Structural Simulation and Frame Reinforcement Technology of Prefabricated Box-type Light Steel Structure Building

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Abstract. In order to recheck the safety of the construction of prefabricated box-type light steel structure house, the structural safety checking calculation is carried out for box connection stress, column bottom stress, anti-wind load design and anti-overturning design. The elastic connection is used for node simulation, and the on-site tensile test is carried out to check the reliability of the model. Based on the connection mode between box column and corner fittings, the frame reinforcement construction technology of prefabricated box-type light steel structure house is studied. A rectangular-ambulatory-plane steel plate is welded at the outer edge of the corner fittings, to reinforce frame structure, and improve the service life and comfort of prefabricated box-type light steel structure house.

Keywords: Prefabricated box-type light steel structure house; Structural safety checking calculation; Frame reinforcement.

1. Introduction

The prefabricated box-type light steel structure house, commonly known as “packing box”, is a kind of modular cold-formed thin-wall light steel structure house [1]. All its components are manufactured and formed in the factory and constructed on site by all dry method. It has the advantages of high quality, light weight, good structural stability, convenient on-site installation, short construction period, energy conservation and environmental protection [2].

Based on the project of health post station of a city, this paper studies the structural simulation and frame reinforcement technology of prefabricated box-type light steel structure house. The project is an emergency rescue and disaster relief project urgently prepared to deal with the input of epidemic situation outside China and prevent the spread of epidemic situation. Except for a few permanent buildings, the project is constructed with packing boxes, and the demand for packing boxes is more than 10000.

In order to review the safety of the project, the structural safety of the packing box is checked, and the elastic connection is used for node simulation [3]. The numerical simulation analysis is carried out for the wall thickness of the roof frame beam and roof secondary beam of the packing box house, wind resistance design and anti-overturning design. At the same time, the field mechanical performance test is carried out. The simulation and test results show that the structural integrity of the project meets the requirements of node stiffness, and the structural integrity and reliability are high.

The purpose of the frame reinforcement construction technology of prefabricated box-type light steel structure house is to optimize the stress of packing box. The floor plates and roof plates of packing box house are prefabricated in the factory, and the column is connected with the floor frame and roof frame by high-strength bolts. Weld the gap between the corner fittings of the upper and lower boxes, and weld a rectangular-ambulatory-plane steel plate at the outer edge of the corner fittings for reinforcement and connection, so as to make the frame of the packing box house more stable.

2. Implementation process

In this paper, the calculation simulation and field test of box structure are carried out, and the frame reinforcement construction technology of prefabricated box-type light steel structure building is studied. The specific implementation process is as follows.

For box structure calculation simulation and field test: box connection stress simulation → column bottom stress simulation → box anti wind pressure simulation → box anti overturning simulation → model reliability verification → field mechanical property test.

For frame reinforcement construction process: connect the floor frame, column and roof frame of packing box with high-strength bolts → connect the horizontal adjacent corner fittings with φ20 bolts → connect the corner fittings of the lower box and the upper box with U-shaped bolts → weld the gap between the corner fittings of the packing box → weld a rectangular-ambulatory-plane steel plate outside the corner fittings.

3. Calculation simulation and field test of box structure

The packing box of the project is a temporary building, the structural design service life is 5 years, and the basic wind pressure is 0.3kN/m2 once in 10 years. The floor frames and roof frames of the packing box are processed in the factory, hoisted as a whole on site, and connected on site by columns. The floor frame is composed of corner fittings, floor frame beam, floor secondary beam, cement fiberboard, PVC floor glue, etc. The roof frame is composed of corner fittings, roof frame beam, roof secondary beam, rock wool, enclosure board, etc.

3.1 Load analysis of the box structure

(1) Dead load of base plate: cement fiber board: 80.144kN/m2; rubber sound insulation pad: 0.05kN/m2; PVC floor: 0.026kN/m2; integral bathroom: 1.45kN/m2.

(2) Roof dead load: color steel coil: 0.039kN/m2; insulation layer: 0.14kN/m2; smallpox: 0.031kN/m2.

(3) Dead load of sandwich panel wall slab: 0.36kN/m2.

(4) Dead load of glass curtain wall: 3.0kN/m2.

(5) Roof sandwich panel dead load: 0.15kN/m2.

(6) Live load: accessible floor: 0.15kN/m2; inaccessible floor: 0.5kN/m2.

The roof frame beam and roof secondary beam shall meet the requirements of Chinese national standard “Load code for the design of building structures” (GB50009), and “Box-type light steel structure houses Part 1: detachable” (GB/T 37260.1), to ensure that its bearing capacity, stiffness and local stability meet the requirements. The column and frame beam of the packing box adopt box-type corner fittings as the beam column connection node, the frame beam and corner fittings adopt factory welding, and the column and corner fittings adopt L-type on-site bolt connection. In order to recheck the safety of the project, the structural safety of the packing box is checked with the basic wind pressure of 0.5kN/m2 once in 50 years, and the node simulation is carried out with elastic connection.

