The research and application of temperature monitoring and warning system of large volume concrete

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ABSTRACT: The concrete will produce a large amount of heat during the curing process because of hydration. If the differential temperature exceeds a certain limit, the cracks will form in the concrete, especially when the volume of concrete is large. A FBG sensor system is used in this paper to monitor the inner temperature distribution of a large volume mat foundation of tall building. The monitoring system consists of three parts: sensors, data acquisition and warning modulus. The temperature stress analysis and early age concrete propertied are considered in the warning modulus. A case study shows that this monitoring system can successfully give warning of cracking of large volume of concrete, and after a certain treatment, prevent the cracking of concrete.

1 PREFACE

The large volume concrete means that the dimension of concrete is too big to ignoring the sub-strain, such as the shrinking and creep deformation, as well as the temperature deformation. During the curing period, the hydration of cement will produce heat. When the volume of concrete is large, the heat stress will be so big that cracking will take place in the concrete. So it is very important to monitor the temperature of the large volume concrete structure during the constructing. Utilizing the traditional sensors, such as thermometer, thermoelectric coupling, would lead to limit the accuracy and precision of the gathering data. Seeking for one kind of good accuracy temperature detection methods has already become the premise of structure site monitoring. The fiber optic sensor is a new-type sensor that has been developed in recent years. An optical fiber sensor is characterized by light weight, small volume, high sensitive, anticorrosion, against electric-magnetic wave, wide transmission frequency band and could be designed in distributed way. This paper introduces temperature monitoring system of FBG and the warning system for large volume concrete construction. It gives the temperature stress of concrete during the construction, and can be used for preventing the cracking of the concrete.

2 THE PRINCIPLE OF THE FIBER BRAGG GRATING SENSOR

The optic fiber grating utilized in Fiber Bragg Grating (FBG) sensor is a kind of grating which refractive index is changed periodically along axial of optic fiber. According to the coupling mode theory, when the broadband light is transmitted in FBG, it produces mode coupling. The relation of wavelength of Bragg reflected apex λ_b and period of fiber grating Λ is as follows:

$$\lambda_b = 2n\Lambda \tag{1}$$

In the formula, n is the effective refractive index of optic fiber.

The change of Λ and n can be measured by FBG, representing the change of the physical quantity, such as temperature, strain, etc. The common light cross the grating of Bragg with no influence while the specific wavelength (the wavelength is λ_b) light will return after reflecting in the grating segment of Bragg, which is shown in Figure 1.

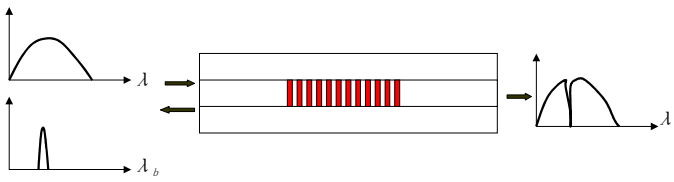

Figure 1. The principle and structure of optic fiber grating.

When the grating segment of Bragg is subjected to an external force, the intervals of grating will change, and the reflected light wavelength will change correspondingly. The wavelength of Bragg λ_b is affected by period of Bragg grating and effective reflected index of fiber core. Therefore, through monitoring the change of wavelength of Bragg, the

variation of strain, temperature, etc. can be reported. The relationship between the changes of center wavelength of FBG reflected light and changes of strain and temperature is as follows:

$$\Delta\lambda_b = \lambda_b\left(1-\rho_\alpha\right)\Delta\varepsilon + \lambda_b\left(1+\xi\right)\Delta T \qquad (2)$$

In Equation(2), $\Delta\lambda_b$ is the change of reflected wavelength due to the change of the stress and temperature, $\Delta\varepsilon$ is the change of strain, ΔT is the change of temperature, ρ_α is elastic coefficient of the optic fiber, ξ is coefficient of calorescence of the optic fiber.

If $\Delta\varepsilon = 0$, then $\Delta\lambda_b = \lambda_b\left(1+\xi\right)\Delta T$, that is, wavelength of reflected light varies with the temperature by direct ratio. By calibrating the temperature of FBG sensor, we can measure the absolute temperature of the monitoring object. The calibration process is as follows: the wavelength of the grating λ_1, λ_2 are measured in the constant temperature $T_1°C$, $T_2°C$ respectively. Because of the linear relation of the wavelength and temperature, the slope K is expressed as follows:

$$K = \frac{\Delta\lambda}{\Delta T} = \frac{\lambda_2 - \lambda_1}{T_2 - T_1} \qquad (3)$$

If the wavelength is λ' at the time of measurement, the temperature of the sensor is $T' = \frac{\lambda' - \lambda_1}{K} + T_1$ at the moment.

