

Opinion Article

Research status and development of assembled lightweight steel composite structures

Abstract: Lightweight steel structure is characterized by lightweight and high strength, quick construction, energy saving and environmental protection, which is in line with the development trend of green building advocated by China. The assembled light steel combined structure has the advantages of high efficiency of force, seismic energy saving, green environmental protection, etc. It is mainly used in low-rise and multi-storey buildings, and it adapts to the development of new building industrialization. The development process, system composition and current research status of seismic performance of typical assembled lightweight steel composite structures, including assembled cold-formed thin-walled steel structure, assembled lightweight steel lightweight concrete structure, assembled lightweight steel composite frame-lightweight steel composite shear wall structure, are summarized. The technical characteristics and advantages of the above structures are analyzed, their applications in the current environment, and the future development direction of assembled lightweight steel combined structures is studied and prospected.

Keywords: assembled building; lightweight steel modular structure; seismic performance; technical standard; research outlook

0.Introduction

Assembled lightweight steel structure refers to the shear wall, frame-shear wall and frame-supported structure assembled from 0.8-10mm thick cold-formed thin-walled steel sections or ordinary steel sections and lightweight steel assembled members composed of concrete, structural panels and thermal insulation materials, etc., and assembled through the connecting structure of beams and columns, nodes of wall panels and other connecting parts such as bolts, self-tapping screws or pre-buried parts. -Braced structure. Assembled lightweight steel combined structure is mainly used in low-rise and multi-storey buildings, and is an assembled building structure system with good development prospect. The assembled lightweight steel modular structural elements mainly include lightweight steel modular columns, lightweight steel modular beams, lightweight steel modular floor covers and lightweight steel modular shear walls.

Typical light steel modular structures mainly include assembled cold-formed thin-walled steel structures, assembled light steel light concrete structures and assembled light steel modular frame-light steel modular shear wall structures.1) The assembled cold-formed thin-walled steel structures can be categorized into modular

assembled cold-formed thin-walled steel wall panel structures, plate-column structures, wall -plate-column structure, etc., i.e., the structure is divided into column modules, wall modules, combined floor slabs and connectors, etc., which are prefabricated and processed in the factory, and then directly assembled and connected after being transported to the site; (2) The assembled light steel and light concrete structure is an industrialized assembled structural system that takes the prefabricated light steel frames as the structural skeleton, and pours light concrete on site. (3) “Flexible bracing” and “light steel combined shear wall” are the first line of defense of high-efficiency anti-seismic unit, so it is also the layered assembled light steel frame - flexible bracing structure and assembled light steel combined frame Therefore, it is collectively called assembled lightweight steel frame - flexible bracing structure and assembled lightweight steel combination frame - lightweight steel combination shear wall structure as assembled lightweight steel frame - high efficiency seismic unit structural system.

The advantages of assembled light steel modular structure applied in low and multi-storey buildings are remarkable: 1) light steel modular structure components are produced, assembled and constructed in factories with high efficiency; 2) compared with light steel structure, the seismic performance, fire resistance and corrosion resistance are significantly improved; 3) the use of structural and thermal insulation integrated lightweight enclosure wall panel system is suitable for the construction of ultra-low-energy consumption houses; 4) ecological and environmentally friendly materials, such as recycled aggregate concrete, slag, etc, can be used. environmentally friendly materials such as recycled aggregate concrete, slag, etc, which is green and has sustainable characteristics.



Figure 1 Prefabricated light steel composite structure system

Assembled lightweight steel modular structures have a wide range of applicability, meeting the needs of both low-rise and multi-storey buildings in urban areas, as well as low-rise and multi-storey buildings in rural areas. This is of key value in accelerating the industrialization of urban and rural buildings, implementing green housing development strategies, and popularizing innovative housing forms such as lightweight steel structures in suitable regions.

1 Research Status

1.1 Assembly cold-formed thin-walled steel structure

Low-rise cold-formed thin-walled steel houses are load-bearing components with light steel keel as the main body, cold-formed thin-walled steel and wall panels are connected by self-tapping screws, wall panels restrain the light steel keel from

destabilizing under pressure and form a combination of both load-bearing and lateral force-resistant walls, and standardized connectors are used to assemble cold-formed thin-walled steel beams and structural panels for a combination of floor cover or light steel beams - pressed steel plate -Concrete cast-in layer combined floor cover system.