3.2 Stress simulation of box connection

The calculation model selects four row box, roof shape, and wall shape for overall calculation and analysis. The column base of the box house is considered as hinged.

The stress simulation of box connection is as follows, and the values are shown in Table 1.

(1) Horizontal connection between the box body and the box body: only considered as tension, and the bolt is considered for simulation.

(2) Vertical connection between box and box: simulate the horizontal direction considering U-shaped bolt connection and friction.

(3) Connection of upper and lower box frame beams: only considered as compression.

Table 1. Stress simulation and numerical setting of box connection.

No.	Type	Angle ([deg])	SD_x (kN/m)	SD_y (kN/m)	SD_z (kN/m)	SR_x (kN*m/[rad])	SR_y (kN*m/[rad])	SR_z (kN*m/[rad])
1	Tension	0	75	0	0	0	0	0
2	Common	0	10000	75	75	10000	10000	10000
3	Compression	0	10000	0	0	0	0	0

Adjust the position of the fulcrum set on the floor frame beam so that the floor frame beam and the roof frame beam can work together.

According to the calculation results of the stress value of the overall model, the maximum stress value of the floor frame beam is 172N/mm2. According to the calculation results of the local stress value displayed by the model, the maximum stress value of the column is 120N/mm2, and the maximum stress value of the roof frame beam is 170N/mm2, which meet the requirements of relevant specifications.

According to the calculation results, the stress values of the floor frame beam and the roof frame beam are basically close and ideal.

3.3 Stress simulation of column bottom

For the stress at the column bottom, the maximum and minimum support reaction at the column bottom under single working condition are as follows.

X direction: 1) Maximum bearing reaction: FX=1.4kN, FY=5.4kN, FZ=19.9kN (compression); 2) Minimum bearing reaction: FX=0, FY=0, FZ=-1.5kN (tension).

Y direction: 1) Maximum bearing reaction: FX=1.2kN, FY=6.7kN, FZ=20.1kN (compression); 2) Minimum bearing reaction: FX=0, FY=0, FZ=-0.1kN (tension).

According to the calculation results, the lateral stiffness of the structure in two directions is similar, the stress at the column bottom meets the requirements of relevant specifications.

3.4 Simulation of wind pressure resistance of box

In order to verify the wind pressure resistance of the box, the horizontal force transmission of the upper and lower boxes under wind load is simulated.

Dead weight load of unit box is 24kN. The friction coefficient is considered as 0.3, so the friction force is 7.5kN. Horizontal wind load of single box is 5.85kN, less than 7.5kN friction.

According to the calculation results, the self-weight of the unit box is enough to resist the horizontal wind load of a single box without relative sliding.

3.5 Anti overturning simulation of box

In order to verify the anti-overturning ability of the box, the anti-overturning simulation is carried out. Only the favorable effect of dead load with a coefficient of 1.0 is considered, and the three storey box house is calculated as a whole.

According to the calculation results, there is no pulling force on the overall bottom support. There is no pulling force at the column root of the roof unit box room, and the upper- and lower-unit box rooms are at the corner fittings, passing through φ16 screws. Tension checking calculation of φ16 screw is 42.2kN. A 50mm wide weld is added between the column heads of the upper and lower packing boxes, which helps to improve the integrity of the box and increase its anti-overturning coefficient. Anti-overturning coefficient of box is 2.61, more than 2.50, which meets the anti-overturning requirements.

3.6 Model reliability checking calculation

The reliability of the above model is verified by load test, the overall horizontal load resistance performance of the three-layer packing box is tested, and the overall lateral force stiffness of the packing box is analyzed and evaluated. In this test, the reaction frame is set from the perspective of the most unfavorable load. The reaction frame is composed of packing boxes. There are 3 packing boxes in each layer and 9 in total in three layers. At the same time, anchor bolts are set at the bottom of the reaction frame for connection, and angle steel is welded on the reaction frame for placing jacks. The distance between the reaction frame and the test packing box is 400mm. A jack is set between the reaction frame and the test packing box to apply the load. The corresponding horizontal load is applied at the roof node of the column on each floor. There are 2 test packing boxes on each floor and 6 on three floors. The loading test scheme is shown in Figure 1 (a), and the test node setting (CS1-CS8) is shown in Figure 1 (b). Specially, F1=6.00kN, F2=F3=2.925kN.

