

# Finite element analysis of hysteretic properties of steel frame embedded dense ribbed composite wall against lateral force system

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**Abstract:** Steel frame and multi-ribbed composite wall-steel frame system were simulated by finite element method using ABAQUS software. The influence of multi-ribbed composite wall on hysteretic properties, skeleton curve, stiffness degradation, ductility and energy dissipation capacity of steel frame structure is studied. The results show that the loading capacity and energy dissipation capacity of steel frame can be effectively improved by adding dense ribbed composite wall.

**Key words:** Steel frame; Dense ribbed composite wall; Hysteretic properties

## 1. Introduction

Steel frame structure is famous for its excellent seismic ability, but its independent bearing capacity is limited, and it is difficult to resist large deformation. In order to enhance the seismic efficiency of this system, the introduction of walls with high bearing capacity has become a key strategy. Dense ribbed composite wall, as an advanced load-bearing material integrating light weight and high strength, energy saving and environmental protection and excellent seismic performance, has become an ideal reinforcement choice. The multi-layer seismic protection system can be built by embedding the multi-ribbed composite wall in the steel frame structure. This design significantly improves the seismic performance of the anti-lateral force system, and effectively reduces the energy consumption of the building, which is consistent with the development purpose of green buildings. In view of the unique stress-strain behavior of steel frame and dense ribbed composite wall when bearing loads, the hysteretic characteristics of steel frame-dense ribbed composite wall composite system are deeply analyzed in this study. Through the investigation of hysteretic curve, skeleton curve, stiffness degradation, ductility and energy dissipation capacity, the role of multi-ribbed composite wall in the whole lateral load system and its influence on the system performance are evaluated.

## 2. Finite element model

### 2.1 Specimen design

The steel frame in this paper is a single-layer single-span structure, the height is set to 3000 mm, the span is 3100 mm. The supporting columns of the frame are HW300×200×8×12 specifications, and the beams are HN200×150×6×10 type steel, both of which are made of Q235B grade steel, and the node design ensures the rigid connection, the specific model is shown in Figure 1.

The set thickness of the multi-ribbed composite wall is 200 mm, and the width and height are the same, both of which are 2800 mm. The section size of the edge ribbed beam and the edge ribbed column equipped with the wall is equal, both are 200mm×200mm; The inner mid-ribbed beam and mid-ribbed column adopt a more compact design, and the size is reduced to 150mm×200mm. The internal blocks of the walls are arranged in an orderly manner with a standard size of 700mm×700mm to ensure a stable and efficient structure. In terms of rebar configuration, HRB335 grade steel was selected for horizontal and vertical distribution, double-layered along the thickness direction of the wall, and the diameter was set at 12 mm. In addition, the stirrups are also made of HRB335 steel, with a diameter of 8 mm and a spacing of 200 mm to ensure the overall strength and stability of the wall.

### 2.2 Establishment of finite element model

This model is mainly composed of steel beam, steel column, concrete frame, aerated concrete block and rebar. S4R unit is used for numerical simulation of steel beam and steel column, while C3D8R unit is used for accurate modeling of concrete rib and aerated concrete block. For the reinforcement network inside the wall, T3D2 unit is used for fine characterization.

When discussing the connection interface between the multi-ribbed composite wall and the steel beam, the complex contact action is simplified into a frictional contact model, in which the normal contact is treated as rigid contact, while the tangential motion follows the Coulomb law of friction, and the friction coefficient is set at 0.45. In order to ensure the stability and accuracy of the model, the bottom end of the frame column is implemented with comprehensive fixed constraints, which means that the movement is strictly limited to zero in all six degrees of freedom directions.

Tie constraints were applied between the block and the concrete floor to achieve a tight connection between the two and ensure structural integrity. The steel bars are Embedded into the multi-ribbed composite wall in a way that ignores the possible bond slip phenomenon at the interface between the steel bars and concrete to simplify the analysis process.

When building the material model, the steel is a bilinear model, The elastic modulus E and Poisson's ratio of the model are selected according to the data in literature. For concrete materials, the curve recommended in Code for Design of Concrete Structures (GB50010-2010) is selected for the simulation of its constitutive relationship, which provides authoritative guidance for the analysis and design of concrete

structures. The constitutive relation of block adopts the relation curve proposed in literature.

### 2.3 Model Verification

For the single steel frame member in literature and the "SPW-3" member in literature, a comparative analysis of skeleton curves was carried out through simulation calculation, as shown in FIG.1 and FIG.2 below.

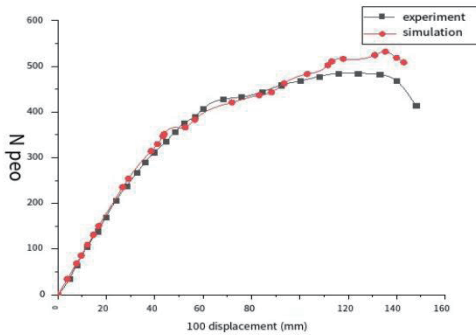


FIG. 1 Comparison of skeleton curves of a single steel frame

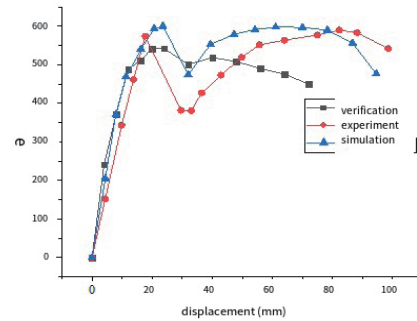


FIG. 2 Comparison of SPW-3 skeleton curves

As shown in FIG.1, the comparison of simulation and test data for a single steel frame shows that the maximum error rate is controlled within 9.7%, indicating a high degree of consistency between the two. Further observation of the skeleton curve simulation results in FIG.2 shows that there is a slight difference of about 10.4% between the simulation results and the test data at the peak load point. This deviation can be reasonably explained by the use of finer meshes (C3D8R solid elements) to simulate steel frames in the literature. Although this method improves the simulation accuracy, it also significantly increases the calculation time cost. In view of this, this paper adopts the S4R element, which has higher computational efficiency within the acceptable range of guaranteed error, to effectively balance the accuracy and efficiency. In addition, the simulation results in this paper are consistent with the description in literature, and both capture the two-stage characteristics of the structural failure process, thus verifying the feasibility and effectiveness of the modeling method adopted in this paper in practical application.

