ADIABATIC TEMPERATURE RISE AND REACTION RATE OF MASS STRUCTURE IN LOTTE CENTER HANOI PROJECT

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Abstract: *It is necessary for concrete structure with mass section to have a rational crack control plan based on analysis of thermal stress from hydration heat. Because mass concrete can cause crack to deteriorate durability of structure. So, this study reports two examples: one is a process to calculate an adiabatic temperature rise and a reaction rate for evaluate thermal stress. And the other is how to control quality of mass concrete with reducing internal restraining stress through finite analysis.*

As a result, a thermal crack index is over 1.0 and a curing time of mass-section foundation decreases within 18 days through minimizing binders in concrete and adjusting hydration heat and delay setting time between the former and the latter placed concrete.

Keywords: mass concrete, hydration heat, thermal crack, finite element analysis, temperature history

1. Introduction

A tensile stress by hydration heat of concrete is a main factor to deteriorate durability of structure because it causes crack in concrete from initial time of hardening. Especially, a volume change in surface of mass-section element is almost same by cooling from low temperature in the air while inside of volume expands by high temperature from accumulating hydration heat. That is, difference between inside and surface of structure causes a thermal crack from occurring a restraining condition.[1] Adding, more high strength concrete with much binder becomes a serious problem.[2]

There are two ways to minimize a thermal crack of mass concrete: One is a construction method such as pre-cooling and pipe-cooling and the other is to control material by adjusting binder to occurea low hydration temperature. And all the methods are essential to check analysis of a thermal stress repeatedly to evaluate thermal crack index for quality and function of structure in terms of design/material/construction sides.

So, this study shows that base material to ensure quality of mass concrete structure by reviewing construction process and analyzing process of an effecting factor to evaluate thermal stress in Lotte Center Hanoi Project.

2. Plan establishment for quality stability on mat foundation

Complex condition is needed to diversely revised because internal restraining stress by hydration is related to material, mixture design, temperature of concrete, curing method, ambient condition, arrangement of bar, structure type. but internal restraining stress happen due to difference in temperature between inside and outside and temperature distribution curve is spreaded in the center of concrete that is the highest temperature. So if peak tensile stress is determined by ascension rate of peak temperature, peak temperature and intensity of restraint, it can be minimized by shop drawing, material, mixture design, construct and curing control. Furthermore, it is necessary to set the plan for controlling the point where tensile strength of concrete in mass member is higher than tensile stress by temperature stress.

Accordingly, In this project the process is established to reduce hydration heat and temperature stress coinciding with construction condition [Figure. 1] so it is planned to secure quality stability.

