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The Theoretical Study on Temperature Effect of Super-length Concrete Structures and its Corresponding Engineering Measures

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The super-length concrete structure isn't easily deformed under the action of temperature difference due to various constraints. It is easy to be cracked because of the excessive temperature stress. Based on the analysis of the characteristics of various types of constraints in the super length structure, and the finite element elasticity calculation of the specific engineering case, we analyze the internal relationship between the temperature effect characteristics and the constraint of the super-length residential structure. According to the formation mechanism of the temperature stress, some technical measures, which can reduce the temperature stress of the super-length structure, are put forward, and applied to engineering design as well. It verify the effectiveness of technical measures through the engineering practice.

1. Introduction

With the increasingly complex shape and function of the building, or for the appearance of the aesthetic requirements, a large number of long length concrete structures have come up, which results in the floor cracking caused by the temperature stress becomes quite common. It affects the normal use of the building and structural durability (Jing, 2006; Gao et al., 2007). Therefore, analysis of the temperature effect is an important part of the design which should be considered. In practice, many long length concrete structures without expansion joints have appeared, and it have accumulated some crack prevention engineering experience. But except that the design of the large concrete structures, it will consider the temperature stress, the general industrial and civil construction of the super-length concrete structure are not taken into consideration d in the temperature effect. Theoretical research lags behind the engineering practice seriously (Liu et al., 2009). The main reason is that the crack problem of super-length concrete structure is very complicated, which involves many factors such as design, construction, materials, external environment and so on. In this paper, we theoretically study on the cracking problem of concrete due to temperature stress. Based on the experience of engineering practice and the finite element analysis, the elasticity analysis of the super-length concrete structure is carried out. At the same time, based on the research results of other related papers, we give some relevant recommendations on the process of concrete structure design and construction (Mah et al., 2017).

1.1 Analysis of temperature difference and creep of concrete

The temperature difference of concrete mainly includes internal hydration heat temperature difference, external environmental temperature difference (including seasonal temperature difference, sunshine temperature difference and sudden drop temperature difference) and concrete shrinkage equivalent temperature difference. Generally, when the floor thick is less than 500mm, the temperature difference of hydration heat can be ignored. Therefore, we can only consider the effect of seasonal temperature difference and concrete shrinkage equivalent temperature difference during the temperature effect analysis of ordinary floor, and the influence of concrete creep on structural stress relaxation should be taken into consideration as well (Zheng et al., 2011; Lan, 2012). In addition, compared to other floors, the construction roof often produces crack and leakage phenomenon, affecting the use of roof. The main reason is that the roof is most direct part

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under the influence of the external environment. When we calculate the roof temperature stress, we should consider the sunshine temperature difference and sudden-dropped temperature based on the specific circumstances of the project, and should pay attention to the internal differences between it and the temperature difference among the seasons.

1.2 Ambient temperature difference

When determining the environmental temperature difference and in order to determine the value of its ambient temperature, we should give a reasonable estimate of the structure of the ambient temperature and take full account of the environmental conditions in which the structure has. The environmental temperature difference is divided into the following three types: sunshine temperature difference, sudden-drop temperature difference and seasonal temperature difference, three types of temperature differences have different characteristics (Zhang et al., 2013), which can be seen in Table 1.

Table 1: Types and characteristics of environmental temperature difference

Temperature difference type	Climatic conditions	temporal	Effect range	Distribution state	Structure effect	Complexity
Sunshine temperature difference	solar radiation	Rapid change	sunlight radiation surface	uneven	Big local stress	The most complex
Sudden-dropped temperature difference	Intense cold air	Rapid change	Surface contacting with air	even	local stress	more complex
Seasonal Temperature Difference	Seasonal Replacement	Long Term and Slow	Overall Structure	Relatively Uniform	large Overall Displacement	Simple

