Analysis of Slab-column Shearwall Structure of 6000 Tons Cold Storage

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Abstract. Combining with the functional requirements, the site conditions and the 6000 tons load characteristics of cold storage, so determine its structure system for the slab-column-shear wall structure. The paper recommends the design of foundation, the settings of column cap, the arrangement of shear wall, the punching shear of floor slab and the analysis and calculation results of main structure. By addition shear wall in slab-column structure to increase the overall stiffness of structure and improve the seismic performance of structure. Take the detached form between the main structure and the external wall insulation, while set anchorage beam between in the main floor and the ring beam along the axis of the column grid to enhance the overall stability of the external wall insulation.

1. Engineering situation

The proposed cold storage is a comprehensive cold storage, which is divided into four layers. The first floor is multi-functional cold storage, the second and third floors are low-temperature storehouse, and the fourth is low-temperature and high temperature dual-purpose storehouse with a total construction area of 4104m². The slab-column structure system can provide a large building space, facilitate the layout and installation of pipelines, and reduce the floor height. There the project adopts the structure of slab-column-shear wall, which use the 370mm brick masonry, 200mm polyurethane insulation layer and 120mm aerated concrete block masonry of the enclosed structure, the floor plan is shown in Figure 1. Different functions of cold storage are separated by light thermal insulation board in the later stage.
2. Design conditions
The design working life and design reference period of the structure design are 50 years, and the structure safety class is second class. The seismic fortification intensity of the proposed site is 7 degrees, and the design earthquake is grouped into second groups, and the basic acceleration is 0.15g. The construction site category is II, and the site characteristic cycle is 0.3s. The ground roughness category is C, and the basic wind pressure of 50 years return period is 0.4kN/m², the standard value of the constant and live loads on the roof of the building is shown in Table 1.

| Serial number | Load type | Dead load(kN/m²) | Live load(kN/m²) |
|---------------|-----------|------------------|-----------------|
| 1             | Roof      | 5.0              | 2.0             |
| 2             | Floor     | 6.5              | 15.0            |
| 3             | 120mm wall line load | 4.0              | ——              |

3. Selection and layout of structure
The shear walls of the main structure are thick 250mm concrete. One to four layers of corner column and side column size is 400mm×600mm, the column size of the first and second layer is 450mm×450mm and the third and fourth layer is 350mm×350mm. The plate thickness except the top layer is 150mm, and the rest are 220mm. The strength of the concrete is C30, and the construction of the whole pouring completed. The layout of the standard layer structure is shown in Figure 2.
3.1. Layout of shearwall
According to the Code for Design of Seismic Design of Buildings (GB 50011-2010) [1], the total height of the proposed cold storage is 20m>12m, and the shear wall shall bear all the seismic actions of the structure. According to the Technical Specification for High-rise Building Concrete Structure (JGJ 3-2010, J 186-2010) [2], the shear wall structure is arranged continuously from bottom to top, and the length of the wall is taken as 1650mm.

3.2. Selection of frame beam
According to the requirements of Code for Design of Seismic Design of Buildings (GB 50011-2010), a beam frame should be adopted around the slab-column-shear wall structure house. The structure is selected according to the general beam section. The beam section height is h=1/10, L=600mm (L=6000 mm), beam width b=300mm.

3.3. Column cap selection
Based on larger load of structure, so to increase the punching shear capacity of the top plate and reduce the calculation span of the plate, and is arranged in the top of the column cap, and its form and size are shown in Figure 3. In the mid-column column cap, the fascia width is 2400mm, and the 1/3 is greater than the column space. For flat slab with spandrel beam, the protruding thickness of the fascia under the column is not greater than the 1/4 from the side of the fascia to the edge of the column (or the edge of the column cap), that is, the total thickness shall not be greater than 1025mm. The h₁ is generally taken as the plate thickness, plus the thickness of the top layer, take h₁=250mm, h₁:h₂=2:3, then take h₂=325mm, and the protruding thickness is $250 \times 2 + 325 = 825mm < 1025mm$ [3].
4. Structure calculation and analysis

4.1 Calculation and analysis of girderless floor

Using the SATWE software in PKPM series [4] to consider the function of the elastic deformation of the floor slab, the elastic floor 6 is used to simulate the stiffness of the floor and the calculation of the deformation. In the position of the frame beam of the same generation, the rectangular cross section with section size of 100×100mm is arranged, and the three-dimensional analysis and calculation of the beam free floor system are carried out.

