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Thermal Stress by Hydration Heat in Tendon Gallery Wall of Containment Building

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ABSTRACT

This paper presents the thermal behavior of concrete structure due to hydration heat. To determine thermal properties in concrete induced from hydration heat, temperature variation, strain and thermal stress were measured by using the embedded type concrete gauges in the tendon gallery wall of the containment building. The test results showed that concrete temperature, strain and thermal stress were strongly affected by the location of measuring points and surrounding environmental conditions of members. A finite element analysis was also performed to clarify the thermal behavior of concrete. The analytical results correlated very well with the tendency of measuring value. Slight differences in stress value and generation timing were noticed due to the differences in restraint condition of the basemat against the walls and creep characteristics of high temperature concrete.

1. INTRODUCTION

In mass concrete structures, the thermal stresses due to hydration heat of concrete cause cracking and builds up residual stresses. It is a primary factor in loss of strength, durability and water-tightness of concrete structures. The thermal stresses in the concrete structures are dependant upon the temperature variations, concrete properties and environmental conditions etc. Therefore, an overall review considering all the factors influencing heat of hydration is required to reasonably evaluate the thermal stresses.

In general, an analytical method which appropriately simulates the thermal & physical properties of concrete and the field environmental conditions is used to evaluate temperature development and thermal stresses in structures. However, it is very difficult to estimate an accurate temperature development and thermal stresses by simulating concrete properties and field conditions. Therefore, the analytical results should be used to predict temperature development and progress of the thermal stress after on-site verification in actual concrete structures.

In this study, temperature variations, strains and thermal stresses occurring immediately after concrete placement in the tendon gallery wall of the containment building were measured using embedded type gauges. And the thermal behavior of the tendon gallery concrete wall was analyzed by finite element method.

2. Field Measurement

2.1 Measuring Structures & Intervals

The northern part of the tendon gallery inner walls of Unit 5 Young Gwang Nuclear Power Plant, where concrete is placed in three blocks, was selected as measuring structure. Measurement was performed for 14 days and recorded every 30 minutes right after concrete placement to the completion of test, to provide continuance and accuracy of measuring value. To evaluate thermal stress, strains and temperature variations in the measuring point, four sections of the walls were selected as shown in Fig. 1. These were installed as follows; thermo-couple for A section, strain gauge for B section, thermo-couple, strain gauge & none-stress gauge for C section, and effective stress gauge & strain gauge for D section.

2.2 Types of Instruments and Usuage

Instruments for field measurement are effective stress gauge, none-stress gauge, concrete strain gauge and thermo-couple. The number of measuring scores and usage of embedded gauge are as shown in Table 1. Each embedded gauges were firmly tied with installed rebar to prevent moving of location during concrete placement and its vibration. The location of gauges installed in each section is shown in Fig. 2. Description of symbols in Fig. 2 are shown in Table 2.

2.3 Mix Design

Concrete used in the tendon gallery inner walls has design strength of 5500 psi (385kg/cm2) and the mix is as shown in Table 3. The temperature of concrete during placement was about 22℃. Concrete was pre-cooled mixing ice into water and placing was done using pump car.

Table 1 Types of Instruments Gauge and Usuage

Type of Gauge	Number of Measured Point	Usuage
Effective Stress Gauge	2 EA	Stress being influenced concrete structure
Strain Gauge	9 EA	Total strain (thermal stress + temperature variations + shrinkage)
None-stress Gauge	3 EA	Temperature variations strain and shrinkage strain
Thermo-couple	16 EA	Temperature variations

