Temperature stress analysis of the overlong concrete structure in the basement of the Shangshenbei block project in Hunnan New City

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Abstract. This paper is based on a typical project in Shenyang Shangshenbei Block Project, using Midas software to analyze the temperature stress of the basement concrete structure and the temperature stress changes of various parts of the basement, combining the conditions and characteristics of the concrete structure cracks, and putting forward optimization suggestions and effective resistance. Cracking measures, through the implementation of measures, effectively reduced the occurrence of cracks and ensured the stability of the structure.

1. Introduction

The Hunnan New City Shangshenbei block project construction site is located in Shenyang Hunnan New District. The total land area of this project is 75172.69 square meters.

The project is about 300 meters long and 190 meters wide. There are 15 high-rise residential buildings on the ground, and the thickness of the overburden on the roof of the basement is 1.5m. The basement is 1 storeys with a height of 3.7m and adopts a slab-column structure. The column mesh size is 8.4mx8.4m, and the column cross-section size is 700mmx700mm; the basement roof adopts a seamless floor with column caps, and the air defense area is 500mm thick. The thickness of the civil air defense area is 360mm; the thickness of the basement exterior wall is 350mm. Residential buildings are all shear wall structures.

During the construction process, there are multiple expansion reinforcement belts at intervals of about 30meters along the length and width direction of the basement roof. Post-settlement pouring belts have been send along the periphery of the residential building.

The high-rise part of the project adopts the raft foundation, and the basement garage part adopts the independent foundation under the column and the waterproof board. And CFG pile foundation treatment is carried out on the foundation.

The basement of this project is an over-long structure, which is not common at the time. The underground part plays an extremely critical role in the transmission of the overall structure. Too many cracks are extremely unfavorable to the safety of the structure, and the ultra-large concrete structure is due to its own particularity, it is easy to produce cracks after the final setting of the concrete. In order to reduce the cracks, this paper puts forward a feasible method through multiple analysis and calculation, which effectively alleviates the occurrence of cracks.
2. Construction status
The bottom plate of the project was poured in September 2011 and the top plate was poured in April 2012. After the main body of the basement has been completed, the basement was overwintered in the winter of that year.

In April 2012, the post-settlement pouring zone was poured and closed, and at the same time, the temperature of the concrete pouring into the mold was controlled at about 10°C.

In May 2012, the pre-stressed steel bars of the roof were stretched in blocks and each with a distance of about 60 meters to 70 meters. In October 2012, after the tensioning of the prestressed steel bars was completed, the covering soil above the basement roof was backfilled. After the backfilling of the covering soil is completed, anti-freezing measures shall be taken for the main building and basement. In August 2013, the main building was fully capped and already have the conditions for check-in.

3 Temperature effect value

3.1 Difference of Seasonal temperature difference

Table 1. Shows the statistical data of monthly average temperature in Shenyang for years

| Month | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|------|-----|-----|-----|
| Average temperature | -11.5 | -7.8 | 0.7 | 9.8 | 17.2 | 21.7 | 24.5 | 23.6 | 17.3 | 9.5 | 0.3 | -7.9 |

3.2 Determination of environmental temperature difference
The environmental temperature difference refers to the difference between the temperature when the post-pouring tape is closed and the minimum temperature that can be reached during the construction period, which is \( \Delta T_y = T_0 - T_{\text{min}} \) (1)

In the above formula, \( \Delta T_y \) is the environmental temperature difference. \( T_0 \) is the temperature when the post-cast tape is closed. \( T_{\text{min}} \) is the lowest temperature value during the construction period.

The project was closed in April 2012 with the post-casting tape. The average temperature of the month was 10°C, so the initial temperature was 10°C.