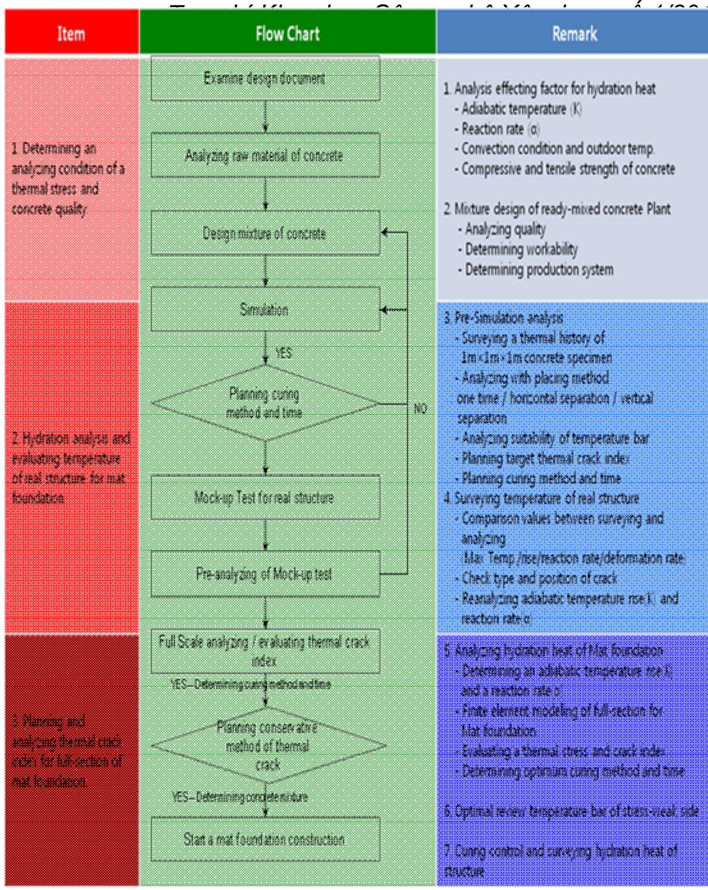


Figure 1. *Process to minimize a thermal stress of mat foundation*

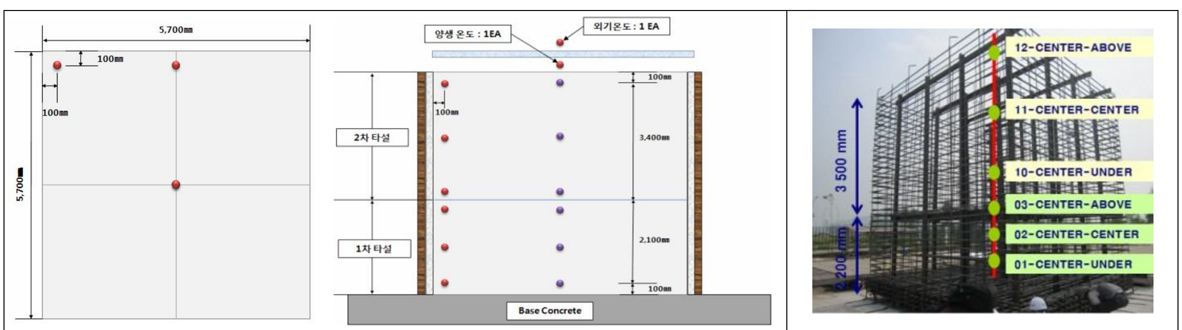
2.1 Analysis on affecting factor of hydration heat

The hydration heat on concrete depends on Adiabatic temperature rise and reaction rate according to property and quantity of cement. In order to analyze hydration heat of concrete, thermal property of concrete that is related to Adiabatic temperature rise(K), reaction rate(α) mixture design is needed to confirm. So I measured the hydration exothermic rate to review the lowest hydration heat & the highest strength of cement and checked Adiabatic temperature rise experiment & strength of test piece with fly-ash.

2.2 Comparative analysis of experimental value and measured value in the mock-up test

Thermocouple installed in the Center, Side, Edge of member is measured to reanalyze Adiabatic temperature rise, reaction rate and hydration heat through the mock-up test(5.7mx5.7mx5.7m).

The rebar and temperature reinforcement were installed according to the design drawing.



(a) Plane (b) Cross section (c) Front of the Mock-up

Figure 2. *5.7mx 5.7mx 5.7m location of hydration heat sensor and image*

3. Analysis of internal restraining stress for mat foundation

3.1 The amount of hydration heat and adiabatic temperature rise

In hydration heat of cement itself there were some differences about 15 to 20 J/g for each product of cement. The results indicate that there was a nothing specific change in hydration heat of the concrete. And in a different product family of the same cement company affiliation of PCB30 showed low heating value. However, this is resulted from low cement fineness and relatively high amount of other admixtures. Also in the experiment of adiabatic temperature rise the temperature rise of hydration heat and the highest temperature showed insignificant differences so that the quality of cements for each company would not affect on the hydration heat of concrete. And a compressive strength of the hydrated concrete demonstrated exceeded 110 percent at 28 curing days and at the same time the compressive strength for each company just showed slight gaps 1 to 5MPa.

Hence, in order to designate the amount of binders for the mix design the amount of adiabatic temperature rise (K from now on) and the reaction velocity (α from now on) was first calculated under the assumed temperature of concrete placement and then the values were corrected and re-analyzed. The final results are shown in figure 4. Throughout this procedure in the case of using fly-ash in designing binder quantity it is assumed that the total hydration heat would be decreased and the peak point of hydration heat for the total amount of binder would be increased as increasing the quantity of cement.

Therefore, the amount of cement was designed as the minimum value and fly-ash was designated as the maximum value for the mix design, considering air contents for workability and properties by the quality of fly-ash.