Liu Zhanke et al^[1] conducted an in-depth analysis of the performance of lightweight steel members under different stress states such as axial compression and compression bending, and systematically collated and summarized the theories and methods in the current design standards in China, the U.S., and Europe, and the study further explored the effect of initial geometric defects on the stability of cold-formed thin-walled steel sections, and proposed the corresponding design methods on this basis. Xiang Yi et al^[2] carried out axial compressive performance tests on cold-formed thin-walled steel columns with complex rolled edges, analyzed the effects of different section sizes and column lengths on the specimen load carrying capacity, and verified the test results using finite element software, which showed that the flange width-to-thickness ratio and the web height-to-thickness ratio are the key factors influencing the axial compressive load carrying capacity. POST^[3] evaluated the axial compressive performance of the cold-formed thin-walled steel composite wall through tests and finite element simulations, and evaluated the axial compressive performance of cold-formed thin-walled steel composite walls by tests and finite element simulations, and calculated the axial compressive load carrying capacity of the composite walls by using the direct strength method and finite strip method. YE et al^[4] carried out experimental research on the axial compressive performance of cold-formed thin-walled steel composite walls, and explored the damage characteristics and load carrying capacity of the wall panels, and the results showed that the axial compressive load carrying capacity of the wall was significantly enhanced when the lightweight steel keel column used a composite cross-section. Shen Zuyan et al^[5], Li Yuanqi^{[6][7]}, LI et al^[8] for the seismic performance of cold-formed thin-walled steel structural system carried out low circumference reciprocating test and the whole foot-scale model shaking table test and finite element simulation, the study of the cold-formed thin-walled steel structure of the working mechanism, the establishment of the bearing capacity calculation model and put forward a practical design method, part of the simulation results and the measured hysteresis curves shown in Figure 2.

