기계기초 매스콘크리트의 균열제어를 위한 온도관리기법의 개발

Development of Temperature Control Technology for Massive Machine Foundations

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Abstract

최근 비약적인 경제발전에 힘입어 장대교량, 항만, 댐, 도로, 원자력 발전소 등과 같은 대규모 기간구조물의 건설이 증가하고 있으며, 구조물은 대형화 혹은 고강도화되는 추세에 있다. 특히, 전술한 구조물을 매스콘크리트로 가설하게 되면, 초기재령시에 수화열로 인한 균열이 발생할 가능성이 매우 높기 때문에 효율적인 매스콘크리트의 개발과 매스콘크리트 구조물의 설계기술 및 시공방법이 중요한 연구대상으로 등장하게 된다.

본 논문에서는 가로 52.6m, 세로 14.4m, 높이 8.5m의 기계기초 매스콘크리트의 시공에 적합한 온도관리기법을 다음과 같은 단계로 제안하고자 한다. 먼저 온도상승요인을 최소화하는 콘크리트의 배합비를 산정한다. 산정된 콘크리트의 열특성을 측정하기 위해 단열온도실험을 수행하여 각종 열특성상수와 단열온도 상승곡선식을 도출한다. 이와 같은 열특성치를 콘크리트 구조체에 적용하여 열응력해석을 수행한다. 이와 같은 열응력해석을 통하여 구조물의 분할타설높이에 따라 온도균열이 발생하지 않는 콘크리트 내외부의 온도차를 결정한다. 이때 열응력해석에 범용 유한요소 프로그램인 Diana를 사용한다. 콘크리트의 타설은 현장조건과 타설시점을 최대로 고려하고 양생방법으로 콘크리트 내외부의 온도차를 최소화하기 위해 이중단열효과가 있는 거푸집과 가열장비을 사용한다. 또한 콘크리트의 온도관리를 위하여 구조물 내외부에 온도게이지를 매립하고 30분마다 계측을 수행하면서 콘크리트 내외부 온도차가 허용 해석범위를 유지하도록 한다. 양생기간은 7-10일 정도를 유지한다. 전술한 온도관리기법을 통하여 완공후 수평정밀도가 기초의 허용침하량으로 환산하여 1 μm 인 고정밀도의 기계기초는 완벽하게 시공되었다. 따라서 매스콘크리트의 온도균열을 제어할 수 있는 시공방법으로 제안한다. 또한 매스 콘크리트의 내외부 온도차를 단열온도실험과 온도해석으로부터 정한 값이내로 제어하고 충분한 양생관리를 병행하면 수화열에 의한 콘크리트의 온도균열을 최소화할 수 있을 것으로 기대한다.

keywords : 매스콘크리트, 균열제어, 단열온도실험, 열응력해석, 온도계측, 양생방법

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● 본 논문에 대한 토의를 2001년 12월 31일까지 학회로 보내주시면 2002년 4월호에 토론결과를 게재하겠습니다

1. INTRODUCTION

This paper presented the crack- controlling process of massive machine foundation. The dimensions of the machine foundation is 52.6m(L) x 14.4m(W) x 8.5m(H).[1] The temperature control technology of mass concrete contained a discussion of materials, mix proportioning, thermal analysis, curing method, temperature control, and measurement of hydration heat. The temperature control technology which found to be an effective process for controlling the temperature-related cracks on the mass concrete structures was proposed.

One characteristic that distinguishes mass concrete work from ordinary concrete work is thermal behavior.[2] Since the cement-water reaction is exothermic by nature, the temperature rise within a mass concrete structures, where the heat is not quickly dissipated, can be quite high. Significant tensile stresses develop due to the volume change associated with the increase or decrease of temperature within the mass concrete structures.

This paper contained a discussion of materials, mix proportioning, construction methods, measurement of hydration heat in laboratory and in situ, and thermal analysis. The machine foundation introduced here as an example of mass concrete structure was constructed by Hyundai Heavy Industry (HHI), designed by Hyundai Engineering (HE), technically supported by Hyundai Institute of Construction Technology (HICT), respectively. Finally, the temperature control technology which was used during the construction was proposed.

2. MATERIALS and MIX PROPORTION

As is the case with other concrete, mass concrete was composed of cement, aggregates, water and sometimes pozzolans and admixtures. The objective of mass concrete mix design was the selection of combinations of materials that will produce concrete to meet the requirements of the structure with respect to economy, low temperature rise, workability, dimensional stability, and freedom from cracking. [3],[4]

Portland cement was generally accepted in mass concrete constructions. Pozzolans, which usually include fly ashes, were used to decrease temperature rise, improve workability, reduce permeability. When the portland cement is used with pozzolan or with other admixtures, the materials were separately batched at the batch plant. Economy and low temperature rise were both achieved by limiting the total cement content to as small an amount as possible. When Type I portland cement was used in mass concrete construction, special cares for controlling the temperature rise might be recommended because of its higher heat of hydration.

