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Abstract of doctoral dissertation:

"The formation of the concrete mix composition due to early thermal-shrinkage influences in massive concrete structures"

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Concrete volume changes caused by hardening temperature of concrete and its non-uniform distribution between the surface layer and the interior are the cause of the formation of thermal stresses of considerable value, which excess the tensile strength of concrete, what in consequence leads to cracks in the structure. Thermal stresses may be either self-induced or forced stresses. Self-induced stresses are caused by the existence of internal restrains of the structure that result from non-uniform volume changes across the element. These stresses may be induced, even if the element has complete deformation freedom. For structures with limited strain capacity volume changes also generate forced stresses.

Volume changes associated with the high temperature of the concrete (65 ÷ 70 °C) at an early stage of the hardening may also be the result of secondary ettringite formation i.e. internal sulphate corrosion. After reducing the temperature of concrete recrystallization of ettringite occurs, which has a higher volume comparing to the hardened cement matrix. Concrete shows at this stage limited strain capacity and is not able to compensate the generated tensile stresses, what in result lead to the formation of cracks and reduction in the strength and durability of concrete.

Preventive measures taken to reduce the risk of cracking, aim to lower the hardening temperature and reduce the temperature difference between the interior and the surface of the element. Most of the recommendations in this area suggest that the difference should not exceed 15 ÷ 20°C and the maximum temperature which is generated in the hardening process should not be higher than 65 ÷ 70°C.

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Preventive measures used to reduce arising temperature gradients can be divided into material and technological. Material factors relate to the proper selection of the components of concrete, which should guarantee:

- possibly slow heat of hardening,
- low coefficient of thermal expansion and high heat conductivity of concrete,
- appropriate mechanical properties of concrete.

Technological factors refer to the conditions of production, transportation, placing and curing of concrete.

Typically, the selection of the composition of concrete mix for the construction of massive structures, particularly for massive foundation plates, is made mainly due to the limitation of the maximum temperature and the reduction of the temperature gradient. Normally no complex analysis is carried out, which would take into account result of the strains (including different thermal coefficients of concrete prepared with various aggregates), stresses (which is significantly influenced by the modulus of elasticity, which depend on cement and aggregate type used in the concrete) and the damage intensity factor (it depends on the development of tensile strength of concrete, which is based on the type of cement and aggregate).

Since the sum of the mechanical and thermal-moisture properties of concrete, resulting from the properties of the components of fresh concrete mix, determine the final result which is durable massive structure. Selection of cement and aggregate type should be considered in a comprehensive way due to the early thermal-shrinkage influences in concrete massive structures.

The aim of this study was such a comprehensive analysis of the impact of the composition of the concrete mix on the temperature, the development of strength and stress in massive concrete structures including risk assessment of crack occurrence in these structures. This paper is composed of experimental and theoretical study. The experimental part consists of:

- the characteristics of the mechanical, physical and chemical properties of cement used and constituents used in its manufacture,
- determination of the influence of type and amount of main non-clinker constituents components on the cement heat of hydration,
- determination of the influence of the w/c ratio and the temperature on the development of cement heat of hydration,

- determination of the influence of the type of cement and aggregates on concrete hardening temperature,
- determination of the influence of the type of cement and aggregate on heat capacity and thermal conductivity of concrete,
- determination of the influence of the type of cement and aggregate on mechanical properties (modulus of elasticity, compressive and tensile strength) and rheological properties of concrete.

The experimental results were used to calibrate and validate the numerical model of hardening of concrete and related programs TEMWIL and MAFEM, which have been developed from the 1990s in the Department of Civil Engineering on Silesian University of Technology.

Afterwards, the above mentioned numerical models were used to the analysis of massive structures, in which early cracks caused by thermal – shrinkage genesis are commonly observed. In these analyses the results of experimental studies were taken into account, by varying the type of cement and aggregates in composition of concrete mix. Distributions of hardening temperature, humidity changes, stress and damage intensity factor of the two types of structure: massive foundation slab and reinforced concrete wall made on previously casted foundation were analysed.

The conducted analyses confirmed that the use of cements containing main non-clinker constituents in the composition of the mass concrete, reduces the risk of cracking in the concrete structure. Analyses also showed that use of cements which contain siliceous fly ash in the composition of massive concrete, reduces the risk of thermal cracks more than the cement containing only granulated blast furnace slag. It was also demonstrated that the use of cements with granulated blast furnace slag as a component of the concrete cannot guarantee the lack of cracks occurrence in the massive structure. It was also shown that the type of aggregate applied affect the value of the stress and the damage intensity factor of the massive structure.

Obtained work results show that the assessment of the risk of cracking in the massive concrete structure, should be carried out in a comprehensive manner, taking into account not only the impact of the type of cement, but also influence of the type of aggregate. Risk analysis regarding cracks occurrence should not only focus on the values of maximum temperature and temperature gradient, which are good parameters for the preliminary assessment of the risk of thermal cracks, but it should also consider the development of strength, thermal stress, deformations, humidity changes and the damage intensity factor.

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The doctoral dissertation is divided into seven chapters. The first chapter describes the overview of the problem associated with risk in the construction of massive structures. In second and third chapter the literature review on the role of material factors (concrete composition) and technological factors are presented, as well as the experience of realization of massive concrete structures. In the chapter four the purpose and the thesis of the work is defined. The fifth chapter contains a description of research methods, characteristics of the materials used and the results of experimental tests. In the chapter six numerical models used in the analyses, methods of calibration and validation of the models used, based on the test results obtained in the fifth chapter are described. In the following section the results of numerical analyses of foundation slabs and reinforced concrete walls on pre-made foundation are presented, concerning the development of thermal stress, tensile strength and the time of their occurrence. In numerical analyses variables were the type of cement and aggregates in the composition of the concrete. Chapter seven includes a summary and conclusions.

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