3 THE TEMPERATURE MONITORING SYSTEM OF FBG

3.1 *The general instance of project*

Modern mansion is located in Industry Park of Suzhou, with a frame core structure system, 20 floors over ground, and 2 floors under ground. The total structural height is 98.595 meters. The foundation adopts pile and mat, the thickness of mat under the main building is 2.5 meters, under the core is 7.8 meters. The concrete is C40 grade, and is cast in place. Because the mat is very thick, the concrete will produce a large amount of heat of hydration during the process of curing. When the temperature within the concrete exceeds a certain limit, it will produce the temperature stress, generating the cracks within the concrete. So it is necessary to monitor the differential temperature between the surface and the inside of concrete. In this project, the Fiber Bragg Grating sensors are buried in the concrete to monitor the variation of temperature during the process of curing. Then it is possible to know the temperature stress of the concrete, and to take the corresponding methods to assure the quality of the concrete foundation. The temperature monitoring system of FBG in this project is shown in Figure 2.

3.2 *The laying and demarcating of FBG sensor*

The thickness of the mat is 2.5m, 6m and 7m in different position respectively. The thicker the foundation, the greater the temperature is within it. So these two places under the core should be especially classified as emphases zone of measuring temperature. It is buried 13 Fiber Bragg Grating sensors altogether at three zones, zone 1 (the mat is 2.5m thick) has 3 sensors; zone 2 (the mat is 7m thick); zone 3 (the mat is 6m thick) has 5 sensors respectively. The sketch of location of FBG sensors is shown in Figure 3. The results indicate that this method has better representative.

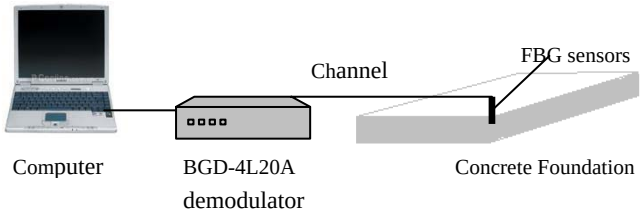

Figure 2. The temperature monitoring system of FBG in this project

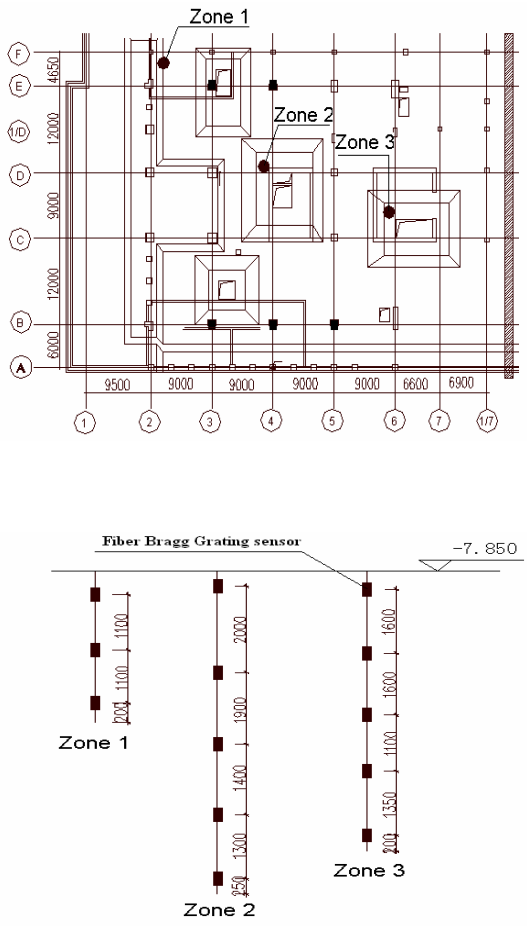

Figure 3. The sketch of location of FBG sensors

3.3 *The data acquisition*

The monitoring instrument is composed of demodulator of FBG, 13 Fiber Bragg Grating sensors, 100 meters of optical cables and the computer. The base

concrete has been cast at the afternoon of January 5 and be finished in the morning of January 7. We have carried on the monitoring the concrete temperature of the sensor position from Jan 5 to Jan 7. We get the variational curve of temperature of each sensor within 12 days at last, and draw the heaviest differential temperature curves of measuring zones one by one, which is shown in Figure 4. All the detail can refer to literature [5].