The basic wind pressure selected for detecting node strength in this project is 0.5kN/m2, once in 50 years. Take 60% of the loading data to check the displacement value under normal use (amount to 0.3kN/m2, once in 10 years). See Table 2 for the maximum displacement monitoring records of each node under simulated state and test state.

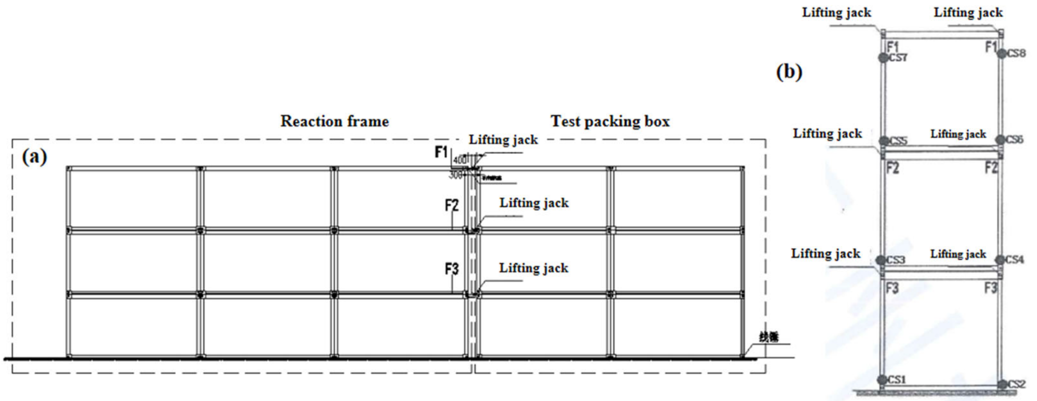

Figure 1. (a) Packing case loading test scheme and (b) test node setting.

Table 2. Displacement monitoring record of packing box under 60% load.

	CS1	CS2	CS3	CS4	CS5	CS6	CS7	CS8
Analog displacement (mm)	6.5	7.1	11.2	11.0	12.9	13.4	16.7	15.9
Simulated inter story displacement angle	1/448	1/463	1/378	1/381	1/295	1/294	1/266	1/252
Test displacement (mm)	6.1	7.3	11.5	10.8	13.2	12.6	15.9	16.3
Displacement angle between test layers	1/436	1/459	1/366	1/375	1/300	1/287	1/263	1/258

The displacement and inter story displacement angle of the packing box calculation model are basically consistent with the results of displacement test, and the inter story displacement angle meets the specification requirements (less than 1/250). The simulation of elastic connection by the overall calculation model can be considered to be close to the actual situation, that is, the analysis results of the above numerical simulation are reliable.

During the load test, no abnormal phenomena such as abnormal sound and vibration are found. After the test, the welds between the corner fittings of the upper and lower packing boxes were not cracked, and no abnormal phenomena such as deformation, cracking, inclination, dislocation, looseness or damage were found in each component and corner fittings node of the packing box. Therefore, the overall horizontal load resistance performance and overall lateral force resistance stiffness of the packing box meet the requirements, and the whole process of the test is elastic deformation.

According to the calculation simulation and node optimization results of the box structure, the beam column connection node of the packing box has a certain connection stiffness (node bending stiffness), which can meet the requirements of the structural integrity of the project for the node stiffness and the safety requirements of the project.

4. Reinforcement construction of packing box frame

The floor plates and roof plates of the packing box house are prefabricated in the factory. The floor frame corner fittings are assembled with 4mm steel plate and the roof frame corner fittings are assembled with 4mm steel plate. In order to ensure that the box can resist wind load and achieve shear and pull-out resistance, six M12 × 40, 8.8s high-strength bolt connection pairs are used to connect the column of the packing box to the floor and roof keel frame, as shown in Figure 2. The column, floor frame and roof frame are connected by high-strength bolts, which make the assembly process simple and convenient, improve the construction efficiency and ensures the structural safety.