The measured and studied results show that the short - term sunshine temperature difference and the sudden drop temperature difference have a greater effect on the structure than the seasonal temperature difference. Seasonal temperature difference is a long-term slow effect, due to creep will lead to stress relaxation, which released part of the temperature stress (Gao and Kuang, 2014). The seasonal temperature difference is the temperature difference between the concrete construction temperature and the most unfavorable working conditions in the later stage. The temperature of the construction can be controlled by controlling the temperature of the concrete into the mold and strengthening the construction and maintenance of the later construction. The standard value of the seasonal temperature difference during the use of concrete can be calculated as follows:

Structure of the largest cooling conditions: △Tk=Ts, min-T0, max

Where: △Tk - Standard value of uniform temperature (°C)

Ts, min - Structure minimum average temperature (°C)

T0, max-Structure of the highest initial average temperature (°C)

The minimum average temperature of the structure $T_{s,\ min}$ is determined by the principle of thermodynamics based on the basic temperature T_{min}. The basic temperature T_{min} can be determined according to Appendix E of the literature (Zhang and Liu, 2011). For the enclosed interior structure, the average temperature of the structure should be taken into account the effect of indoor and outdoor temperature difference. For the structure exposed to the outdoor structure or during the construction period, the influence of solar radiation should be taken into account according to the structure orientation and surface heat absorption properties. The maximum initial mean temperature $T_{0,\ max}$ of the structure shall be determined by the time of closing or forming the restraint of the structure or on the basis of the most unfavorable temperature that may occur during construction.

1.3 Concrete shrinkage equivalent temperature difference

Concrete shrinkage increases with the extension of age, there are many factors that affect the contraction of concrete, mainly cement varieties, water-cement ratio, aggregate gradation, curing conditions, the use of the environment. Engineering design is usually the concrete shrinkage deformation equivalent to shrinkage equivalent temperature difference; you can use the following formula (Zhang et al., 2011):

$$\varepsilon y(t)=\varepsilon 0(\infty)\cdot M1\cdot M2\cdot M3\cdot \cdots \cdot M10(1-e-mt) \tag{1}$$

$$Ty=\varepsilon y(t)/\alpha \tag{2}$$

Where: T_y - concrete shrinkage equivalent temperature difference;
α- the linear expansion coefficient of concrete, ordinary concrete desirable 1 × 10-5/°C;
M_i - correction coefficient of concrete under different conditions;
ε0(∞) - constant 3.24 × 10-4, the final shrinkage strain of concrete under standard condition;
$\varepsilon_{y(t)}$ - any time shrinkage strain, m = 0.01;
t - The time value in d units from pouring to calculation.

1.4 Effect of concrete creep on temperature effect

In the case of the long-length concrete structure, the simplified elastic calculation method is generally used, but considering the seasonal temperature difference and the shrinkage equivalent temperature difference of the structure are carried out for a long period of time. Only the elasticity analysis is too conservative and must be taken into account the creep of concrete and the stress relaxation is caused by the micro-cracks of the concrete, thus releasing part of the temperature stress. Therefore, in calculating the temperature effect of super-long concrete structure should be multiplied by the stress relaxation coefficient H (t, τ), according to curing conditions and cooling rate of 0.3 to 1, generally in the insulation, moisturizing conditions are better, which take 0.5 under normal conditions , sudden cooling and drastic conditions to take 0.8 ~ 1 (Lei et al., 2009).

2. Case study on temperature effect of super long concrete structure

A large-scale residential floor on the 31st floor, the ground is a local 2-story large basement, frame - shear wall structure, the total building height of 98.2m, the standard layer size 91.2m × 18.3m, the standard layer layout shown in Figure 1. Due to the impact of the layout of the building, do not have the conditions to set the expansion joints, only by setting the post-pouring to release part of the temperature stress. The problem of design and construction is how to control the overall temperature stress within a reasonable range, as far as possible due to the structure of the long lead to shrinkage cracks.

