현장조건을 고려한 콘크리트 기초 및 교각구조의 온도 및 열응력에 관한 실험적 연구

An Experimental Study on the Temperature and Thermal Stresses in Massive Footing and Column

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매스콘크리트에서는 수화열에 의하여 유발된 높은 온도가 열응력을 일으키는 원인이 되며 구속의 정도에 따라 인장응력이 발생되어 균열이 발생하게 된다. 따라서, 매스콘크리트 타설시 시멘트의 수화열에 의한 균열이 심각한 문제가 된다.

본 연구에서는 매스콘크리트 기초 및 교각구조에 대한 수화열 실험을 통해 온도분포 및 변형분포를 측정하고 이에 대한 온도 및 열응력 해석을 통해 매스콘크리트에 대한 수화열 특성을 규명하였다.

1. INTRODUCTION

The reaction of cement with water is exothermic and liberates a considerable quantity of heat. Modern cements are finer, and have increased heat outputs. The early rate of hydration heat generation of concrete increases significantly with temperature, hence a higher placing temperature of concrete results in a larger temperature rise, and greater temperature differentials.

The temperature distribution in mass concrete structures depends on the amount and rate of hydration heat emission, and the three-dimensional heat flow. The former is a function of cement type, mix design and concrete temperature, while the latter is a function of ambient conditions, the properties of the concrete, subgrade material and insulating material, and the temperature distributions. Thus simulation of the temperature curves for points within the structure is a complex problem.

It is difficult to simulate hydration heat problems using scale models. However apparatus has been developed where the measured temperature and strains in a prototype structure can be simulated on a laboratory specimen and thus the corresponding stress function can be obtained.

In this study, in order to estimate hydration heat generation of concrete, an experimental block is made. Analyzing the measured temperature of the concrete block, we predict the adiabatic temperature rise. A theoretical and experimental study about temperature and stress distributions induced in concrete structures during the hardening process is presented. Based on test results, the characteristics of hydration heat of concrete are determined. We develop an

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efficient finite element analysis program for temperature and thermal stress of the mass concrete structures including the time dependent effects due to temperature, creep, shrinkage and aging of concrete. In order to examine the temperature and thermal stress distribution of the mass concrete structures, a test member is made. So the temperature and thermal distributions within the test member are measured. Finally, we predict the characteristics of hydration heat of concrete through the comparison of experimental and analytical results.

2. TESTS ON HYDRATION HEAT OF MASS CONCRETE

2.1 Outline and Object of Tests

Since dimension of concrete structures is determined differently according to the type of structure, materials and conditions of construction, it is difficult to classify mass concrete structure by accurate dimension. According to rough standard, we consider mass concrete structure as the slab of which thickness is over 80-100cm, and, in case that the lower end of wall is fixed, the wall of which thickness is over 50cm.

In the case of normal concrete structures, its section is small, so hydration heat of cement is instantly emitted to the outside. Then temperature difference between inside and outside of concrete structure is small. Therefore, the volume change of concrete structure caused by this temperature difference and the stress change caused by restricted boundary condition is small, then the probability of occurrence of cracks is very low. But, in the case of mass concrete, the inner temperature gradually increases like almost adiabatic state. In the restricted boundary condition, it can cause very high stress, then thermal cracks can occur. Therefore, it must be necessary to consider thermal stress caused by hydration heat of cement in the mass concrete structures.

In this tests, we predict the adiabatic temperature rise through experiment of cubic blocks. And temperature distribution of the inside caused by hydration heat of cement is predicted by mass concrete model test. In addition, thermal stress caused by this temperature distribution is examined experimentally.

2.2 Design and Fabrication of Test Member

In the mass concrete structures such as large footing and pier, when they are placed, the extreme hydration heat by cement occurs. Such temperature difference between the internal and external causes high thermal stress. Thermal stress causes the cracks in mass concrete, so it brings about serious stability problems in structures. Therefore, in order to explore the temperature distribution and thermal stress distribution by hydration heat in mass concrete structures, one has to test with the model similar to the real structure size. But, in hydration heat test of mass concrete, the degree of hydration heat occurrence varies as structure size, so it is the most important to define the size of structure.

In this study, we modeled structure shape for the pier footing and column shape, which can bring about sufficient hydration heat by cement. That test model is as shown in Fig.1. Footing is

$3m \times 2m \times 1m$ and column is $2m \times 1m \times 1m$. In addition, in the test of temperature distribution and thermal stress by hydration heat of mass concrete structure, the reinforcements of structures are also very important because they restrain the cracks. But, in this test, we designed the footing and column without consideration of loads. So we adopt 0.15% of member area as the minimum reinforcement ratio recommended by ACI. We embedded the temperature gauges and strain gauges in the center of structure with a constant interval. Because the cross section of mass concrete structure is symmetric, we embedded the gauges in 1/4 cross-section of test members.

