Research on Seismic Performance of Assembled Shear Wall with Grouted Anchors under Different Lap Parameters

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Abstract. In order to study the performance of the anchor-connected shear wall under different lap parameters, ABAQUS was used to establish its analysis model. The C3D8R unit and T3D2 unit were used to model the concrete and steel bars respectively, and the steel bars were embedded into the concrete by embedding. Through the finite element analysis calculation and comparison with the test results, the applicability of the numerical analysis model is verified. On this basis, the structural skeleton under low-cycle repeated load tests is studied by changing the parameters of the connecting steel bar diameter, anchor length, and other parameters. Changes in curves, stiffness degradation curves, and energy dissipation capabilities. Through the finite element analysis calculation and comparison with the test results, the applicability of the numerical analysis model is verified. On this basis, the structural skeleton under low-cycle repeated load tests is studied by changing the parameters of the connecting steel bar diameter, anchor length, and other parameters. Changes in curves, stiffness degradation curves, and energy dissipation capabilities.

Keywords. Slurry-anchor connection, shear wall, finite element analysis, seismic performance.

1. Introduction
In order to achieve the goals of energy conservation and emission reduction, as well as the green, healthy and sustainable development of the construction industry, China's Ministry of Housing and Urban-Rural Development recently released the "Thirteenth Five-Year Plan for Construction Industry Development." According to the "Planning", by 2020, the area of prefabricated buildings will account for 10% of newly-built buildings. "Planning" also formulated the development task of promoting the modernization of the construction industry, the key of which is to promote intelligent and prefabricated buildings.

The shear wall currently strongly advocated by China can be flexibly arranged in combination with the building plane, and there are many options to choose from, so it is widely used in residential buildings. The prefabricated shear wall structure is prefabricated in the factory and assembled on site, which shortens the construction period a lot. Industrialized production and production saves a lot of manpower and material resources, which is in line with the national energy-saving, emission-reduction, and environmental protection policies. Vigorous promotion of the country. The prefabricated shear wall is widely favored by people in the industry due to its advantages of industrial production, convenient construction, fast construction speed, smooth surface of prefabricated components, good appearance, accurate size, short construction period of prefabricated structure, and fast investment recovery [1]. However, due to the market's dependence on cast-in-place structures, the frequent
occurrence of large earthquakes, the difficulty of seismic design of fabricated shear walls, and the need for continuous improvement of research, its promotion and application have been limited [2]. Therefore, the seismic performance of prefabricated shear walls [3] needs to be continuously studied to promote the application of prefabricated shear walls. The numerical simulation of the seismic performance of fabricated shear walls requires further research [4, 5].

2. Finite Element Model Analysis

2.1. Analysis Model

The analysis model is taken from [6]. The size of the structure is shown in figure 1. The specimen includes three parts from top to bottom including loading beam, wall and ground beam. The load beam is 2 m long, the section size is 0.4 m×0.4 m, the wall height is 2.8 m, the width is 1.4 m, the thickness is 0.2 m, the ground beam length is 2.4 m, and the section size is 0.5 m×0.5 m.

![Figure 1. Analytical model structure.](image)

2.2. Finite Element Model

In this paper, the mortar-anchor connection to the assembled shear wall [7] is modelled using a separate model. The loading beam, shear wall and ground beam are all three-dimensional solid elements C3D8R, and the reinforcement is the truss element T3D2. When modeling, the concrete stress, inelastic strain, damage factor and other parameters were obtained through the concrete constitutive relationship. The steel bar and concrete are modeled separately, and then the steel bar is embedded in the concrete by embedding. The interface between concrete and ground beams takes into account the effect of the interface of concrete, using surface-to-surface contact and setting normal parameters. The analysis steps of the model are divided into two steps: The first step is the loading of the vertical force. The vertical force of 720 KN is loaded onto the loading beam by the equivalent of a uniform load; the second step is horizontal displacement loading. In the horizontal direction, the loading surface is coupled to a point out of the surface through a coupling method, and then the displacement loading method is used for repeated loading. For the load beam and ground beam in the model, the grid size is 100 mm and the encryption area grid is 50 mm. The specific model and grid division are as figure 2:

![Figure 2. Finite element model.](image)
2.3. Material Constitutive Relationship

