Research on the Reasonable Spacing of Post-casting Belt of 100m Long Inverted-T Shape Concrete Structures on Soft Foundation

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Abstract: Setting up post-casting belt is one of the most important measures for temperature control and crack prevention of mass concrete, but current specifications have not given unified and clear rules on the spacing of post-casting belt. In this paper, a 100m long inverted-T shape concrete structure on soft foundation in Yangtze River Delta region is taken as the research object. The temperature and stress field of concrete during construction under different conditions are simulated by finite element method, and bottom plate’s and gate pier’s recommended spacing of post-casting belt is obtained when poured in different seasons. This will be of guiding significance to the construction of such mass concrete structure.

1. Introduction
During the construction of mass concrete structure engineering, hydration reactions of cement generate a lot of heat. Many engineering cases show that the post-casting belt has become an effective measure for concrete temperature control and reduction of cracks.

The post-casting belt is a temporary deformation joint that remains during construction. It is retained for a certain period of time according to specific conditions, and then filled and sealed, and then poured into a continuous overall non-expansion-slit structure. Its purpose is to eliminate the permanent deformation joints in the structure and is related to the temperature shrinkage stress and differential settlement of the structure. It exists only during construction and is a special construction joint. Therefore, it is not only a kind of expansion joint and settlement joint in design, but also a temporary deformation joint, and is both a construction measure and a design means. The post-casting belt can be divided into three categories according to its function: a post-casting settlement belt for solving the problems brought by settlement difference between the high-rise main body and the low-rise podium; a post-casting temperature belt for solving the problems brought by reinforced concrete temperature stress during the construction; a post-casting shrinkage belt for solving the problems brought by concrete’s shrinkage deformation [1].

The literature [2] pioneered the special study of the construction of large-volume concrete for workers and civilians. Combined with the specific engineering cases, considering the influence of the
drying shrinkage of concrete, the non-linear relationship between temperature stress and the length of the structure was obtained. Zhu Bofang [3] proposed the use of block-and-slit method to replace cluttered spontaneous cracks with pre-designed artificial seams equipped with keyways and grouting equipment. You Baokun[4] and Wu Zhongwei[5] suggested using compensation concrete to solve the crack caused by the deformation of concrete or to use the "expansion strengthening belt" to replace the post-casting belt completely or partially. The ACI committee[6], the Japanese Architectural Society JASS and the British design specifications all believe that the method of splitting and dividing the block is adopted in the construction.

However, there are still some deficiencies in the current specification for the post-casting belt. One of the obvious deficiencies is that the spacing is not clear. The spacing given by different specifications varies, resulting in a large difference in the spacing of the post-casting strips in actual engineering. In some projects, the spacing between the post-casting belts is less than the standard limit value, but cracks still occur during the construction process, while some engineering post-casting belts are set at a distance exceeding the limit value of the specification, but no problems are found during construction and use [7].

Based on the above situation, this paper takes the inverted-T shape structure under the climatic conditions of the Yangtze River Delta as the object, and studies the value of the post-casting belt spacing, which can guide the construction of mass concrete engineering.

2. Simulation calculation model and parameters

2.1. Finite element model

In this paper, the finite element model of different post-casting spacing is established for the inverted T-shaped structure of 100m length, as is shown in Figure 1~8. The origin of the model coordinate is at the center of the downstream surface of the first pier on the left bank. The Z-axis is vertically up and the X-axis is across the river, and the Y-axis points to the upstream according to the right-handed spiral rule. The number of model elements and nodes with different post-pour spacing are shown in Table 1.

| The spacing of post-casting belt (m) | The number of elements | The number of nodes |
|-------------------------------------|------------------------|-------------------|
| 100                                 | 133744                 | 152775            |
| 50                                  | 128880                 | 147275            |
| 40                                  | 128880                 | 14725            |
| 30                                  | 133744                 | 152775            |
| 15                                  | 176508                 | 204990            |
| 8                                   | 213248                 | 246710            |

2.2. Main calculation parameters

In addition to cushion which is made of C25 concrete, the concrete piles and other structures of the pumping station are made of C30 concrete, and the foundation is silty silty clay. The specific thermal and mechanical parameters of each material are shown in Table 2.

