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Early-age Temperature Distribution in a Massive Concrete Foundation

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Abstract

Early-age cracking appertains to massive concrete elements on the account of thermal gradients due to highly exothermic hydration reaction of cement. The cracking as a result of thermal strains can in turn lead to undesirable consequences on structural durability. In this paper, a degree of hydration-based finite element simulation procedure is developed and implemented in order to determine the temperature distribution of young concrete within a massive solid circular raft foundation. The developed finite element program is validated with experimental results available in the literature. The information regarding temperature development can effectively be used to compute thermal stresses while designing the massive foundation for structural as well as durability considerations. Appropriate measures can also be taken to bring down the temperature levels during the phased casting operations so as to avoid early-age cracking problems.

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Keywords: Early-age cracking; mass concrete; degree of hydration; numerical model; phased casting.

1. Introduction

The early age behaviour of concrete has proven to be decisive with regard to massive concrete constructions like thick foundations, roller compacted dams, piers, etc. Hardening of fresh concrete associated with exothermic chemical hydration process, raises the temperature of the concrete within the domain of the structure. The cooling of the massive concrete results in considerable thermal gradients primarily attributed to the low thermal conductivity of the young concrete. These thermal gradients aggregated with external as well as internal restraint to volume changes

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induce stresses. These stresses if surpass the limits, induce cracking, especially 'through cracking', which covers the full thickness of the massive concrete [1]. As a result of this, potential self-induced damage can occur in the structure well before the action of working loads.

In view of the imperceptible influence of the mechanical field of concrete on the thermal evolution and hydration process, it is customary to consider a unidirectional coupling in which, the stress analysis is performed after the thermal computations [2]. The temperature distribution in concrete structures and its evolution with time depends on thermal parameters such as evolving concrete properties, ambient conditions, placement temperature, phased casting operation sequence, etc., making the problem highly non-linear [3]. Many researchers have proposed different approaches for numerical simulation of temperature distribution in early age concrete [1-5]. A degree of hydration - based finite element formulation [6] for the simulation of the thermal profile of thick reinforced concrete circular raft foundation during its early age is presented in this paper. The computed temperature data can be utilised for mechanical analysis of concrete raft so as to evaluate the resulting thermal stresses and hence the possible risk of cracking.

Nomenclature

χ	number of moles of water combined with cement
ξ	degree of hydration
$\dot{Q}$	rate of heat production
$f(\xi)$	normalised chemical affinity function
k	conductivity
C	volumetric specific heat capacity
T	temperature
h_c	convection coefficient
t	time

2. Modelling of Concrete Hydration

The prominent mechanism associated with the chemical kinetics of hydrating cement is observed to be dispersion of water. The number of moles of water combined with cement at any instant χ can be utilised to charecterise the chemical demeanour of concrete. A normalised format is often preferred for convenience, so that the term 'degree of hydration' is defined as[7]

$$\xi = \frac{\chi}{\overline{\chi}_\infty} \tag{1}$$

where, $\overline{\chi}_\infty$ being the ideal value of χ at infinite time. In practical situations, the full hydration of cement will never be attained and the ultimate hydration degree ξ_∞ is always less than unity [8]. The rate of heat production due to the hydration of concrete, $\dot{Q}$ can be expressed in terms of $f(\xi)$, called as normalised chemical affinity and $g(T)$, which is the function describing the influence of temperature on heat production as [9]

$$\dot{Q} = Q_\xi \cdot f(\xi) \cdot g(T) \tag{2}$$

where, Q_ξ is the maximum value of the heat produced at 20°C isothermal hydration. It is customary to denote Eq. (2) in terms of rate of hydration as $\dot{Q} = Q_\xi \dot{\xi}$, and the rate of degree of hydration $\dot{\xi}$ can be expressed using an Arrhenius function in the following form [10]: