Research Progress on The Seismic Performance of Fabricated Concrete Structures

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Abstract. In recent decades, the application of prefabricated structures has become more and more extensive, especially for prefabricated concrete structures. The research on its seismic performance plays a significant role in the process of application and promotion of this structure. This paper mainly summarizes the research results on the seismic performance of prefabricated concrete structures, and it is actually based on the seismic research of dry connections, wet connections, new connections and different structural systems. The new dry connections with good seismic performance are considered to have better application prospects. In addition, it analyses the application of seismic design with recoverable functions in this field, and it is concluded that new seismic technologies such as recoverable function structures and damage control structures should be widely used. Finally, the research status of seismic performance of prefabricated concrete structures is summarized and analyzed. In the future promotion and application, it is necessary to continuously update the relevant regulations and improve seismic design methods and technologies.

Keywords: Prefabricated Concrete Structure; Prefabricated Connection; Structural Systems; Seismic Performance; Recoverable Function Structures.

1. Introduction

Nowadays, although the scale of China's architecture is huge, there are still a number of problems in the low construction standards, poor adaptability, comfort, and durability. In addition, the construction industry has a backward construction process, and there is a large gap with developed countries, and a large amount of energy and materials need to be consumed. In addition, labor resources have decreased sharply, and energy conservation is imperative. In this background, the development of prefabricated buildings is the general trend, which is of great significance for construction industrialization. In the 1990s, some developed countries, including the United States and Japan, had already begun the development and application of prefabricated architectural structures. In the 21st century, with the upgrading of the construction industry, China gradually vigorously developed prefabricated buildings. In February 2016, the State Council issued the "Several Opinions on Further Strengthening Urban Planning and Construction Administration". This document clearly proposes to vigorously promote assembly buildings, and formulate prefabricated building design, construction and acceptance specifications. In the latest "14th Five-Year Plan" Construction Industry Development Plan issued by the Ministry of Housing and Urban-Rural Development, it is proposed that China should initially form a framework for the high -quality development system framework of the construction industry. The level of construction industrialization, digitalization, and intelligence has been greatly improved, and the construction industry has changed from a large to strong. In 2026, prefabricated buildings will account for 30% of new constructions. Therefore, the related research of prefabricated buildings is of prime importance to the development of the construction industry.

Compared with traditional structures, prefabricated buildings have the advantages of improving the quality of building, improving operational efficiency, and saving materials. At the same time, it helps save energy and emission reduction, save labor, and improve labor conditions. The prefabricated concrete structure, as one of the main structures of prefabricated buildings, has a significant effect in improving the quality of the building. Its design is more refined and coordinated, and the building accuracy is higher. Concrete pouring, vibration and maintenance are more sufficient.

In practical applications, the scope of adaptive concrete structures is very wide and can adapt to a variety of architectural styles. With the large design and application of prefabricated concrete structures, we should also study its seismic performance. As we all know, the impact of earthquake disasters on human production and life has a huge threat. Whether the prefabricated concrete structure can have good shock resistance will largely determine its further development and application. Therefore, we need to conduct more in -depth research in this field to ensure that the prefabricated concrete structure system can meet the seismic demand.

In the above background, this paper summarizes the research progress of seismic resistance on prefabricated concrete structures in recent years. From two perspectives, the seismic resistance performance is summarized from the perspective of prefabricated concrete structure connections and the overall structure system. In addition, analysis shows that the recovery functional seismic design method will gradually occupy the mainstream. The recovery function and the prefabricated concrete structure with damage control conform to the development trend and will become a hot spot for research. The last part of the paper summarizes the status and problems in the field of earthquake resistance in prefabricated concrete structures, and looks forward to the application prospects of new seismic technology and the application prospects of prefabricated concrete structures.

2. The seismic performance of different connectionS

2.1. Wet Connection

Wet connection is the main connection method of prefabricated concrete structures, and the reinforced grouting sleeve connection is currently the most common wet connection method. This connection refers to inserting steel bars in a metal sleeve embedded in prefabricated concrete components and irrigation cement grouting materials. As the main connector technology recommended by "Technical Regulations for Prefabricated Concrete Structure", the sleeve grouting connection is an important basis for various prefabricated concrete structures. The grouting sleeve is divided into semi -grouting sleeve and full grouting sleeve. Commonly used sleeves are shown in Figure 1.

Figure 1. Grouting sleeves.

Compared with the traditional reinforcement connection method, the reinforced grouting sleeve connection can reduce the pre -processing workload of the steel, and the on -site construction is relatively simple. The sleeve assembly is easy, and it is not easy to be flexed, which is conducive to post -earthquake repair. According to the research of Gao et al., in the prefabricated concrete frame structure, the edge nodes connected to the steel bars grouting sleeve and the concrete nodes of the cast -in -law have similar seismic properties. In similar actual projects, the principle of equivalent cast can be adopted.

