A Study on the Thermal Crack Control of Large Turbine Foundation using Automated Curing System

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ABSTRACT

The thermal crack occurrence from hydration heat is one of the most important factors that significantly affect structural quality and construction period in mass concrete. Therefore, appropriate methods to control the thermal crack are necessary for mass concrete. In this study, the probability of thermal cracking was checked by FEM analysis prior to the construction of turbine foundation in a combined thermal power plant. Subsequently, the change of concrete mix design and application of automated curing system were proposed to prevent thermal crack occurrence.

The proposed concrete mix design and automated curing method have been applied to actual turbine foundation construction site and the effect of the proposed thermal crack control methods has been evaluated through field measurement of the temperature, strain, thermal crack occurrence.

Keywords

Mass concrete , Automated curing system, Thermal crack control

Introduction

Recently, it is unlikely to predict electricity demands due to abnormal temperature, uncertainty of the increase rate of electric charges, expansion of economic volatility, etc. Under the circumstances, 28.8 % of the whole existing generators are more than 20 years old, and the number of failures rapidly increases, which expands the uncertainty of power supply.[1]

In constructing combined thermal power plants under the recent rise trend, a turbine is the most core building, and the foundation structure of the turbine takes most important role. The foundation of the turbine should be able to withstand the electromotive force caused by its own weight and engine operation, and the vibration caused by operation should not make harmful effects on other equipment or buildings. In order to reduce the transmission of vibration, we generally increase the weight of the foundation, and the concrete foundation is a very massive structure, thus in the massive concrete, the temperature stress caused by temperature difference of the structure due to cement hydration heat frequently generates cracks in the structure or makes considerable effects. The measures of the thermal cracking control include appropriate materials, mix design, mixing temperature, curing method selection, etc.[2]

As a part of thermal cracking control measures of large turbine foundation concrete, this study conducted hydration heat and temperature stress analysis with variables including changes in concrete mixing, and application of curing methods actively controlling inside and outside temperature differences.

Moreover, based on analysis results, we applied the changed concrete mixing and curing methods to actual construction, and evaluated thermal cracking control effects in the turbine foundation concrete structure through concrete temperature and strain rate monitoring and crack investigations.

FEM Analysis Method and Condition

Analysis Model

In thermal analysis, finite element method (FEM) is widely used for the analysis of temperature distribution in concrete foundation and FEM can take into account geometry shape, material properties, and arbitrary boundary conditions. In this study, a multi-purpose FEM software package in civil engineering, DIANA, was employed. The size of mass concrete model is 34.3m long, 8.7m wide, and 2m deep. In Figure 1, a half model of mass concrete was visualized with 8-node solid finite elements due to the symmetric structure instead of whole model.

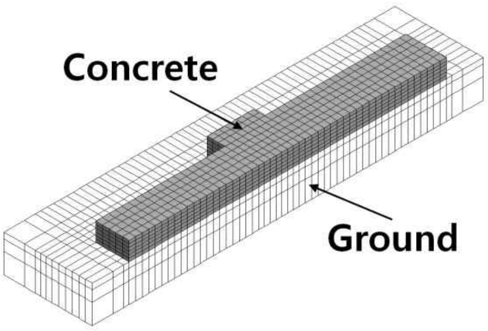


Figure 1-Modelling for Thermal Analysis

Material Properties of Concrete

The mix design for concrete is shown in Table 1. For the thermal analysis, Portland cement Type 1(OPC) and slag cement (40% replacement) were used, respectively. The characteristics of concrete adiabatic temperature rise used in numerical analysis were determined by actual test. The concrete material properties such as thermal conductivity, specific heat, tensile strength, young's modulus referred to Manual of concrete practice.[3-4] (ACI 207.2R, 209R)

Table 1 Concrete mix proportion

MPa	W/C	S/A	Unit Weight(kg/ m3)				Air (%)
			W	C	S	G	
24	49.6	46.8	170	346	834	970	4.3

Curing Condition

For thermal analysis, automated curing method was applied to control the thermal cracking of mass concrete and was compared with the results of general curing method.

(1) General curing method

In general, wet covering with blanket is widely used for the concrete moist-curing treatment. The period of curing and mould release is about 7 days after concrete placement.

(2) Automated curing method

Automated curing method is a novel curing method to control thermal crack occurrence based on real-time temperature monitoring equipment. The principle of this system is the automated water circulation system of heated curing water. Applied curing water on the surface of mass concrete keeps the temperature difference between center and surface of the structure below the threshold of specification.[5] This system can reduce the occurrence probability of thermal cracks, and the validity of this system has been already turned out from the application of mock-up test[6] and construction field.[7-9]

Analysis Results and Discussion

Temperature Analysis Results

The measuring locations of thermal analysis were marked in Figure 2.

