Research Progress on Prefabricated Concrete Shear Wall

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Abstract

Prefabricated buildings have the advantages of high efficiency, a short construction period, high quality, and green environmental protection, making them the development trend and representatives of construction industrialization in the construction industry. Prefabricated buildings are also considered the future direction of the construction industry. Among various types of structures, the prefabricated shear wall structure has rapidly developed due to its weight advantages and various other benefits. It was the most mature and widely used prefabricated concrete structure. Numerous studies on prefabricated shear wall structures have been carried out in the United States and other countries to further promote the development of this structure. The connection mode of the prefabricated shear wall structure greatly influences its structural performance. It is necessary to ensure a reliable connection both between the precast wall panel and other components and among the components themselves to optimize the structure's performance. The current study introduces the development status of precast concrete structures and presents its research results. It also reviews the seismic performance, main connections, and design methods of precast concrete shear wall structures, offering valuable insights for the research and application of such structures.

Keywords

Prefabricated concrete shear wall structure, Seismic performance, Connection nodes, Research prospects

1. Introduction

Prefabricated concrete structures refer to concrete structures in which concrete components (such as slabs, wall panels, columns, beams, etc.) are fabricated in factories and transported to construction sites for assembly using reliable connection methods. Compared to cast-in-place concrete structures, prefabricated concrete structures offer advantages such as rapid construction, low energy consumption, and savings in formwork and materials. As a result, prefabricated concrete structures are widely used worldwide.

The main forms of prefabricated concrete structures include prefabricated frame structures, prefabricated frame-shear wall structures, and prefabricated concrete shear wall structures. Among them, prefabricated concrete shear wall structures exhibit excellent load-bearing capacity, outstanding lateral stiffness, and effective partitioning of space, making them the most widely used form of prefabricated concrete structures. This paper provides an overview of the research history of prefabricated concrete structures and highlights the characteristics and prospects of prefabricated concrete shear wall structures.

2. Research and development of precast concrete shear wall

Prefabricated concrete structures originated in Europe in the 19th century. In June 1875, the precast concrete wallboard system designed by William Henry Lascell of England obtained invention patent No. 2151, marking the emergence of precast concrete structures. In 1878, William Henry Lascell presented to the world the first building using
precast concrete technology at the Paris Exposition. The load-bearing members were wooden, and the walls were made of precast concrete panels. In the 1990s, the National Institute of Standards and Technology of the United States carried out a major study on the seismic resistance of prefabricated building structures [1]. In addition to the United States, the seismic performance of prefabricated buildings has been extensively studied in other countries. Among them, a full-scale 4-story precast concrete building was tested on a shaking table in Japan. The test and modeling results provided valuable insights into the dynamic response and design of a full-size three-dimensional precast concrete building. In France, pseudo-static cycle experiments of shear walls with different connection modes were carried out to verify the applicability of various connection modes. Prefabricated floor slabs and large slabs have been studied in Germany, and significant achievements have been made in floor slab design and connection details. Although China abandoned the development of prefabricated buildings after the 1976 Tangshan earthquake, efforts have been made in recent years to revive this form.

3. Research on connection technology and theory of precast concrete shear wall

Previous studies have shown that the seismic performance of precast shear wall structure depends largely on the joint part of the shear wall. Reliable joints can ensure the transfer of forces between the precast shear wall and other components, and provides bearing capacity and ductility for the shear wall. Precast shear wall has two connection types "wet" and "dry". A precast shear wall using a wet connection type has better integrity and can tolerate a certain degree of manufacturing and installation errors; however, the construction is tedious and complicated. In contrast, a precast shear wall with a dry connection type can withstand the load after installation, which is conducive to accelerating the construction process and is more suitable for precast buildings. Currently, the common wet connection in engineering mainly includes sleeve grouting connection, grouting anchor connection and prestressed connection.

The sleeve connection technology involves inserting the connecting steel bar into a high-strength sleeve with a concave-convex groove and then injecting high-strength grouting material. After hardening, the steel bar and the sleeve are firmly combined to form a whole, and the force is transferred through the grout material between the concave-convex groove on the inside of the sleeve and the concave-convex grain of the deformed steel bar. Wu [2] studied the seismic performance of the precast short-leg shear wall connected by a grouting sleeve and found that the steel bars connected by a grouting sleeve were reliable before yielding. The bearing capacity of each characteristic point of the precast concrete shear wall was close to that of the cast-in-place concrete shear wall, and the ductility and energy dissipation capacity of the precast concrete shear wall were slightly lower than that of the cast-in-place concrete shear wall. Xu [3] conducted a quasi-static test to study the seismic performance of precast concrete shear walls connected by single row grouting sleeve. The results show that the failure mode, bearing capacity, ductility, stiffness degradation and energy dissipation capacity of precast shear walls are similar to those of cast-in-place shear walls. Seifi [4] studied the seismic performance of precast concrete shear walls connected by single row grout metal pipes. It is found that the stiffness and nonlinear behavior of the single row connected lower wall panels are consistent with that of cast-in-place concrete, and the contribution of shaking to the lateral deformation of the single row connected wall panels is small due to the bending deformation caused by panel cracking. Similarly, single row connection can also be applied to precast sandwich concrete shear walls, but there is no relevant research at present, and its seismic performance needs to be further studied. Due to the technical limitations of assembly workers, there are often defects in sleeve grouting, which seriously affect its performance. Therefore, Yang [5] conducted an experimental study on the seismic performance of precast concrete shear walls with sleeve grouting defects and found that the grouting defects significantly affected the yield bearing capacity, peak bearing capacity, and ultimate bearing capacity of the specimens. The more grouting defects are, the more significant the reduction in bearing capacity is. Additionally, a method of defect prevention and evaluation for precast concrete shear walls with sleeve grouting defects is proposed.