For the grouting sleeve connection, the performance of the grouting material plays a decisive role in the seismic performance of the connection. In actual engineering, the sleeve grouting defect is often caused by the blockage of the sleeve or the irregular grouting. In addition, the impact of the steel band sleeve grouting connection is also needed, and its mechanical properties will determine the seismic resistance of the connection to a certain extent. Properly increasing the anchor length and diameter of the reinforcement can improve the bearing capacity of the connection, thereby improving the seismic resistance of the connection.

Liu et al. proposed to use cement base composite materials (ECC), which can improve the ductility and energy-dissipating capabilities of the component, but in the meantime, the intensity and stiffness are slightly reduced. The test uses a vertical load on the beam end. The hysteresis curve of the test parts is obtained as shown in Figure 2. The A test parts use ordinary concrete materials. Both the b and c test parts are connected by sleeves made of ECC. It can be easily found that the hysteresis curve of B and C is fuller than A. They have stronger energy dissipation capabilities and better shock resistance.

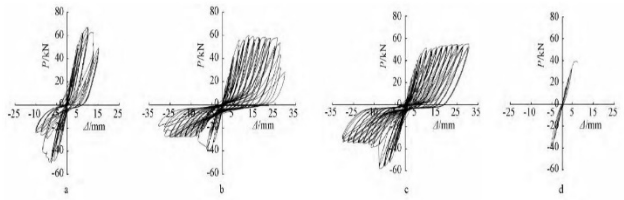

Figure 2. Hysteresis curve.

Compared with traditional paddling connection and other forms of prefabricated structure connection, wet connections have many advantages, including stronger generalization. Studies have shown that its seismic performance is subject to the performance of grouting materials and the quality of the grouting sleeve itself, and sometimes depends on the performance of rear pouring concrete. There are currently many measures to improve their seismic resistance. However, no matter which method is adopted, the corresponding costs will be improved, and the requirements for on -site construction will be higher.

2.2. Dry Connection

Dry connection does not use wet materials such as grouting and concrete for connection, but pre-embeds connection devices in components and connects by bolts, welding, etc. Bolted connection specifically refers to the use of bolts and embedded parts to connect prefabricated components to prefabricated components or prefabricated components to the main structure. Etras et al. proposed a bolted dry connection and performed low-cycle repeated loading tests on the joint. The test results show that the bolted joint exhibits better performance in strength, ductility and energy dissipation (The connection details are shown in Figure 3). The construction simplicity and assembly speed of this connection show obvious advantages compared with other connections.

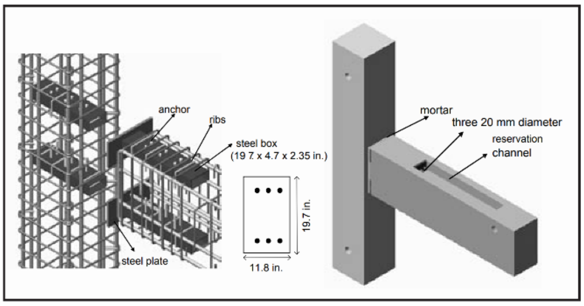

Figure 3. Improved detail and general views of bolted connections.

In addition to bolted connections, dry connections also have welded connections. Steel plates are embedded in precast concrete components, and the components are connected by welding in the same way as steel structures. Miao et al. designed a four-piece prefabricated composite wall connected by welding. The hysteresis curve of the welded joint node is shown in Figure 4. The results conform to the seismic design concept of strong nodes and weak components, and it can also meet the structural stress requirements. However, the connection has low energy consumption and complicated construction, and poor welding process may lead to brittle failure of the joint.

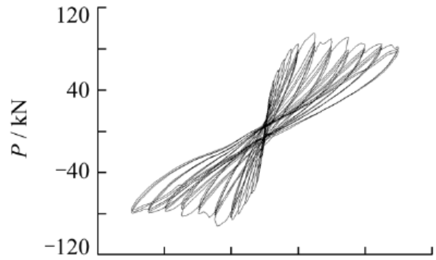

Figure 4. Hysteresis curve of welded joint specimen (horizontal load on top of specimen - horizontal displacement).

The dry connection construction is simpler. There is no on-site wet work. It is not limited by temperature, and its cost is lower. However, at the same time, for the prefabricated concrete structure, its scope of application is narrow, and the integrity of the structure is poor. Welded connections have high requirements on the quality of the welds, and the welds are easily damaged and deformed. At present, the seismic research of dry connection still needs more engineering experience and theoretical breakthrough. In the future, with the increase in the combined application of prefabricated concrete structures and steel structures, dry connections will usher in more development.