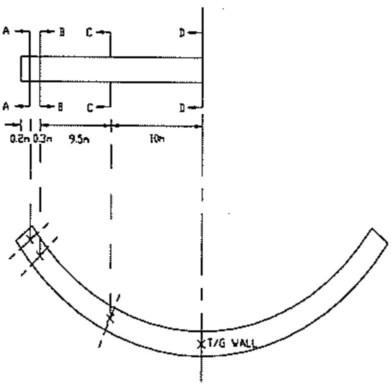


Fig 1 Measured Section

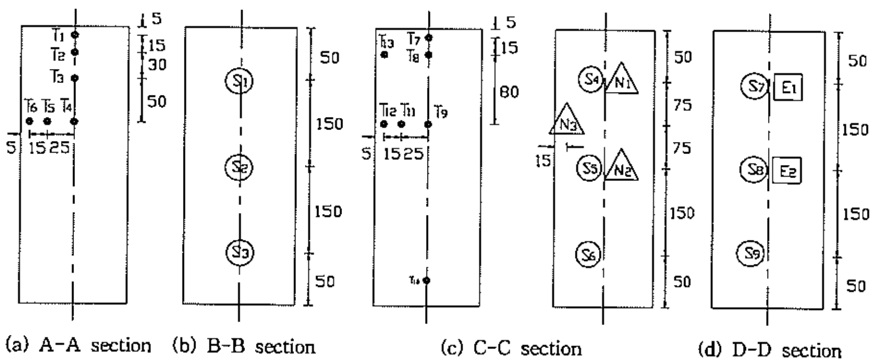
Table 2 Symbol and Description of Guage

Type of Gauge	Symbol	Product Model
effective stress gauge	E	GK-100-505
strain gauge	S	KM-100B
none-stress gauge	N	KMF-51, KM-100B
Thermo-couple	● T	T-type

Table 3 Concrete Mix

W/C (%)	s/a (%)	W	C*1	S*2	G*3	WRA	AEA
		(kg/m^3)					
44.0	44.5	172	391	757	945	1.345	0.012

*1: TYPE V Cement *2: F.M=2.90 *3: crushed aggregate (Gmax=19 mm)



[Fig 2] Location of Installed Gauge

3. FEM Analysis

Thermal behavior in the tendon gallery wall of the containment building in YGN Unit 5 is evaluated using the finite element program which makes it possible to estimate temperature and thermal stress resulting from hydration heat. The half of the object structure is simulated considering axis-symmetric model as shown in Fig 3. Input data in analysis is selected to reflect field condition, if possible, as shown in Table 4. To consider restraint degree of connection surface between the basemat and wall, nodes of the bottom surface of the wall share the same nodes with the basemat. Also, the atmosphere convectivity is applied to incorporate the effect of temperature variation due to forming and demoulding. It should be noted that input data such as adiabatic temperature rise value(K) and reaction rate(α) are determined by experimental tests.

Table 4 Input Data for Analysis

properties	value
adiabatic temperature rise (℃)	62.0
reaction rate (α)	0.70
atmophere convectivity ($kcal/m^2hr℃$)	8.0 ~ 10.0
	10.0 ~ 15.0
concrete temperature (℃)	22.0
ambient temperature (℃)	30.0
thermal conductivity ($kcal/m^2hr℃$)	2.5
specific heat (kcal/kg℃)	0.23
concrete unit weight (kg/m^3)	2400

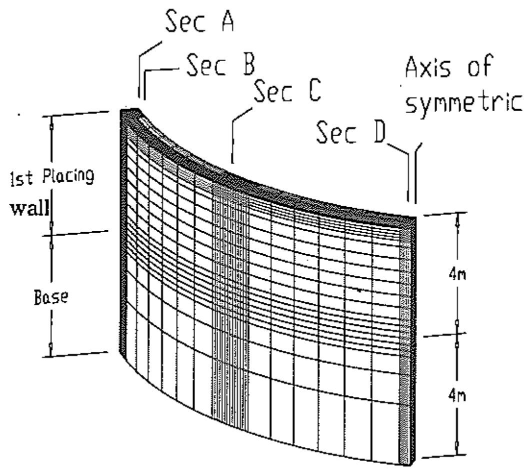


Fig 3 Finite Element Mesh of tendon gallery

4. RESULTS OF THE MEASURING AND ANALYSIS

4.1 Concrete Strength and Elastic Modulus

To review hardening properties of concrete, compressive strength, splitting tensile strength, and elastic modulus of the specimen (15×30 cm) which was cured by standard method were measured at the age-days of 1, 3, 7 and 28. Wire strain gauge (gauge length = 60 mm) was used to measure the elasticity. Compressive strength, splitting tensile strength, elasticity obtained from the three specimens which has same conditions is shown in Table 5.

