Thermal Stress Simulation of Mass Concrete Using Thermal Stress Device

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ABSTRACT

To predict thermal stress independent of uncertain material properties of early age concrete, such as elastic modulus and creep, thermal stress device is used. In order to verify the application of various degree of constraint in the thermal stress device, a series of experiments were performed on mass concrete followed by numerical simulation. The application of various degrees of constraint can be achieved by using constraint frame material with different thermal expansion coefficient, length, and cross sectional area. Temperature development in the real structure has been simulated using temperature and humidity control chamber. The results from experiments and numerical analysis show that the thermal stresses estimated from simulation agree well with the general stress variations in the real structure even though the properties of concrete are uncertain.

1. Introduction

Specific thermal stress damages a structure and degrades the structural serviceability, water tightness, and durability. Therefore, these kinds of structures should be constructed by paying due attention to the generation of cracks due to thermal stress to make sure of safety and serviceability of these structures.

Specific thermal stresses are calculated by finite element method (FEM), which is the most commonly used analytical method, and are measured by experimental methods using a special equipment or gauge in actual and simulated structures or a thermal stress measuring device in controlled laboratory setting equipment. With respect to the analytical methods, a fundamental limitation is derived from the difficulty of predicting concrete properties, such as modulus of elasticity, coefficient of thermal expansion, and others. The problems with experimentally obtained results are their economic inefficiency and uncertainty
related to field conditions, such as measurement accuracy of stress meter[1)] are not much known and it is difficult to evaluate thermal stress by an embedded type strain gauge unless the mechanical properties of concrete from the newly placed state through the hardened state are properly estimated. An experimental tool called "thermal crack apparatus[2)] used thin copper or polyethylene plate to prevent shrinkage and "cracking frame" estimated thermal stresses and cracking pattern of early age concrete[3)] was based on semi adiabatic condition using wood and polystyrene for temperature control .However, in this study a laboratory test device measuring thermal stress[4)] was used. The concept of variable degree of constraint (internal & external) and shape of thermal stress device is shown in figure 2.1 & 2.2, respectively. The experimental results were compared with the analytical results for the sake of verification.

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2. Experimental procedure

Mix proportion of concrete and test variables used in experiments is shown in Table 2.1 and Table 2.2 respectively. In this study, experiments for two representative cases are performed one is interior of concrete structure subjected to internal restraint or whole section subjected to external restraint. The other is the surface of concrete structure subject to internal restraint.

Strain gages were used for measuring restrained forces in a frame with thermo-couples set at a chamber, frame, and concrete specimens to ascertain the applied temperature. To reduce plastic and drying shrinkages from occurring in concrete specimens at early ages, humidity is kept at over 85%.

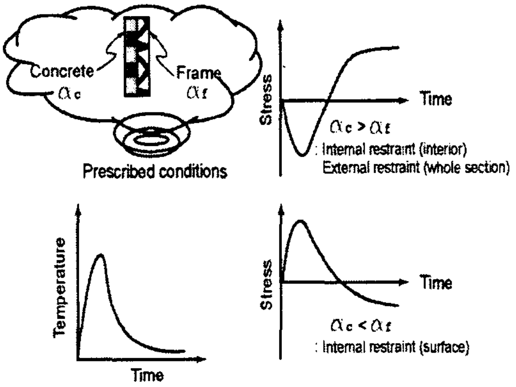

Figure 2.1 Concept of thermal stress device

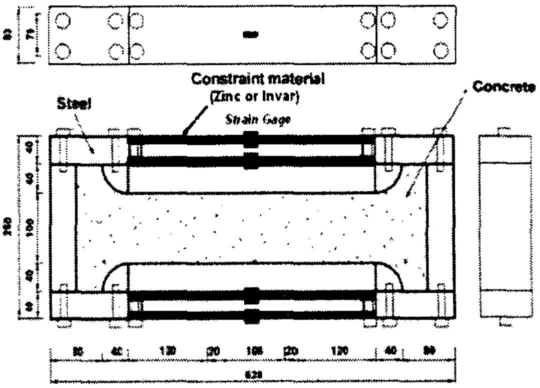

Figure 2.2 Shape of thermal stress device

Table 2.1 Mix proportion of concrete

W/C (%)	S/A (%)	Unit Content (kgf/m3)					
		W	C	S	G	Admixture	
						AE	WR
40	39	181	450	630	989	0.023	2.23

Table 2.2 Test variables

Material	Serial No.	Thickness of plate(mm)	Thermal expansion coefficient($\times 10^{-6}$ /℃)	Elastic modulus (MPa$\times 10^3$)	Remarks
Invar	1	10	1.5	28.3	Degree of internal restraint
	2	20			
Zinc	1	10	25	108	Degree of internal restraint
	2	20			
	3	40			

The left and right side surfaces of the specimen indicated as a dotted line in Figure 2.2 is covered with thin steel plates before placing concrete. The plates are removed six hours later. Also, the friction between specimen and thin bottom plate supporting a frame is minimized by painting grease and oil on thin steel plate. The application of lubrication during the test is controlled based on preliminary examinations. To predict thermal stresses in structures using the thermal stress device, a temperature analysis is first performed and followed by experiments in a temperature and humidity chamber pre-programmed based on analysis results.