## 3. Analysis of finite element results

### 3.1 Skeleton curve

Skeleton curves of F1 and F2 are shown in FIG.3. The analysis shows that the stress process of F1 covers three stages: elasticity, elastoplasticity and failure. Because of its good ductility, the skeleton curves do not show an obvious inflection point at the yield point. Densely ribbed composite wall can significantly enhance the bearing capacity of steel frame. In the initial stage, when the lateral force resisting system is still working in an elastic state, the slope of the skeleton curve of F2 is large, indicating that its bearing capacity increases rapidly. However, with the gradual increase of displacement load, the composite wall begins to crack, and the system enters the elastoplastic working stage, at which time the slope of the curve decreases. The growth rate of bearing capacity of the structure slows down.

### 3.2 Stiffness degradation

Refer to the calculation of tangential stiffness of components in "Building Seismic Test Method Regulations", and the stiffness degradation curve can be obtained according to the calculation results, as shown in FIG.4. As shown in FIG.4, the initial stiffness of F1 is only 8.74kN/mm, while that of F2 is as high as 87.76kN/mm. The stiffness of F1 and F2 degenerated rapidly in the initial stage, and with the increase of displacement, the degradation rate gradually slowed down and eventually became stable. Since the initial stiffness of F1 is low, its stiffness decay in the later stage is not obvious in the figure. The use of multi-ribbed composite walls can significantly improve the initial stiffness of the structure.

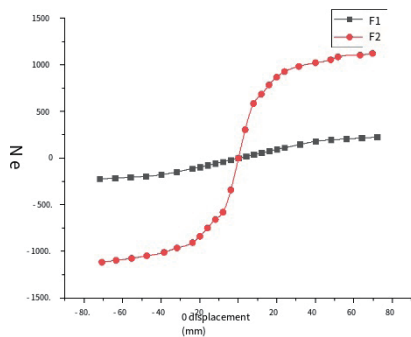


FIG. 3 Skeleton diagram

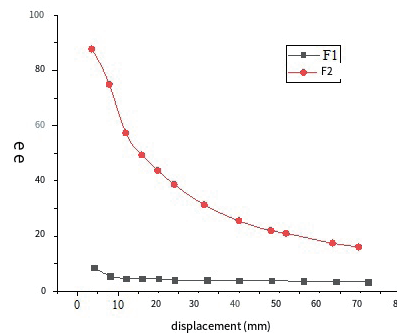


FIG. 4 Stiffness degradation diagram

### 3.3 Ductility

Ductility is measured by the ductility ratio, the ductility of F1 and F2 is shown in Table 1 below.

**Table 1 Displacement ductility coefficient of the model**

Model name	Yield displacement	Ultimate displacement	Ductility ratio
F1	32mm	72mm	2.25
F2	The 15.95 mm	The 70.22 mm	4.4

According to Table 1, the ductility ratio of the multi-ribbed composite wall integrated into the steel frame structure can be significantly improved. The ductility ratio of the lateral force resisting system is 4.4, and the wall can effectively enhance the plastic deformation resistance of the whole system.

#### 3.4 Energy dissipation capacity

The energy-consuming capacity of F1 and F2 is shown in Table 2 below, expressed by the equivalent viscous damping coefficient.

**Table 2 Equivalent viscous damping coefficients of F1 and F2**

Model name	Yield	Limits
F1	0.02	0.19
F2	0.23	0.29

As can be seen from Table 2 above, after the introduction of the dense ribbed composite wall structure, the energy dissipation capacity of the structure is increased by about 10.5 times in the yield stage and about 53% in the limit stage. In the later stage, the energy dissipation capacity gradually slowed down because the wall gradually tended to be destroyed.

## 4. Conclusion

4.1 F1 goes through three stages of elasticity, elastoplasticity and plasticity during loading; F2 exhibits a unique energy dissipation mechanism during the loading process. In the initial stage, the block, as the primary defense line, absorbs and digests the external load energy; Subsequently, the concrete frame and the block work together to jointly bear the external load; When the concrete frame is damaged to a certain extent, the steel frame begins to take over the main bearing task.

4.2 The hysteresis curve shape of F1 and F2 is fusiform as a whole, and the hysteresis ring is full, with excellent energy dissipation performance. Compared with F1 model, F2 has a significant increase in load bearing capacity, which verifies its feasibility of application as a load-bearing wall in steel frame structures. In addition, the ductility coefficient of F2 model is increased by 95.6% compared with F1 model, which reflects the excellent performance of F2 in structural deformation capacity, and has stronger adaptability and safety.

4.3 The introduction of multi-ribbed composite wall has a significant contribution to improving the stiffness of the lateral force resistance system. The initial stiffness of F2 is as high as 17.21 times that of F1. In terms of stiffness degradation characteristics, F1 model shows a relatively gentle degradation trend, while F2 has undergone a transformation process from fast to slow. This change is directly attributable to the strengthening effect of the densely ribbed composite wall, which not only greatly improves the overall stiffness of F2, but also effectively enhances the energy dissipation capacity of F2 model through its unique structural characteristics, making the structure play a more stable and lasting role in the face of external forces.

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