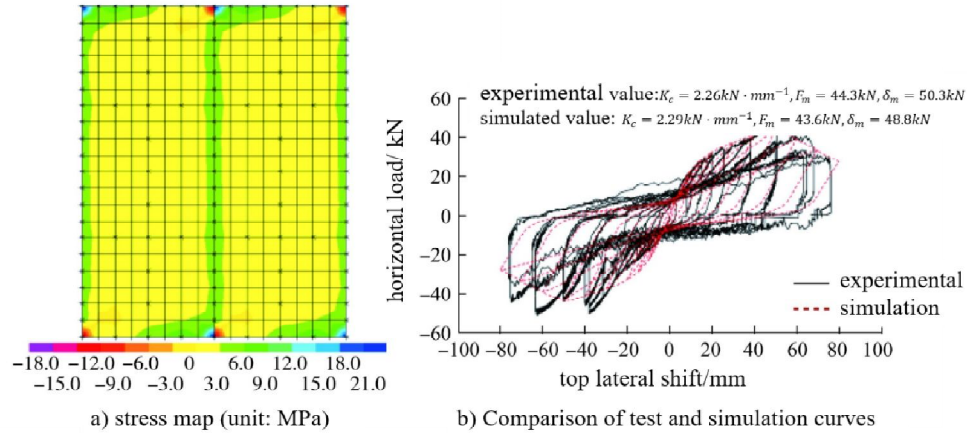


Fig. 2 Seismic test of cold-formed thin-walled steel wall

SHIYU et al^[9] tested the flexural performance of cold-formed thin-walled steel roof racks of different construction forms and thoroughly explored their working mechanisms and damage modes. It was found that steel strength, cross-section form and steel thickness had a significant effect on the load-bearing capacity of the roof frame. CHEN et al^[10], CELIS-IMBAJOA et al^[11] and LIU et al^[12] carried out research on compression molded steel plate combination floor slabs and steel-wood combination floor slabs, etc., and found that compared with the traditional site-cast concrete floor slabs, lightweight steel structure floor cover has obvious advantages in terms of weight and ease of installation. Shi Yu et al^[13] and Guan Yu et al^[14] investigated the flexural and dynamic properties of cold-formed thin-walled steel beam-OSB plate combination floor cover and cold-formed thin-walled steel-gypsum-based self-leveling mortar combination floor cover, etc. The results showed that the cold-formed thin-walled steel beam-structural plate combination floor cover has a significant advantage over traditional site-cast concrete floor slabs in terms of weight and ease of installation. The results show that the cold-formed thin-walled steel beam-structure plate combined floor cover has better stress performance and can reduce the difficulty of assembling and constructing cold-formed thin-walled steel structures.

1.2 Assembled lightweight steel and lightweight concrete structure

The main materials of light steel light concrete structure are thin-walled light steel, demolition-free formwork and new lightweight concrete, through the combination of thin-walled light steel and demolition-free formwork to form a light steel combination frame, light concrete is poured on the basis of the light steel combination frame to form a demolition-free formwork of the light steel light concrete wall. The structure is characterized by the lightweight steel frame and lightweight concrete working together with good structural performance^[15].

The application of lightweight concrete materials to lightweight steel composite structures is a hot spot in current research. Li Dongbin et al^{[16][18]} conducted experimental studies on the seismic performance of lightweight steel polystyrene granular concrete walls, and the results showed that the walls had high bearing capacity and good ductility. Wang Jingfeng et al^{[19][20]} studied the axial compressive

performance of light steel structural walls filled with light polymer and the shear performance of light steel composite wall panels filled with lightweight slurry, and the results of the research provide a basis for the design and calculation of polymer-filled light steel walls. Tian Le et al ^[21] conducted an experimental study on the mechanical properties of lightweight steel and foam concrete combination wall, the study shows that the foam concrete density, steel content and other parameters of the combination of the wall has no effect on the destruction of the morphology of the combination of the wall, while the combination of the wall of the shear capacity has a greater impact. Hu Xibing et al ^[22] proposed a lightweight steel foam concrete wall panel composed of foam concrete, lightweight steel and steel wire mesh, which has good overall stiffness and elastic-plastic deformation capacity. Huang Qiang et al^[23] conducted a proposed static test of 3-story foot-size specimens of light steel lightweight concrete structure and analyzed the structural damage pattern, hysteresis characteristics and deformation capacity, etc., and the results showed that the structure had good seismic performance. The damage phenomena and measured hysteresis curves of some lightweight steel and lightweight concrete structures are shown in Figure 3.

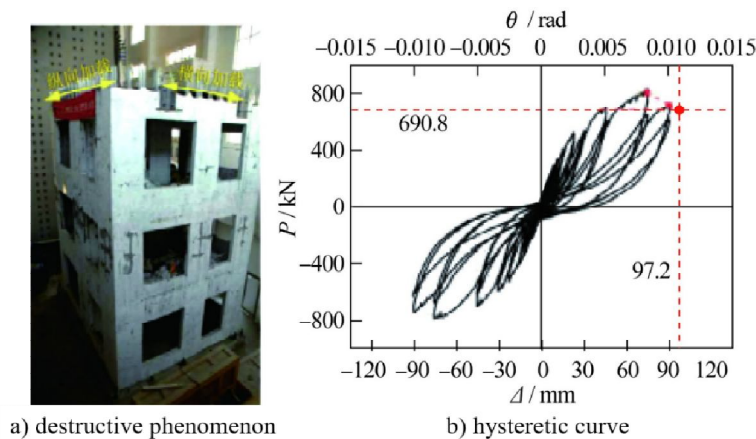


Fig. 3 Seismic performance test of light steel and light concrete structure

1.3 Assembled light steel composite frame-light steel composite shear wall structure

Li et al ^[24] conducted a steel frame- aerated concrete exterior wall panel foot-scale structural shaking table test, through which they compared the differences in the effects of the embedded assembly method and the externally mounted assembly method on the seismic response of the structure, and through the proposed static test ^[25] compared the differences in the hysteretic performance of the steel frame- aerated concrete exterior wall panel structure using the two assembly methods, and concluded that the use of a simple connection of the embedded wall The improvement of stiffness and bearing capacity of the steel frame is much larger than that of the external wall, and it is advisable to consider it in the structural design. Wang Bo et al^[26] implemented low circumferential repeated load tests on steel-tube concrete pure frame and steel-tube concrete frame structural specimens with ALC slats and blocks, and investigated in detail the effects of parameters such as wall panel thickness, wall panel connection form and wall panel type on the seismic performance of the