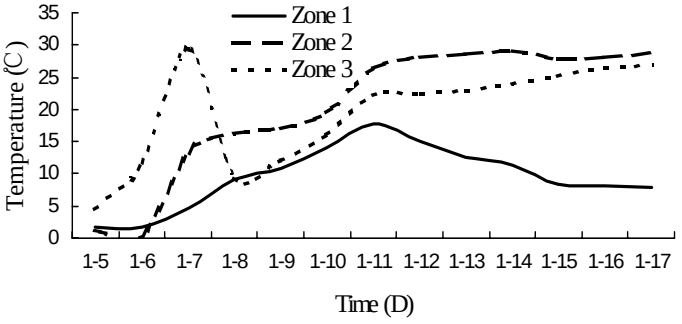

Figure 4. The heaviest differential temperature curve of measuring zone

4 THE RESEARCH AND APPLICATION OF TEMPERATURE WARNING SYSTEM

The warning system of concrete temperature is divided into two major modulus altogether, One part is concrete temperature analysis; another is concrete temperature stress analysis. The sketch of the warning system is shown in Figure 5.

4.1 *The analytical method*

The inner temperature of concrete can be calculated as follows:

$$T_{\max} = T_j + \frac{WQ}{c\rho}(1 - e^{-m\tau}) \cdot \xi \tag{4}$$

The external temperature of concrete can be calculated as follows:

$$T_{b(\tau)} = T_q' + \frac{4}{H^2} h'(H - h')\Delta T_{(\tau)} \tag{5}$$

The temperature stress of concrete can be calculated as follows:

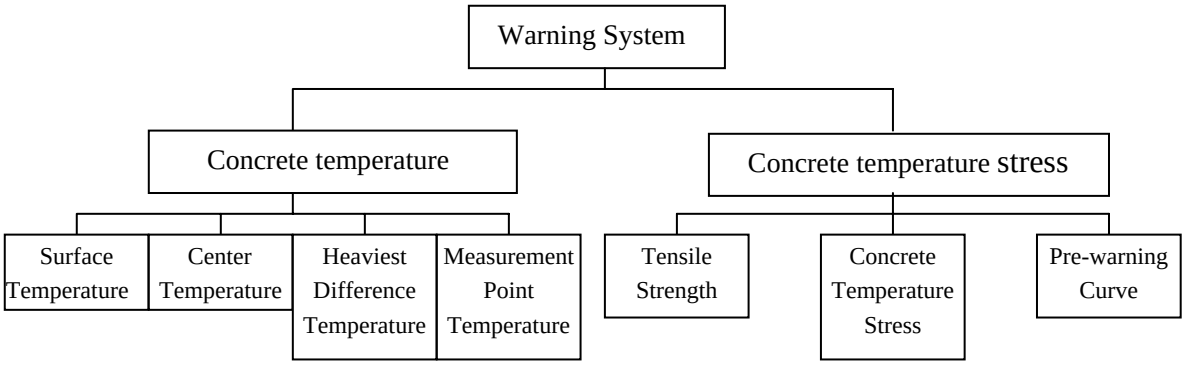

Figure 5. The sketch of the warning system

$$\sigma = -\frac{E_{(\tau)} \cdot \alpha \cdot \Delta T}{1 - \mu} S_{h(\tau)} \cdot R_K \tag{6}$$

The tensile intensity of concrete can be calculated as follows:

$$R_t(\tau) = 0.50 \cdot R_c(\tau)^{2/3} = 0.50 \cdot \{R_{c28}[1 + m\ln(\tau / 28)]\}^{2/3} \tag{7}$$

All the detail can refer to literature [3] and [4].

4.2 *The Finite Element Analysis*

In order to guarantee the accuracy of pre-warning, we use ANSYS software to carry on finite element analysis, so as to imitate the change of concrete temperature and change of the temperature stress. Soil body, concrete and template imitate with SOLID45 body element, there are 14400 units in all. Its three-dimensional finite element entity and temperature profile are shown in Figure 6.

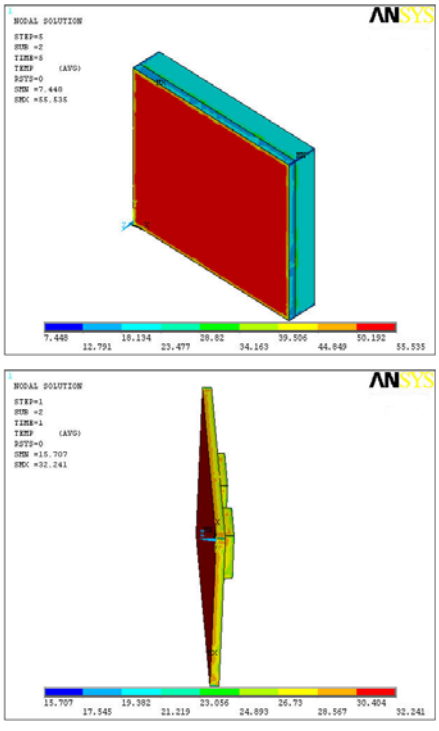

Figure 6. The three-dimensional finite element entity and concrete temperature profile

According to assorted rate of the concrete, the temperature of each sensor can be calculated out. Comparing it with metrical value, we can check measuring reliability of sensing system. Let's take the maximum differential temperature in zone 1 as the example. The comparisons of calculation value, finite element analysis results and measured ones are shown in Figure 7. From Fig. 7, it can be concluded that all the three curves give the same variation trend approximately while and the three maximum differential temperatures are very same. Meanwhile, we can get the relation of the temperature stress, finite element analysis and the tensile strength of concrete at different age (shown in Figure 8). From these data, the warning information could be given for further decision making to prevent the crack in concrete.

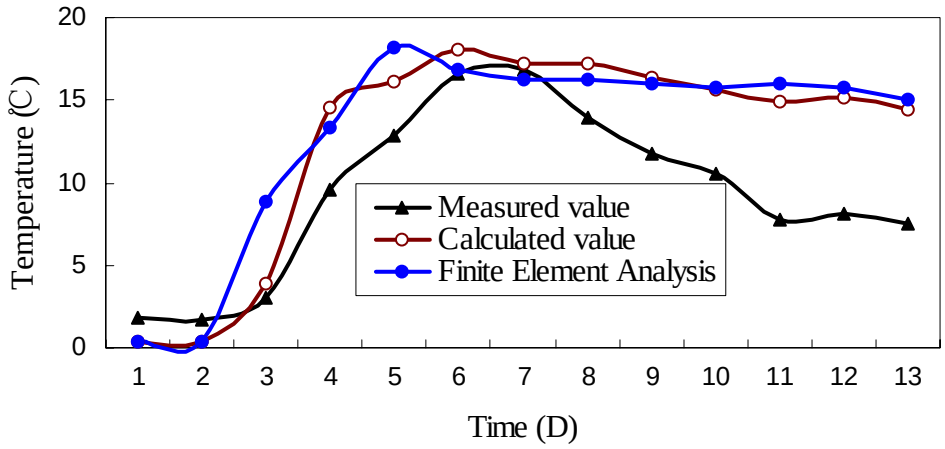

Figure 7. The comparison of calculation, FEM and measurement of the most differential temperature in zone 1

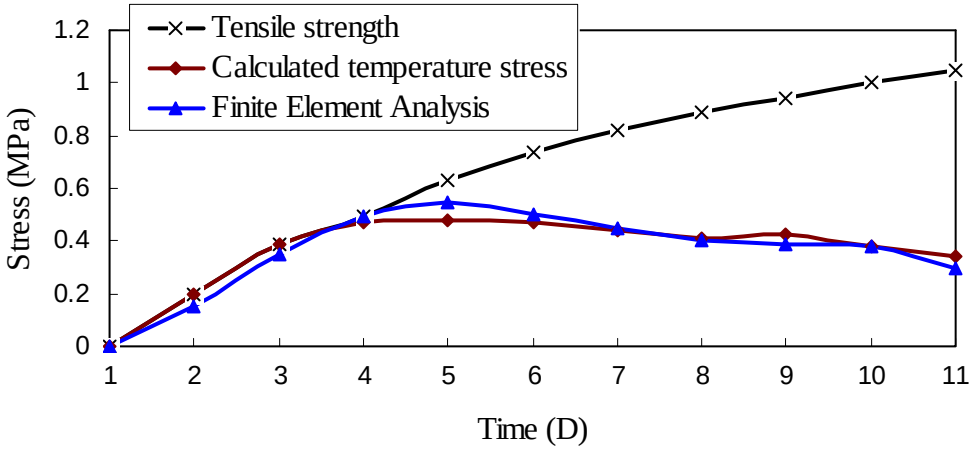

Figure 8. The relation of the temperature stress, FEM and the tensile intensity of concrete in different periods

5 CONCLUSION

The construction quality of large volume concrete and the highrise structure foundation is more extensively concerned in recent years. How to control the crack generation due to the temperature stress in the constructing is focus by many researchers and engineers. The correct method is to predict the inner temperature stress accurately and the corresponding heat isolating treatment. This paper presents temperature monitoring system of FBG and warning system of large volume concrete, and this is maybe a good way to control the crack of large volume concrete. The case study shows that this monitoring and warning system could gives out the exact temperature of the measure zone. It is also proved that this system has very good suitability on construction site.

6 REFERENCE

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