The concrete damage model uses the model of isotropic damage elasticity combined with isotropic tensile and compressive plasticity to represent the inelastic behavior of concrete. The model can be used in single-item loading, cyclic loading and dynamic loading, and has good convergence. Therefore, this paper studies the seismic performance of assembled shear walls under low-cycle repeated loading, and selects the concrete damage [8] model for simulation. The steel bar model adopts the PQ-Fiber v2.0 material uniaxial hysteretic constitutive [9] model developed by ABAQUS. The method of importing this subroutine in the ABAQUS software considers the package Singer effect of the steel bar. This constitutive model integrates three sets of concrete hysteretic constitutive models and three sets of steel hysteretic constitutive models, and is generally applicable to the elastoplastic analysis of beam element beam structures. Considering that PQ-Fiber can only be used for the constitutive model of the fiber rod element, the reinforced element of the concrete wall panel is modeled by Truss element. At the same time, the USteel02 constitutive model in PQ-Fiber is used in this paper. In the simulation process of nonlinear finite element of reinforced concrete, the use of this constitutive model can reduce the workload of modeling and calculation in simulation calculation.

3. Verification and Comparative Analysis

Through the low-cycle repeated load test of the shear wall in [6], the characteristic parameters and measured values of the shear wall during the failure process are obtained and compared with the simulation results of the finite element model D1. The hysteresis curve comparison chart is as figure 3:

![Figure 3. Comparison of test and simulated hysteresis curves](image)

| Result                  | Test | Simulation |
|-------------------------|------|------------|
| Positive displacement(mm)| 30.4 | 29         |
| Positive load(mm)       | 337  | 330.6      |
| Negative displacement(mm)| 30.1 | 29.6       |
| Negative Load(mm)       | 372  | 341        |

The comparison of simulated and experimental peak data is shown in table 1. In the experiment, the connection of the shear wall has the reinforcement effect of the spiral stirrups, but the finite element simulation fails to simulate the effect of the stirrups on the connection, so the simulated peak data is slightly lower than the test, the maximum difference is 8.3%. The simulated descent section is not obvious compared with the test, which is because in the later stage of the finite element simulation, it does not well reflect the decrease or loss of the bearing capacity of the steel bar after necking or even fracture. Therefore, the simulation result curve in the later period is gentler than the experimental result curve, and there is no steeper descent.
4. Parameter Analysis
In order to study the seismic performance of fully assembled mortar-anchor connected assembled shear walls, this chapter compares and analyzes the parameters such as the diameter of the vertical connecting steel bars and the anchoring length of the connecting steel bars. And under the low-cycle repeated load test, by analyzing the skeleton curve, stiffness degradation curve and energy dissipation capacity of the structure under different parameters, the difference in seismic performance of the assembled shear wall under the influence of different parameters was studied [10].

4.1. Parameter Analysis of Different Steel Bar Diameters
The model is simulated by changing the diameter of the steel bars at the edge of the test piece. Originally, the steel bar diameter at the edge of the test piece is 14mm. This time, the steel bar diameters of 12 mm, 16 mm and 18 mm are selected to replace the steel bars. The obtained test pieces are F12, F14, F16, F18. By modeling calculations on the four test pieces, and then comparing with the data of the original test pieces, the seismic performance of the assembled shear wall under different steel bar diameters is analyzed.

4.1.1. Skeleton Curve. It can be seen from the skeleton curves of each test piece in the figure 4 that the effect of the connecting steel bar diameter on the bearing capacity of the test piece is more obvious. As the diameter of the connecting steel bar increases, the bearing capacity of the test piece also increases. When the diameter of the steel bar increases to 18 mm, the change in the bearing capacity of the specimen begins to be insignificant.

4.1.2. Stiffness Degradation Curve. As shown in the figure 5 below, as the diameter of the connecting steel bar increases, the initial stiffness of the test piece also increases. The four specimens have the same stiffness degradation trend as the horizontal displacement increases. Before the specimen yields, the load and deformation increase proportionally, and the stiffness degradation rate is faster; after the specimen reaches yield, the load growth lags behind the displacement increase, making the stiffness degradation rate slow. Comparing the stiffness degradation curves of the four specimens, F12 is the steepest and F18 is the smoothest, indicating that the increase in the diameter of the connecting steel bar can slow the deterioration of the rigidity of the test specimen. Properly increasing the diameter of the connecting steel bar is beneficial to earthquake resistance.

