19 New-type Antiseismic and Energy-Saving Building

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Abstract: This paper introduces a new-type of anti-seismic and energy-saving building system based on a panel-column-lightweight steel construction that meets the requirements of reconstruction in earthquake-stricken areas. Emphasis is laid on three areas in terms of structure type and construction technologies, anti-seismic technologies and energy-saving technologies. It is expected that this system can be popularised to set a science and technology example of reconstruction in earthquake-stricken areas.

Key words: Panel-Column- Lightweight Steel Construction Building; Building System; Anti-seismic, Energy-Saving, Application

1. Introduction

A majority part of China is located in earthquake active zones. Millions of people are left homeless due to the collapse of buildings or demolition of dilapidated buildings after a high-intensity earthquake strike. Rehabilitated houses usually need to be completed in short time. Earthquake-stricken areas often lie in high intensity zones. Therefore, new houses need to meet requirements of earthquake resistance, cost-effectiveness and local energy-saving and construction strategy. Furthermore, energy-saving and anti-seismic building system will be popularised and used broadly along with the promotion of China's New Socialist Countryside Construction Projects (NSCCP). In view of the aforementioned situation, the research on panel-column-lightweight steel construction building system is proposed. The objective is to develop a building system applicable to the reconstruction in earthquake-stricken areas and set a science and technology example for rehabilitation in these areas and the NSCCP. This paper will focus on three areas: panel-column-lightweight steel construction building system, anti-seismic technologies and energy-saving technologies.

2. Research on the structure and construction technologies of building system

This system consists of panel, column and lightweight steel structure. A steel structure made of

H-section and rectangular hollow section (RHS) sits on the concrete ground beam. Ancillary concrete columns are mounted on the steel columns. Concrete cladding panels, partition wall panels and roof panels as well as insulation materials are installed on the steel structure respectively forming a panel-column-light weight steel structure building system.

The self-weight of this system and the seismic load is supported by the steel structure. Steel usage is estimated to be 40-60 kg/m^2. As the building enclosure, concrete cladding panels allow free deformation. Therefore, no failure stress is formed from thermal expansion/shrinkage, wet expansion/dry shrinkage and carbonation shrinkage. This solves the cracking problems in traditional precast façade construction.

Concrete columns, concrete cladding panels, GRC partition wall panels and GRC roof panels are all precast in the factory and assembled on site. It is possible to use large amounts of construction and industrial waste during the precast process. Figure 1 shows samples of the aforementioned elements and their physical properties are listed in

Table 1 to Table 4.

Concrete Cladding Panel

Concrete Column

Insulated GRC Roof Panel

GRC Partition Wall

Figure 1 Precast elements

Table 1 Performance index of cladding panels

Number	Item		Unit	Standard	Test result	Conclusion
1	Appearance		-	Flat surface, Even corner, uniform colour	Conformed	OK
2	Dimension Tolerance	Length	mm	±2	0～+1	OK
		Width		±1	-1～+1	OK
		Thickness		±1	0～+0.5	OK
3	Density		kg/m^3	2200-2300	2264	OK
4	Breaking force		N	≧600	880	OK
5	Impact strength		-	5kg sand bag free fall 3 times from 1m height, no cracking occurs	Conformed	OK
6	Permeability		-	After 24 hrs, no leaking on the other side	Conformed	OK
7	Water absorption		%	≦15	8.1	OK
8	Combustibility		-	Blue flame of natural gas 30mm-50mm away from the sample burning for 5 min, no failure phenomena like cracking etc.	Conformed	OK
9	Frost-resistance	Appearance	-	No cracks, delamination, pin holes, air pockets and raw edges etc.	Conformed	OK
		Weight loss	%	≦10	0	OK

Table 2 Performance index of external precast columns

Number	Item		Unit	Standard	Test result	Conclusion
1	Appearance		-	Flat surface, Even corner, uniform colour	Conformed	OK
2	Dimension Tolerance	Length	mm	±5.0	0～+3.0	OK
		Width		±1.0	-0.5～+1.0	OK
		Thickness		±1.0	-0.5～+1.0	OK
		Distance to main structure		±2.0	—1.0～+1.0	OK
3	Weight		kg/m^3	2200-2300	2231	OK
4	Hanging force		—	≥600N，no damage	Under 600N load, resting for 4h, no damage in the hanging area	OK
5	Compressive strength		MPa	≥20	30.5	OK