$$m_\alpha = 0.05\,T \quad m_K = 0.931\,e^{1.49/T}$$

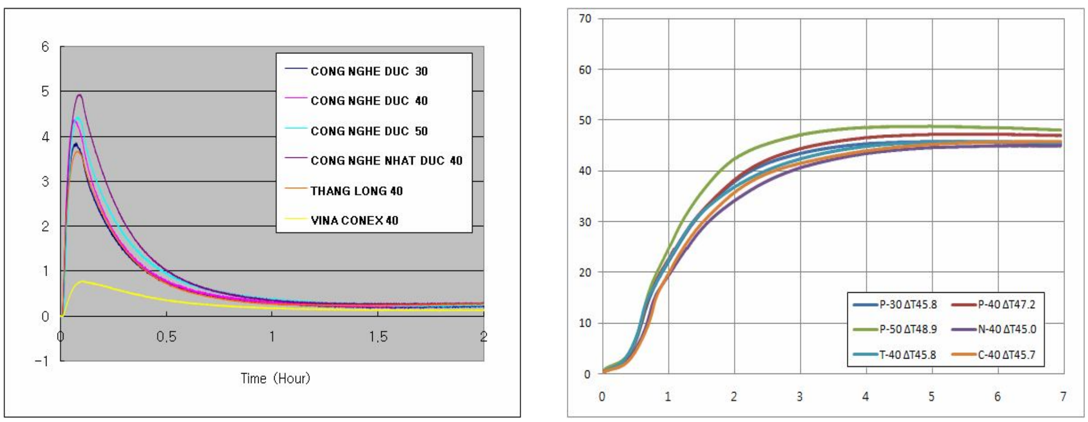


Figure 3. *The result of the heat and adiabatic temperature rise by cement types*

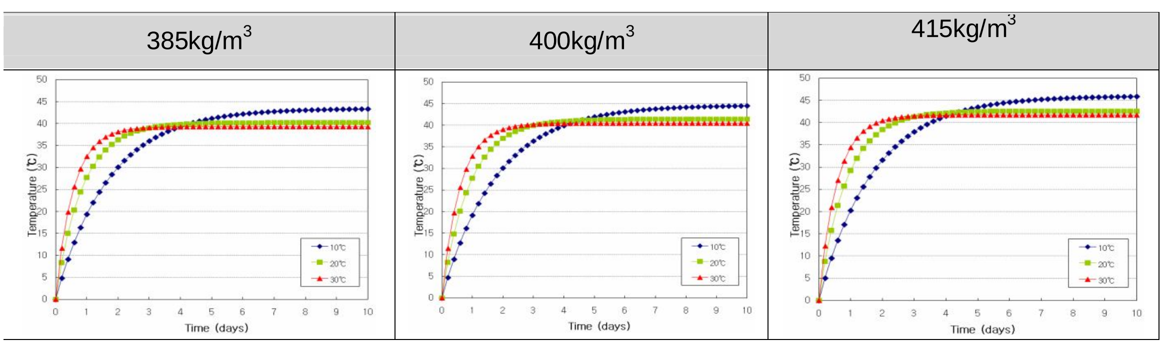


Figure 4. *The corrected value of adiabatic temperature rise and reaction velocity by classification of binder quantity*

3.2 Temperature rise quantity and analysis of Mock-up Test

The time reaching the highest temperature of 5.7meter Mock-up test implemented on Jun. 2011 (under the condition of over 38^{o}C in ambient temp. and 33^{o}C of concrete temp.) was about 70 hours. This hour was postponed up to 20 hours through designing delayed concrete. And the highest temperature classified by height of concrete placement showed 70.4^{o}C at 2.2m and 77.4^{o}C at 3.5m. This result indicates that the more accumulated hydration heat the higher hydration temperature. And the temperature differences between the center and surface of the member were 14.3 and 20.6^{o}C at the highest temperature. These rages are stable to keep the quality control for the mix design and this demonstrates that radiant heat of the hydration heat was lasted long by delaying as much as 7 days at the highest point.

In addition even though the measured rising velocity and highest temperature were similar to each other, comparing to the value analyzed, the period of radiation was somewhat shorter than the value analyzed. This can be assumed that the amount of rise temperature and reaction velocity are accelerated by accumulated hydration heat and influence on high ambient air temperature. Therefore it can be assumed that the pattern of hydration history can be changed by the temperature of concrete placement, the size of member, and delayed time.