The formula of local multi-year monthly average temperature fitting curve (°C)

\[
T_0 (r) = 17.1 + 12 \times \cos \left[ \frac{\pi}{6} (r - 7.2) \right]
\]  

(1)
Table 2. Thermal and mechanical parameters of concrete and foundation

| Category         | Thermal convection (kJ/m·h·℃) | Specific heat (kJ/kg·℃) | Thermal diffusivity (m²/h) | Adiabatic temperature rise (℃) | Linear expansion coefficient (×10⁻⁶/℃) | Final value of autogenous volume deformation (×10⁻⁶) | Density (kg/m³) | Final elasticity modulus (MPa) | Poisson ratio |
|------------------|--------------------------------|-------------------------|---------------------------|--------------------------------|----------------------------------------|------------------------------------------|----------------|-------------------------------|---------------|
| C25 Concrete     | 6.575                          | 0.934                   | 0.0031                    | 38                             | 9.489                                  | 65.27                                    | 2261           | 28000                         | 0.167         |
| C20 Concrete     | 10.82                          | 0.89                    | 0.00529                   | 51.3                           | 8.90                                   | 77.26                                    | 2318           | 35000                         | 0.167         |
| foundation       | 2.41                           | 1.91                    | 0.0012                    | /                              | 8.0                                    | /                                        | 1793           | 10                            | 0.30          |

2.3. Boundary conditions of calculation
In the temperature field simulation calculation, the four sides and the bottom surface of the foundation are adiabatic boundaries, and the upper surface is the heat dissipation boundary. The other surfaces are thermal boundaries. In the stress field simulation calculation, the four sides and the bottom surface of the foundation are applied with a normal constraint, and the upper surface is a free boundary. The concrete surface is a free boundary.

3. Calculation of working conditions and analysis of calculation results
The finite element model of different post-casting belt spacing is simulated by the following series of working conditions.

3.1. Calculation conditions
Working condition 1 series: The bottom plate is poured in summer, and the post-casting belt is poured after the temperature of the first block is lowered to 30℃. The first block of the pier is poured after the temperature of the second block of bottom plate is lowered to 30℃ and the second block of the pier is
poured after the temperature of first block of pier is lowered to 30°C. The pouring temperature is 35°C.

Working condition 2 series: The bottom plate is poured in spring, and the post-casting belt is poured after the temperature of the first block is lowered to 25°C. The first block of the pier is poured after the temperature of the second block of bottom plate is lowered to 25°C and the second block of the pier is poured after the temperature of first block of pier is lowered to 25°C. The pouring temperature is 25°C.

Working condition 3 series: The bottom plate is poured in winter, and the post-casting belt is poured after the temperature of the first block is lowered to 20°C. The first block of the pier is poured after the temperature of the second block of bottom plate is lowered to 20°C and the second block of the pier is poured after the temperature of first block of pier is lowered to 20°C. The pouring temperature is 15°C.

3.2. Calculation results and analysis

The finite element method is used to simulate the construction of the structure, and the maximum tensile stress and maximum temperature of the bottom plate and the gate pier inside the inverted-T shape structure with different lengths of 100m long can be obtained. The calculation results of the maximum temperature are shown in Table 3. The calculation results of the maximum tensile stress are shown in Table 4.