2.3. New Connection

In order to improve the on-site fabrication efficiency of prefabricated concrete frames, Yang Hui, Guo Zhengxing and others proposed a new type of dry-wet hybrid local post-tensioned pre-stressed pre-fabricated concrete frame connections. In the construction stage, the dry connection of the local post-tensioning stress at the beam end is adopted, and the construction can be assembled span-by-span and three-dimensional cross. During the use phase, the precast beams are wet-connected to the post-cast concrete surface on top of the precast slabs.

Cai et al. proposed a new type of self-resetting prestressed precast concrete frame connection (PTED joint) using top and bottom angle steel as energy-consuming components. The connection uses angle steel to dissipate energy. The seismic performance of the joint meets the requirements, and the residual deformation is small, and the post-earthquake repairability is high. The PTED joint has a good application prospect.

Wet and dry connection, unbonded prestressing technology, additional angles, additional friction dampers, these are just a few of the many joint technologies. All types of connections have good seismic performance and advanced design ideas. Some designs take into account the residual deformation of the joint, as well as the self-resetting ability, and the seismic performance can reach the level of the cast-in-place joint. If designed properly, it can even exceed the seismic performance of cast-in-place joints. However, there are still many problems in the field of new nodes that need to be solved urgently, such as cost control and specific measures for post-earthquake repair.

3. The seismic performance of different structural systems

In the 1990s, the United States and Japan started the PRESSS (Prefabricated Seismic Structural System) program in order to study multi-layer prefabricated structures with good seismic performance. The project influenced the history of research on precast concrete for earthquake resistance. The first stage of the project is to evaluate the precast concrete structural system, prepare the analytical tools, and construct a framework for the proposed revision of the code. The second stage is the test and analysis of the node. The third stage is mainly the test and analysis of the structure, and a series of studies on the seismic performance of concrete frame structures are carried out. These included a quasi-dynamic test of a five-story precast concrete structure at the University of California in 1999. The structure is a 3/5 scale model, and the elevation is shown in Figure 5. The two directions are different systems, one is a prefabricated frame system and the other is a prefabricated frame-wall system. The frame joints are prestressed joints with nonlinear elastic connection and common post-cast joints with tensile and compressive yielding connections. The structure is designed by a displacement-based design method. The results illustrate that this structural system performs well in the experiment, and the reliability of the displacement-based design method is verified.

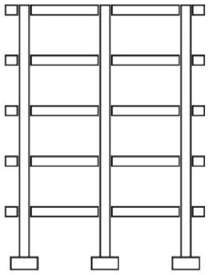

Figure 5. Elevation of prefabricated frame.

In 2004, the European Union launched the "Seismic Behavior of Precast Concrete Structures with Repect Eurocode 8" project. The ELSA laboratory has conducted a series of quasi-dynamic experimental researches on prefabricated concrete frame structures. The experimental results show that, in comparison with the cast-in-place frame, the natural vibration period of the prefabricated frame is slightly larger, the deformation is larger, and the ductility is smaller. However, the seismic capacity of the two is roughly the same. In 2005, the Tongji University team conducted a shaking table test of a 1/5 scale model of a 3-span, 3-story precast concrete frame structure (Figure 6). The beam-column and plate-beam joints are all bolted. The test shows that the overall stiffness of the structure is weak, the interlayer displacement is large, and the post-cast concrete at the connection is severely damaged, but the connection is still intact.

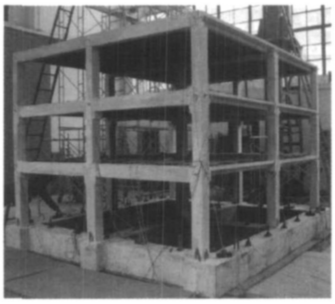

Figure 6. Shaking table test.

At present, the prefabricated concrete frame structures at home and abroad are mainly non-prestressed forms. In this structure, the arrangement of longitudinal reinforcement in the beam-column joint area is complicated. Considering the connection of steel bars and the pouring of concrete, the construction is difficult and the efficiency is low. Liu et al. focused on the seismic performance of pre-pressed prestressed concrete frames. In this structure, the post-tensioned prestressed tendons can not only be used as a means of fabrication in the construction stage, but also can bear the bending moment of the end of the beam in the use stage, forming an overall stress node and a continuous stress frame (Figure 7). The structure solves the joint force problem and the assembly problem at the same time. Liu Bingkang et al. also passed the test of two pre-pressed prestressed concrete frames under low-cycle repeated loads, showing that the structure has good energy dissipation capacity, and the beam end section has good rotation capacity. In addition, the effect of prestress makes the structure have certain deformation recovery ability, which is conducive to the repair after earthquake.

Figure 7. Frame diagram.