Table 1. *Comparison between measured and analyzed hydration heat value of Mock-up Test*

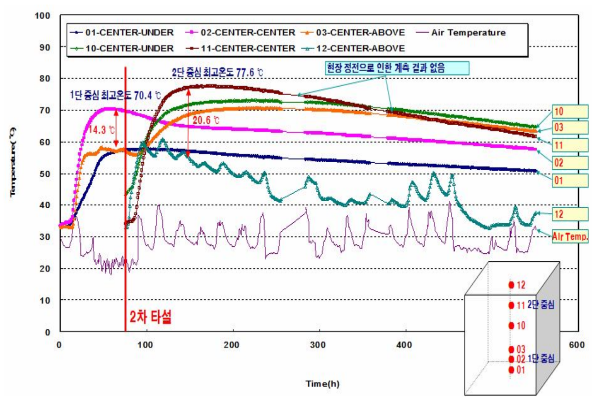
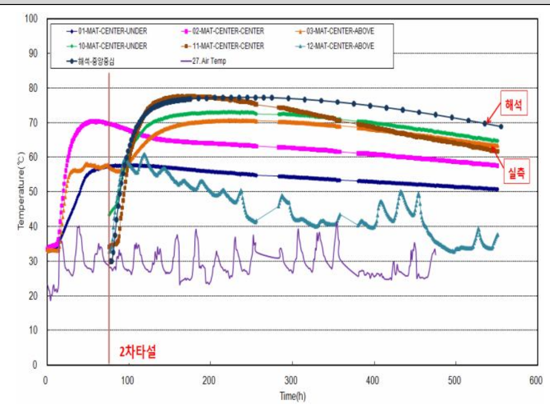
<table>
<tr><td colspan="2">Class.</td><td>Central temperature (CENTER)</td><td>External teperature (CENTER)</td></tr>
<tr><td rowspan="2">MAT</td><td>The first(2,200 mm)</td><td>70.4</td><td>56.1</td></tr>
<tr><td>The second(3,500 mm)</td><td>77.4</td><td>57.0</td></tr>
<tr><td colspan="2">The measured results (Center)</td><td colspan="2">The value compared between measured and analyzed (Center)</td></tr>
<tr><td colspan="2">
</td><td colspan="2">
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Table 2. *The amount of adiabatic temperature rise and reaction velocity of the real member*

Class.	Temp. of concrete placing	Temp. increased	Reaction velocity
Mock-up Test	32^{o}C -35^{o}C	44.3	1.15
The First Full-Scale	10 20 30	49.3 45.6 44.6	0.471 0.943 1.414

Although harmful cracks were not observed in the Mock-up test it can be predicted that the same situation would not be appeared in Mat foundation due to different method of concrete placing and size. Hence, re-analyzed methods to cure concrete and period are required so that the data earned via the Mock-up test such as the amount of adiabatic temperature rise and reaction velocity are applied to Full-scale by the first Full-scale analysis. The optimal values are shown in Table 2.

3.3 Consideration by analyzing Full-Scale of the total cross section

Even though decreasing concrete temperature by controlling hydration heat is a so basic method, it is impossible to apply the method due to the situations of local ready mixed concrete plants and external environment such as extremely high ambient air temperature.

Hence in order to verify the effect of controlling thermal stress by curing condition as seen in Table 3 the relation between concrete and curing temperature is re-analyzed, considering the results measured in Mock-up test and external conditions.As the results if concrete temperature carried into the field were controlled below 30. and curing temperature were kept greater than 35. the stable thermal cracking index (TCI from now on) of over 1.02 would be ensured.

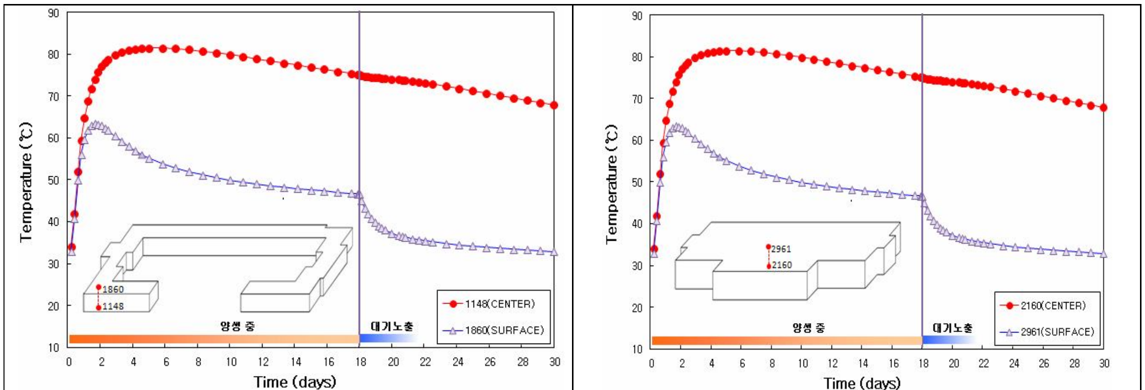
However, in extremely high external temperature and considering consecutive production it is impossible to control concrete temperature less than 30.. Thus a method which keeps internal space temperature of curing blanket not to generate thermal convection from surface after concrete placing was adopted. Table 4 demonstrates the applied section, method of concrete curing, and curing periods. According to the table applied curing method can prevent from harmful cracks, recording TCI of 1.03 to 1.19.