Table 3 Performance index of insulated roof panels

Sample name	**Insulated roof panel**	**Testing category**	**Entrusted inspection**
Number	Testing items	Unit	Testing result
1	Density	kg/m^3	325
2	Heat Transfer Coefficient	$W/m^2{\cdot}K$	0.38
3	Uniform loading capacity	N	3020

Table 4 Performance index of GRC partition wall panels

Sample name	**GRC partition wall panels**	**Testing category**	**Entrusted inspection**
Number	Testing items	Unit	Testing result
1	Density	kg/m^3	842
2	Sound Transmission loss	dB	46
3	Hanging force	N	1500N hanging load，no cracking around hanging area
4	Fire resistance	h	1.5h
5	Impact resistance	times	After 6 impacts，no through crack

The construction procedure of this system is as follows -

Ground works (levelling land, excavating foundation trench) → concrete foundation (casting concrete, anchoring steel columns, casting concrete ground beam) → steel structure (assembling column, perimeter beam, girder, purlin) → roof (insulated roof panel, waterproof layer) → concrete cladding panel (concrete column, concrete cladding panel, thermal insulation materials, insulation lining) → partition wall → roof tile → door and window → external finish → internal finish.

Details of key procedures are as follows:

A. Construction of lightweight steel structure

a. One column is selected as control beam based on the design drawing and is installed, adjusted and fastened to the concrete ground beam.
b. Referred to the control column, all other columns are installed in turn, followed by the installation of tie bars.
c. The steel roof truss is installed, so as the purlins and tie bars.
d. In case of two-story building, the secondary beam is installed after the primary beam.
e. After a thorough check, joints are finally fastened and welded, and the welded joins should be derusted and covered by impregnating material.

Figure 2 Control column **Figure 3 Installation of steel**

B. Installation of concrete column

The installation of concrete column is started from one end of the wall, the top edge is connected to ties bars on the channel section using structural adhesive and fastening bolts. The bottom is fixed using wedges and connected to the concrete perimeter beam. Anti-seismic rubber rod is tucked into the top of the concrete column. The levelness of hanging claws and the planeness of hanging columns should be precisely controlled.

Figure 4 Installation of concrete column

C. Installation of roof panel

For the purpose of indoor operation under rain weather, the installation of roof panel is carried out right after the accomplishment of structural installation. Roof panels are fixed to steel channel section purlins via 120mm-long screws and the joints of panels are filled with mortar or aerated polyurethane.

Figure 5 Installation of roof panels

D. Installation of precast panel:

Concrete cladding panels are sorted and put in order, the planeness, perpendicularity, levelness of cladding panels and the rigidity of hanging claws are checked. The installation sequence is from the bottom to the top and from the middle to both sides. Structural adhesive is injected to the back of panels as well as panel joints.

Figure 6 Installation of cladding panels and finished view

E. Installation of external wall lining

The lining is divided into suitable dimensions; individual sections are cut accordingly and installed using the structural adhesives and power-actuated nails. Section joints are filled with mixture of anti-cracking polymer and flexible putty then levelled. The filling of external wall insulation materials is implemented at the same time.

Figure 7 Finished external wall lining

F. Construction of partition wall

Cement based lightweight composite studs (100mm×30mm) are set out and assembled by iron nails. Lightweight cement based composite boards (3000mm×1200mm×16mm) are fixed to studs on both sides using power-actuated nails. Joints are filled with mixture of anti-cracking polymer and flexible putty then levelled.

Figure 8 Installation of partition wall

G. Outside view of completed building

After the aforesaid procedures, Panel-Column- Lightweight Steel Construction Building is ready to brought into use. Figure 9 shows the pictures of a project in Dujiang Weirs area.

Figure 9 Outside view of completed building

The Construction Guide of Panel-Column-Lightweight Steel Construction Building System was drafted to regulate the construction of this new type of anti-seismic and energy-saving building. Contents include ground and foundation, steel structure, roofing, control points, installation of external wall, partition wall, door and windows, ceiling and coating & painting etc.