In this test, we use the following mix proportioning of Table 1, where unit cement content is 382 kg/m^3, sand to total aggregate ratio is 45%, water-cement ratio is 49.8%, some amounts of AE admixure.

Table 1 Mix proportion of concrete(kg/m^3)

Cement content	Water	Fine aggregate	Coarse aggregate	Admixure
382	190	768	942	0.76

2.3 Test Results

2.3.1 Temperature Distributions

In this test, Thermo-couple temperature gauges are embedded within the test member to investigate the distributions of the interior temperature after placing of concrete.

Fig.2 shows temperature according to time at the observation points of footing middle. As shown in figure, it is known that the interior temperature increases rapidly up to the maximum value at the early age and tends to decrease smoothly. Finally, it gets to atmospheric temperature after 10 days. The maximum value of temperature reaches about 68℃ at 17 hours after placing of concrete.

Fig.3 shows temperature according to time at the observation middle points of column. As shown in figure, the maximum value of temperature reaches about 70℃ at 16 hours after placing of concrete. The temperature distribution of the upper surface of column top varies in the same manner with variance of atmospheric temperature. Compared with footing, maximum temperature is similar to footing. The reason why the maximum temperature of column is nearly equal to that of footing in spite of size difference is that the temperature of the footing is maintained to some extent when column is placed.

Generally, since the conductivity of concrete is low, the high temperature associated with the exothermic hydration heat of concrete may occur between the interior and the exterior of the mass concrete structures at early ages. And, it takes long time to dissipate the heat generated by hydration to the exterior. Finally, the high temperature generated hydration heat of concrete may causes the thermal stresses of concrete. Therefore, it is the most important to control to decrease maximum temperature.

2.3.2 Strain Distributions

In this test, we embedded strain gauges

in test model and measured the strain of the interior of test model after placing of concrete. The results of strain distributions at the observation points are as follows. Fig.4 and 5 show the strain caused by hydration heat within the footing and column. As shown in figures, it is a tendency that strain increases at early age and decreases gradually in the same as temperature distribution.

3. CONCLUSIONS

From this study, the following conclusions can be drawn.

① In this test, since K and α of an adiabatic temperature-rise equation are 55, 4.25, respectively, the heat generation of domestic cement is found to be very high and heat generation rate is very fast.

② The analytical temperature and strain distributions are very similar to the experimental results.

③ Compressive stresses are induced in the interior of the test member, while tensile stresses are induced in the exterior.

④ In this test member, the cracking index of all the points are less than 1.0, so the test member does not have the possibility of cracking.

REFERENCES

1 ACI Manual of oncrete Practice, Mass concrete, Cracking fo Mass Concrete 207.1R-207.2R, 1992

2 Bogue,R.H., "Studies on the Volume Stability of Portland cement Paste," PCA Fellowship Paper No.55, National Bereau of Standards, Washington,D.C.,1949

3 Owen, A.R.J., and Dajanic, F., "Reduced Numerical Integration in Thermal Transient Finite Element Analysis," Computer & Structures, Vol.17, 1983, pp.261-276

4 Yu, J.R. and Hsu, T.R., "Analysis of Heat Conduction in Solids by Space-Time Finite Element Method," International Journal of Numerical Method in Engineering, Vol.21, 1985, pp.2001-2012

5 Carlson, Roy W., and Thayer, Donald P., " Surface Cooling of Mass Concrete to Prevent Cracking," ACI JOURNAL, Proceedings V.56, no. 2, Aug. 1959, pp.107-120.

6 Davis, Raymond E., "Historical Account of Mass Concrete," Symposium of Mass Concrete, SP-6, American Concrete Institute, Detroit, 1963, pp.1-35.

7 Dusinberre, D. M., "Numerical Methods for Transient Heat Flow," Transactions, American Society of Mechanical Engineers, V. 67, Nov. 1945, pp. 703-772.