Considering the above mentioned conditions for mass concrete, mix proportion with Type I portland cement was shown in Table 1.

Table 1 Mix proportion using Type I portland cement

Max. size of coarse agg. (mm)	Slump ranges (cm)	Air contents (%)	W/C ratio (%)	S/a ratio (%)
25	15±2.5	2.5	55	53

Unit Weight (kg/m^3)				
Water	Cement	Fine agg.	Coarse agg.	Admixture*
193	350	907	814	approx. 1%

* AE Water-reducing Admixtures (PHOENIX-R#1, Jin-Woong Co.)

In this study, the ordinary portland cement (OPC) was used. Specific gravity of the OPC was 3.15. Coarse and fine aggregates used in the mix were of crushed gravel and sea sand conformed to ASTM C 125. Bulk specific gravities of the aggregates were 2.6 and 2.57, respectively. The maximum size of the crushed gravel was 25 mm

Superplasticizer was used as a additive to satisfy the required workability.

3. ADIABATIC TEMPERATURE TEST and FE ANALYSIS

From the above mix proportion, the thermal characteristics of the concrete were determined through adiabatic temperature experiment. An estimate of temperature distribution used in thermal analysis of mass concrete could obtained as Eq.(1)

$$Q(t) = Q_{\infty}(1 - e^{-rt}) \qquad (1)$$

where,

t = curing period, day

Q(t) = adiabatic temperature rise at t day, °C

Q_{∞} = final adiabatic temperature rise, °C

r = controlling coefficient in velocity of temperature rise

The equation of adiabatic temperature rise obtained by the experiment was shown as Eq (2)

$$Q(t) = 53.4(1 - e^{-0.41t}) \qquad (2)$$

In modelling the structure, finite element method was used. Only one half of machine foundation was modelled with two dimensional plane strain elements because massive machine foundation had plane of symmetry. The plane of symmetry was assumed to be adiabatic plane. (Fig. 1)

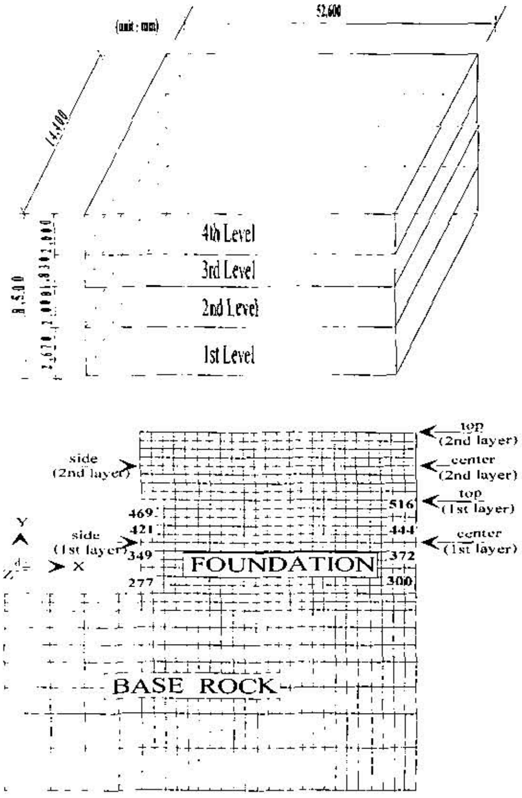


Fig. 1 Dimension of the structure and finite element mesh

The ambient temperature was assumed to be maximum of 20°C at 2 p.m., and minimum of 10°C at 2 a.m. and the fluctuation of the temperature was modelled by sine function as shown in Eq. (3).

$$T = 5.0\sin\left\{\frac{\pi(t-8)}{12}\right\} + 15.0 \qquad (3)$$

Young's Modulus of concrete in terms of ages was assumed as following Eq. (4) recommended in Korean Standard Specification : [5]

$$E_e(t) = 1.1 \times 10^4 \sqrt{f'_c(t)} \quad (before\ 3\ days)$$

$$E_e(t) = 1.5 \times 10^4 \sqrt{f'_c(t)} \quad (after\ 5\ days) \tag{4}$$

where, $f'_c(t)$ was the compressive strength at t day, kg/cm^2.

The thermal properties of concrete and rock and the coefficients of heat transmission were shown in Table 2 and Table 3.

The estimate of temperature distribution obtained from temperature history analysis and the result of thermal stress analysis were shown in Fig. 2.

