Application of Assembled Building with Steel-structure in Earthquake-prone Areas in Sichuan Province

Hongzhou Pan

1College of Art and Technology, Chengdu College of University of Electronic Science And Technology of China, Chengdu, Sichuan, 611731, China

*Corresponding author e-mail: 233515942@qq.com

Abstract. Anti-seismic, energy-saving and environmental protections are the core themes of residential development in any country or region. China is one of the countries with the most serious seismic hazards in the world. The occurrence frequency of strong earthquakes is in the forefront of the world. Sichuan is located in the relatively active Eurasian seismic belt. In recent years, after the Wenchuan, Ya’an and Jiuzhaigou earthquakes, another earthquake of magnitude 6.0 occurred in Changning County of Yibin City in June 2019. Assembled building with steel-structure has the advantages of high anti-seismic property, high degree of industrial production, short construction period, energy conservation and environmental protection, convenient transportation, and fast construction speed, which can effectively protect people’s lives and property in the event of earthquake. Based on the analysis of the development status of steel earthquake-resistant structures at home and abroad, combined with the particularity of Sichuan geography and geomorphology, this paper discusses the advantages of assembled building with steel-structure in earthquake-prone areas, and the implementation methods of assembled building with steel-structure in Sichuan seismic hazard reconstruction.

1. Definition of assembled building with steel-structure

Assembled building is a kind of building which is made up of parts and components by assembling and connecting in the construction site. Assembled building with steel-structure is a kind of steel-structure building, which is made of steel-structure components produced in factory and assembled and connected in the construction site.

The steel-structure residential building system has become a branch of the building system because of its steel-structure form as the basis of the classification of the building system. Generally speaking, the steel-structure residential building is a kind of residential building, which is composed of economical steel sections as load-bearing framework and new lightweight, heat-insulating, heat-insulating and high-strength wall materials as envelope structure.

2. Development status of assembled steel-structure earthquake-resistant buildings at home and abroad

2.1. The development of assembled steel-structure earthquake-resistant buildings in foreign countries

The steel-structure housing technology in the United States is a comprehensive technology, which is integrating structural main body, building energy conservation, building fire prevention, sound insulation, profile and design and construction. The social division of labor is clear and the production efficiency is high. Depending on the uniform design and construction standards, the supply of building
products can be coordinated with each other. The construction quantity of steel-structure houses is developing rapidly, the proportion of steel-structure houses is more than 25%, and the assembled houses are the main ones.

Japan put forward the concept of assembled houses in 1968. In 1990, it put forward the "middle-high-rise housing production system", which adopts component-oriented, industrialized production mode, high production efficiency, variable internal structure of housing and adapts to various needs of residents. It has undergone constant evolution and improvement from standardization, diversification, and industrialization to intensification and informationization. The assembled building structures during this period were tested by the 1998 Hanshin-Awaji-daishinsai.

At present, more than 80% of the newly-built houses in Sweden adopt the general assembly of building components, which is the first country in the world to legalize the modulus. The way of building industrialization in Denmark is to develop a general system centered on "catalogue design", and at the same time pay more attention to diversification on the basis of generalization. At present, the proportion of steel structure buildings in major countries in the world is shown in figure 1.

Figure 1. At present, the proportion of steel structure buildings in major countries in the world

2.2. Present situation of assembled steel-structure earthquake-resistant building in China

The low level of construction assembly industrialization has resulted in the unsustainable development of construction waste and building energy consumption in China. According to the data, building energy consumption accounts for 47% of the country's total energy consumption, and construction waste accounts for 45% of all social waste. Building energy consumption and building waste need to be reduced urgently.

On March 5th, 2016, in his report on the work of the Government, the Prime Minister stated, “We should actively promote green buildings and building materials, vigorously develop steel-structures and assembled buildings, and improve construction standards and quality”. This is the first time that "assembled buildings" have been written into the government work report, which shows the important position of "assembled buildings" in the industrial strategic layout of the Party and the country.

The Ministry of Housing and Urban-Rural Development of the People's Republic of China released the "13th Five-Year Plan" Action Plan for Assembled Buildings, and then all provinces and cities have issued relevant policy documents to vigorously promote the development of assembly construction industry. Some prefectures and cities have also issued documents requiring public buildings such as schools with social investment in central urban areas and public buildings such as schools with government investment in other counties and districts to promote the use of assembled building with steel-structures. Steel structure output and growth projection in China from 2009 to 2017 is shown in following figure 2.
2.3. Current situation of assembled building with steel-structures in Sichuan

2.3.1. Regional particularity of Sichuan. Sichuan is located in the relatively active Eurasian seismic belt. It is located at the eastern end of the Qinghai-Tibet Plateau, which is a high mountain area. The eastern part of the middle basin is mostly mountainous, while the Sichuan earthquake is generally distributed in the area west of 104 degrees east longitude. It is mainly concentrated in the Xianshuihe seismic belt, the Anning River-Zemuhe seismic belt, the Jinsha River seismic belt, the Songpan-Jiaochang seismic belt, the Longmen Mountain seismic belt, the Litang seismic belt, the Muli-Yanyuan seismic belt, the Mingshan-Mabian-Zhaotong seismic belt and so on. In recent years, after the Wenchuan, Ya'an and Jiuzhaigou earthquakes, another earthquake occurred in Yibin City in June 2019. The number of earthquakes with $m \geq 4.5$ in Sichuan Province and its surrounding areas in recent 40 years is shown in following Figure 3.