4.1.3. Energy Consumption Capacity Curve. As shown in the figure 6 below, comparing the energy dissipation curves and equivalent viscous damping coefficients of four different connecting steel bar diameters, it can be found that as the connecting steel bar diameter increases, the energy dissipation capacity of the test pieces continues to increase, especially The increase is most obvious when the
loading displacement is the limit displacement.

![Graph of energy consumption capacity curves](image)

**Figure 6.** Comparison of energy Consumption capacity curves.

### 4.2. Parameter Analysis of the Anchorage Length of Different Connection Bars

In the experimental shear wall model, the anchorage length of the steel bar with diameter 14 on both sides is 560 mm, and the anchorage length of the steel bar with the middle diameter of 8 is 320 mm. The anchor length taken this time is as table 2 according to the specifications:

| Specimen number | Side (mm) | Mid (mm) |
|-----------------|-----------|----------|
| M1              | 500       | 320      |
| M2              | 560       | 260      |
| M3              | 620       | 380      |
| M4              | 680       | 440      |
| M5              | 740       | 500      |

**Table 2.** Anchorage length of test piece.

4.2.1. **Skeleton Curve.** As shown in the figure 7, the skeleton curves of specimens with different anchor lengths are very similar, and it is difficult to visually see their changes from the graph. However, through the skeleton curve data, it can be seen that the M1 specimen with the shortest anchor length has the lowest bearing capacity. As the anchor length increases, the bearing capacity of the specimen also increases. The M5 specimen with the longest anchor length has the highest bearing capacity, although the overall difference between them is small, but it can still be obtained by increasing the anchoring length to increase the bearing capacity of the test piece.

![Graph of skeleton curve](image)

**Figure 7.** Skeleton curve comparison chart.
4.2.2. *Stiffness Degradation Curve*. It can be seen from the figure 8 that the stiffness degradation trends of the above five specimens are basically the same. But through the stiffness degradation curve data: the initial stiffness of M1 specimen is 69.27, the initial stiffness of M2 specimen is 74.78, the initial stiffness of M3 specimen is 76.72, the initial stiffness of M4 specimen is 77.75, and the initial stiffness of M5 specimen is 79.01. It can be seen that the initial stiffness of the M1 specimen is the smallest, and the initial stiffness of the M5 specimen is the largest. Although the overall difference is not large, it can be seen that the effect of anchor length on the rigidity of the specimen is positively correlated, indicating that the increase in anchor length can increase the rigidity of the shear wall specimen.

![Figure 8. Comparison of stiffness degradation curves.](image)

4.2.3. *Energy Consumption Capacity Curve*. As shown in the figure 9, the energy dissipation capacity of the specimen gradually increases with increasing horizontal displacement. According to the analysis of the energy dissipation curve and the equivalent viscous damping coefficient, the M1 curve is at the top and the M5 curve is at the bottom, indicating that the M1 specimen consumes the most energy, and then slowly decreases in sequence as the anchor length increases. Therefore, although the anchoring length can increase the rigidity of the shear wall specimen, it cannot increase the energy consumption of the specimen.

![Figure 9. Comparison of energy consumption capacity curves.](image)
5. Conclusion
In this paper, the finite element model of the assembled shear wall with slurry-anchor connection is established, and the correctness of the model is verified through the comparison between the experimental results and the model. By changing the parameters of the connecting steel bar for analysis, the following conclusions are drawn:

(1) The influence of the diameter of the connecting steel bar on the bearing capacity of the test piece is more obvious. As the diameter of the connecting steel bar increases, the bearing capacity of the test piece also increases. However, when the diameter of the steel bar is increased to 18mm, as the connecting steel bar, it has no effect on the overall bearing capacity of the test piece. It shows that the increase of the diameter of the connecting steel bar can slow the deterioration of the rigidity of the specimen. At the same time, as the diameter of the connecting bar increases, the energy dissipation capacity of the test piece is continuously increasing, so appropriately increasing the diameter of the connecting bar is conducive to earthquake resistance.

(2) The bearing capacity of the test piece increases with the increase of the anchor length. The influence of the anchor length on the stiffness of the test piece is positively correlated, and the influence on the energy consumption of the test piece is negatively correlated, but the increase is very small. It shows that the increase of the anchoring length can increase the rigidity of the shear wall specimen, but it reduces the energy dissipation capacity of the specimen, but the impact is smaller.

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