3 Research on anti-seismic technologies

The use of this lightweight steel structure in high intensity earthquake zones as well as the adoption of new materials and new structural forms in external wall requires high anti-seismic performance. The anti-seismic performance of this system was investigated through simulated earthquake shaking table test. This test is able to reproduce various seismic waves and the seismic damage of the experimental model was observed and examined.

An experimental model of panel-column-lightweight steel structural building system was constructed at a scale of 1:1. The unit is double floored with the floor height of 2.65m and the overall dimension was measured to 2.4m×2.4m. Test set-up is shown in Figure 10 and the loading information is shown in Table 5.

Figure 10 Anti-seismic experiment

Table 5 Loading information

No.	Loading wave	Maximum acceleration	Testing items	Relative Intensity
1	White noise	0.05g	Vibration mode, frequency, damping	7 Richter -Medium
2	KOBE	0.1g	Acceleration, displacement	
3	Hujialou wave	0.1g	Acceleration, displacement	
4	EL-CENTRO	0.1g	Acceleration, displacement	
5	Artificial wave	0.1g	Acceleration, displacement	
Observation and Results				
6	White noise	0.05g	Vibration mode, frequency, damping	7 Richter -Medium (8 Richter -high)
7	KOBE	0.2g	Acceleration, displacement	
8	Hujialou wave	0.2g	Acceleration, displacement	
9	EL-CENTRO	0.2g	Acceleration, displacement	
10	Artificial wave	0.2g	Acceleration, displacement	
Observation and Results				
11	White noise	0.05g	Vibration mode, frequency, damping	7.5 Richter -High (8 Richter -medium)
12	KOBE	0.3g	Acceleration, displacement	
13	Hujialou wave	0.3g	Acceleration, displacement	
14	EL-CENTRO	0.3g	Acceleration, displacement	
15	Artificial wave	0.3g	Acceleration, displacement	
Observation and Results				
16	White noise	0.05g	Vibration mode, frequency, damping	8 Richter -High (9 Richter -medium)
17	KOBE	0.4g	Acceleration, displacement	
18	Hujialou wave	0.4g	Acceleration, displacement	
19	EL-CENTRO	0.4g	Acceleration, displacement	
20	Artificial wave	0.4g	Acceleration, displacement	
Observation and Results				
21	White noise	0.05g	Vibration mode, frequency, damping	8.5 Richter-high
22	EL-CENTRO	0.5 g	Acceleration, displacement	
Observation and Results				
23	White noise	0.05g	Vibration mode, frequency, damping	9 Richter-high
24	EL-CENTRO	0.6g	Acceleration, displacement	

The dynamic characteristics of the structural model before and after various earthquake loading scenarios were studied systematically via simulated earthquake shaking table tests. The anti-seismic performance of the entire model and of the wall was examined, the damage intensity and mode of the structural model under various seismic intensity (frequent, normal and rare) was investigated and hence, the relative seismic intensity (acceleration) of the structural model under various damage intensity was derived. When the input acceleration of the shaking table was set to 0.2g (relative to 8 Richter - normal earthquake acceleration), the induced stress of the steel frame in the experimental model was found very small, the steel frame works in the elastic stage. When the input acceleration reached to 0.4g (relative to 8 Richter – rare), it was found the induced stress was also relatively small, basically the steel frame still works in the elastic stage. This denotes that the anti-seismic performance of this building system is very sounding. When the input acceleration reached to 0.6g (relative to 9 Richter), cladding panels on the upper floor was found shifted in certain area and panels on the ground floor displaced a bit. No large displacement or falling of cladding panels was observed, the external wall lining was still in good condition and the connection of the wall and the steel main structure was intact. The experimental model can stand high intensity earthquake and the anti-seismic performance was proved.

4. Research on energy-saving technologies

Firstly, the energy-saving performance of the building used in the exampled project was studied. An energy-saving and environmental friendly cladding system was adopted, which consists of cladding panels, precast columns and external wall lining. The hollow core was filled with EPS insulation mortar on site, the design of external wall system is shown in Figure 11. The roofing system consists of 80mm-thick composite panel, waterproof roll, mortar screed coat and coloured asphalt decoration tiles as shown in Figure 12.