| Season | Block length (m) | Maximum temperature inside the bottom plate (m) | Maximum temperature inside the gate pier (m) |
|--------|-----------------|-----------------------------------------------|-----------------------------------------------|
| Summer | 50              | 66.1                                         | 66.5                                         |
|        | 40              | 65.8                                         | 66.0                                         |
|        | 30              | 66.1                                         | 66.2                                         |
|        | 15              | 66.1                                         | 66.2                                         |
|        | 8               | 65.0                                         | 66.2                                         |
|        | 4               | /                                            | 64.4                                         |
| Spring | 50              | 56.0                                         | 60.0                                         |
|        | 40              | 55.7                                         | 60.0                                         |
|        | 30              | 54.6                                         | 58.0                                         |
| Winter | 100             | 40.0                                         | 40.2                                         |
|        | 50              | 40.2                                         | 40.2                                         |
|        | 40              | 39.8                                         | 40.2                                         |
|        | 30              | 39.5                                         | 39.7                                         |

It can be seen from the calculation results that the pouring season has a significant influence on the highest temperature inside the structure, and the length of the pouring block has little influence on the maximum temperature.

| Season | Block length (m) | Maximum tensile stress inside bottom plate (MPa) | Maximum tensile stress inside bottom plate under the gate pier (MPa) | Maximum tensile stress inside gate pier (MPa) |
|--------|-----------------|-----------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Summer | 50              | 2.30                                         | 3.04                                         | 4.73                                         |
|        | 40              | 2.40                                         | 3.04                                         | 4.68                                         |
|        | 30              | 2.34                                         | 2.97                                         | 4.47                                         |
|        | 15              | 1.80                                         | 2.43                                         | 3.35                                         |
|        | 8               | 1.75                                         | 1.98                                         | 3.17                                         |
|        | 4               | /                                            | /                                            | 2.58                                         |
| Spring | 50              | 2.50                                         | 3.12                                         | 3.07                                         |
|        | 40              | 2.40                                         | 3.08                                         | 3.04                                         |
|        | 30              | 2.30                                         | 2.98                                         | 2.92                                         |
| Winter | 100             | 2.17                                         | 2.26                                         | 2.87                                         |
|        | 50              | 2.00                                         | 2.22                                         | 2.76                                         |
|        | 40              | 1.95                                         | 2.15                                         | 2.72                                         |
|        | 30              | 1.87                                         | 2.15                                         | 2.64                                         |
According to the stress calculation results, the bottom plate’s optimal pouring length is 30m when poured in summer, and the pier’s is 4m. When poured in spring, the bottom plate’s optimal pouring length is 30m, and the pier’s is 30m; In winter, the bottom plate’s optimal pouring length is 100m, and the pier’s is 100m.

As the length of the block is shortened, the maximum tensile stress generally decreases. Due to the direct constraint of the upper pier, the maximum stress of the bottom plate under the pier is greater than that of the other parts. Since the pier is strongly restrained by the bottom plate, the maximum tensile stress of the pier is greater than that of the bottom plate. The winter temperature and pouring temperature are lower, so the maximum tensile stress is the smallest. Similarly, the maximum tensile stress is the largest in summer and lower in spring.

According to the stress calculation results, the relationship between the maximum internal stress and the post-casting belt’s spacing of the 100m long inverted-T shape structure in different seasons can be fitted, as shown in Figure 9~11, where x is the length of casting block (m), and y is the maximum tensile stress (MPa) inside gate pier.

According to the temperature calculation results, the relationship between the optimal length of the block of 100m long inverted-T shape structure and the maximum temperature inside the pier can be fitted as shown in Figure 12, where x is the optimal pouring length of pier (m), and y is the maximum temperature inside pier (°C).

**4. Conclusion**

In this paper, the temperature field and stress field during construction of the 100m inverted-T shaped concrete structure are simulated, and the recommended values of different post-casting belt’s spacing are obtained when the anti-cracking safety factor during construction is 1.0:
For the bottom plate of the inverted-T shaped structure with a length and width of 100m, the optimum pouring block length of the bottom plate is 30m when poured in spring and summer, while in winter, there is no need for post-casting.

For the pier of inverted-T shaped structure with a length of 100m, the optimal pouring block length of the pier is 4m when poured in summer; the optimal pouring block length of pier is 30m when poured in spring; There is no need for post-casting when poured in winter.

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