Since the basement is not heated, the lowest temperature experienced by the structure during the winter can be -5°C. The environmental temperature difference of this project:

\[ \Delta T_y = 10^0°C - (-5^0°C) = 15^0°C \] (2)

3.3 Determination of the equivalent temperature difference of concrete shrinkage
According to literature [1], the shrinkage deformation of concrete is calculated according to the following formula:

\[ \varepsilon_y(t) = \varepsilon_y^0 \cdot M_1 \cdot M_2 \cdots M_n (1 - e^{-bt}) \] (3)

\( \varepsilon_y(t) \): The amount of shrinkage any time, in days
b: The experience coefficient is generally 0.01, and 0.03 when the maintenance is poor
\( \varepsilon_y^0 \): The limit shrinkage in the standard state is 3.24x10^-4
\( M_1 \cdot M_2 \cdots M_n \): Consider the correction coefficients of various non-standard conditions. Refer to relevant information, the correction coefficient is 0.8.
The final shrinkage and deformation of the basement:

\[ \varepsilon = 0.8 \cdot \varepsilon_y^0 = 0.8 \times 3.24 \times 10^{-4} = 2.6 \times 10^{-4} \quad (4) \]

The shrinkage equivalent temperature difference is equal to the ratio of the shrinkage of concrete to the linear expansion coefficient of concrete. When the casting tape is closed, the concrete has a shrinkage deformation occurring after the assumption of the residual shrinkage is (1-a%), the shrinkage of concrete is equivalent temperature difference:

\[ \Delta T' = \frac{(1-a\%)\varepsilon_y(t)}{\alpha} \]

(5)

\[ \alpha = 1 \times 10^{-5} / ^\circ C \] is the linear expansion coefficient of concrete.

The basement of this project has been constructed for 180 days when the post-pouring belt is closed, 80% of the total shrinkage of the concrete has been completed and 20% has not been completed \[3\], which means the shrinkage has not been completed.

\[ \Delta \varepsilon = 0.2 \times 2.6 \times 10^{-4} = 0.52 \times 10^{-4} \quad (6) \]

Difference of concrete shrinkage equivalent temperature is \[ \Delta T = \frac{\Delta \varepsilon}{\alpha} = 0.52 \times 10^{-4} / 1 \times 10^{-5} = 5 ^\circ C \].

3.4 Determination of Expansion Equivalent Temperature Difference of Compensating Shrinkage Concrete

The shrinkage-compensating concrete used in the basement of this project and the limiting expansion rate is 2.0 \times 10^{-4}. The linear expansion coefficient of concrete is 1 \times 10^{-5}/^\circ C, which is equivalent to heating up to 20 ^\circ C, taking into account the material mix of the compensation concrete, construction and maintenance Uncertainty, the expansion equivalent temperature difference of the compensation concrete is taken as \[ \Delta T'' = 5 ^\circ C \], which is only used to compensate the concrete shrinkage equivalent.

3.5 The value of the calculated temperature difference of the basement structure

Calculated temperature difference of over-long basement structure:

\[ \Delta T = \Delta T_y + \Delta T' - \Delta T'' = 15 ^0 C + 5 ^0 C - 5 ^0 C = 15 ^0 C \]

(7)

4. The value of relaxation coefficient consider creep and stress relaxation \[4\]

Creep and stress relaxation can greatly reduce the elastic stress. Considering the effect of creep, the stress of structural components can be accurately analyzed, the strength of the material can be fully utilized, and the engineering quantity and the engineering cost can be reduced. The beneficial effect of stress relaxation on structural design is mainly achieved by determining the relaxation coefficient in engineering applications. In the literature \[1\], the stress reduction coefficient is approximately taken as 0.3-0.5. In the checking calculation of this project, the relaxation coefficient is taken as 0.3.

5. The determination of the combined coefficient of the temperature effect

According to the Code for Loads of Building Structures (GB50009-2012), the combined value coefficient of the temperature effect is taken as 0.6, and the partial coefficient of variable load is taken as 1.4.

6. Analysis and verification of temperature effect

Using finite element analysis and design software Midas, beam elements are used for beams and columns and slab elements are used for floors and walls. The overall deformation diagram is shown in Figure 1. The basement floor and beams are made of C35 concrete, with an elastic modulus of 31500MPa; the concrete Poisson’s ratio is 0.2, and the steel bars are made of HRB400, fy=360N/ mm².
6.1 Analysis of Temperature Stress of Basement Roof
Only under the effect of cooling conditions, the temperature stresses of the basement ceiling and the top of the basement are basically the same in value and distribution \[^5\]. Stress concentration will occur at the connection between the basement exterior wall and the basement roof, the junction between the basement roof and the main building, and also the narrow connecting slab.

The temperature stress in the X direction of the basement roof is mostly 0.7 MPa, and the temperature stress in the middle connecting channel is 1.7 MPa; the temperature stress in the Y direction is mostly 1.3 MPa. The temperature stress of the slab between the main building is relatively large. It is 1.5MPa.