2.3.2. Development of assembled building with steel-structures in Sichuan. April 19th, 2018, the 6th International Conference on Earthquake Proofing Technique for Building Structures, the 10th Anniversary Summit Forum of the Wenchuan Earthquake and the Annual Meeting of the Structural Design Branch of the China Association for Survey and Design opened in Chengdu. Experts and scholars from home and abroad and relevant enterprises have deeply discussed the latest technologies and achievements of anti-seismic of building structures. Many experts attending the meeting believe that the assembled steel-structure with high anti-seismic property and green and pollution-free will usher in a good opportunity for development.

Experts, scholars and representatives of enterprises from home and abroad have an in-depth exchange of views on the development of preassembled reinforced concrete buildings, the research on deformation damage and energy dissipation of shear walls, the technical system and engineering
application of preassembled building with steel-structure, and the preliminary study on the seismic isolation technology of preassembled buildings in view of the earthquake damage of buildings in Wenchuan earthquake.

Huayuan Village, Qingquan Town, Qingbaijiang District Project in Chengdu is a co-ordinated urban and rural housing project jointly developed by Beixin Group and Chengdu Qingbaijiang District Government. It covers an area of 140 mu and can accommodate 266 households. This is a demonstration project of Qingbaijiang new rural construction, and also a new type of light steel energy-saving building in Chengdu. The project of Huayuan Village, Qingquan Town, Qingbaijiang District, reflects the breakthroughs in the construction process, integration of energy-saving and environmental protection products and anti-seismic property of steel-structure buildings.

3. Advantages of assembled building with steel-structure in post-disaster reconstruction

3.1. High timeliness
In post-disaster reconstruction, the building usually needs a lot of manpower and time, and the processing period is long, but the construction period of assembled steel-structure is short. Usually three or four days can be built on a floor, fast only one or two days, to ensure that people need to be resettled after the earthquake can move in as soon as possible. Most of the steel-structure residential systems are made in factories and installed in the field, so the construction period can be greatly shortened, and the noise and dust generated in the construction, as well as the consumption of field resources and various field costs are correspondingly reduced. Compared with the reinforced concrete structure building, it can shorten the construction period by half, bring the investment benefit into play in advance, speed up the capital turnover and reduce the construction cost by 3%-5%.

3.2. Good anti-seismic property
The steel-structure assembly type building main body structure is light and high-strength, which is composed of high-corrosion cold-formed section material. When it encounters the earthquake, it can instantaneously unload the external force and release the huge shear deformation stress, so it can greatly improve the safety and reliability of the building. Steel-structure with high strength, good ductility and light weight can greatly improve the mechanical properties of the structure, especially the anti-seismic property. From the domestic and international situation after the earthquake, the number of collapses of steel-structure residential buildings is very small. Especially in the high-intensity seismic region, it is more advantageous to use steel-structure. The ductility of reinforced concrete structure is guaranteed by the low stress of the structure. In high-intensity earthquake area, if the self-weight of high-rise buildings with fortification requirements is reduced by half, it is equivalent to reducing the seismic fortification degree by one degree. However, Sichuan is an earthquake-prone area, and the earthquake-resistance level of the post-disaster reconstruction buildings needs to be strengthened.

3.3. Energy saving and environmental protection buildings
Concrete structures cannot be reused after demolition, the resulting construction waste is not only non-degradable. Steel can be recycled, construction and demolition of environmental pollution is small, but also can reduce the production of new steel components raw materials, reduce the production of exhaust gas emissions, to achieve the goal of energy conservation and emission reduction, in line with the building energy conservation development direction. Using steel as frame and thermal insulation wallboard as envelope can replace clay brick, reduce the consumption of cement, sand, stone and lime, reduce the damage to non-renewable resources, reduce the site wet construction, and improve the construction environment.
3.4. **High degree of industrialization.**
Most of the structural components of steel-structure residential buildings are manufactured in factories, which is convenient to install and suitable for mass production. This has changed the traditional housing construction mode and realized the transformation from "building houses" to "manufacturing houses". It promotes the transformation of housing industry from extensive type to intensive type, and promotes the development of productive forces at the same time.

3.5. **Modular production, flexible space separation**
The steel-structure residence adopts the column net with large bay and large depth, which provides the residents with large space that can be separated flexibly and can meet the different needs of the users. It can not only satisfy the construction of rural monomer buildings, but also be used as apartment buildings and public supporting buildings in rural resettlement areas after reconstruction.

