Seismic Performance of Assembled Building Structure in Smart City

Qinyuan Chen
School of Information and Architectural Engineering, Anhui Radio and Television University, Anhui, China
*Corresponding author e-mail: chenqinyuan@ahou.edu.cn, 772447689@qq.com

Abstract. In recent years, prefabricated buildings have made good development. Compared with ordinary reinforced concrete construction projects, prefabricated buildings have higher requirements for seismic resistance. In this paper, the seismic performance of the assembled building structure in smart city is studied. In the study, we use open sees to establish the finite element model, and take the common seismic performance indexes as the evaluation indexes, and compare the prefabricated structure with the cast-in-place structure from the aspects of ductility, stiffness degradation and energy dissipation. The results show that when the displacement reaches 80 mm, the energy consumption of the two structures reaches the maximum value, and the energy consumption of prefabricated structure is 20000 KN / mm, and that of cast-in-place structure is 30000 KN / mm. In addition, the research results show that the ductility coefficient of prefabricated structure is slightly smaller than that of cast-in-place structure, but its stiffness degradation is better than that of cast-in-place structure. Generally speaking, the seismic performance of prefabricated building structure is better than that of cast-in-place structure. The research results of this paper will provide certain reference value for the development and construction of smart city.

Keywords: Smart City; Prefabricated Building Structure; Seismic Performance; Finite Element Model

1. Introduction
Smart city is an advanced form of urban modernization and informatization, which takes information and communication technology facilities as the cornerstone, promotes social development, strengthens social management and enriches social life as the core task, and is characterized by more optimization, greener, more beneficial to the people and more refined [1-2]. With the development of science and technology, the construction of new smart city has gradually risen to the national strategic level, and has been supported by all sectors of society [3-4]. At present, China's environmental pollution is serious, labor costs are rising, strictly speaking, the traditional construction industry has been unable to meet the needs of smart city. In addition, at this stage, the state is constantly vigorously promoting green and energy-saving buildings, and the construction industry is facing the situation of transformation and upgrading. In this case, prefabricated buildings are highly valued by all sectors of
society [5]. At present, the national leadership proposes to promote the reform of the construction industry and develop industrialized buildings. Therefore, the state and the industry have also issued some goals and policies on the development of prefabricated buildings. At the same time, it has also promoted the construction of Industrialization Bases and pilot demonstration projects [6].

As a kind of construction form with relatively low cost and component production site in the workshop, prefabricated building causes relatively small waste of resources and environmental pollution, and has considerable environmental value and application prospect [7-8]. At any time, the seismic performance of buildings is very important. If the seismic performance is too poor, once an earthquake occurs, it may seriously affect the safety of human life and property [9-10]. Therefore, it is of great significance for the construction of smart city to study the seismic performance of prefabricated building structure and explore its application.

In this paper, the finite element model is established by using open sees. The three seismic performance indexes of ductility, stiffness degradation and energy dissipation are taken as evaluation indexes, and the cast-in-place structure is taken as the contrast to study the seismic performance of prefabricated building structure. The results show that the prefabricated building structure has good seismic performance, and its seismic performance is better than that of cast-in-place structure.

### 2. Prefabricated Building and Seismic Performance Analysis Method

#### 2.1. Prefabricated Buildings

Prefabricated building is a reform in China’s construction industry. It changes the traditional construction method and adopts a new building block construction method. From the previous low efficiency, high cost of extensive change to the current high efficiency, low cost of fine construction mode. Compared with traditional structure and material pollution, prefabricated building can effectively improve the construction period and reduce material consumption. With the development of society, prefabricated building develops rapidly and has become a novice in the construction industry and is being promoted worldwide. Prefabricated buildings have many advantages, which can be summarized as follows:

1. **The degree of industrialization is relatively high**
   
   Compared with ordinary reinforced concrete construction project, prefabricated building can realize industrial assembly. No matter floor panel, wall panel, insulation layer, load-bearing structure, etc., can be assembled at the construction site for prefabrication, production and transportation. With high serialization and assembly, it can be mass produced like ordinary goods.

2. **More flexible design**

   The shape design of prefabricated building is relatively free, which can provide designers with sufficient imagination space, and the appearance is relatively beautiful. The span and column spacing can be reasonably adjusted and arranged according to the actual needs. The design of non load-bearing wall is also more flexible, which can carry out good indoor zoning, improve the space utilization rate, and meet the requirements of modern construction projects.

