Finite Element Analysis of Prefabricated Concrete Box Structure System on OpenSees software

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Abstract: This paper presents a new type of prefabricated concrete structure system and the corresponding shear wall structure. The finite element analysis of the prefabricated wall base on OpenSees is carried out to analyze its mechanical properties. The rationality and correctness of the finite element analysis are obtained by comparing it with the test hysteresis curve.

1. Introduction
The box structure system refers to that the box type is taken as a unit in the factory, and different box types are hoisted on site to form a box structure. Experts at home and abroad have done a lot of research on box structure. Habitat 67 was built in Montreal, Canada. Prefabricated accessory units, stairs, elevator shafts, air platforms and passageways are all constructed with exposed concrete boxes. The lower box supports the upper box. The support points between the upper and lower boxes are made of steel plates and rubber pads and anchored together with steel bars to form an energy-dissipating structure to absorb seismic loads. In 1972, Hiragawa designed the cabin building of the Bank of China in Japan [2]. A total of 140 cabin modules are connected by prefabricated modular units measuring 2.3m x 3.8m x 2.1m. They are suspended from reinforced concrete cores with internal elevators and pipes. In 2009, the Wolverhampton Student House was completed in the United Kingdom. It is the tallest integrated modular building in the world, consisting of three buildings of 8-25 floors. There is also a 12-storey student apartment building in Bristol, England. Module units are special-shaped modules. In this paper, a new prefabricated shear wall structure is proposed, as shown in Fig. 1. Through finite element analysis, its mechanical properties and mechanical properties are analyzed, and compared with the test hysteresis curve, the rationality and correctness of the finite element analysis are obtained.

Fig. 1 Configuration details of specimens
2. Finite element analysis

2.1. Software Introduction
OpenSees is an integrated platform for finite element numerical analysis, finite element response sensitivity analysis, and finite element reliability analysis. Its full name is Open System for Earthquake Engineering Simulation. In OpenSees, there are many integrated nonlinear material constitutive relationships of reinforcement and concrete. For shear wall structures, the initial fiber section division has gradually evolved to include many elements nested in the OpenSees source program, such as strut elements, layered shell elements, truss strut elements, and strut elements with bending-shear coupling. This chapter first introduces the method of using OpenSees to build an analysis model of the assembled shear wall. Then, numerical analysis of the assembled shear wall is performed according to the model. Finally, the results of the analysis model built by OpenSees are compared with the results of the test data.

2.2. Material constitutive relation

2.2.1. Steel constitutive
Steel fiber is simulated using the Steel02 model, as shown in Figure 2. This model was proposed by Giuffrè-Menegotto-Pinto, and the stress can be expressed by an explicit function of strain, so it has high computational efficiency. At the same time, the calculated results of the model are in good agreement with the repeated loading test results, and can reflect the Bauschinger effect. In addition, the model has an initial stress attribute that can define initial values to simulate prestressed tendons.

The loading and unloading curves of the model are determined by two asymptotic lines whose slopes are elastic modulus $E_s$ and strengthening modulus $E_h$ respectively. The shape of ITD of loading and unloading curve is controlled by parameter $R$, which reflects the Bauschinger effect of reinforcement. Its value depends on the strain difference between the intersection point $A$ of the current asymptote and the reverse point $B$ of the previous load:

$$ R = R_0 - \frac{a_1 \xi}{a_2 + \xi} $$  \hspace{1cm} (1)

Where, $R_0$ is the initial value of parameter $R$ during the first loading; $A_1$ and $A_2$ are the parameters determined by the test. $R_0$ is also associated with parameters $C_{R1}$ and $C_{R2}$ in the model definition, refer to the OpenSees user manual.

![Fig. 2 Constitutive model of steel structure](image)
2.2.2. Concrete constitutive
In the nonlinear fiber beam-column element, it is necessary to give the corresponding constitutive relation to the concrete fiber. In this paper, the Concrete02 model is adopted. The skeleton curve of the tensile part of the model is a double broken line model, that is, the elastic ascending section and the linear descending section. The skeleton curve of the compression part is based on the Kent-Park model and consists of three parts: the parabola ascending section, the oblique straight line descending section, and the flat straight line residual section. The hysteretic rules of the model are composed of a series of straight lines, and the stiffness degradation and hysteretic energy dissipation in the process of concrete loading and unloading can be taken into account. Compared to the earlier Concrete01 model in OpenSees, the Concrete02 model is more accurate because it takes into account the tensile properties of concrete and the different unloading and reloading paths under compression.

2.2.3. Other material constitutive relations
Under the lateral force of the shear wall, even the steel bars with sufficient anchorage length will have strain permeability, that is, the slip between the steel bars at the bottom of the shear wall and the concrete will occur. The monotone stress-strain curve of Bond_SP01 model is shown in Figure 3. The stress-slip relationship is adopted in the model. The corresponding slip amount is obtained by defining the yield strength of reinforcement and putting it into Equation (2). The slip corresponding to the ultimate strength of reinforcement can be calculated by Equation (3).

\[
S_y = 2.54 \cdot \left[ \frac{d}{8437} \cdot \frac{f_y}{f_y} \cdot (2\alpha + 1) \right]^{1/\alpha} \\
S_u = (30 \sim 40) \times S_y
\]

2.3. Model establishment
Because the fiber model ignores the shear deformation and only considers the coupling of the component under the action of bending moment and axial force, it will lead to the deviation of the component in the nonlinear analysis, especially for the component with shear failure or bending shear failure. Therefore, in order to be able to simulate the shear deformation of a member, OpenSees considers the shear effect of the member by combining the shear material into the fiber cross section, as shown in Figure 4. Using the Section Aggregator command in OpenSees, the original fiber Section and the Elastic shear material group are combined into a new Section to take into account the shear deformation of the shear wall.

In this paper, a fiber model considering shear effect is adopted to conduct numerical modeling analysis on the prefabricated shear wall, and concrete fiber and reinforcement fiber are divided along the direction of cross-section height, as shown in Fig. 4. The main body of shear wall adopts nonlinear beam column unit DisbeamColumn, the concrete of the fiber section is endowed with Concrete02 model, steel bar is endowed with Steel02 model; At the bottom of the shear wall, a zero-length rotating spring ZerolengthSection is adopted. The concrete of the fiber section is endowed with the Concrete02
model, and the steel bar is endowed with the Bond_SP01 model, so as to simulate the reinforcement slip caused by the deformation incompatibility between the concrete and the steel bar at the bottom support. See Fig. 4 for the establishment of the component model and the fiber arrangement of the section.

![Fig4 Construction of shear wall fiber model](image)

### 3 Finite element calculation

#### 3.1. Model Verification

![Graphs of model verification](image)

### 4. Conclusion

1. This paper proposes a new box structure system. The precast walls and floor slabs are firmly connected through the connection of cast-in-place nodes to form a box structure system.
2. Through the finite element analysis of the mechanical properties of the wall, the ultimate bearing capacity of the wall is obtained. Compared with the hysteresis curve of the wall, it is quite close, which verifies the effectiveness of the finite element.

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