After the analysis and calculation of the beam free floor is completed, the analysis and calculation of the floor are carried out by using the "complex floor finite element calculation" SLABCAD module in SATWE software. The hole and the column cap member of the beamless floor, and modify the top slab thickness. The finite element analysis and calculation software is used to divide the strip automatically, and the horizontal and vertical seismic actions are taken into account to calculate the internal force, displacement, reinforcement and punching calculation of the slab. Among them, one layer of column joints has the most concentrated counterforce, and a laminate column is taken to check the impact shear. The checking calculation results of the punching shear capacity of the plate column are shown in Table 2.

| Column number | 1   | 2   | 3   | 4   | 5   | 6   | 7   |
|---------------|-----|-----|-----|-----|-----|-----|-----|
| Maximum design of concentrated counterforce(kN) | 582.91 | 450.93 | 514.53 | 619.99 | 577.37 | 630.15 | 767.18 |
| Punching resistance(kN) | 798.51 | 1186.66 | 619.92 | 1169.79 | 946.51 | 1166.94 | 1394.87 |
| Ratio of concentrated counterforce to punching resistance α | 0.73 | 0.38 | 0.83 | 0.53 | 0.61 | 0.54 | 0.55 |

| Column number | 8   | 9   | 10  | 11  | 12–14 | 15  | 16  |
|---------------|-----|-----|-----|-----|-------|-----|-----|
| Maximum design of concentrated counterforce(kN) | 770.21 | 904.26 | 630.25 | 772.51 | 990.68 | 772.50 | 751.42 |
| Punching resistance(kN) | 1400.38 | 2055.14 | 1313.02 | 1136.04 | 1981.36 | 1266.39 | 1138.52 |
| Ratio of concentrated counterforce to punching resistance α | 0.55 | 0.44 | 0.48 | 0.68 | 0.50 | 0.61 | 0.66 |

| Column number | 17–19 | 20  | 21  | 22–24 | 25  | 26  | 27–29 |
|---------------|-------|-----|-----|-------|-----|-----|-------|
| Maximum design of concentrated counterforce(kN) | 990.66 | 751.41 | 767.07 | 990.66 | 767.11 | 698.97 | 990.67 |

Figure 3. Size of column cap
| Punching resistance (kN) | 1981.32 | 1273.58 | 1128.04 | 1981.32 | 1278.52 | 1145.85 | 1981.34 |
|-------------------------|---------|---------|---------|---------|---------|---------|---------|
| Ratio of concentrated counterforce to punching resistance $\alpha$ | 0.50 | 0.59 | 0.68 | 0.50 | 0.60 | 0.61 | 0.50 |
| Maximum design of concentrated counterforce (kN) | 698.89 | 592.57 | 697.40 | 769.20 | 697.31 | 594.55 |
| Punching resistance (kN) | 1294.24 | 800.77 | 1143.28 | 1131.18 | 1143.13 | 792.73 |
| Ratio of concentrated counterforce to punching resistance $\alpha$ | 0.54 | 0.74 | 0.61 | 0.68 | 0.61 | 0.75 |

It can be seen from Table 2 that the ratio $\alpha$ of the concentrated reaction force and the impact resistance force is less than 1, which meets the requirements for the punching shear resistance of the slab under the Code for Design of Concrete Structures (GB 50010-2010) [5].

