Research on Damage Mechanism and Structural Optimization of Joints in Cavity Shear Wall Structure

Yong Tian, Guanghui Shi, Bo Zhang, Kun Guo, Fajiang Luo, Shengjie Chen, and Yibo Bai

Abstract After pouring concrete precast cavity shell structure has been developing rapidly in recent years, compared with cast-in-place structure, the new fabricated structure has low cost, high construction efficiency, and the advantages of green environmental protection, the shear wall structure is most widely used, which includes the prefabricated plate shell, annular tendon layout, cast-in-situ construction important process. But by several times with the stress of the casting of concrete and the overall disposable pouring forms have obvious differences, including the layered interface, the material interface, the cross section of damage caused by the stiffness degradation, and eventually results in the decrease of carrying capacity. In this paper, the damage mechanism of precast shear wall with cavity is analyzed, and the optimization method of connecting parts is studied and discussed.

Keywords Shear wall structure · Connection node · Damage mechanism · Structural optimization

1 Introduction

Prefabricated composite shear wall is a combination of double-sided composite shear wall, and then the reinforcement is inserted into the central cavity, and then the concrete is poured to complete. Due to the large size of the cavity, the construction of double-sided superimposed shear wall is convenient and fast in the process of component installation [1, 2].

Prefabricated superimposed shear wall is widely used because of its high applicable height, good applicability, good integrity and seismic performance. In order to meet the requirement of "equivalent cast-in-place", the joint connection is the key, and the quality of joint connection directly affects the safety performance of assembled concrete structure [3]. As shown in Fig. 1.

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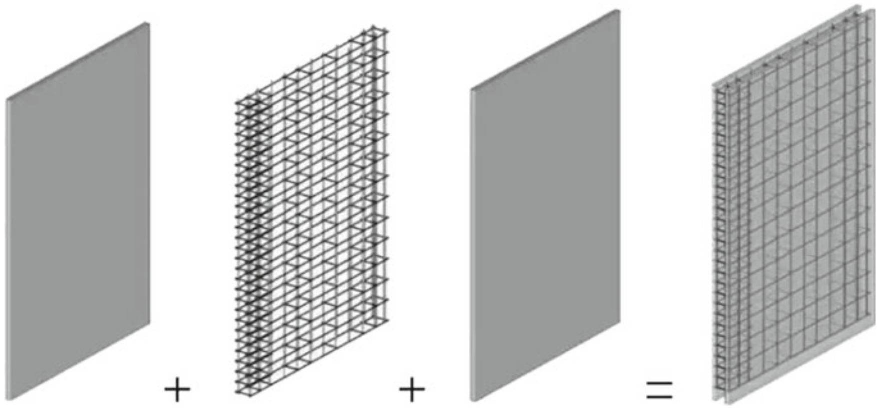

Fig. 1 Structure of cavity shear wall structure system

However, because the connecting steel bars in the shear wall are inserted artificially in the construction site, rather than buried in advance in the component factory, the following problems may occur:

(1) The difficulty of vibration leads to the incompactness of cast-in-place concrete, which affects the grip of reinforcement in concrete [4].
(2) The combination quality of old and new concrete is poor, and the bond is not strong enough to lead to the hollow of the laminated surface.
(3) transportation, storage and other non-construction factors caused by the deformation of the panel, steel distortion.

At present, there are many researches on the mechanical and seismic performance of prefabricated composite shear wall at home and abroad [5, 6], but the damage mechanism derived from the above basic problems and optimization measures for construction need to be solved urgently. In this paper, based on refined finite element analysis software, a systematic analysis is made on the multiple factors affecting the composite shear wall.

2 Engineering Survey

The construction project includes 7 prefabricated residential buildings, office buildings, commercial and community facilities and supporting underground garages. The total land area is 50109 m^2, the construction area is about 248,000 m^2, the highest height is 94.45 m, the structure form is the frame shear wall structure, is a collection of residential, commercial, office and community supporting in one of the comprehensive building. To meet the needs of the building owners, the assembled shear wall adopts the cavity wall system, composed of two sides of the page with internal precast steel cage, the thickness of the two sides of the precast page is 50 mm, using the sandwich area of concrete cast-in-place with forming the connection of the steel cage connection form. The cavity precast shear wall panel is shown in Figs. 2 and 3.