Table 5 Concrete Mechanical Properties

Items \ Age(day)	1	3	7	28
Compressive strength (kg/cm^2)	134	231	297	447
Splitting tensile strength (kg/cm^2)	17.5	26.2	28.3	37.8
Modulus of elasticity (kg/cm^2)	2.15×10^5	2.57×10^5	2.72×10^5	2.97×10^5

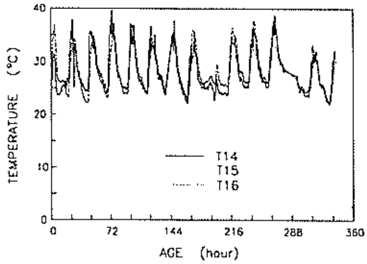


Fig 4 Air Temp. history

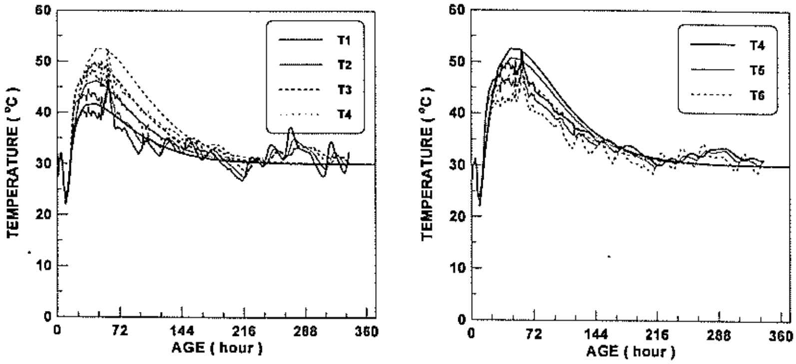
4.2 Field Weather Condition

Initial temperature change of concrete structures is decided by hydration heat of cement and heat exchange with the surrounding air. Thermal stress in concrete structures caused by temperature rise and fall are dependent upon amount of relative temperature change against ambient temperature, and therefore it is absolutely necessary to measure ambient temperature changes in advance during the periods of thermal stress occurrence.

The changes of temperature during field measuring periods were measured every 30 minutes using thermo-couple (T14, T15, T16) installed in near the structure. The measuring results are shown in Fig. 4.

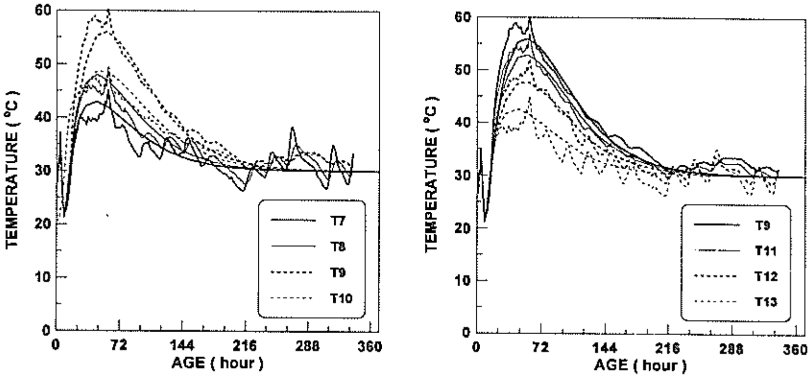
According to Fig. 4, temperature changes of three(3) points installed near the tendon gallery wall were almost same. Results of T16 measuring the surrounding temperature, influenced by tent which was installed to protect measuring equipment, shows the different tendency with the surrounding temperature of structures. Ambient temperature during measurement was 30℃ in average and it varied within ±7℃ being influenced by a temperature gap of highs and lows of the day.

