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ScienceDirect

Procedia Engineering 193 (2017) 234 – 241

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Analytical Models and New Concepts in Concrete and Masonry Structures AMCM'2017

Analysis of Cracking Risk in Early Age Mass Concrete with Different Aggregate Types

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Abstract

The main cause of early age cracks often observed in massive concrete structures is inhomogeneous volume changes associated with thermal and moisture gradients occurring in these structures due to the hydration process. Significant impact on a temperature rise which is the main reason of significant changes in concrete volume, and as a consequence, on the cracking risk in the massive foundation slab has the type of aggregate, which forms the thermal properties of concrete. In the paper, thermal properties of concretes made with different aggregate types and their impact on the cracking risk in a massive concrete slab are discussed. Thermal conductivity and heat capacity of concrete with different aggregate types have been experimentally measured and next used in the numerical study. The influence of gravel (consisting mainly of quartz), basalt, granite and limestone aggregate on the temperature development, stress level and the cracking risk has been studied in the numerical tests. The presented numerical analyses are conducted for a massive foundation slab with use of the original numerical model and computer programs TEMWIL and MAFEM. It has been shown that the use of the aggregate with the appropriate thermal properties may result in the reduction of thermal stresses and the cracking risk in early age concrete slabs.
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Peer-review under responsibility of the scientific committee of the International Conference on Analytical Models and New Concepts in Concrete and Masonry Structures

Keywords: early age concrete; foundation slabs; temperature; aggregate; stresses; cracking risk.

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Peer-review under responsibility of the scientific committee of the International Conference on Analytical Models and New Concepts in Concrete and Masonry Structures
doi:10.1016/j.proeng.2017.06.209

1. Introduction

The temperature increase during concrete hardening is caused by an exothermic cement hydration process. It is important in massive elements, in which conditions are close to adiabatic and maximum temperature can reach even 50÷70°C [1÷3]. One of the causes that affect high temperature rise and its non-uniform distribution between surface layers and interior of thick slabs is low thermal conductivity of concrete, which slows down the natural cooling process. In the meantime, during hydration of concrete shrinkage deformations are formed, as a result of a chemical reaction and the moisture exchange with the environment.

The consequence of non-uniform volume changes of the hardening concrete is the formation of thermal-shrinkage stresses in the structure. The originating non-linear and non-stationary coupled thermal-humidity fields generate stresses in the slab, related to the internal constraints of the structure resulting from inhomogeneous distribution of thermal-humidity fields. During the phase of temperature increase (heating phase) the tensile stresses are induced in surface layers of the slab while compressive stresses are observed inside the slab. The induced stresses compared to the temperature development in the curing time are shown in Fig.1. It should be mentioned that during the cooling phase an inversion of the stresses occurs. In this phase the tensile stresses are observed inside and compressive stresses appear in the surface layers of the slab.

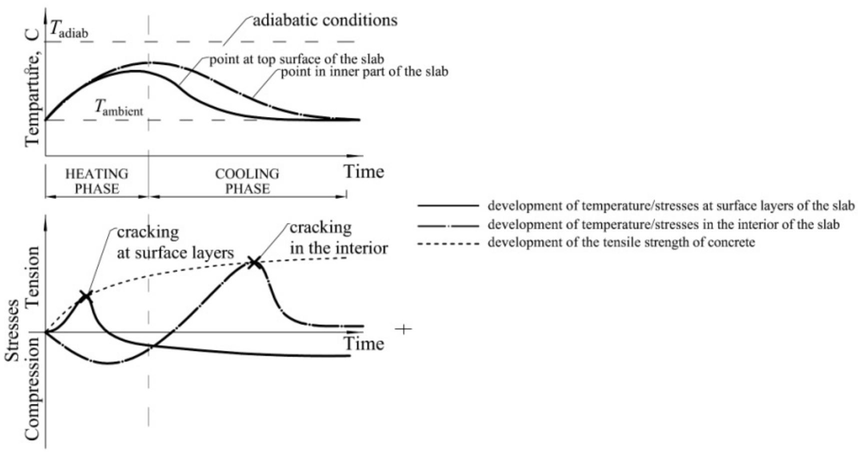

Fig. 1. Temperature (upper) and stress (lower) development in a massive foundation slab.

The mentioned stresses often reach significant values and can cause cracks and micro-cracks in the structures, which is important from the durability point of view. The size of thermal-shrinkage tensions, generated in concrete during hardening, depends on many technological and material factors, such as: concrete mix composition and type of materials used, concrete placing, curing condition, dimensions and support conditions determining the level of freedom deformation of the concrete subjected to changes in volume [4÷5]. In massive concrete members such as foundation slabs the cracks are usually observed on the top surface of the member, especially when it is unprotected with insulation layers. According to the stress development shown in Figure 1 (lower), such cracks appeared in the heating phase, when the tensile stresses exist in surface zones of the slab. These cracks can occur at the surface of a massive concrete slab within the first few days after placement.

2. Factors affecting early age cracking risk

The most important factor when analyzing early age thermal-shrinkage stresses is the temperature development in a concrete member. The complex variables that affect the rate of temperature rise, the maximum temperature and the temperature difference in the cross-section of the slab are:

- amount of used cement

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