3. Test Results

3.1 Plate material (invar) with lower thermal expansion coefficient than concrete

Figure 3.1 (a) & 3.1 (b) shows the comparison of results for temperature and stress in concrete obtained from experiment and analysis.Figure 3.1 (a) depicts that the concrete temperature programmed in the chamber and the temperature of concrete obtained from thermal analysis are almost same.

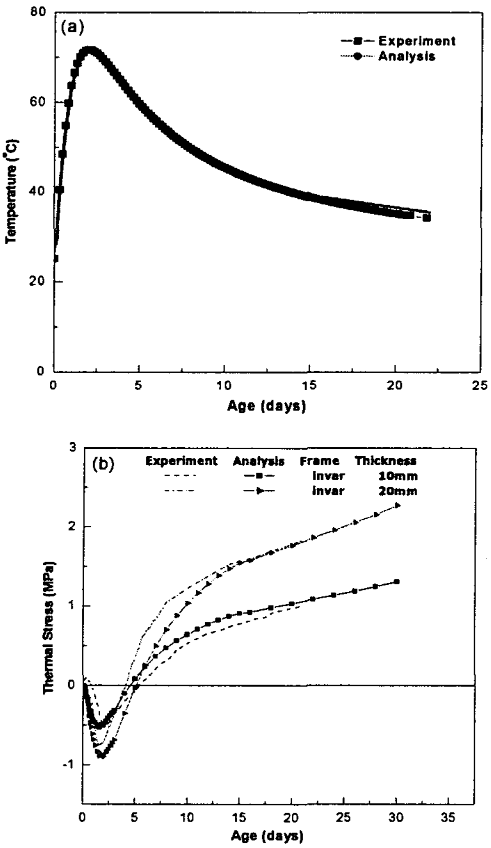

Figure 3.1 (a) Temperature history
(b) Stress of concreteC

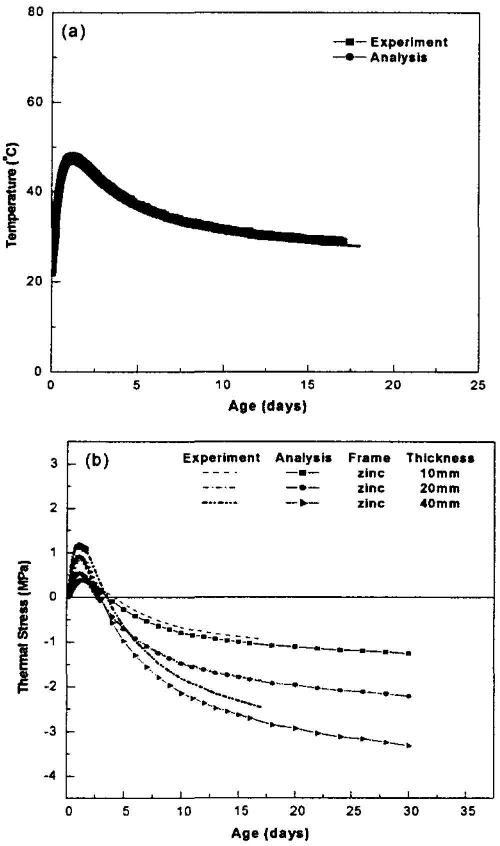

Figure 3.2 (a) Temperature history
(b) Stress of concrete

Figure 3.1(b) is similar to the variation of thermal stresses appearing at the interior of mass concrete structures[5]. As we increase the thickness of frame material (i.e. restraining force), stress of concrete increases remarkably both in compression and tension which is also verified by the numerical analysis.

3.2 Plate material (zinc) with higher thermal expansion coefficient than concrete

Figure 3.2(a) and 3.2(b) shows a similar tendency as the test results obtained using invar plate. Figure 3.2(b) is similar to the variation of thermal stresses appearing in the surface of mass concrete structures$^{6)}$. Figure 3.2(b), however, indicates that the device can be used to reproduce thermal stresses at surfaces of a structure subjected to internal restraint condition. Numerical results can be used to verify the experimental results and to develop a model for reproducing of variable degree of restraint in the device

4. Conclusions

Thermal stress variationsubjected to internal and external restraints in actual structures can be simulated by the application of various degree of restraint in the thermal stress device. Occurrence of Plastic and drying shrinkage can be avoided by using a commercialized temperature and humidity control chamber. Numerical analysis verifies the experimental results which can also be used to extend the experimental results in order to define the perfect degree of restraint in the thermal stress device. Experiments using embedded strain gages can be used to verify the experimental results in this study if reliable data concerning mechanical properties of concrete (the time dependent-behavior of the modulus of elasticity of concrete and unit creep strain) are available.

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