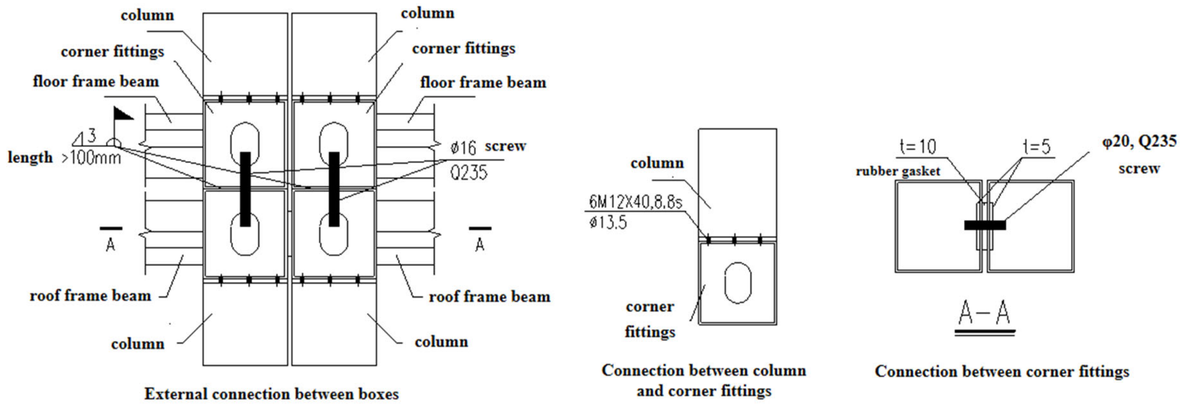

Figure 2. Schematic diagram of box node connection.

The corner fittings of the lower box roof frame and the upper box floor frame are connected with U-shaped bolts. The corner fittings of the left and right boxes are connected by screws. The gap between the corner fittings of the upper and lower boxes is strengthened by electric welding to make the packing box house frame more stable. Based on the horizontal force transmission of the upper and lower boxes under wind load, a rectangular-ambulatory-plane steel plate is welded on the outer edge of the corner fittings of the adjacent upper, lower, left and right boxes, so that the corner fittings of the packing boxes are connected with steel plates, which can further strengthen the connection between different packing boxes and improve the overall stability.

The specific embodiments are as follows.

(1) The corner fittings of the lower box roof frame and the upper box floor frame are connected of Q235, φ16 U-shaped bolts. The corner fittings between the roof frames and the floor frames of the left and right boxes are connected with Q235, φ20 screws.

(2) On this basis, a rectangular-ambulatory-plane steel plate is welded on the outside of the corner fittings of the adjacent upper, lower, left and right boxes, as shown in Figure 3. The rectangular-ambulatory-plane steel plate has an outer frame size of 350mm × 290mm, frame width of 50mm, thickness of 6mm, with hollow rectangular iron sheet in the middle, which can further strengthen the connection between different packing boxes. Change the position of the section steel plate on site according to the connection of adjacent packing boxes, and the short side may be welded upward or the long side may be welded upward. When welding the rectangular-ambulatory-plane steel plate, pay attention to make it close to the packing box frame to reduce the gap between the rectangular-ambulatory-plane steel plate and the frame. When the rectangular-ambulatory-plane steel plate is used at the connection of four corner fittings, the length of the longitudinal weld connected with the corner fittings is > 1200mm. When used at the vertical connection of two corner fittings, the length of longitudinal weld connected with the corner fittings is >600mm. When used at the horizontal connection of two corner fittings, the length of longitudinal weld connected with the corner fittings is > 500mm.

Allowable tensile force of each weld:

$$F = 0.7 \times 5mm \times (100mm - 5mm \times 2) \times 160N/mm2 = 5040N = 5.04Kn \qquad (1)$$

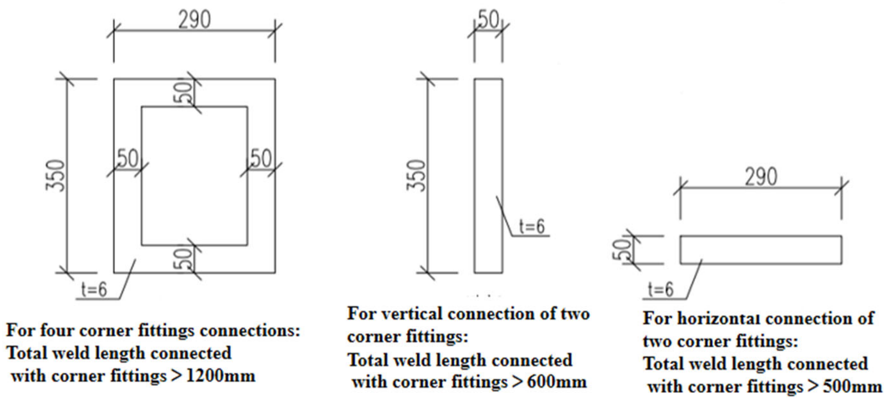

Figure 3. Schematic diagram of reinforced box with rectangular-ambulatory-plane steel plate.

5. Conclusion

Based on the construction background of a health post station, this paper carries out calculation simulation and field test on the box structure to verify the reliability and safety of the box node design. In order to optimize the stress of box structure, the frame reinforcement construction technology of prefabricated box-type light steel structure building is studied. Structural simulation and frame reinforcement technology do not affect the construction period, which are economical and applicable. The structural bearing capacity meets the design requirements. It is of great significance to promote the production and application and the development of construction technology of prefabricated box-type light steel structure houses.

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