Research status of new reinforced concrete box structure

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Abstract: This paper presents a new type of prefabricated concrete structure system and the corresponding shear wall structure. The development status of the new shear wall system in various countries is described, and the advantages and disadvantages of the new shear wall as well as the research status are analyzed.

1. Introduction
Rising along with the resources and environment constraints, energy conservation and environmental protection requirements is increasing day by day, the demographic dividend out cause of rising labor costs and other problems in the housing industry development is increasingly outstanding, to be built by the housing industrialization to transform residential construction mode, fundamental change in the way to promote housing industry development in our country. Assembly house is the final product of housing industrialization and an important symbol of housing industrialization. Prefabricated housing has been widely used in developed countries due to its fast construction speed, low cost of large-scale production, energy conservation, reduction of dust on construction sites and reduction of PM2.5.

Prefabricated concrete structure (PC structure) is a concrete structure which is mainly composed of prefabricated components and partly cast in situ after assembly, connection, etc. The structural buildings can realize industrial production with prefabricated components in industrial flow construction with a high degree of industrialization. Molding mold and production equipment can be reused, saving resources and costs; On-site assembly is conducive to environmental protection, energy saving and consumption reduction. Short construction period; Mechanization degree higher a series of advantages.

2. Research status of prefabricated box structure
The box structure system refers to the box made in the factory with the open room as the unit, and the different boxes are hoisted on the site to form the box structure. In the foreign experts have carried out a lot of research on the box structure. Box structure in the early days of the United Kingdom, France, Germany, Japan, Italy, Canada, Romania, the Soviet Union and other countries have different degrees of development, the invention of different box structure and modular building.

2.1. Engineering application of box structure and modular building
(1) "House 67"[1]

It was one of the major thematic exhibits at the 1967 Montreal World's Fair, and pioneered three-dimensional prefabricated living units. A total of 158 residences are assembled by 354 structural modules. The apartments range in size from 56m² one-bedroom units to 167m² four-bedroom units,
with a total of 15 different apartment sizes. In House 67, prefabricated accessory units, stairs, elevator shafts, aerial platforms, and walkways are constructed in exposed concrete. All components of the building are load-bearing elements, including modules, pedestrian walkways, and elevator cores. The lower box supports the upper box, and the center of gravity of the upper box is located within several support points of the lower box. The support points between the upper and lower boxes are made of steel plates and rubber pads, and are anchored together with steel bars, forming an energy-dissipating structure that absorbs seismic loads. The rich modeling of "Habitat 67" is a bold attempt of the modeling ability of the box structure, which reflects the characteristics of the box structure. However, due to the complex way the boxes are stacked and the need to create multiple apartment types in the building, even though the same size (5.3m ×11.7m×3.0m) is used, there are still more than 130 types of boxes.

(2) Nakagin Capsule Tower in Tokyo, Japan [2]

The Nakagin Capsule Tower is located in the Ginza area of Tokyo, Japan. It was designed by the famous Japanese architect Kurokawa Kio in 1972. The main cabin will consist of two concrete floors of 11 and 13 storeys, which can be connected by prefabricated modules. The building is constructed using structural components manufactured in advance in the factory and then assembled on site, including furniture and equipment inside the building, which are installed in the cabin module units of 2.3m×3.8m×2.1m. A total of 140 cabin modules are suspended from reinforced concrete cores containing elevators and pipes. These reinforced concrete cores, which contain stairwells, elevators, and various equipment pipes, serve as the transportation hub and load-bearing structure of the entire building. Each cabin is fixed on the concrete core tube through four high-strength bolts. The figure shows the overall effect and partial cabin pictures of Nakagin Capsule Tower.

![Fig.1 Nakagin Capsule Tower](image)

(3) Wolverhampton Student Housing [3][5]

The apartments consist of three buildings ranging from eight to 25 floors, with a total of 824 modular units. The tallest building was Block A, which was the tallest modular building at the time. The weight of modules is about 10~25t according to their size, and the weight of modules is about 5.7kN /m2. The weight of modules for higher floors is about 14% steel members and 56% concrete floor slabs.
(4) A bachelor pad in Brooklyn, USA
A single apartment building in Brooklyn, New York City, USA, has a total of 6 floors, among which the first floor is a traditional steel frame structure, and the second to the sixth floors are composed of building module units. The building consists of 85 module units, comprising 65 apartment rooms and the public space of the building. The module units are special-shaped modules.

(5) Zhenjiang Gangnan Road Security Housing Project
The building is located in the Gangnan Road public rental community in the East New District of Zhenjiang City, which is a government-developed affordable housing. The total land area of the project is about 12.6m², and the construction land area of the first phase is about 49,700 m². It consists of 10 18-storey single-unit residential buildings, all of which are constructed by modular building system.