Fig. 2 Cavity shear wall

Fig. 3 Cavity shear wall joint

3 Structural Modeling and Analysis

3.1 Calculation Assumption

In numerical simulation analysis, the following assumptions are made [7, 8]:

(1) It is assumed that concrete is an elastic body and is in the elastic deformation range in the whole process simulation.
(2) The relative slippage of the contact part between reinforcement and concrete is not considered [9].
(3) There is no difference in the uniform quality of concrete.

3.2 Finite Element Modeling

According to the actual construction situation, the proposed working condition is: there is an initial dislocation of 5 mm between the plates. Finite element program Midas was used to establish a shear wall panel with a size of 1 m $\times$ 1 m, and the spacing between transverse connecting bars was 20 cm. The concrete shell is built by plate element, and the steel bar is built by beam element, which is divided into 200 units and 485 nodes. The basic model is shown in Fig. 4.

3.3 Finite Element Model Calculation

Stress calculation result

According to the present working condition, one side is consolidated and the other side is moved 5 mm down the vertical direction. The reinforcement stress calculation results are shown in Figs. 5 and 6.

Displacement calculation result

Taking the same working conditions for calculation, the displacement results of shear wall panels in different directions obtained are shown in Fig. 7–8. (The uncolored line segment is the position before deformation).

4 Data Analysis and Processing

Through the calculation of the overall model, the consolidation part is taken as the initial origin, and the vertical connection part of steel bar and wall plate is taken as the data extraction point. The internal force of steel bar and deformation displacement

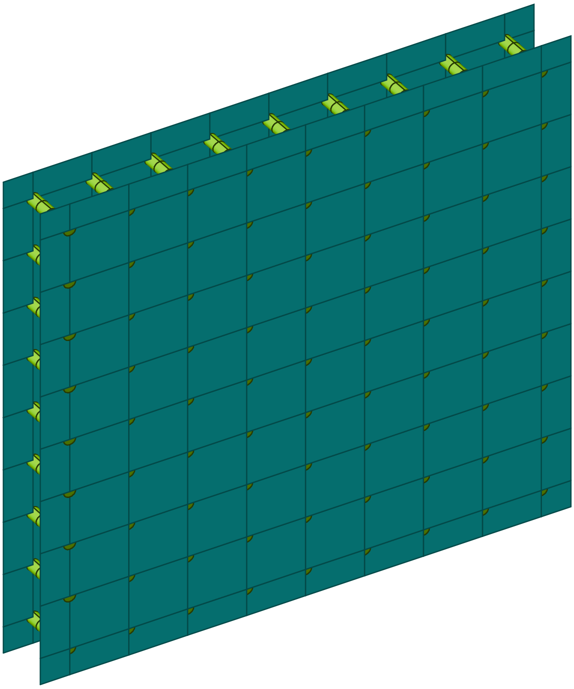

Fig. 4 Finite element modeling of cavity shear wall structure

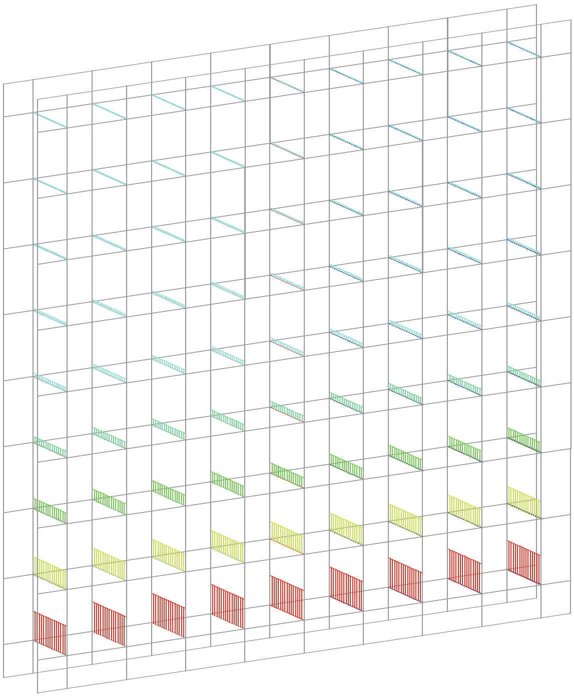

Fig. 5 Cloud diagram of maximum shear calculation results. (unit: kN)

