shear wall was the same as the fabricated shear wall. The specific model parameters are shown in table 1 and figure 2.

Table 1. Model design parameters.

| Test piece | Material Science | Connection mode | Joint position | Joint height / mm |
|------------|------------------|-----------------|---------------|------------------|
| XW-1       | C30               | Cast in situ member | —             | —                |
| ZW-1       | HRB400            | H-type connector | bottom        | 50               |
| ZW-2       | Q235B             | H-type connector | bottom        | 100              |

3.2. Element Types and Boundary Conditions of Finite Element Model

The element type of finite element model was as follows: three-dimensional solid reduced integral element (C3D8R) was selected for concrete, and truss element (T3D2) was selected for steel bar element. According to the force characteristics of the connector, the H-shaped connector is simplified as a steel bar element for the convenience of modeling and analysis.

The boundary conditions of the model are: the end face of the bottom beam of the model is hinged to restrict the out-of-plane displacement and torsion of the wall. A general contact pair is set at the joint...
between the new and old concrete in the fabricated shear wall, the tangential friction coefficient is taken as 0.7, and the normal direction is hard contact.

The load conditions of the shear wall model are as follows: according to the axial compression ratio of the wall, the vertical compression load is applied to the top-loading beam, and the horizontal load is applied at the coupling point of the end face of the top-loading beam. The analysis is realized by applying horizontal displacement.

3.3. Mechanical Properties of Materials
The compressive constitutive relationship of concrete adopted the stress-strain relationship given by Saenz 7, and the tensile constitutive relationship adopted the stress-strain relationship given in code for design of concrete structures (GB50010-2010) 8. The stress-strain relationship of reinforcement and H-shaped connector adopted the bilinear constitutive model, and the curve slope of the strengthened section was 0.01 times that of the elastic section, i.e. $E_s' = 0.01E_s$. See table 2 for specific values of material mechanical properties.

| Material Science | Elastic modulus / MPa | Poisson's ratio | Yield strength / MPa |
|------------------|-----------------------|----------------|----------------------|
| C30              | 3×10^4                | 0.2            | 20.1                 |
| HRB400           | 1.98×10^5             | 0.3            | 452                  |
| Q235B            | 2.06×10^5             | 0.3            | 380                  |

4. Analysis Results and Analysis of Prefabricated Shear Wall

4.1. Reinforcement Stress Analysis
Figure 3 shows the stress program of reinforcement when XW-1, ZW-1, and ZW-2 reach yield load and ultimate load. The bearing capacity and deformation results of each model are shown in table 3. Ultimate load state refers to the bearing capacity of concrete when it reaches the ultimate compressive strain.

| Model | Yield load / kN | Yield displacement / mm | Ultimate load / kN | Ultimate displacement / mm |
|-------|-----------------|-------------------------|--------------------|---------------------------|
| XW-1  | 206.60          | 1.65                    | 268.04             | 3.98                      |
| ZW-1  | 199.40          | 1.78                    | 264.30             | 4.15                      |
| ZW-2  | 193.45          | 1.68                    | 253.70             | 4.24                      |

(a) Reinforcement stress program of XW-1 model.
Figure 3. Reinforcement stress program of model.

It can be seen from Figure 3 that the reinforcement stress development state of the model of the integral shear wall and the fabricated shear wall is the same. Under the combined action of vertical load and horizontal load, the vertical reinforcement on the side with large compression of the wall first yields. When the concrete on this side reaches the ultimate compressive strain, the concrete is crushed and damaged. Table 3 shows that the bearing capacity and deformation performance of the fabricated shear wall with an additional H-shaped connector U-lap joint for vertical reinforcement is equivalent to that of the overall shear wall.

4.2. Concrete Stress Analysis

Figure 4 shows the program of normal stress of concrete under yield and limit states of model reinforcement. It can be seen from the model concrete stress program in Figure 4 that the compressive stress of the overall shear wall and the fabricated shear wall is mainly concentrated at the bottom of the compression side of the wall, and the oblique compressive stress decreases gradually along the wall. The maximum tensile stress is at the bottom of the tensile side of the wall, and the oblique tensile stress decreases gradually along the wall. The main compressive and tensile stress traces of concrete of integral and fabricated shear walls are X-shaped, showing the same mechanical performance of concrete.
I. Yield state
II. Limit state

(b) Normal stress program of concrete in ZW-1 model.