specimens. Hu Jingwu et al^[27] conducted shaking table tests on steel frame-inserted spliced aerated concrete infill wall panel footing structures, where the frame and walls were connected through pre-buried parts in the wall panels, and the results showed that the connection node had a certain seismic damping effect, and the model had a maximum interstorey displacement angle of 1/49 at 8 degrees of rare ground shaking, and only the wall panels had localized damage while the steel frame did not have any significant damage, so the structural seismic performance was good. Varela-Rivera J et al^[28] carried out low circumferential reciprocating tests to investigate the effect of axial compression ratio and shear span ratio on the seismic performance of AAC masonry wall and gave the lateral load carrying capacity of the wall in case of shear and bending-shear damage.

BIAN Jinliang et al^[29] and BIAN et al^[30] proposed double L-shaped nodes with diagonal stiffening ribs welded on steel pipe concrete columns and bolted to H-shaped steel beams, the node domain of light steel beam-column nodes increased significantly, especially the increase of the cross-section height scale can be quickly improved node stiffness; 38 different configurations of double L-shaped nodes with diagonal stiffening ribs, ordinary nodes comparative seismic performance tests were carried out, and the damage characteristics, hysteresis characteristics, and energy dissipation capacity of the various specimens were analyzed. Comparative tests on the seismic performance of 38 double L-shaped diagonally stiffened rib nodes with different configurations and ordinary nodes were conducted to analyze the damage characteristics, hysteresis characteristics and energy dissipation capacity of each specimen. The results show that the double L-shaped diagonally stiffened rib nodes have simple structure, small steel consumption, low bolt consumption, and superior seismic performance, and the comparison of the structure of the double L-shaped stiffened rib nodes, some measured hysteresis curves and the hysteresis curves of the current ordinary nodes is shown in Fig. 4.

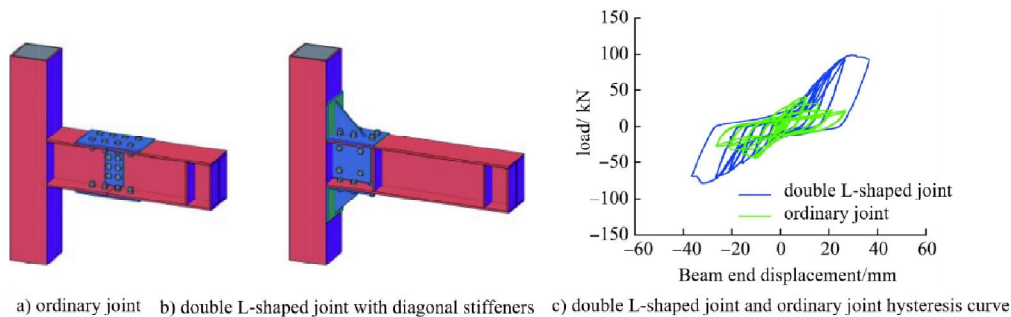


Figure 4 Comparison between ordinary joints and double L-shaped joints with diagonal stiffeners

2 Structural features and technical advantages

2.1 Structural characteristics

Assembled cold-formed thin-walled steel structure, the wall is not only the main vertical load-bearing member of the structure but also the lateral force-resisting member, with the significant characteristics of the shear wall structure stress, assembly rate is high. Assembled cold-formed thin-walled steel structure: foot-scale

structural shaking table tests show that the main structure can be realized at 8 degrees without damage; good thermal insulation, to meet the building energy-saving standards; wall thickness of about 1/2 of the traditional structure, the set of area increased by about 10% or more, the self-weight of about 1/3 of the traditional brick-cemented structure; most of the materials can be recovered, recycled; construction process of environmental protection and conservation, low noise, dry construction operations, only the traditional brick-cemented structure, and the construction process can be carried out in the same way. The construction process is environmentally friendly, low noise, and requires only 10% of the water consumption of traditional building construction.