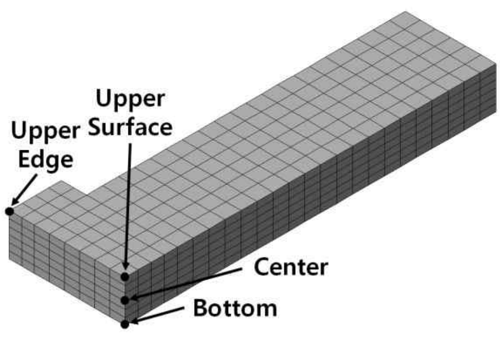
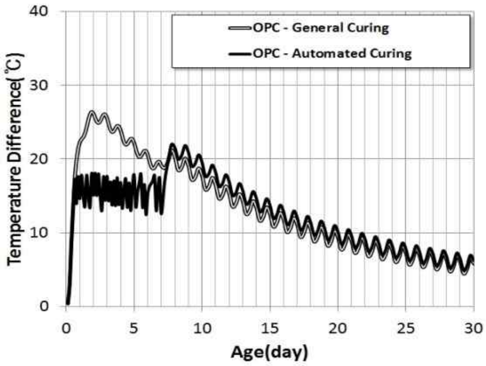
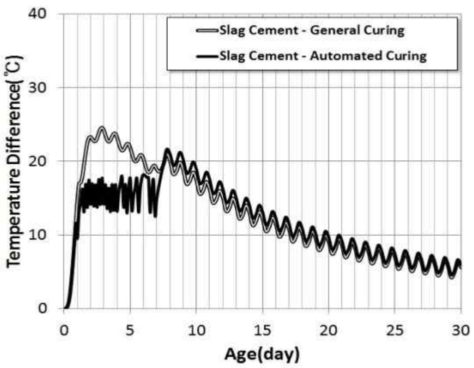


Figure 2-Locations of Temperature Results

There are two types of analysis parameters: cement (OPC, Slag cement) and curing method(General curing, Automated curing). The temperature difference between surface and center of concrete over time is indicated in Figure 3 and Table 2.



(a) OPC Concrete



(b) Slag Cement Concrete

Figure 3-Temperature Difference between Centre and Surface

Table 2 Results of Temperature

Type	Curing	Max. Temperature		Max. Temp. Difference	
		Temp (℃)	Age (day)	Temp (℃)	Age (day)
OPC	General curing	74.2	1.1	26.4	1.9
	Auto curing	74.2	1.1	22.0	7.8
Slag	General curing	70.8	2.0	24.6	2.9
	Auto curing	70.9	2.1	21.6	7.8

As a result of temperature analysis, the maximum temperature of slag cement concrete can be dropped down up to 3°C rather than that of OPC concrete. The time of maximum hydration temperature of slag cement concrete was between 48 hours and 50 hours after placing and this time period was delayed by about 24 hours comparing with the period of OPC concrete.

In British standard, the temperature difference for controlling thermal cracking is prescribed at 20°C.[10] As shown in Figure 3, in general curing method, the temperature difference rises up more than 20°C within the early curing period of about 1~2 days. At the age, thermal cracks could be initiated due to the early low tensile strength of concrete. On the other hands, in automated curing method, the maximum temperature difference between centre and surface of concrete is much lower than general curing method, and the time exceeding over 20°C of temperature difference criterion is 7 days after concrete placement when the application of the automated curing method was finished and the early tensile strength could be more developed relatively. Therefore, the possibility of thermal crack can be much lower than in case of applying general curing method.

Thermal Stress Analysis Results

The locations of thermal stress analysis are shown in Figure 4.