I. Yield state
II. Limit state

(c) Normal stress program of concrete in ZW-2 model.

5. Load Displacement Curve
From the horizontal load-displacement curve of the shear wall model in figure 5, it can be seen that the horizontal displacement of the integral shear wall and the fabricated shear wall are consistent with the increase of the horizontal load. Below the yield load, the horizontal load-displacement curve of the model changes linearly and maintains the elastic working state. The difference is that the stiffness of the elastic working range of the fabricated shear wall is lower than that of the integral shear wall due to the existence of the horizontal joint of the fabricated shear wall, which shows that the slope of the horizontal load-displacement curve of the fabricated shear wall is lower than that of the integral shear wall. After the reinforcement yield, the slope of the horizontal load-displacement curve of the model decreases rapidly, and the slope of the curve of the fabricated shear wall model decreases faster than that of the integral shear wall. The peak load of the integral shear wall is greater than that of the fabricated shear wall, but the horizontal displacement corresponding to the peak load is not different, which is about 4mm. After all shear wall models exceed the peak load, the load-displacement curve is a horizontal straight line, showing a plastic stress state.
6. Conclusion
In this paper, the static load analysis of the steel bar lap connection model and the integral shear wall model with H-shaped connectors in the horizontal joint of the fabricated shear wall is carried out, and the analysis results are compared. The following conclusions can be drawn:

(1) The horizontal joint of the fabricated shear wall adopts the U-shaped overlapping mode of reinforcement with H-shaped connectors, which can reliably realize the force transfer of steel bar between the components at the joint.

(2) The mechanical performance of the fabricated shear wall with additional H-shaped connectors at the butt joint is consistent with that of the cast-in-situ shear wall. Due to the existence of joints, the bearing capacity and shear stiffness of fabricated shear walls are lower than those of cast-in-situ shear walls.

(3) From the beginning of loading to concrete crushing, the additional H-shaped connector is always in an elastic working state, the connector is less stressed, and the section size can meet the equal strength of reinforcement.

Acknowledgments
This work was supported by Mentoring Program Project of Natural Science Foundation of Liaoning Province (2019-ZD-0674).

Reference
[1] Yu Z W, Peng X D, Guo W, Peng M P. 2015 Study on anchorage performance of u-hoop reinforcement connection in fabricated shear wall structure [J] Journal of Railway Science and Engineering 12 (04) 879-886.
[2] Chen Q, Qian J R, Li G Q. 2004 Static elastic-plastic analysis of shear wall with macro model [J] Journal of civil engineering (03) 35-43.
[3] Liu L P, Yu J, Liao D F, Liu J J, Deng X H, Li Y M. 2019 In-plane mechanical behavior of fabricated reinforced concrete shear wall with combined longitudinal reinforcement [J] Journal of Civil and Environmental Engineering (Chinese and English) 41 (06) 135-142.
[4] Smith B J, Kurama Y C. 2010 Analytical Model Validation of a Hybrid Precast Concrete Wall for Seismic Regions[C] Proceedings of the 2010 ASCE Structures Congress 2914-2924.
[5] Ozturan T, Ozden S, Ertas O. 2006 Ductile Connections in Precast Concrete Moment Resisting Frames[J] PCI Journal Prestressed Concrete Institute Jou 51 66-76.
[6] Wilson J F, Callis E G. 2004 The dynamics of loosely jointed structures [J] International Journal of Non-Linear Mechanics 39 (3) 503-514.
[7] Saenz L P. 1964 Discussion of 'Equation for the Stress Strain Curve of Concrete' by Desayi and Krishnan [J] Journal of the American Concrete Institute 61 (9) 1229-1235.
[8] GB 50010-2010, code for design of concrete structures [S].