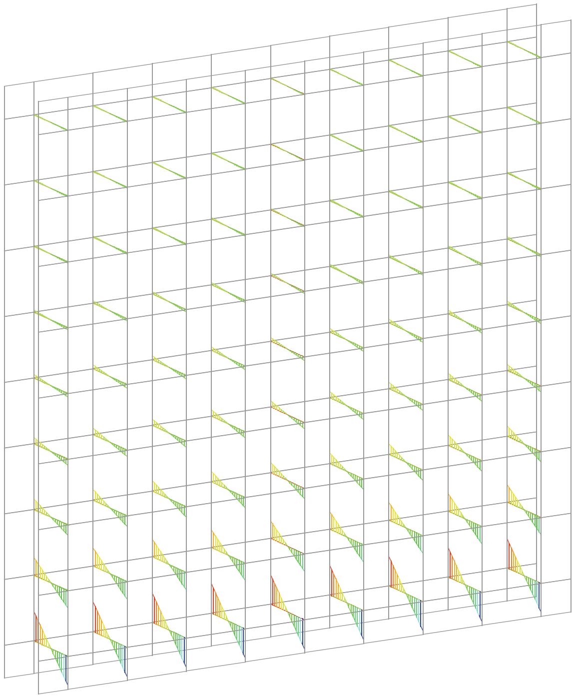

Fig. 6 Cloud image of calculation results of maximum bending moment. (unit: Mpa)

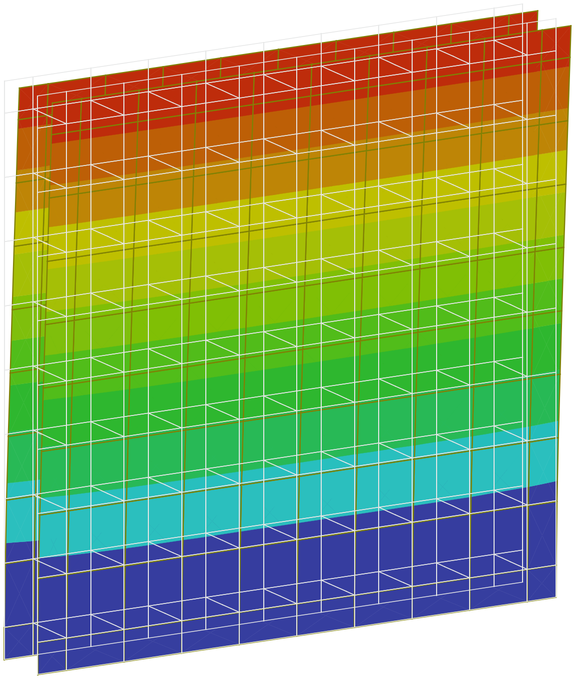

Fig. 7 Cloud image of lateral displacement calculation results. (unit: mm)

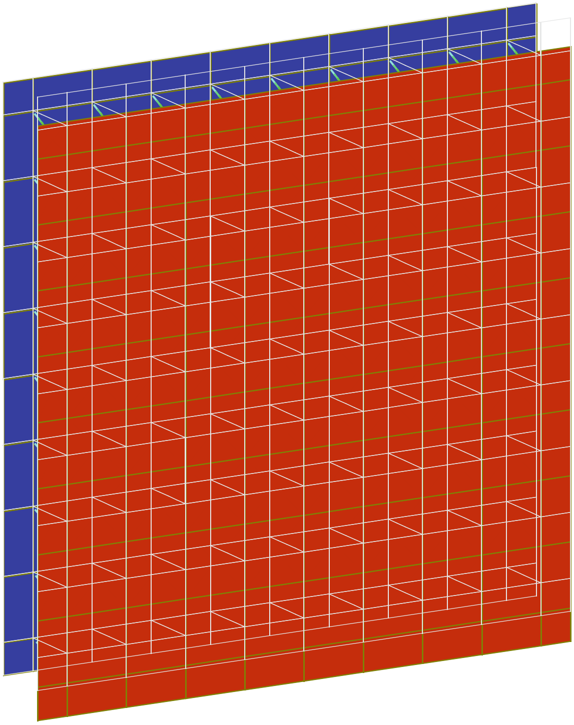

Fig. 8 Cloud image of vertical displacement calculation results. (unit: mm)

of shear wall plate are summarized, and the internal force and displacement change analysis chart is obtained in Table 1:

The abscissa is the fixed distance, and the ordinate is the corresponding data value of a specific position. They're all shown in Figs. 9 and 10.