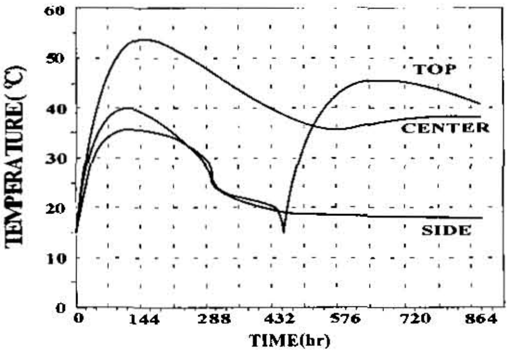
Based on the results of thermal stress analysis, the level of first concrete placing was assumed to 2.67m as shown in Fig. 1. And the heights of other levels were decided on the basis of the calculated and the measured outputs from the previous level. This level was the maximum height for controlling the thermal cracks, which was generally occurring when the tensile strength was exceeded by the tensile stress due to the poor temperature control at the early stage.

Table 2 Thermal properties of concrete and rock

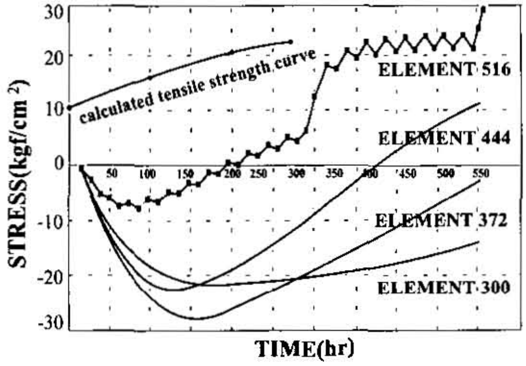
materials Properties	Concrete	Soil
Unit weight (kg/m^3)	2,350	1,600
Thermal conductivity ($kcal/mh^\circ C$)	2.3	1.2
Specific heat ($kcal/kg^\circ C$)	0.27	0.45
Heat capacity ($kcal/m^{3\circ}C$)	648	720

Table 3 Coefficients of heat transmission

Form stripping (days)	Concrete-Air ($kcal/m^2h^\circ C$)	Concrete-Wood-Air ($kcal/m^2h^\circ C$)
7	3.5	3.5



(For 1st and 2nd level)



(In the X-direction at center)

Fig. 2 Temperature history and stress distribution

4. FROM PLACING CONCRETE TO MEASURING TEMPERATURE

To minimize the temperature difference between the interior and the exterior parts of the structure, adiabatic double form was used (Fig. 3). Water curing was sustained for twelve days.[6],[7]

The volume of the first concrete placing was about $2020m^3$, and the concrete placing had been run during 24 hours by using two pumping cars, twelve vibrators, and 10 inclined chutes. A scene of concrete placing was shown in Photo 1.

To measure temperature rise of mass concrete structure, eight thermocouples were installed in the interior parts of the structure. The installed location is shown in Fig. 4.

The temperature rises at eight locations were measured every 30 minutes or one hour during 12 days. The measured temperature rise at top, center, and side of the structure was shown Fig. 5

It was found that these measured results shown in Fig. 5 were analogous to the analyzed outputs in Fig. 2 for the first level.

After 12 days, the forms were stripped. No cracks were found around the structure. These results mentioned above were stemmed out of performing the preliminary experiment and analysis, forecasting the environmental conditions, making the measurement of the temperature in situ, and preparing the curing methods suitable to the structure.[8),9)]

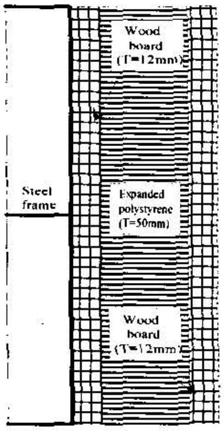


Fig. 3 Adiabatic double form

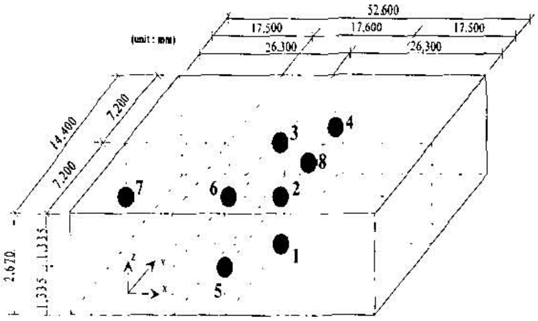


Fig. 4 Temperature measuring points (1st layer)