The grout anchor connection technique involves lapping the steel bar through grout, and the tension of the connecting steel bar is transferred to the grout material through shear force, which is then transferred to the interface between the grout material and the surrounding concrete. Xiao [6] studied the seismic performance of a precast composite shear wall with a composite spiral stirrup connection and found that the composite spiral stirrup connection can improve the wall's bearing capacity. Additionally, the precast concrete shear wall shows higher initial stiffness and ductility coefficient. Xue [7] designed a double row staggered protrusion bar lap connection and studied the seismic performance of precast concrete composite shear wall under high axial compression ratio by horizontal reciprocating test. The results show that the properties of precast shear wall are similar to those of cast-in-place shear wall. Subsequently, Li [8] verified that the connection mode could effectively transfer seismic force and maintain the overall performance of the structure under various working conditions through shaking table tests. Xiao [9] studied the seismic performance of prefabricated composite shear wall with composite spiral stirrup connection, and found that the composite spiral stirrup connection can improve the wall bearing capacity, and the prefabricated shear wall exhibits higher initial stiffness and ductility coefficient. Li [10] conducted a low cyclic load test on three L-shaped precast reinforced concrete shear walls and one fully cast-in-place concrete shear wall assembled from the middle cast-in-place node. They found that the precast con-
crete shear wall connected through the post-cast node had a similar bearing capacity to the cast-in-place concrete shear wall, and it also had better deformation capacity and ductility.

Prestressed connection means setting aside holes in the precast concrete shear wall, according to the position of prestressed tendons, before pouring concrete. When the concrete reaches the specified strength, prestressed tendons are used to penetrate the holes that were previously reserved. An anchor is used to secure the prestressed reinforcement at the end of the shear wall, and finally, high-strength grouting material is injected into the channel to connect the upper and lower shear walls into a whole. Soudki [11] conducted seismic performance tests on prestressed connections of precast concrete shear walls and presented relevant design methods and calculation models. Kurama [12] studied the bonding properties of unbonded post-tensioned steel. It is found that, compared with the cast-in-place wall, the prefabricated wall has a larger lateral displacement during the earthquake, but the accumulated residual lateral displacement is obviously smaller. Zhang [13] proposed a new type of a prestressed concrete composite shear wall. The failure mode, hysteresis curve, stiffness degradation and energy dissipation capacity of the specimens were analyzed and compared by pseudo-static tests. It is found that the use of prestressed reinforcement reduces the expansion of inclined cracks in the wall and the composite shear wall has almost the same seismic performance as the cast-in-place concrete shear wall.

Dry connection means that there is no need to pour concrete at the construction site. All precast components, embedded parts and connectors are prefabricated in the factory and connected by bolts or welding. Soudki [14] studied the influence of five reinforcement connection modes on the performance of shear wall joints and pointed out that the ductility and energy dissipation characteristics of shear walls could be guaranteed under these connection modes. Ertas [15] conducted low-cycle reciprocating loading tests on cast-in-place connection, composite welded connection and bolted connection, and compared the seismic characteristics of the three connection forms. The results show that bolted connection has better energy dissipation capacity, which is conducive to strengthening and improving the seismic performance of the structure. Han [16] proposed T- and H-steel connectors for the connection of precast shear walls. Both connection methods can effectively provide stiffness and strength to a precast concrete shear wall system, showing good seismic performance. Sun [17] proposed a combined connection method for the H-shaped steel connectors and bolts. The horizontal bolt connection can provide sufficient strength and ductility for the precast shear wall.

4. Summary, comments and future directions

Since the 1980s, a great deal of research related to prefabricated structural systems has been conducted in the United States and other countries. In addition, the connection of precast concrete shear wall structure has also become the focus of research. The research and use of various connection modes promotes the development of precast concrete shear wall structures. Although precast concrete shear wall structures have been widely used in the field of practical engineering, they are far from sufficient at present, and there are many problems to be further studied and discussed.

(1) Some relevant research has focused on precast concrete shear walls of small size and low load. However, there is little research on large size and high load precast concrete shear walls.

(2) The connection nodes are the weak points of the prefabricated shear wall structure under seismic load. In special areas, energy dissipation connection methods should be developed to reduce structural damage during earthquakes.

(3) Due to the different applicability of various connection modes, the single connection mode should be avoided in a complex environment. Due to the different applicability of various connection modes, the single connection mode should be avoided in a complex environment.

(4) Precast concrete shear walls interact with other parts of the structure, such as columns and floors, during actual earthquakes, but little research has been done. Further research and improvement are needed in the future.

(5) At present, the design content of precast concrete shear walls has been relatively comprehensive in the codes of various countries, but the design methods for different connection modes still need improvement.

To sum up, the precast concrete shear wall structure has been developed rapidly because of its good bearing capacity and excellent lateral displacement resistance. However, there are still many problems in the connection method. Further research will be carried out in the coming years to overcome these problems and develop the design method and theory. In the future, precast concrete shear wall structures will be more material-efficient, more efficient in transportation, and more efficient in site installation.

References