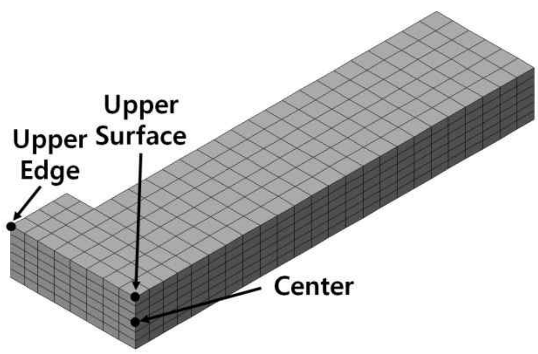
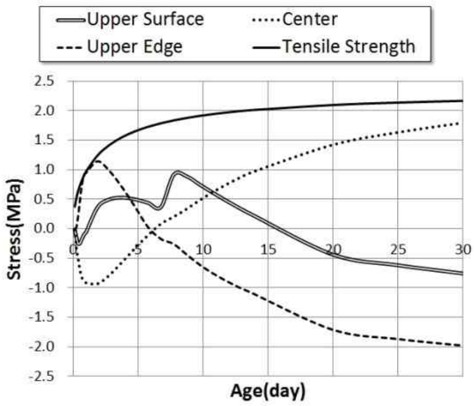
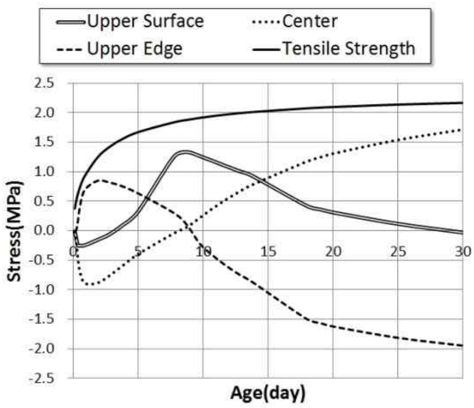


Figure 4-Locations of Stress Results

Figure 5 and Figure 6 demonstrate the results of thermal stress analysis according to types of concrete and curing methods. As shown in Figure 5(a), the tensile stress caused by the internal restraint at the early age stage increased up to design tensile strength in case of applying general curing in OPC concrete. On the other hand, the automated curing system can reduce the thermal stress by 26% as shown in Figure 5(b).

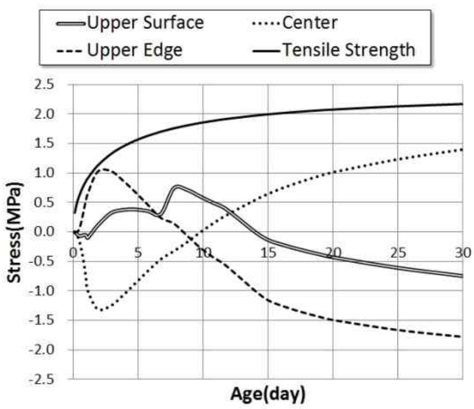


(a) General Curing

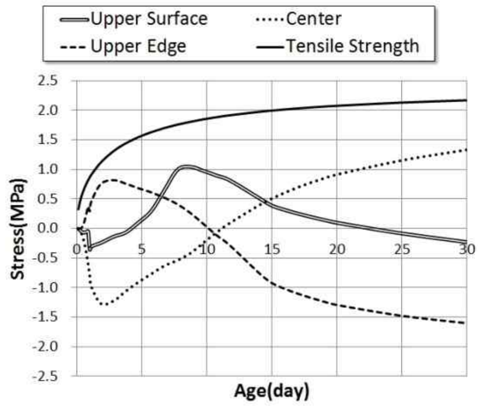


(b) Automated Curing

Figure 5-Results of Thermal Stress - OPC Concrete



(a) General Curing



(b) Automated Curing

Figure 6-Results of Thermal Stress - Slag Cement Concrete

In Figure 6, the external restraint stress of slag cement concrete can be decreased by 22% rather than that of OPC at 30 days age. At the beginning stage of concrete curing, the tensile stress of concrete surface resulting from the internal restraint can also be reduced by 9% in comparison with OPC. As shown in Figure 6 (b), automated curing method can be applied in order to diminish tensile stress, and the tensile stress can be reduced by 21%.

From the results of stress analysis, it was confirmed that the change of mix design and curing method can have effects on the control of thermal restraint stresses, and slag cement and advanced curing method were decided to be used for increasing thermal crack resistance in the field application.

Field Application

Introduction

In this study, as the target structures for analysis and measurement, two turbine foundations of combined cycle thermal power plant with the size of 34.3m long, 8.7m wide, and 2m deep were selected. In two concrete foundations, slag cement was used as concrete binder since slag cement was proved to be effective to control thermal crack from the analysis results. The monitoring of temperature and strain and the investigation of surface cracks were conducted in both foundations.

Curing Method

In two mass concrete foundations, the insulation curing method using styrofoam was applied in one foundation(T-1) and the automated curing method was applied in another foundation(T-2). The insulation curing method is widely used for retaining the curing temperature when the ambient temperature is not too low.[11] For the insulation in this field test, the surface of concrete specimen was covered with vinyl and then 50mm thick of styrofoam was placed. Also, the whole surface of concrete foundation was wrapped one more time with another insulation blanket in order to minimize the effect of environmental condition such as water evaporation, wind and rain.

For applying automated curing method, the curing blanket and curing water pipe were installed on the surface of concrete after concrete placement. When the temperature difference between centre and surface exceeded the criterion for crack control (generally 20°C), heated water around 60 °C was supplied automatically on the surface of structure to reduce the temperature difference.

Measurement

Table 3 shows the types of sensors embedded in concrete for measuring temperature, strain of concrete and for the operation of automated curing system. The measurement of temperature and strain was carried out on the surface, centre, bottom, and upper edge of concrete. The monitoring of temperature and strain was respectively kept for 3 weeks and for 1 week after concrete placement.

Table 3 Type of Sensors

Type	Purpose
I-Button	Temperature Monitoring
Thermocouple (T-Type)	Operating for Automated Curing Method
KM-100B	Strain Monitoring

Measurement Results and discussion

Temperature Measurement Results

Figure 7 and Table 4 show measurement results of temperature differences between centre and surface of concrete.

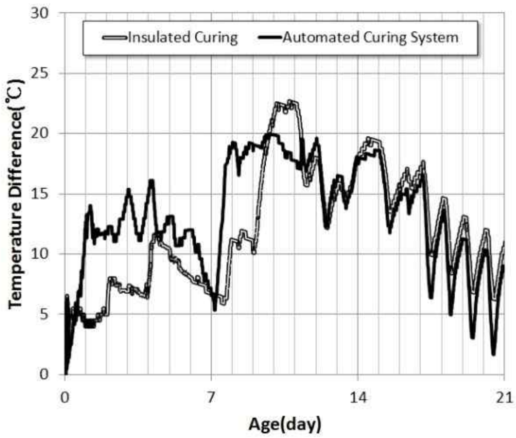


Figure 7-Temperature Difference Measurement Results

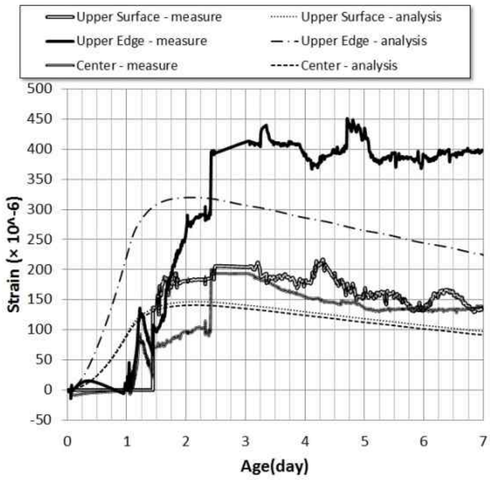
Table 4 Temperature Monitoring Results

Type	Maximum Temperature	Maximum Temperature Difference
Insulated Curing Method(T-1)	71.5 ℃	22.7 ℃
Automated Curing Method(T-2)	67.9 ℃	20.0 ℃

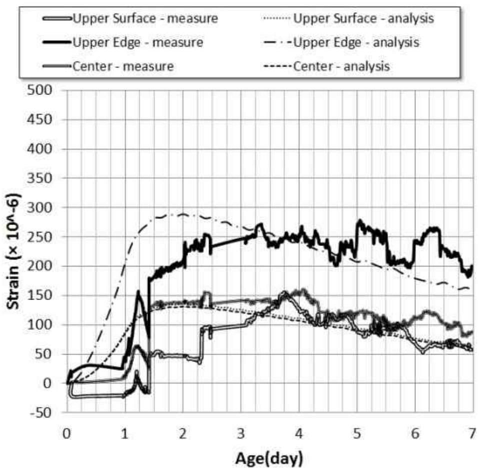
The temperature measurement results of T-1 foundation showed that the maximum temperature of the central concrete was 71.5℃, and during the thermal insulation curing period, temperature difference between the top surface and the centre was maintained mostly at 10℃, which implies that the probability of cracking by inside and outside temperature difference at initial placement is very low. However, it can be thought that after the end of curing, the top surface is exposed to the air and rapidly cooled down, which makes a temperature difference rise up to 22.7℃ and increases the probability of cracking. In T-2 foundation, the maximum temperature of the centre increased up to 67.9 ℃, and during the entire measurement period, the temperature difference between the top surface and the centre was maintained below 20℃. As keeping surface temperature at a certain level using heated curing water, inside heat of T-2 foundation was smoothly released rather than T-1 foundation and temperature difference could be effectively reduced at the end of curing.

Strain Rate Measurement Results

The results of strain rate measurement of foundation concrete applying the insulation curing method (T-1) and the automated curing method (T-2) are shown in Figure 8 and Table 5.



(a) Insulated Curing Method (T-1)



(b) Automated Curing Method (T-2)

Figure 8-Strain Histories - Measurement versus Analysis

Table 5 Strain Monitoring / Analysis Results

Location / Type	Measure / Analysis (μ)			
	Upper Surface	Upper Edge	Centre	Max. Difference
Insulated Curing Method (T-1)	216.8/ 146.8	450.7/ 320.0	200.0 / 141.1	303.9 / 178.9
Automated Curing Method (T-2)	155.5/ 135.5	278.3/ 288.9	159.9 / 131.2	155.5 / 158.7

According to the strain rate measurement results, the maximum strain rate change in the centre and the top surface was 100~200μ in both T-1 foundation and T-2 foundation, and it was 250~450 μ in the upper edge portion, which was a larger strain rate compared to that of other locations. Comparing T-1 foundation with T-2 foundation, in the thermal insulation curing, the strain rate of the upper surface and upper edge was greater than that of T-2 foundation by 39%, 62%, respectively. Additionally, the maximum strain rate of the centre was also about 25% greater than that of T-2 foundation. This is consistent with the trend of FEM analysis results. Moreover, in T-2 foundation, when comparing measurement values with analysis ones, approximately +4~22% differences appeared, while in T-1 foundation, +41%~48% differences appeared. In T-2 foundation, the measured value difference of the strain rate between the upper edge and the centre was maximum 155.5 μ, while it was maximum 303.9 μ in T-1 foundation, which was by 96% higher than that of T-2 foundation. Therefore, it is thought that the probability of cracking due to concrete internal restraint is higher in T-1 foundation.

Crack Inspection

The crack inspection of mass concrete foundations cured with insulated curing method and automated curing method was conducted at 28 days after concrete placement. The results of surface crack inspection after releasing the concrete moulds are demonstrated in Figure 9 and Table 6.

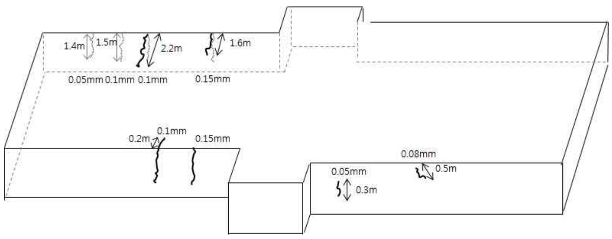


Figure 9-Diagram of Cracking at T-1(Insulated Curing)

Table 6 States of Cracking

Crack Width	Insulated Curing Method	Automated Curing Method
> 0.15 mm	-	-
0.10 ~ 0.15 mm	2	-
0.05 ~ 0.10 mm	4	-
0.05mm >	2	-

Based on the results of surface crack inspection in Figure 9, the total number of cracks of concrete with insulation curing method was 8 spots: 3 of them were placed on the surface of concrete and 5 on the side. On the other hands, in case of T-2 foundation, there was no crack on all sides of mass concrete. The field test results were well matched with the simulation results of thermal analysis. Therefore, it could be confirmed that the automated curing method is valid to control the thermal cracks of mass concrete.

Conclusions

In this study, in order to control thermal cracking of the turbine foundation concrete of large power plants, we conducted hydration heat analysis, field application and measurement with variables including changes in concrete mix design, curing methods, and the results are as follows:

(1) In case of mass concrete, there is a risk of cracking due to internal and external restraint caused by hydration heat, and it is thought that the effects of risks and measures can be predicted through preliminary hydration heat analysis similarly to actual construction.

(2) By changing type1 normal cement concrete mixing to slag cement concrete for low hydration heat, it was possible to lower the probability of cracking caused by external restraint of large mass concrete structures.

(3) By applying the curing automation system that actively controls inside and outside temperature difference, we were able to control inside and outside temperature difference below 20℃ at the initial concrete placement, which controlled the surface cracking caused by hydration heat internal restraint.

(4) Upon applying thermal insulation curing, we could control inside and outside temperature difference to a very small degree, but when we removed the thermal insulation materials after the end of curing, the surface rapidly cooled down, which caused surface cracking from thermal shock. To prevent this, the thermal insulation should be appropriately controlled by preliminary hydration heat analysis.

(5) The turbine foundation of large power plants is a very important structure, and due to the size, the risk of cracking caused by hydration heat is high. However, after reviewing the probability of cracking by hydration heat analysis, when required, we can control cracking appropriately through applying low heat concrete mix design and active temperature control curing.

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