Table 3. *The results of thermal stress by temperature of concrete and curing*

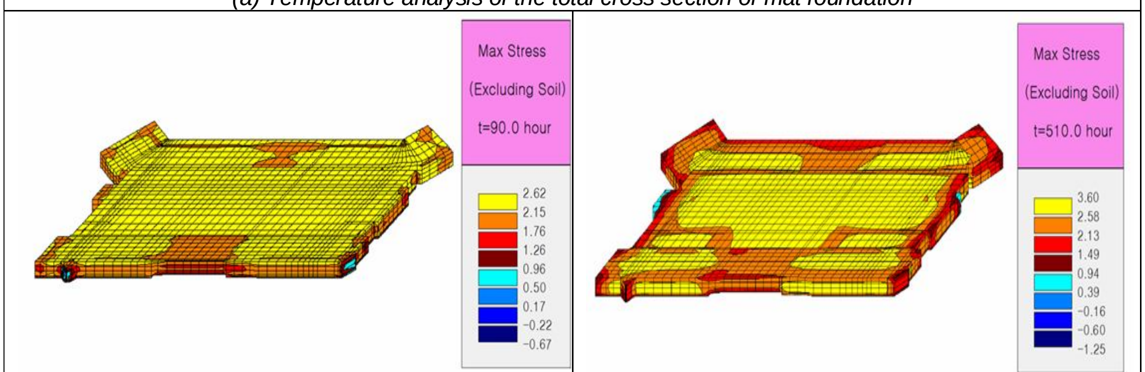
Class.	Concrete temp.	Curing temp.	The analyzed results			
			Thermal stress	Tensile stress	TCI	Evaluation
CASE 1	30°C	30°C	2.84	2.62	0.92	N.G
CASE 2	30°C	35°C	2.49	2.63	1.06	O.K
CASE 3	35°C	30°C	3.03	2.63	0.87	N.G
CASE 4	35°C	35°C	2.56	2.63	1.02	O.K

Table 4. *Curing method and period*

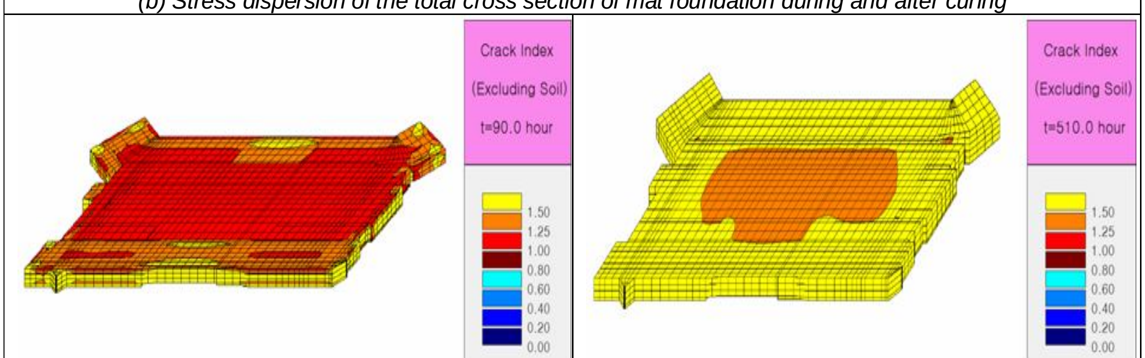
Class.	Curing method	Curing period
THK 3,000 mm, 3,500 mm section	1 layer of vinyl + 3 layers of curing blanket + roof	12 days
THK 4,000 mm, 5,000 mm, 5,700 mm section		20 days



(a) Temperature analysis of the total cross section of mat foundation



(b) Stress dispersion of the total cross section of mat foundation during and after curing



(c) TCI of the total cross section of mat foundation during and after curing

Figure 5. *Full-Scale thermal stress and TCI of mat foundation*

4. Hydration history of mat foundation via actual construction of Lotte Center Hanoi Project

4.1 The mix design for mat concrete

The amount of binder required for the mix design was initially designated from 385 to 425 kg and finally designated as seen Table 6 through analyzing the thermal stress and properties of concrete. For upper level the amount of binder was increased. On the other hand, fly-ash replacement ratio was decreased as the level of structure goes up. This is to lead to decreasing temperature differences between the center and surface of mat foundation and then to minimize the highest temperature of lower level, accelerating hydration heat rise of upper level.