3.6. **Independent load /Independent bearing structure**
The architectural elevation design is free, which can adapt to the site landscape on the architectural appearance requirements and in line with the local characteristics of the architectural style.

4. **Implement method of assembled steel-structure building in Sichuan seismic hazard reconstruction.**
Most of the collapsed houses and dilapidated houses affected by the Sichuan earthquake were rural self-built houses. There are a lot of structural defects and functional defects in the design. In the design and reconstruction, the assembled steel-structure can be unified design, production, assembly, processing integration, unified architectural structure and appearance style. It can not only anti-seismic, but also in line with the development direction of new rural construction. It can be widely used in rural self-built housing, centralized placement of apartment housing and public supporting buildings.

4.1. **Fully integrate local characteristics**
The architectural design should be integrated with the local topography, natural environment and ecological landscape of Sichuan. The earthquake-prone areas in Sichuan are mostly mountainous and hilly areas, so the buildings should be built according to the topographic trend. The appearance of the building should fully consider the aesthetic taste of the local residents, especially in the residential design of Ganzi area, the architectural symbols with national characteristics should be incorporated, and the national beliefs and living habits should be respected. In the rainy areas such as Ya'an and Yibin, the dehumidification and dampness prevention of building materials and the ventilation system design of building space should be fully considered.

4.2. **Make full use of local materials**
In material applications, local environmentally friendly materials can be incorporated. Sichuan Province is located in the subtropics with mild climate, abundant precipitation and high humidity, which is suitable for the growth of bamboo plants. It is one of the main distribution areas of bamboo plants in China. Bamboo materials can not only be used as auxiliary structural materials, but also as decorative materials for external walls, balustrades, door panels and internal walls.

4.3. **Flexible and variable functional modules**
Beam penetrating form is adopted inside each structural module, and column penetrating form is adopted between the modules. The beams in each module are in the form of single channel steel, and a structure similar to double channel steel is formed between the modules, and the arrangement track of columns is reserved in the middle. The positions of columns are flexible and can be moved and arranged on the track, and the positions of columns are determined according to the requirements of the building and the principle of uniform stiffness. The spatial function module mainly includes kitchen module, toilet module, living module and rest module, which are the key modules. Through
different arrangement and combination, the spatial function module can be combined with the envelope structure and traffic space to form a variety of functions. Diversified combination of adaptability, flexibility and changeability, can adapt to different families and different living patterns.

4.4. Seismic design of load-bearing structures

Beam penetration is adopted inside each module, and column penetration is adopted between modules and then determined a clear path of force transmission. Vertical load is mainly borne by the steel column, horizontal load is mainly borne by the horizontal support, as long as the horizontal support to bear axial tension, the support does not bear pressure, bending moment and shear. The main load-bearing structure inherits the light steel frame structure, which makes the structure easy to assemble and correct and correct the deviation after the structure is installed conveniently. It can also strengthen the safety and anti-seismic property of the structure and prolong the service life of the structure.

4.5. Utilization of environmental protection energy

To achieve high environmental protection and energy conservation, the maintenance of walls, floors and roofs using foamed cement, lightweight ceramsite cement and other lightweight, high-strength new materials, and preassembled into a large factory with steel edges, internal configuration of two-way steel truss maintenance board, the overall installation of the site, greatly reducing the construction of energy consumption and construction waste generation. Moreover, the low heat transfer coefficient of foamed cement makes the maintenance wall have good heat insulation effect, and the energy saving can reach 70%-80%. Make full use of solar energy system and biogas system to increase the supply of heat energy for building life.

5. Conclusion

Concrete buildings are prone to collapse in seismic hazards, resulting in a large number of casualties. The ductility of steel-structure buildings can attenuate seismic waves and absorb more seismic energy. Under the same seismic intensity, the damage of steel-structure buildings is much less than that of rigid concrete structure buildings, which can effectively protect people's lives and property. In recent years, the state has issued a series of intensive policies to promote green energy-saving assembled building with steel-structure. Assembled building with steel-structure will usher in a huge development opportunity.

References

[1] The Ministry of Housing and Urban-Rural Development of the People’s Republic of China, (2017) Technical Standard for Assembled Building with Steel-structure GB/T 51232-2016, China Construction Industry Press, Beijing.
[2] Ye, J.H., Feng, R.Q., Chen, W. (2013) Anti-seismic Technical Manual Series for Village and Town Building Structures: Seismic Technical Manual for Light Steel-structures in Villages and Towns, Southeast University Press, Nanjing.
[3] Cornelia, D., Sarah. Z,(2019) Handbook of Container and Preassembled Building Design, Guangxi Normal University Press, Guilin.
[4] (2010) GB 50011-2010Code for seismic design of buildings, China Architecture& Building Press, Beijing.
[5] Yang, R.L. (2015) Seismic Design Of Structures, China Architecture& Building Press, Beijing.