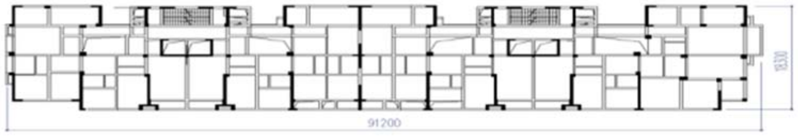

Figure 1: A high-rise residential standard layer layout plan

2.1 Finite element analysis of the whole distribution law of floor temperature effect

The basement is placed in the soil, affected by the external temperature change is small, and the rigidity is large. When analysing the temperature effect of the upper structure, the bottom of the upper structure model is often simulated by the fixed bearing, of the constraints will produce temperature stress in the floor. In order to master the law of temperature effect, the finite element program ANSYS is used to calculate the elasticity of the structural model. The structural model adopts two kinds of unit types: beam and column adopts BEAM188 unit + shear wall and floor with SHELL63 unit, which can better reflect the spatial force and force transmission characteristics of the structure. According to the specific conditions of the project, the temperature difference of the floor shrinkage equivalent is -20°C, the ambient temperature difference is -15°C, and the temperature effect is calculated according to the comprehensive temperature difference -35°C. The calculated temperature stress is multiplied by the stress relaxation coefficient H(t, τ), The value is 0.3. The temperature difference between the roof temperature and the temperature is adjusted to -25°C, the comprehensive temperature difference of -45°C, and considering the sunshine temperature difference and sudden drop temperature difference in a short time to change faster, stress relaxation The coefficient H(t, τ) is adjusted to 0.5. The temperature stress of the floor after adjustment is shown in Table 2.
In theory, the shear wall fixed to the basement, the pillars on the upper floor of the constraints in the two-story floor at the largest, with the floor increment, the shear wall, column lateral stiffness of the relationship between the three-party declines. The floor constraints will be fast reduced. From the results of the calculation of the temperature stress of each floor of Table 2, the maximum value of the floor temperature stress in the local stress concentration is found in the two-floor slab and the layer is reduced to 4 to 29 layers. Basically stable and in the same layer of the plane: the basic layer of each layer is in the middle of the greater tensile stress, the end of the tensile stress is small. The tensile stress of the middle layer is more than 1.2Mpa, that is, the temperature stress distribution of most slabs in the middle floor is more uniform, and the maximum temperature stress doesn’t exceed the tensile strength of concrete. The difference between the end and the middle of the tensile stress decreases or tends to be no significant difference, the smaller deformation

constraint rate and temperature stress is mainly due to the shear wall. And the column in the plane is caused by uneven distribution of stiffness, and the structure of long. The stress in the middle of the roof is 1.5 ~ 2.5Mpa, mainly due to the large temperature difference between the inside and outside of the roof and the temperature difference between the sunshine and the temperature difference, the smaller the temperature and the larger temperature stress, the main part is the top 2 Floor. The structural shrinkage deformation is the uniform shrinkage of the integral stiffness of the structure, and the deformation is basically proportional to the distance from the heart. From the ANSYS finite element analysis results, the above calculation results are consistent with the mechanism of the temperature effect, but also in line with other research literature conclusions (Xie et al., 2008).

Table 2: The floor slab stress calculated by ANSYS

Vertical position of floor	Central stress/Mpa	End force /Mpa	Actual deformation/mm	Free deformation /mm	Deformation constraint rate/%
2 Floor	2.0~4.2	1~2.0	-24.22	-31.92	24.12
3 Floor	1.4~2.0	0.7~1.3	-29.23	-31.92	8.43
4Floor ~29 Floor	0.5~1.2	0.4~0.8	-31.18~-31.92	-31.92	0~2.3
30 Floor	1~2	0.6~1	-30.58	-31.92	4.2
Roofing	1.5~2.5	1~1.4	-35.54	-41.04	13.4

Note: deformation constraint rate = (free deformation - constraint deformation) / free deformation; total free deformation = thermal expansion coefficient × temperature difference × length

2.2 Technical measures for reducing temperature stress on floor

In the bottom of several layers of the strong confinement area, the top of several layers of the temperature difference between the sudden changes in the temperature and local weak parts of the temperature stress has been greater than the tensile strength of concrete, which must take some technical measures to be resolved, in addition to passive weak local. In addition, according to the formation of the aforementioned temperature stress mechanism, it takes the initiative to reduce the overall structure of the constraints and reduce the indoor and outdoor temperature difference between the two aspects.