The project has 18 floors on the ground and two floors underground. Building height: 56.50m. The total building surface volume: 134500m³. The project adopts the core tube system of modules for construction. Each residential suite is composed of 2-3 modules, each module is composed of concrete floor slab, steel-tight column wall and ceiling truss, and the modules are separated into different rooms by non-load-bearing walls. Module state residential engineering center and authority is the company's design team has conducted a similar proportion of whole model shaking table test is 1:8 (see figure 10), a similar proportion of 1:4 local model shaking table test (see figure 11), key seismic connection node structure strength test module, module inside and outside wall surface mechanical performance test, etc., The seismic performance of the modular building system was systematically studied, and the seismic design and structure of the public rental housing project of Gangnan Road in Zhenjiang New District were modified and optimized according to the experimental results.
(6) Romanian box structure [6]

Romania's Brasov box with a hole between the steel plate, set on the two boxes of embedded steel, the upper and lower the reserved steel welding, vertical direction with prestressing, from the foundation to the roof section by section to apply prestressing earthquake. The pilasters on the vertical wall are vertically aligned between the upper and lower boxes that are staggered and stacked in the American Shelly system. After the steel pins in the column cavity are connected, pressure grouting is carried out, and the load is directly transferred to the foundation.

(7) Yuanda buildable prefabricated building-Yuanda buildable system [8]

The main board refers to the structural part of the integrated building, including the floor and the lower ceiling of the floor, as well as the pipelines of all equipment, such as air conditioning, ventilation, water supply and drainage, and electrical, which have been installed between the two panels. The dimensions of the main board are 15.6m long (part is 11.7m, 7.8m), 3.9m wide and 0.45m high. Each truck can tow 2~3 motherboards (up to 180m2). When the motherboard leaves the factory, each motherboard can be filled with columns, inclined bracing, walls, doors and Windows, and other components needed for the floor. After on-site lifting of the motherboard, workers can use bolts to install pillars, walls, Windows, etc., as well as connecting pipes between floors to complete the installation project quickly and accurately. Broad's buildable technology has been applied in many places in China, such as the New Ark Hotel in Changsha, a 30-storey building with a total floor area of 17,000 square meters. The hotel building was constructed using Broad's buildable system and the total construction time was only 15 days. The 1/10 scale model of the 30-story building was used by Broad Group to conduct shaking table test in China Academy of Building Research. The main structure did not show obvious damage under the earthquake of 7 degrees, 8 degrees and 9 degrees, and the whole structure did not collapse under the earthquake of 9 degrees, which proved that its seismic performance was good. The structure system is mainly suitable for buildings with a height of less than 100m.
3. Installation and transportation of box structure

The basic requirements for transportation mainly include the maximum width and height of the road load, which will be on the produced module single

There is a limit to the size of the yuan. According to the relevant requirements of the Implementation Regulations of the Road Traffic Safety Law of the People's Republic of China, the contents carried by a motor vehicle shall not exceed the load mass approved on the motor vehicle driving license, and the load length and width shall not exceed the compartment; The height of heavy and medium trucks and semi-trailers carrying goods shall not exceed 4 meters from the ground, and the height of vehicles carrying containers shall not exceed 4.2 meters. That is, the requirements for the module unit are: the maximum width of the module unit is generally allowed to be 2.5m~3.5m (which can be increased by the transportation route); Maximum load height should be 4.2m and lower trailers should be used as appropriate when vehicle transport is required under Bridges or through tunnels. In the box structure adopted in the Soviet Union, Romania, the United States and other countries [10], transportation and installation are both problems affecting the development of the box structure. In the Soviet Union and the United States, trailers are used for transportation. In order to reduce transportation costs, water transportation is adopted in some parts of the United States. Romanian Box Structure Transport The box structure was transported to the site by a trailer, and the box members were lifted from the trailer directly onto the treated foundation by a tower crane. Each box member was placed for 30 minutes.

4. Development constraints [7]

Modular building and box structure represent a trend of building industrialization development, which is suitable for various fields of construction. However, its development is also faced with various contradictions and challenges:

(1) The transportation of modules and boxes has become an important factor restricting their development. The modules have to be transported from the factory to the construction site. The height of the modules is limited by the road transport height limit, and one vehicle can usually only transport one box module at a time, which is less efficient and more costly.

(2) Modular structure and box structure are suitable for the construction of residential, hotel, student dormitory, kitchen, toilet and other standardized rooms, but have no advantages for buildings with complex functional requirements and diverse Spaces, as well as some large-span Spaces in buildings.

(3) The shape of the house is often relatively simple. However, there can also be rich modeling of the building blocks that reflect the characteristics of the box. There are a pair of contradictions: using
the building blocks modeling, it is necessary to deal with the complex load situation, which is not conducive to the use of industrial and repetitive production of the box. The use of a single slab building modeling, not reflect the characteristics of modular modeling, but can give play to the advantages of modular industrial production. Specific operation, have to make a trade-off.

(4) A major factor affecting the development of modular buildings is a large investment, which is 20-25% higher than the investment required by a large plate factory with the same production capacity. One of the main reasons for the high investment in modular component factories is that the price of non-standard equipment is set on the high side. Some countries envisage building module component production lines in large plate factories to produce module components and develop modular buildings. In this way, the additional investment required is not much, but the benefit is large, and all the investment can be recovered in a few years.

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