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Evaluation of concrete resistance to freeze-thaw based on probabilistic analysis of damage

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Abstract

It has been years since the resistance of concrete to internal cracking induced by cyclic freezing and thawing was first evaluated according to Polish standard PN-88/B-06250 through checking the so called freeze-thaw resistance level. Concrete is most often classified as F-T resistant when after 150 cycles of freezing and thawing, the relative strength loss ΔR is equal to or lower than 20%, this value being based on average strength values of reference specimens (cubes) and those subjected to freezing, with no scatter taken into account. Previous research has shown that strength loss ΔR is accompanied by mass gain resulting from microcrack formation in concrete – for ΔR=20% the critical mass gain Δm is about 10 g. Knowing the variation history of the specimen mass in relation to the number of F-T cycles, the critical number of cycles leading to structural damage can be determined for each specimen being tested. This can be the basis for determining the parameters of Weibull distribution and developing a damage model for concrete subjected to freezing - the number of freeze-thaw cycles needed to damage the concrete for the assumed level of probability. The paper analyses the results from the tests performed on two concretes with different freeze-thaw durability.

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Keywords: concrete; freeze-thaw resistance; probabilistic damage analysis

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1. Introduction

The concept of "durability" is difficult to quantify and its classification into "good" or "better" is insufficient and needs to be revised. Durability is a "behavior" (performance) of a concrete structure under certain conditions of exposure rather than a property of a concrete material or structure [1].

Because the freeze-thaw resistance of the same concrete varies with different environmental conditions, the durability of concrete cannot be determined based on simple parameters of its composition [2].

The service life is viewed as a period during which concrete meets performance requirements without the need for excessive repair. Service life thus quantifies durability in units (years). To define the service life, it is necessary to clearly identify and detail the requirements for the performance of concrete.

The performance and service life of reinforced concrete structures rely on many physical and chemical phenomena that are difficult to combine and describe using various analytical models for simulating real degradation processes. Because of random character of the parameters responsible for the performance of concrete in reinforced structures, probabilistic model-based prediction of service life seems to be a better solution.

The ability to accurately predict service life is a prerequisite for the rational design and operation of building structures, having a considerable effect on optimization of the composition, proper selection of materials and manufacturing technologies, etc. It is therefore of great practical and economic importance. However, a number of technical and cost-related barriers make it impossible to implement fast solutions to relevant issues.

Technically the best approach to durability is based on the service life concept. Certain performance requirements (strength, durability) must be met with the probability of damage specified. There are, however, some practical and logistical difficulties with the application of this concept. Although the EN 206 standard recommends service life-based specification, specifiers are not willing to use this approach. The standard provides very little information on the selection of adequate mathematical models for the durability of concrete, which would help determine performance-related requirements precisely and quantitatively with regard to a given service life [3].

Stochastic models have long been successfully used to estimate the durability of reinforced concrete structures, in which the corrosion of steel due to carbonation and/or chloride ingress is the basic problem.

Few examples exist for the modeling used to analyze the concrete in terms of its freeze-thaw durability. One of the first such examples is the Fagerlund model (1999), in which the real content of moisture Sact and the critical degree of saturation with water SCR are treated as stochastic variables. This mode was used by Duan t al. [4], who calculated frost damage probability assuming a triangular distribution of the probability density function, Sact and SCR.

The analysis of concrete deterioration due to freeze-thaw cycles in the probabilistic approach was presented by Qiao and Chen [5], who assumed a relative decrease in fracture energy G_n after n cycles against energy G_0 determined after 60 cycles (at this point the highest value of energy was determined) to be an indicator of concrete damage (D). In the statistical analysis of the results, they used a model based on the three-parameter Weibull distribution and found the number of F-T cycles needed for the specimen to reach a given damage level D at various probabilities.

Knowing this relationship, the service life of concrete can be determined directly based on the number of freezing cycles at the assumed reliability level. Reliability is defined through the probability of damage to concrete as a function of time (number of freeze-thaw cycles).

The key factor in the internal deterioration of concrete due to cycles of freezing and thawing is the movement of water from the environment into the concrete [6,7].

Jakobsen et al. [8] found a strong correlation between the amount of moisture absorbed by the concrete and its internal cracking. Analysis of microscopic images of deteriorated concrete indicated that the crack volume corresponded to the specimen mass, i.e., the mass of water absorbed by the concrete. Jakobsen et al. [9] used calorimetry to show that deterioration in concrete is accompanied by the increase in water amount capable of freezing at the level of 3-7% of the cement paste volume. Assuming that the paste volume is about 30% of the volume of concrete, this corresponds to about 1-2% of the concrete volume. The relatively small amount of the resultant ice may initiate the degradation process in the structure, starting from the surface in contact with water and progressing deep into the concrete.