3. **Lighter weight**

   Compared with the ordinary reinforced concrete building, the biggest feature of prefabricated building is lighter weight, which is less than 20% ~ 50% of reinforced concrete. Lightweight wallboard can be selected for enclosure structure, and the steel consumption is relatively small. Due to the small self weight, the requirements for foundation are not high, which can reduce the cost of foundation treatment.

4. **Good seismic performance**

   Due to the steel structure of prefabricated building, it has high strength, strong toughness and light weight. Compared with traditional reinforced concrete, it has better seismic performance.

#### 2.2. Seismic Performance Analysis Method

In the seismic performance analysis, ductility, stiffness degradation and energy dissipation are usually
analyzed.

1) Ductility

Ductility is a key index which can reflect the plastic deformation performance of structure or specimen. Good ductility can assist structure to absorb and dissipate seismic energy and prevent brittle failure. In addition to the static and ductility of the structure, it also needs good bearing capacity. If the deformation of the structure is large when it is subjected to a strong earthquake, the more seismic energy it consumes, the smaller the damage of structural components, and the safer the structure is. If the static bearing capacity of the structure is large, the stiffness is large, and the ductility is poor, then the possibility of collapse of the structure under strong earthquake action is greater.

When the displacement ductility coefficient ($\mu$) represents the ductility of the specimen under loading, it can be expressed as follows:

$$\mu = \frac{\Delta_u}{\Delta_y}$$ (1)

Where $\Delta_u$ represents the ultimate displacement and $\Delta_y$ represents the yield displacement.

2) Stiffness degradation

With the increase of loading times, the cumulative damage in the specimen develops continuously, and the stiffness decreases with the increase of loading times. The stiffness degradation is described by the ring ratio stiffness under the same loading amplitude

$$K_j = \sum_{i=1}^{n} f_{i,j} \frac{n \delta_j}{\delta_j}$$ (2)

3) Energy consumption performance

The energy dissipation coefficient $e$ can be used to measure the energy dissipation capacity of the model in earthquake

$$\Delta Y = \mu \Theta K \Theta E$$ (3)

The energy dissipation capacity of the structure determines the degree of its resistance to damage.

3. Establishment of Finite Element Model

In this paper, the finite element model is established by using open sees, and the model is a frame model. In the process of establishing the model, it is very important to analyze the position of each node, the form of constraint, the constitutive relation of material, the concentrated mass of node, the type of element, the type of external load, the restoring force model of section and the type of geometric coordinate transformation. On this basis, the sub objects of the finite element model are constructed and combined into a finite element model.

1) Constitutive model of concrete

In the model, the constitutive model of concrete is very important. Therefore, in the study, we adopt the Concrete 02 Material constitutive model. The stress mode of this model is Kent Scott Park uniaxial stress. In other words, this model considers the restraint effect of transverse stirrups by modifying the relevant strain, peak stress and slope of softening section on the skeleton compression curve influence.

2) Constitutive model of steel bar

The steel bar constitutive model in this paper is Steel 02 Material ordinary steel bar constitutive model. In Steel 02 Material model, the prestress effect is considered by setting the initial prestress level of reinforcement. When the initial prestress value is zero, it is non prestressed reinforcement.

3) Section object

The section object used in this paper is Fiber Section.
Generally speaking, we take the post tensioned unbonded prestressed precast concrete joint as the analysis object, and in the test, we place high-strength prestressed steel strand in the beam axis position to assemble the precast concrete beam and column on site. On the other hand, we design three joint specimens, considering the influence of the initial prestress, the strength and area of the energy dissipating steel bar respectively, and conduct the low cycle repeated loading test on the joint to study its seismic performance.

4. Seismic Performance of Assembled Building Structure in Smart City

In order to ensure the accuracy of the finite element model established in this paper, we verify the model. The results show that the load, loading mode and the selection of frame structure parameters of the finite element model established in this paper are verified. The performance of the fabricated structure is analyzed below.

4.1. Ductility Analysis

Ductile structure has the following advantages:

(1) The bearing capacity of ductile structure is not only for the predicted load, but also has good bearing capacity when unexpected load occurs (such as accidental overload, load reversal, foundation settlement or temperature stress, etc.).

(2) The failure process of ductile structure is slower than that of brittle structure, and there are obvious omens before the failure. In this way, people will have more time to escape in case of earthquake, and the safety of life and property will be better protected.