The research on the seismic resistance of prefabricated concrete structures was mostly focused on frame structures in the previous stage. In fact, prefabricated concrete shear wall structures are also worthy of in-depth study. Ma uses a variety of model comparison and analysis methods to analyze the seismic performance of the fabricated shear wall structure and the cast-in-place structure under frequent earthquakes. In the inverted triangle loading mode, PKPM&PUSH is used for static elasto-plastic analysis, and ABAQUS is used for dynamic elasto-plastic analysis. The plastic hinge distribution obtained from the static pushover analysis can be seen in Figure 8.

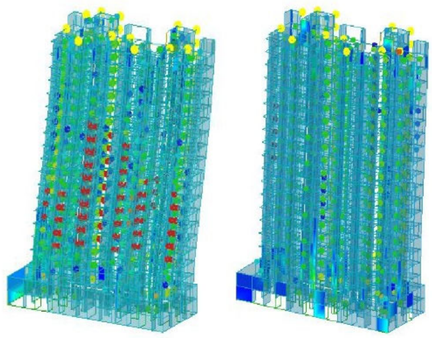

Figure 8. Distribution of plastic hinges after loading in X and Y directions.

The research results show that the displacement development of the fabricated concrete structure is more serious under the action of seismic waves. More seams result in less stiffness and severe bottom damage. Based on the results of the study, Mar Depot recommended strengthening the middle floors of the structure.

4. Recoverable Function

Based on the damage degree of components under the action of earthquake, the "Code for Seismic Design" clearly puts forward the "three-level, two-stage" seismic fortification target. Under the action of rare earthquakes, the components consume the seismic capacity and cause plastic deformation and damage. At the same time, the overall structure may not be able to continue to be used because of the large amount of damage to the components or the large residual deformation. In order to reduce this economic loss, the concept of seismic design with recoverable functions has gradually been paid attention to in practical engineering projects. Restorable functional structures have gradually become a research hotspot. This kind of structure has light damage and residual deformation, which is conducive to the rapid recovery of normal use functions after earthquakes.

Guo proposed a beam-column connection of self-centering prestressed concrete frame with web friction device. The specific structure is shown in Figure 9. This connection greatly increases the energy dissipation capacity of the structure, and it has the function of self-resetting after the earthquake. In addition to serving as a friction surface, the steel sleeve at the beam end can also improve the local pressure bearing performance.

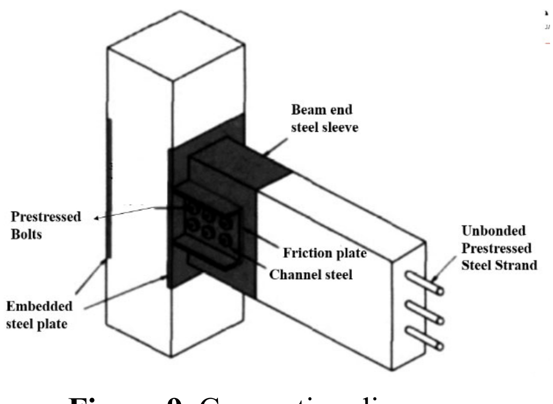

Figure 9. Connection diagram.

Unlike Guo, who started from the point of view of node energy consumption, Zhang Siyan proposed a structural damage control method for prefabricated shear walls connected by damping devices. He designed a new connection mechanism and developed a new friction damping device and viscoelastic damping device that can improve the energy dissipation efficiency of damping materials. He carried out numerical simulation with ABAQUS using a simplified analytical model, and further explained the advantages of the new damping device in structural plastic damage control.

5. Conclusion

(1) The component connection method, component node design, construction deviation and other factors of prefabricated concrete structures will affect the mechanical properties of the structure to a certain extent. At this stage, a majority of seismic research projects are mainly conducted from the component connection level, from the structural level of research Relatively few. In fact, the good seismic performance of components does not necessarily guarantee the good seismic performance of the whole structure. The connection between the components and the whole is extremely complex, which is a complex system engineering. In the future, with the advancement of numerical simulation technology, the specific characteristics and deformation methods of prefabricated concrete structures under the action of earthquakes will have more accurate results.

(2) The connection nodes of most prefabricated concrete structures adopt structures whose seismic performance tends to be "equivalent cast". This will cause problems such as complex node structure, many wet operations, and low construction efficiency. Therefore, in the future, dry connections with good seismic performance and easy construction will occupy a more important position. Compared with the wet strong connection, this connection has better ductility and is easy to carry out seismic design.

(3) When carrying out the seismic design of prefabricated concrete structures, we should focus on the specific impact on the structure after the earthquake, emphasize the recoverable function after the earthquake, and flexibly use the self-reset technology and damage control technology.

(4) The preparation of relevant specifications for the design and construction of fabricated concrete structures should be promoted. In the actual engineering application of prefabricated concrete structures, relatively perfect seismic design and seismic technology should be properly used to accumulate engineering experience to promote the development of prefabricated concrete structures.

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