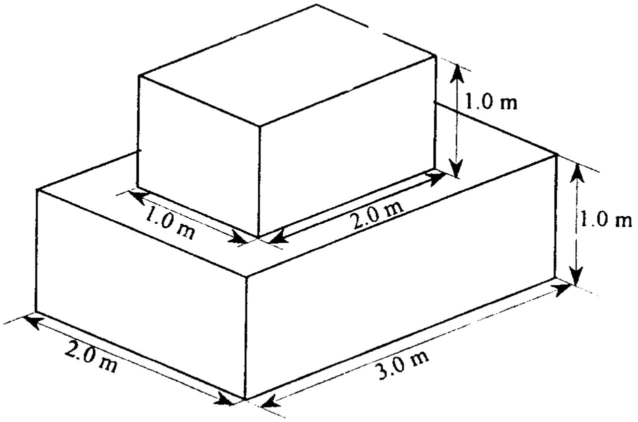

Fig.1 The size of test member(m)

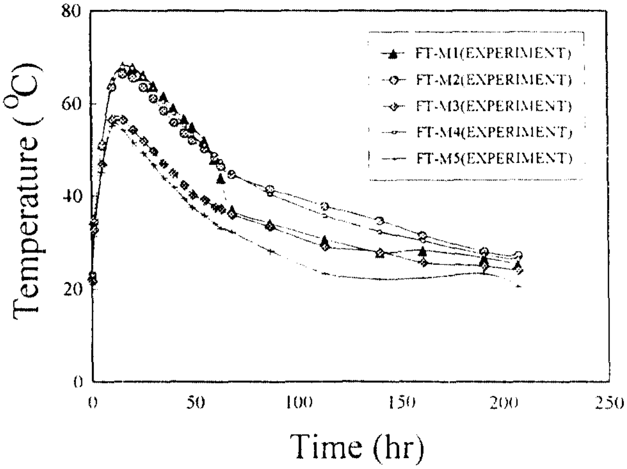

Fig.2 Temperature according to time(at the middle of footing)

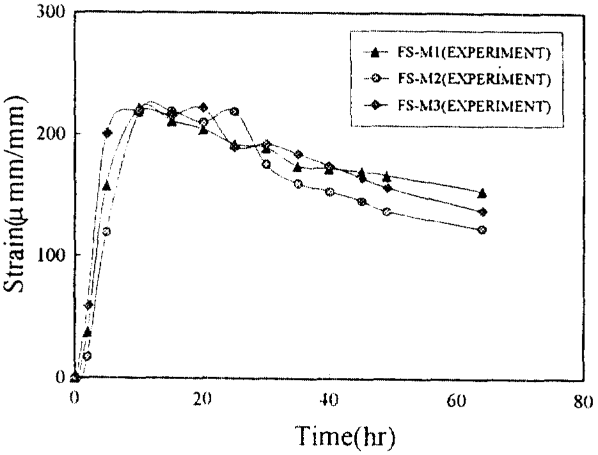

Fig.4 Strain according to time(at the middle of footing)

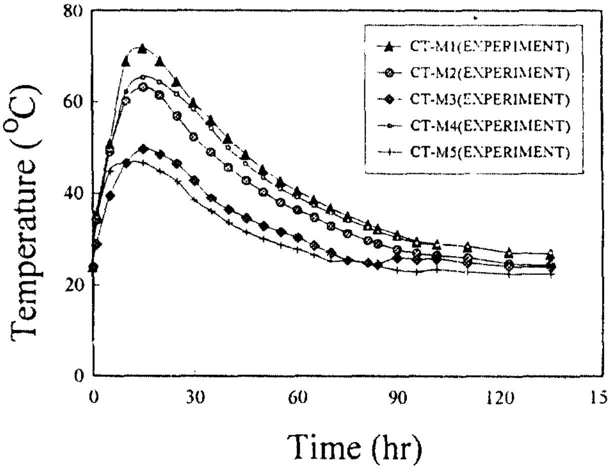

Fig.3 Temperature according to time(at the middle of column)

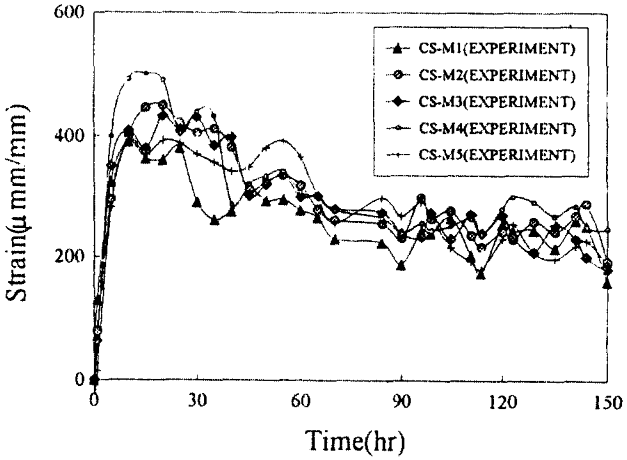

Fig.5 Strain according to time(at the middle of column)