(3) When the ductile structure is subjected to vibration, explosion, earthquake and other dynamic or accidental actions, the inertia force will be reduced, the seismic energy will be absorbed, and the damage degree will be reduced, which is more conducive to the later structural repair.

(4) In the design of the structure, it is usually required to form plastic hinge in some specific parts of the structure to form the same failure form as the expected result, so as to realize the redistribution of the plastic internal force of the structure. However, in order to achieve the predetermined position distribution of plastic hinge, the structure or component must have enough ductility.

In this paper, the ductility of cast-in-place structure and fabricated structure are compared, and the displacement ductility coefficient of characteristic points of the two types of structures is shown in Table 1.

| Table 1. Displacement ductility coefficient of characteristic points |
|---------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Structure type      | Load direction  | Yield load (kN) | Yield displacement (mm) | Ultimate load (kN) | Ultimate displacement (mm) | Ductility coefficient |
| Cast in place structure | Forward         | 229.52          | 31.86             | 275.67          | 79.75           | 2.51             |
|                     | Reverse         | 221.64          | 26.66             | 266.05          | 80.00           | 3.00             |
| Fabricated structure | Forward         | 252.34          | 25.66             | 294.05          | 78.74           | 3.12             |
|                     | Reverse         | 232.52          | 21.32             | 272.17          | 80.00           | 3.78             |

It can be seen from Table 1 that under forward loading, the yield load of prefabricated structure is 229.52kN, the yield displacement is 31.86mm, the ultimate limit is 275.67kN, the ultimate displacement is 79.75mm, the ductility coefficient is 2.51, the yield load of cast-in-place structure is 221.64kN, the yield displacement is 26.66mm, the ultimate load is 266.05kN, the ultimate displacement is 80.00mm, and the ductility coefficient is 3.00. Under reverse loading, the yield load, yield displacement, ultimate displacement and ductility coefficient of prefabricated structure are 252.34kN, 25.66mm, 294.05kN, and 78.74mm, respectively. Under reverse loading, the yield load, yield displacement, ultimate displacement and ductility coefficient of prefabricated structure are 232.52kN, 21.32mm, 272.17kN, and 80.00mm, respectively. Generally speaking, the ductility coefficient of prefabricated structure is lower than that of cast-in-place structure, and the positive ductility coefficient is smaller.
4.2. Stiffness Degradation Analysis

Under the action of low cycle reciprocating load, the structure will degenerate due to the cumulative damage. Usually, the stiffness of the structure will degenerate. In this paper, the stiffness degradation of cast-in-place structure and assembly line structure is analyzed. The results of stiffness degradation are shown in Figure 1.

![Figure 1. Analysis of stiffness degradation results of two structures](image)

It can be seen from Figure 1 that when the displacement is 10 mm, the stiffness difference between the two structures is relatively large. The stiffness of the fabricated structure is 10000 N / mm, and that of the cast-in-place structure is 16000 N / mm. When the displacement gradually increases, the stiffness of the two structures gradually decreases, but the stiffness of the fabricated structure is always less than that of the cast-in-place structure. When the displacement reaches 80 mm, the stiffness of the two structures reaches the minimum. At this time, the stiffness of the fabricated structure is 4000 N / mm, and that of the cast-in-place structure is 4100 N/ mm. In addition, we can see from the figure that during the whole loading process, the stiffness degradation trend of prefabricated structure is basically consistent with that of cast-in-place structure. With the increase of displacement, the stiffness gradually decreases. Moreover, the stiffness degradation is fast in the early stage, and the reduction range gradually tends to be gentle in the later stage, and the stiffness of the two gradually approaches, and the difference is smaller and smaller.

4.3. Energy Consumption Analysis
Figure 2. Energy consumption analysis of two kinds of structures

It can be seen from Figure 2 that when the displacement is 10 mm, the energy consumption of fabricated structure is 500KN / mm, and that of cast-in-place structure is 510KN / mm. With the increase of displacement, the energy consumption of the two structures also increases. When the displacement reaches 80 mm, the energy consumption of both structures reaches the maximum value. At this time, the energy consumption of prefabricated structure is 20000 KN / mm, and that of cast-in-place structure is 30000KN / mm. From this, we can see that the energy consumption capacity of prefabricated structure and cast-in-place structure is basically the same with the change trend of displacement. In the early stage of loading, the energy consumption capacity of the two structures is roughly the same, and both are small. With the increase of displacement, the gap between them is more and more. The final result is that the energy consumption of prefabricated structure is less than that of cast-in-place structure.