Table 1 Summary of calculation results of internal force and displacement

Position (bottom as origin)	Maximum shear force (kN)	Maximum bending moment (Mpa)	Lateral displacement (mm)	Vertical displacement (mm)
1 (0.05 m)	65.71	3.29	0.29	5.00
2 (0.15 m)	39.34	1.97	2.11	4.95
3 (0.25 m)	23.28	1.16	5.06	4.89
4 (0.35 m)	13.73	0.69	8.69	4.86
5 (0.45 m)	8.10	0.41	12.73	4.84
6 (0.55 m)	4.83	0.24	17.01	4.83
7 (0.65 m)	2.98	0.15	21.42	4.82
8 (0.75 m)	2.00	0.10	25.90	4.81
9 (0.85 m)	1.58	0.08	30.43	4.81

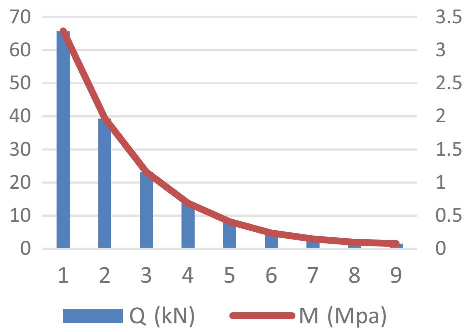

Fig. 9 Trend of shear force and bending moment

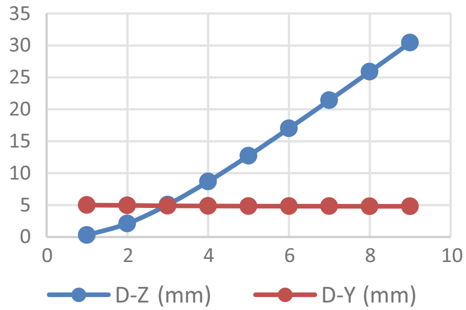

Fig. 10 Trend of transverse and vertical displacement

It can be clearly seen from the table and picture data that in the case of initial damage caused by relative dislocation of the wall panels on both sides, the overall change of displacement and internal force presents a nonlinear trend, mainly as follows:

(1) When the prefabricated slabs of cavity shear wall are constrained at one end, the relative dislocation of 5 mm will cause the reinforcement at the connecting part to produce the shear force of 65.71 kN (The corresponding bending moment is 3.29 Mpa), and the shear stress can reach 328 Mpa according to the reinforcement diameter of 16 mm.

(2) The rebar nearest to the constraint end bears 79.4% of the internal force, while the rebar at the free end only bears 4.06% of the internal force, and the actual bearing ratio at both ends is about 20:1.

(3) There is little difference in vertical dislocation displacement between nodes, the maximum value is 5 mm, the minimum value is 4.81 mm, and the difference ratio between the maximum and minimum value is 3.8%, basically no difference.

(4) The transverse dislocation displacement of each node varies greatly, the maximum displacement is 30.43 mm, the minimum displacement is 0.29 mm, and the warpage Angle is only $1^\circ 43'$, which shows a linear change trend relative to the calculation plate.

5 Conclusion

According to the calculation and data analysis in the preceding chapters, the following conclusions can be drawn:

(1) For the shear wall panel with cavity system, the relatively small dislocation between the two plates will cause the initial internal force, which is mainly concentrated at the near fixed end, because the shear transfer at the near fixed end lags behind the displacement transfer, and the larger the structure size, the more obvious this effect will be.
(2) The horizontal and vertical deformation is not synchronous, on the one hand, because concrete is an elastic body that can resist partial deformation, and on the other hand, because the reinforcement as a stressed structure produces energy dissipation effect, which leads to the slope of deformation along the reinforcement direction and the slope of vertical reinforcement direction is not synchronous;
(3) The transfer of internal force and deformation is not coordinated, which will cause the warping deformation of the structure in a specific direction. Considering that there is no difference between the inside and outside of this kind of wall panel, the warping deformation is completely random, and irregular distortion will occur in the plane under the stacking of multiple layers.

In order to meet the construction quality requirements, it is recommended to optimize as follows on the basis of meeting the requirements of the specifications:

a. It is necessary to increase the number of steel bars connected near the constrained end, and the number of steel bars should be gradually increased from the free end to the fixed end.
b. Attention should be paid to the connection between the steel bar and the wall panel to ensure that no concrete spalling or loosening occurs.
c. In the construction of high-rise buildings, due to the randomness of warpage direction, it is necessary to measure single error and accumulate error in time to ensure accurate positioning.

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