The assembled light steel and light concrete structure is a light steel and light concrete combined shear wall structure, with light steel frame and demolition-free formwork assembly, and polystyrene granule concrete cast-in-situ for the wall, with better integrity of wall panels. Assembled lightweight steel and lightweight concrete structure: the full-scale structural seismic test shows that it can realize the main structure of 8-degree earthquake without any damage; the amount of steel used is only 25-35kg/m²; compared with the ordinary reinforced concrete construction, it can save 30% of manpower, save 25% and 35% of the construction water and electricity, shorten the construction period by 30%, and reduce the consumption of timber and construction garbage by more than 50%.

2.2 Technical Advantages

Assembled steel structure and light steel structure belong to one kind of steel structure, they have the technical characteristics of flexible space arrangement, and can meet the design and construction requirements of large-span and high-elevation buildings and the diversified requirements of owners. Similarly, assembled steel structure often adopts the assembling and splicing method in the construction process, so the construction waste produced is relatively small, and the processing technology of construction materials is rarely involved, so the amount of pollutants and the concentration of pollutants produced can be effectively controlled, and thus it has a good performance of green environmental protection. In addition, with the continuous development of material technology, the material performance of assembled steel structure itself has been effectively improved, and the use of lightweight steel materials and alloy materials has improved the performance of the structure while reducing the weight of the structure. Assembled steel structure integrates many construction processes, and many components can be processed and produced directly from the factory, so the construction process is simplified and the construction efficiency is effectively improved. At the same time, compared with traditional buildings, the application of assembled steel structure technology also creates many favorable conditions for the maintenance of the building later.

3 Application status of assembled lightweight steel structure

As light steel structure and assembled steel structure itself has better technical advantages, it can bring positive impacts to the project itself, whether in the design and construction or in the use period of the building, which is specifically manifested in the aspects of environmental protection, cost control, and improvement of

structural safety, etc. Therefore, in the future development of steel structure, lightweight, assembling and energy-saving are gradually taken as the main development direction. Therefore, in the future development of steel structure buildings, lightweight, assembly and energy-saving will gradually be taken as the main development direction. At the same time, these technologies will be continuously optimized and upgraded to give full play to their technical advantages and solve the existing technical application problems. Meanwhile, China's government has provided abundant and favorable policy support for the development of lightweight steel structure and assembled steel structure, and the norms and standards of related technologies are also in the process of continuous optimization and improvement. Therefore, the application field of steel structure technology in China is also in the process of continuous improvement. The standardization of technical management and technical standards has also played a certain role in promoting the healthy development of the industry.

The development of assembled lightweight steel modular structural system depends to a large extent on the development of its industrialized construction technology. There are many industrialized production bases of assembled lightweight steel structural components in China, such as Beixin Housing Co., Ltd, Hefei Guorui Integrated Building Technology Co., Ltd, Tangshan Jidong Development Integrated Housing Co.

4 Conclusion

The advantages of assembled lightweight steel structure house with high construction efficiency, low energy consumption, recyclable components, and energy-saving and environmental protection reflect the feasibility of greening the building in the new era. The assembled light steel structure house has many advantages, but in the actual application of rural residents need to be improved, which is of great significance for the assembled light steel structure house to be popularized and applied in the western rural areas, even on a larger scale. More application of light steel structure is not only conducive to the dissolution of steel production capacity process, but also conducive to the western rural economic development. Assembled lightweight steel structure housing in China's future development and construction, especially in rural resettlement, new rural construction and other aspects will play an important role in improving the western rural backwardness of the human environment, improve the level of happiness of the people's life is of great significance. At present, although the development of assembled building still has a lot of places that need to be solved and improved, with the vigorous promotion of the country, industry and enterprises, the technology will be improved day by day, and the assembled lightweight steel structure residence will have a huge space for development in the rural areas.

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