The equivalent viscous damping coefficient is an evaluation index to judge the energy dissipation capacity of the structure. We analyze the equivalent viscous damping coefficient of the two structures, and the results are shown in Table 2.

Table 2. Equivalent viscous damping coefficients of two structures

| Displacement(mm) | Fabricated structure | Cast in place structure |
|------------------|---------------------|------------------------|
| 1Δ               | 0.10                | 0.10                   |
| 2Δ               | 0.10                | 0.10                   |
| 3Δ               | 0.11                | 0.12                   |
| 4Δ               | 0.10                | 0.13                   |
| 5Δ               | 0.11                | 0.14                   |
| 6Δ               | 0.10                | 0.15                   |
| 7Δ               | 0.11                | 0.16                   |
| 8Δ               | 0.12                | 0.18                   |
| 9Δ               | 0.13                | 0.20                   |
| 10Δ              | 0.20                | 0.22                   |

(The table shows the reference value of Δ horizontal displacement loading)

It can be seen from Table 2 that with the gradual increase of displacement, the equivalent viscous damping coefficient of prefabricated structure and cast-in-place structure shows a gradual increase trend, and that of cast-in-place structure is relatively larger, which is basically consistent with the law of energy dissipation capacity. The maximum equivalent viscous damping coefficient of prefabricated structure is 0.20, and that of cast-in-place structure is 0.22. We know that the equivalent viscous
The damping coefficient of reinforced concrete structure is between 0.1 and 0.2, which shows that the equivalent viscous damping coefficient of fabricated structure and cast-in-place structure basically meet the requirements.

4.4. **Hysteresis Curve**

The hysteretic curve can reflect the deformation, bearing capacity, ductility, stiffness change and energy dissipation performance of the structure, and the seismic performance of the structure can be judged from these actual parameters. Figure 3 shows the hysteretic curves of cast-in-place structure and fabricated structure.

![Hysteretic Curve Comparison](image)

**Figure 3.** Comparison of hysteretic curves of the two structures

It can be seen from Figure 3 that when the displacement is -80mm, the load of both is -275kN, and when the displacement is -60mm, the load of the prefabricated structure is -269kN, and that of the cast-in-place structure is -262kN. Moreover, it can be seen that the envelope area of the hysteretic curve of the fabricated composite frame structure is smaller than that of the cast-in-place structure, indicating that the energy consumption performance of the fabricated structure is less than that of the cast-in-place structure, and its seismic performance is weakened to a certain extent. This is mainly due to the constraint at the splicing area of the assembled structure defined as the friction type contact surface, which will lead to the partial loss of the energy consumption capacity of the structure.

4.5. **Skeleton Curve**

Skeleton curve is the envelope of hysteretic curve, which is the track of peak bearing capacity of each stage of cyclic loading. It can reflect the properties of the structure in each stage. According to Fig. 3, the skeleton curve comparison diagram of fabricated structure and cast-in-place structure is drawn, as shown in Figure 4.
Figure 4. Comparison of skeleton curves of the two structures

It can be seen from Figure 4 that when the displacement is -80mm, the load of prefabricated structure is -261kN, and that of cast-in-place structure is -249kN. With the continuous change of displacement, the load of the two structures is also different. When the displacement is -60mm, the load of prefabricated structure is -259kN, and that of cast-in-place structure is -245kN. Although the skeleton curve trend of prefabricated structure is basically consistent with that of cast-in-place frame structure, the envelope area of fabricated structure is larger than that of cast-in-place structure, which indicates that its energy consumption capacity is better than that of cast-in-place structure.

5. Conclusions
With the development of science and technology, the development of smart city in China is also accelerated. Although China's urbanization is getting higher and higher, at the same time, China is still a developing country. The government needs to provide some affordable housing for the residents in need. However, the traditional cast-in-place structure, which was popular in the early stage in China, has exposed some prominent problems such as environmental pollution and waste of resources. In this case, prefabricated architecture came into being. The seismic performance of buildings is very important. Therefore, this paper studies the seismic performance of prefabricated building structure. In the research, we established the finite element model, and compared the prefabricated structure with the cast-in-place structure, and analyzed the ductility, stiffness degradation and energy dissipation performance of the common seismic performance indicators. The results show that the seismic performance of prefabricated structure is better than that of cast-in-place structure.

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