Heat exchanges and evaporable water which occures between concrete structures and ambience are heavily influenced by relative humidity and wind velocity and it is necessary to measure them as external condition of structures. Relative humidity and wind velocity based on the weather data near the measuring structures is respectively 77.3±10 % and 0.5 ~ 1.5 m/sec



(a) Height Direction of Wall (b) Thickness Direction of Wall

Fig 5 Temperature Variation (A Section)



(a) Height Direction of Wall (b) Thickness Direction of Wall

Fig 6 Temperature Variation (C Section)

4.3 Temperature Variation

Temperature variation being influenced by hydration heat and atmosphere convectivity during measuring is shown along with analytical results in Fig. 5 and Fig 6. According to Fig 5, initial temperature history at the most of parts shows similar results. However, maximum increase in temperature at point adjacent to atmosphere decreases as measuring point is closer to the surface due to an influence of atmosphere. Maximum rise in temperature of Section A is 50 ℃ in center (T4) which is 10℃ higher than that of surface(T6). Temperature differences between inside and surface during descendance of temperature is gradually reduced. After form is removed, temperature at all points shows a tendency of depending on the ambience. Temperature variation of surface, specially after age nine days, depends heavily on the influence of ambience. Comparing values of T1, T2, T6 and T5 in Fig. 5, it is observed that maximum increase in temperature and temperature variation are different depending on the presence of the form. According to the results shown in Fig. 5 & 6, temperature variation of concrete have differences depending on the depth of surface and the presence of the form due to heat transfer. Initial temperature of concrete is fairly lower than the ambience because of pre-cooling effect. To simulate the test results using analytical methods, temperature analysis was performed and the results were shown in Fig. 5&6.

4.4 Thermal Stress

According to Fig. 7, compressive stress at the central point increases during ascending temperature. However, as temperature starts to fall down, compressive stress decreases & tensile stress increases. Thermal stress occurring only by the rise & fall of temperature is dependent by the modulus of elasticity of concrete and relative restraint. From this, the mechanism of thermal stress and cracking can be predicted.

Maximum compressive stress(E1) and tensile stress(E2) by effective stress gauge are -15 kg/cm^2 , 10 kg/cm^2 & -19 kg/cm^2 , 4 kg/cm^2 respectively. Tensile stress at central location was higher than that of upper location. This was caused by the discrepancy of restraint degree; the restraint degree of upper location is lower than that of central location.

Because the tensile stress occurred during the measurement shows very lower level than tensile strength owing to pre-cooling effect, it is judged that the thermal cracking would not happen.

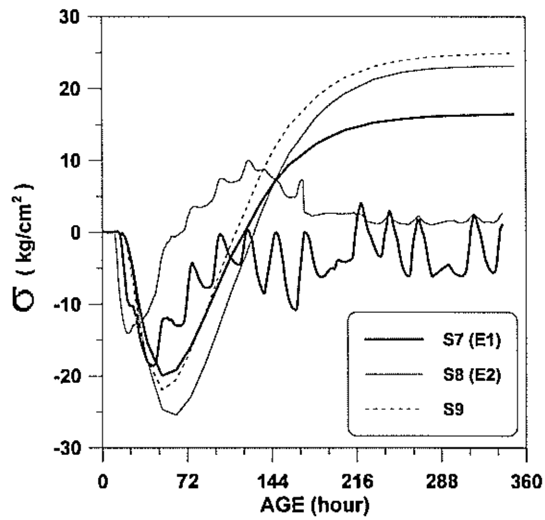


Fig. 7 Thermal Stress (D Section)

According to Fig. 7, the analytical results correlates very well with the tendency of measuring value. There are, however, slight differences in stress values and generation timing. This is presumably caused by the differences in restraint condition of the basemat against the walls and, creep characteristics of high temperature concrete. For the accurate estimation of thermal stress, a further study on restraint and creep should be performed.

5. CONCLUSION

Instrumental observations were carried out to measure thermal stress by hydration heat. FEM analysis was also conducted to examine its applicability by comparison with the observed result.

The conclusions are summarized below.

(1) Temperature distribution at each location in structures depends on the distance from the surface and the presence of the form.

(2) In center section where relative restraint is high, tensile stress occurred during the measurement shows very lower level than tensile strength owing to pre-cooling effect, and it is judged that the thermal cracking would not happen.

(3) The results of the measuring and analysis on thermal stress shows some difference, and this is presumably caused by the differences in restraint condition & creep characteristics.

(4) To draw the accurate analytical results, a further study on restraint and creep characteristics should be performed.

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