6.2 Analysis and Checking Computation of Temperature Stress of Outdoor Basement Wall
According to the characteristics that most of the basement wall cracks are vertical cracks \[^6\], the horizontal and longitudinal (along the long direction of the basement wall) temperature stress of the basement wall should be analyzed. The horizontal stress of the basement exterior wall is about 1.5MPa.

6.3 Analysis and Checking Computation of Temperature Effect of Basement Frame Column
Under the cooling conditions, the maximum bending moment of the frame column foot around the X axis is 55.7kN · m, the corresponding column top displacement is 0.414mm, and the interlayer displacement angle is 1/8937; the frame column foot around the Y axis is the largest. The bending moment is 350 kN · m, the corresponding column top displacement is 1.259mm, and the interlayer displacement angle is 1/2939.

7. Structural crack prevention measures

7.1 Construction measures
According to the specification Technical Regulations for Cracking Prevention of Underground Concrete Structures (DB21/T1745-2009), the following structural measures were taken in the design to reduce concrete cracking caused by temperature changes.

a) Use prestressed steel bars for beams and plates. The concrete strength grade of the pre-stressed beam slab is C35, the pre-stressed steel bar adopts steel stranded wire as S15.2, the tension end adopts QM15-1J clip type anchorage, QM15-1W extrusion type anchorage, when used with the stress plate it can be stretched when it reaches 85% of the design strength. The tension of prestressed steel strand is controlled by both stress and strain at the same time. The profile position of the prestressed steel strand used for the floor slab is arranged in the form of positive and negative parabola.

b) Set up expansion reinforcement belt. The basement floor, roof, and exterior walls are all set with penetrating expansion reinforcement belts, and shrink-compensating concrete is used outside the belts.

c) Foundation: The basement foundation adopts the form of combining the reinforced concrete independent foundation under the column and the structural bottom plate. The thickness of the bottom
plate of this design is 350mm, and the bottom plate reinforcement adopts double-layer two-way pull-through.

d) Basement exterior wall: The reinforcement ratio of the single-sided horizontal structure of the basement exterior wall is not less than 0.20%.

e) Basement roof: The basement roof reinforcement adopts double-layer two-way pull-through, and the spacing is controlled at 150mm.

f) For places where the local stress is concentrated and large in the structure, such as the floor openings, the floor slabs at the corners of the structure and the corresponding shear walls, the plane size is relatively large, check the calculated stress value to ensure that the floor is inside Reinforcement.

7.2 Requirements for concrete materials

a) The cement uses medium and low heat fly ash silicate No. 425 cement, and the 28-day hydration heat value is less than 320KJ/Kg;

b) Concrete cement dosage: 280Kg/m$^3$~300Kg/m$^3$, water-cement ratio ≤0.5, sand ratio 0.35~0.4; on-site pumping concrete slump: 13~15cm

c) Coarse and fine aggregate: 1) Coarse aggregate: use crushed stone with a particle size of 5-25mm; 2) Fine aggregate: medium-coarse sand with fineness modulus ≥2.7 and average particle size ≥0.37mm;

d) The mud content control of sand and stone materials: 1) The mud content of stones is less than 1%; 2) The mud content of medium coarse sand is less than 1.5%;

e) Admixtures and admixtures: internal admixtures are used to add admixtures in concrete;

f) The construction unit shall carry out the concrete mix ratio test according to the above requirements.

7.3 Requirements for concrete construction and maintenance

7.3.1 Concrete construction

a) On the construction site or mixing station, ensure that a sufficient amount of expansion agent is added according to the concrete mix ratio.

b) The mixing time of on-site concrete is 30s longer than that of ordinary concrete to ensure that the expansion agent, cement and water reducing agent (pumping agent) are mixed evenly.

c) Control the temperature of concrete out of the tank and pouring temperature: 1) During the on-site mashing, when the outdoor temperature during the day is> 28°C, the sand and stone storage yard should be equipped with sunshades; 2) The temperature of concrete out of the tank is less than or equal to 15°C, and the temperature of concrete pouring is less than or equal to 15°C. The concrete should be poured early and late; 3) Cover the entire length of the horizontal conveying pipe of the pump truck with a layer of straw bags, and spray cold water frequently to reduce the absorption of solar radiant heat during the concrete pumping process; 4) Use multiple pump trucks to transport at the same time to shorten the concrete pouring time;

d) Strictly control the concrete slump, and the slump should not be more than 15cm;

e) The beam and slab formwork must be fully moistened before pouring the concrete;

f) After the beam and slab concrete is poured, the bleeding on the surface of the concrete should be removed;

1) For the basement floor, side walls and floors below ±0.000, the floor slab adopts anti-cracking waterproofing agent non-shrinkage concrete in order to prevent the generation of concrete shrinkage cracks.