(1) To reduce the length of the floor of the constraints: the original design on the basis of the size of the shear wall, the column to adjust, such as part of the column section 500mm × 600mm adjusted to 400mm × 750mm, shear wall thickness from 200 ~ 250mm Adjusted to 220 ~ 200mm and a series of optimization. Table 3 data for the wall size adjustment of the floor after the calculation of the temperature stress.

Table 3: Shear wall, column size adjusted floor temperature stress

Vertical position of floor	Central stress /Mpa	End force /Mpa	Actual deformation /mm	Free deformation /mm	Deformation constraint rate /%
2 Floor	1.8~3.8	0.9~1.8	-24.80	-31.92	22.30
3 Floor	1.2~1.8	0.6~1.2	-29.50	-31.92	7.61
4 Floor ~29 Floor	0.5~1.1	0.4~0.8	-31.25~-31.92	-31.92	0~2.10
30 Floor	0.9~1.8	0.5~0.9	-30.71	-31.92	3.80
Roofing	1.3~2.3	0.8~1.2	-36.03	-41.04	12.20

Compared with the results in Table 2 and Table 3, it can be seen that for the super-long concrete structure, the shear wall and the cross-sectional dimension of the super-long direction can be reduced to reduce the lateral stiffness and the floor constraint in the long direction to a certain extent Longitudinal temperature of the floor (Lei et al., 2009; Wang and Zhi, 2007)

(2) Increasing the thickness: in the wall size adjustment on the basis of further increase the temperature stress at the bottom and the top of a number of layers of the floor thickness, can further reduce the floor temperature stress (Chen et al., 2016); in addition, Thickness can reduce the stress and increase the cross-section stiffness, to limit the width of the crack have a certain role. Consider the 4 ~ 29 layer temperature stress is relatively small, in order to save the cost, only 2, 3 and roof thickness adjustment, most of the increase of 20mm thick, the stress concentration of the floor to increase the thickness of 30mm. The calculation results of the floor temperature stress are shown in Table 4.

As can be seen from Table 4, with the increase in plate thickness, the floor temperature stress as a whole decreased, the stress distribution has also changed, more even more uniform. In addition, according to the concrete shrinkage mechanism, the shrinkage is caused by the evaporation and bleeding of concrete inside the water, the evaporation of water caused by the volume of contraction, always from the table and that the dry shrink occurs mainly in the concrete surface, A certain size effect (Boucherit, 2010). Thin sections of the entire cross-section are susceptible to shrinkage, and relatively thick sections of the cross-section of almost no shrinkage within the surface will shrink to a certain degree of obstruction, a lot of engineering practice also confirmed that the thinner the easier floor cracking. Therefore, the appropriate thickening of the residential floor is conducive to crack prevention, in order to save the project cost, only the greater the temperature stress at the bottom and the top of a number of layers and stress concentration parts of the appropriate increase in thickness.