4.2 Structural analysis and calculation results

Using SATWE software to analyze the structural, the first 3 modes of the structure are characterized by the natural period and mode characteristics as shown in Table 3.

| Table 3. Periodic and vibrational forms |
|----------------------------------------|
| Earthquake model | Cycle (s) | Corner | Translation coefficient $(X+Y)$ | Torsional coefficient |
|-------------------|-----------|--------|-------------------------------|----------------------|
| 1                 | 1.1502    | 161.07 | 1.00(0.89+0.11)               | 0.00                 |
| 2                 | 1.1464    | 71.05  | 1.00(0.11+0.89)               | 0.00                 |
| 3                 | 0.7345    | 108.09 | 0.00(0.00+0.00)               | 1.00                 |

When taking 12 modes, the effective mass factor of X direction is 99.50%, and the effective mass coefficient of Y direction is 99.50%, which can meet the requirement of specification greater than 90%. The minimum shear-weight ratio of floor is shown as shown in Table 4.

| Table 4. The minimum shear-weight ratio and rigidity-to-gravity ratio |
|---------------------------------------------------------------|
| Structure | X direction | Y direction | |
|           | shear-weight ratio | rigidity-to-gravity ratio | shear-weight ratio | rigidity-to-gravity ratio |
| Bulk     | 3.39%         | 3.89         | 3.42%         | 3.92         |

For the structure of 7 degree seismic design, the document [1] stipulates that the basic period is less than 3.5s, the minimum shear-weight ratio of the floor is 2.4%. The shear-weight ratio of each layer of the structure is in accordance with the law of increasing vertical direction, and the bottom shear-weight ratio is the smallest, the ratio of X to the minimum shear weight is 3.39%, and the ratio of Y to the minimum shear weight is 3.42%, which are more than 2.4%. Meet the requirements of the standard.

Shear-weight ratio of structure as shown in Table 4, the minimum rigidity-to-gravity ratio in X and Y directions is 3.89 and 3.92 respectively, both of which are larger than 1.4, which can meet the norms of the overall stability check, at the same time, the minimum rigidity-to-gravity ratio of the structure is greater than 2.7, so the gravity second-order effect is not considered.

When the accidental eccentricity and bidirectional earthquakes are not considered, the maximum interstory drift and displacement ratio of the structure are shown in Table 5. The interlayer maximum interstory drift is satisfied with the elastic interlayer displacement angle limit 1/800 of the document [1]. According to document [2], when considering the effect of accidental eccentricity under the action of horizontal seismic force, the maximum horizontal displacement of floor vertical members and the average displacement between floors should not be greater than 1.2 times the average floor, which all meet the requirements of the specification.
Table 5. The maximum interstory drift and displacement ratio

| Structure | X direction | Y direction |
|-----------|-------------|-------------|
|           | Interstory drift | Displacement ratio | Interstory drift | Displacement ratio |
| Bulk      | 1/941       | 1.04        | 1/919         | 1.08           |

The maximum interstory drift of the floor under the wind load is shown in Table 6, and the maximum interstory drift of the floor satisfies 1/800 as defined in the document [2].

Table 6. Maximum displacement angle under wind load

| Structure | X direction | Y direction |
|-----------|-------------|-------------|
|           | Interstory drift | Interstory drift |
| Bulk      | 1/5198       | 1/3679       |

The axial pressure of the wall limbs and columns is shown in Figure 4. The parenthesis is the axial compression ratio of the column, and the parenthesis is the axial compression ratio of the shear wall. The axial compression ratio of the wall limbs and columns is less than the limit value of the document [1].

Figure 4. Axial compression ratio of shear wall and column

5. Construction measures of exterior wall
Due to the high demand for temperature in the cold storage, and 200mm thick polyurethane is needed between the 370mm wall and the 120mm wall to meet the temperature requirements of the cold storage. The north-south direction of the proposed cold storage is about 27m long, and the east-west length is about 38m, which is less than 50m, and there is no need to set expansion joint and seismic joint. The 370mm wall use the ordinary brick, and the foundation set up separately, which not connected with the main body of pile foundation, only in the floor and the ring girder to column axis set anchorage beam as shown in Figure 5. The 120mm wall is constructed by autoclaved fly ash aerated concrete block, no longer set up a separate foundation, and 200mm thick polyurethane insulation board together as a linear load on the cantilevered floor.
6. Conclusion
Through the design of slab-column-shear wall structure, we know that the shear wall plays an important role in increasing the overall stiffness of the structure, which greatly improves the seismic performance of the structure. At the same time, the column cap can increase the punching performance of the structure. In the design, the size of the column cap can be properly arranged to meet the requirements of the specification. On the floor and ring beam along the axis of the column grid set of anchor beams, which strengthened the stability of the 370mm wall.

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