7.3.2 Demolition and maintenance of concrete

a) Control the remolding time after the concrete is poured. It is stipulated that the formwork bolts should be loosened 16 hours after pouring, and the formwork will be demolished after 24h. Try to arrange to lift the formwork during the day when the temperature is high to prevent the concrete from being exposed to environmental conditions after the mold is just demolished. Too cold stimulation.
b) Strengthen the watering and curing of concrete, and set up a PVC plastic pipe with a small cavity in the middle of the top of the wall for constant-flow water curing.

C) After the basement wall is demolished, the construction of the waterproof layer and the protective layer should be arranged immediately. After the acceptance by the relevant departments, the earthwork should be backfilled immediately as required to minimize the exposure time of the basement wall.

D) The fertilizer trough should be backfilled after pouring the outer wall with the pouring tape. A retaining plate is set on the outside of the structure, and an additional waterproof layer is made outside the retaining plate. The retaining plate can be 80-100mm thick reinforced concrete prefabricated plate, 5-6mm thick steel plate or 3mm thick belt-assisted steel plate. The additional waterproof layer is a coiled waterproof layer or a 2~3mm thick polyurethane coating film. When the concrete is poured after the outer wall is poured in the future, the retaining plate can be directly used as the outer formwork.

e) After the surface of the floor slab is smoothed with wooden crabs after concrete pouring, lay a layer of straw bags and fully water them for maintenance. The surrounding beams should also be hung with straw bags and watered frequently. After the post-pouring belt is closed, the construction unit should take heat preservation and enclosure measures to ensure that the winter temperature in the basement is more than -5°C.

8. Conclusion
By using Midas to analyze the temperature stress of the basement concrete structure of the Shenyang Hunnan New City Shangshenbei Block Project, the temperature stresses at the bottom and the top of the basement roof are basically the same in value and distribution. At the junction of the basement exterior wall and the basement ceiling, the junction between the basement ceiling and the main building, and the relatively narrow connecting slab, stress concentration will occur. The force of the frame gradually decreases from the side span to the middle span. Corresponding technical measures were adopted for this project and steel bars were configured according to calculations. The project has been completed in 2013. No cracks and water leakage has been found on the roof and outer walls of the basement structure, and no cracks has been appeared in the frame columns either.

The structure used in this project was not common at the time, but it has now been popularized. Crack control is the top priority of this structure. The method proposed in this article has guiding significance for similar projects and plays an important role in structural safety.

References
[1] Wang T M, Comprehensive method for crack control of engineering structure [J]. Construction Technology, 2000(05):5-9.
[2] Zheng Z P, Analysis of temperature stress of super-long concrete structure in Tianjin West Railway Station [J]. China Municipal Engineering, 2010(03):84-85+99.
[3] Wang Q, Yin R, Liu GL, Liu M, Zhang Y B, Zhang Q G, Rong X F, Thermal stress analysis of ultra-long basement concrete structure[J]. Journal of Shenyang Jianzhu University (Natural Science Edition), 2009, 25(03): 437 -441.
[4] Zhao R, Demonstration report on the super long basement of the Hunnan New City Shangshenbei block project [R]. Shenyang: China Architecture Northeast Design and Research Institute Co., Ltd, 2013, 1-16.
[5] Lu C P, Liu X H, Zhao Z F, Ma G, Jin R X, Chang X L. The effect of time-varying thermal expansion coefficient on the simulation of concrete temperature stress [J]. Journal of Zhejiang University (Engineering Science Edition), 2019, 53(02): 284- 291.
[6] Jiang X P, Wang S L, Duan S X, Sun Y. Mechanism analysis of temperature cracks in super-mass concrete and new countermeasures for anti-cracking control [J]. Concrete, 2007(12): 98-102.