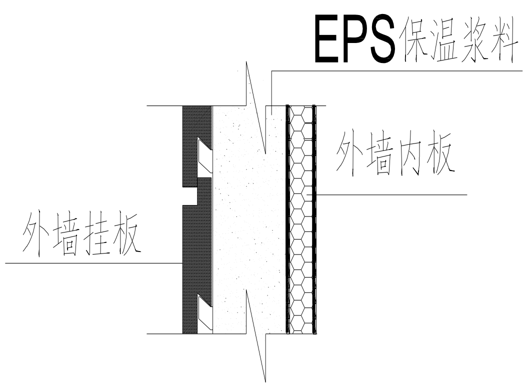

Figure 11 External wall

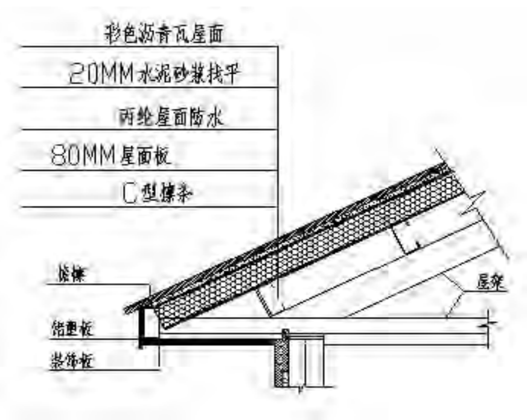

Figure 12 Roofing system

Based on the above design, the energy-saving performance of the entire building was assessed. To obtain the real thermal performance parameters, samples made with same materials and same thickness as the real building used in the exampled project were fabricated and used to conduct the thermal performance test. The external wall sample is shown in Figure 13 and the roofing sample in Figure 14. Testing equipment, sample box and recording equipments are shown in Figure 15 and Figure 16. The heat transmission coefficient of external wall system was found to be 0.73W/(m^2·K) (k≤1.0W/m^2K according to national code), and of the roofing system to be 0.43W/(m^2·K) (k≤0.7W/m^2K according to national code).

Front Back

Figure 13 External wall sample

Front Back

Figure 14 Roofing sample

Figure 15 Hot container, cool container and sample box

Figure 16 Heat flow meter and Microcomputer

Furthermore, windows used in the exampled building were double-glazing plastic steel window with a heat transmission coefficient less than 4.0 W/(m^2·K) (k≤0.7W/m^2K according to national code). The flooring system consists of finish layer, 20mm-thick 1:2.5 mortar screed layer, 70mm-thick EPS board, 80mm-thick C20 fine aggregate concrete and 200mm-thick 3:7 lime loess and the thermal resistance was found to be 1.742m^2K/W (R>1.2m^2K/W according to national code).

The above thermal performance meets the energy-saving requirement in warm-summer and cold-winder area which targets 65% energy saving.

5 Conclusion

The research work in the paper provides a theoretical base for formation of the structure type and construction technologies, anti-seismic technologies and energy-saving technologies of panel-column-lightweight steel structure building system. The theory was materialised through the construction of exampled project and improved during the construction process. The Construction Guide of Panel-Column- Lightweight Steel Construction Building System and the Collection of designs for Panel-Column- Lightweight Steel Construction Building System was drafted. This provides a theoretical and real construction support for the further popularisation of this building system.

As an example of anti-seismic and energy-saving building in China, the panel-column-lightweight steel structure building system has advantages in the following areas: earthquake resistance, energy saving, material saving, economics, durability, construction speed, aesthetics and ease of residence. The market prospect is promising. Once this research outcome is industrialised, it is expected that large amount of construction waste can be consumed. This is particularly attractive in the earthquake-stricken zone since enormous building wrecks are created after the earthquake. The popularisation and application of this system will play a significant role in the rehabilitation of earthquake-stricken zones and development of the countryside. The development principle of this system is 'standardised design, industrialised production, systematised supply and assembled construction', which helps to optimise construction plan and enables the quality and cost control in the production, transport and construction etc.

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