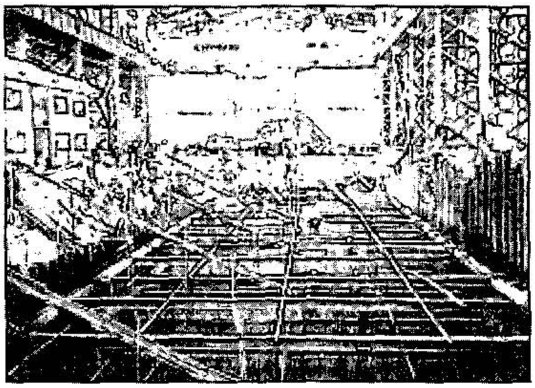


Photo 1 Scene of concrete placing

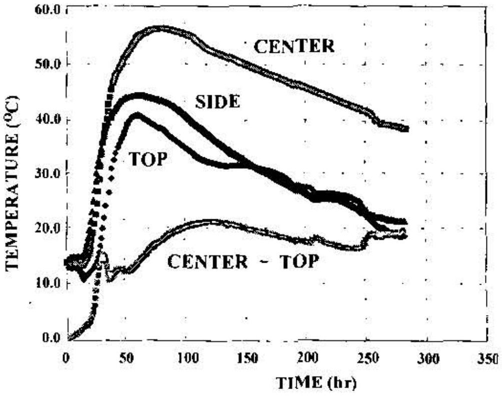


Fig. 5 Measured temperature history (1st layer)

5. TEMPERATURE AND CRACK CONTROL TECHNOLOGY

The temperature control technology of mass concrete structure was proposed in this paper. This technology contained a discussion of materials and concrete mix proportioning, thermal analysis, curing method, temperature control, and measurement of hydration heat. This series of the process was constructed as a temperature and crack control technology, which is shown in Fig. 6. The proposed temperature control technology was found to be an effective process for controlling the temperature-related cracks on the mass concrete structures.[10]

6. FINAL REMARKS

Since cracks have considerable effects on the safety and the utility of the foundation that the differential settlement was limited to 1.0㎛, a special concern was need to control cracks caused by the temperature difference between the interior and the exterior or by the thermal shock on the surface of the structure. For this reason, the temperature control technology has been recommended to keep the structure from cracking.

The acceptable results were obtained by following the recommendation, that is, the temperature control technology of mass concrete structure.

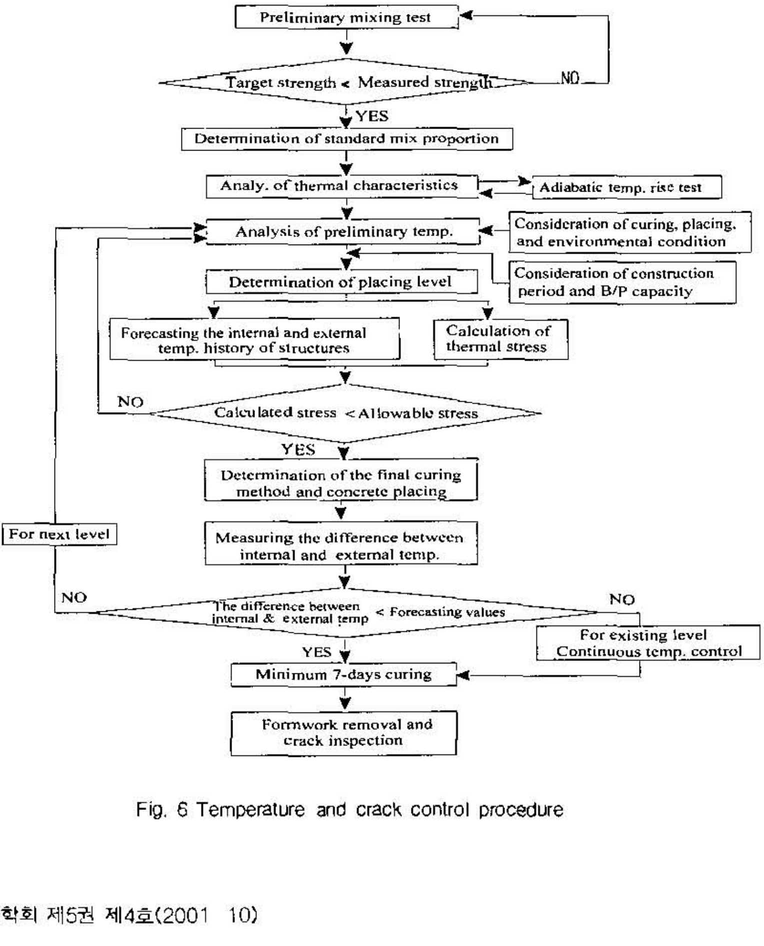


Fig. 6 Temperature and crack control procedure

Therefore, it was thought that the process, which is defined throughout the series of the experiment and the analysis, was worthy of being used to control cracks of any massive concrete structures.

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