Table 6. *Concrete mix design applied to mat foundation*

Class.	G-Max	FA (%)	W/B (%)	S/a (%)	Unit Weight (kg/m^3)								
					W	B	C	F/A	S	G	AD1	AD2	□□
Lower level	20 mm~ 25 mm	25 %	38.6	46.6	160	415	311	104	888	987	0.80~ 1.20 %	0.40~ 0.80 %	Delayed
Upper level	25 mm	10 %	37.6	47.5	160	425	382	43	885	1004	0.80~ 1.30 %	-	-

4.2 Plan of concrete placing and curing management for mat foundation

Mat foundation constructed in this field consists of 14 layers of mass as if stair shape as seen in Figure 6. And concrete was placed by using 16 concrete pumps with continuous placing for 51 hours. Plus, -1,000 mm section from surface was placed by delayed concrete and the rest of section was placed by normal concrete. The method of curing concrete is demonstrated in 3.3 and shown in Figure 6.

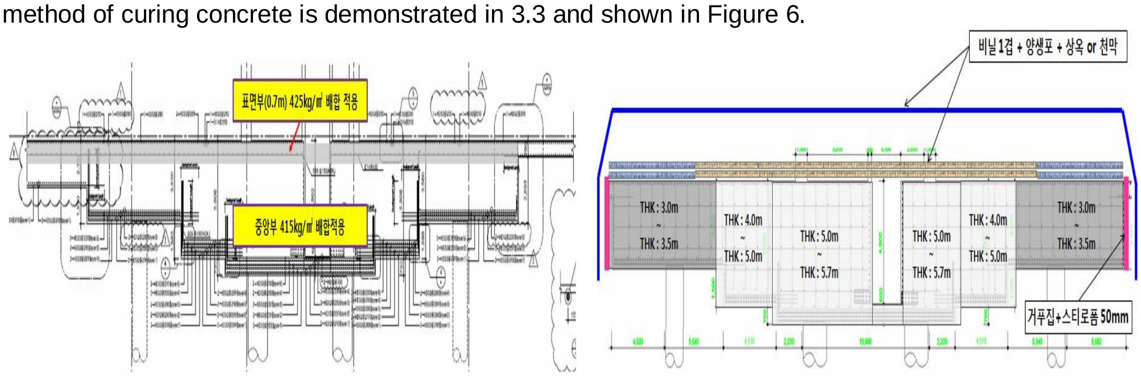


Figure 6. *Shape and curing plan of mat foundation*

4.3 Thermal stress and TCI of mat foundation

Hydration heat generated from internal member was measured in real time since concrete placed. As seen in Table 7 the hydration heat was about 80^{o}C at center and about 67^{o}C at surface when it reached the highest point. And at that time temperature difference between internal and external area was 12.9^{o}C with TCI greater than 2.5 which can prevent from generating cracks at initial curing. In particular at the end of curing the difference was less than 28^{o}C with TCI of 1.1 to 1.6. This result leads to alleviating impact by abrupt heating loss.

Table 7. *Thermal stress and TCI at about 70 hours reached to the highest temperature*

Item		Hydration heat	Temp. deviation(ΔT)	Thermal stress(f_t)	**TCI**
THK 5,000 mm Section	Upper	70.9	9.1	0.347	3.0 □□
	Center	80.0			
THK 5,700 mm Section	Upper	67.4	12.9	0.493	2.57
	Center	80.3			
Internal temp. of curing blanket		54.2		-	-
Internal temp. in ambient air		35.0			

Table 8. *Thermal stress and TCI at the end of the curing (about 470 hours)*

Item		Hydration heat	Temp. deviation (ΔT)	Thermal stress (f_t)	**TCI**
THK 5,000 mm Section	Upper	47.2	26.6	2.54	1.11
	Center	73.8			
THK 5,700 mm Section	Upper	48.2	26.5	2.53	1.11
	Center	74.7			
Internal temp. in ambient air		31.0		-	-

5. Conclusion

In this report, a limit of temperature strain was changed according to mix proportion condition and raw materials property of concrete through process to calculate internal restraining stress result from hydration heat of concrete. An adiabatic temperature rise and reaction rate varies according to element size, concrete mix proportion and convection current condition. Therefore, establishment reducing plan of temperature crack is very important to get a successful quality of mass concrete through solving temperature restrain with the process of calculating rational temperature rise rate and maximum temperature.

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