Table 4: Thickness adjustment of the floor after the temperature stress

Vertical position of floor	Central stress /Mpa	End force /Mpa	Actual deformation /mm	Free deformation /mm	Deformation constraint rate /%
2 Floor	1.6~3.4	0.7~1.5	-25.82	-31.92	19.11
3 Floor	1.0~1.5	0.5~1.0	-29.84	-31.92	6.52
4Floor ~29 Floor	0.5~1.1	0.4~0.8	-31.25~-31.92	-31.92	0~2.10
30 Floor	0.7~1.6	0.4~0.8	-30.90	-31.92	3.21
Roofing	1.1~2.0	0.7~1.2	-36.83	-41.04	10.26

(3) To reduce the comprehensive temperature difference and indoor and outdoor temperature: the temperature difference between the initial temperature of concrete pouring and the latter part of the most unfavorable temperature difference between the project to consider the long and more, set up two after pouring, the initial temperature can be considered After pouring with the temperature of the pouring (Lan et al., 2012; Xie et al., 2008), the temperature stress on the bottom of the bottom and the top of a number of layers in particular to pay attention to the election in the relatively low temperature period closed to reduce the seasonal temperature difference; consider the post-2 months after the concrete pouring, the basic has been completed 60% of the final contraction, that is, shrinkage equivalent temperature difference of only 8°C. In addition, due to the roof by the sunshine temperature difference and sudden drop in the impact of large, long structure in particular to do a good job of roof insulation, insulation measures and early in the top of a number of layers of insulation wall masonry. Table 5 shows the results of the calculation of the temperature stress of the floor after pouring.

Table 5: Set the post-pouring floor temperature stress

Vertical position of floor	Central stress /Mpa	End force /Mpa	Actual deformation /mm	Free deformation /mm	Deformation constraint rate /%
2 Floor	1.1~2.3	0.5~1.2	-18.02	-21.0	13.52
3 Floor	0.6~1.1	0.4~0.8	-20.09	-21.0	4.31
4Floor ~29 Floor	0.3~0.9	0.3~0.7	-20.74~-21.0	-21.0	0~1.23
30 Floor	0.6~1.3	0.3~0.8	-20.49	-21.0	2.43
Roofing	0.9~1.4	0.5~1.0	-28.02	-30.1	6.91

Table 6: The tensile strength and ultimate tensile straining

Conservation conditions	Tensile Strength/ft (Mpa)	Ultimate strength εt (10-5)
mess	0.69	6.1
Wet	1.40	8.0
Water	1.63	9.0

(4) Improve the tensile strength and creep capacity of concrete by good curing: Table 6 shows the tensile strength and ultimate tensile data of the same concrete under static load test under different curing conditions, in water and humid environment, in the concrete tensile strength and ultimate tensile capacity are much higher than the dry environment of concrete. The data in the table is the data of the static load test, but the

deformation in the actual engineering is generally accompanied by the large creep, and the good insulation and the moisture-preserved concrete will have more creep ability because of the higher quality, Change will also bring greater temperature stress relaxation, is conducive to floor crack prevention. Therefore, the ultra-long concrete structure with particular attention to the maintenance of concrete slab, both to improve the ultimate strength of concrete, but also help to improve the ability of concrete creep, bring greater temperature stress relaxation.

3. Conclusion

Based on the theoretical analysis of all kinds of constraints, this paper analyzes the temperature stress of a high-rise residential building with finite element elasticity. Although the temperature field distribution and shrinkage parameters of high-rise buildings are difficult to determine and the concrete is not elastic material. There is a plastic deformation, as well as creep and stress relaxation, the actual temperature stress is generally much smaller than the elasticity of the calculated value, but this doesn’t prevent the finite element elasticity calculation to determine the long structure of the weak links. Through the practice of a long residential case, this paper makes a deep comparative study on the weak boundary area and the local weak parts of the temperature stress, and so on. From the aspects of reducing the floor constraints, reducing the temperature difference and strengthening the conservation, several technical measures to release the temperature stress are put forward, which greatly reduces the risk of cracking of the floor and is finally confirmed in the engineering practice. At the same time, the construction of the floor of the anti-cracking weak part of the structure was strengthened, not the temperature stress on the majority of the floor to crack the cost of investment, to avoid a substantial increase in the cost of the project, so that anti-crack design, which can be used as other similar long structure design reference.

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