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# Numerical Model for Durability Design of Reinforced Concrete Structures

Today, reinforced concrete structures are designed in those sections that are critical under the ultimate limit state or serviceability limit state criteria. Among all possible criteria, general environmental conditions are taken into account only in limit state of cracking where the corresponding restriction is given through the crack width limitation. A strict criterion of this limitation usually results in increase of the reinforcement quantity, which still satisfies other serviceability limit states or ultimate limit state conditions. On the other side, one cannot be sure that the occurrence of cracks wider than the calculated will be avoided. Therefore, instead of the limit state of cracking, a new limit state, which would enable greater flexibility of the aforementioned crack width criterion, is proposed in this research. In this new limit state, environmental loads representing environmental influences on durability of reinforced concrete are introduced.

Environmental loads initiate or accelerate deterioration processes, especially the corrosion process of steel in concrete. Besides the cracking and spalling of the cover, a reduction of the active reinforcement cross section is caused, which can in time result in reduction of the section capacity. Based on this fact, the new limit state is named "limit state of corrosion". In the limit state of corrosion it is necessary to verify that the reinforcement bar diameter in the ultimate life of the structure is greater than, or at least equal to the given ultimate value. Environmental loads, such as chlorides (the most prominent environmental load), Carbon Dioxide ($CO_2$), temperature and sulfates, which contribute to the corrosion initiation, are analyzed. On the basis of the mathematical models of their acting mechanisms, a corrosion initiation time is determined. Using the well-known analytical solutions of the chloride ion diffusion problem in a semi-infinite medium, and a computer experiment, an expression which best fits continuous diffusion process is created. Time dependent diffusion coefficient and initial concentration of chloride ions are considered. The factors influencing the diffusion coefficient are analyzed in detail, especially those which contribute to the binding capacity of chloride ions ($C_3A$, fly ash, sulfates...), those which improve density of concrete (slag, silica fume, superpalsticiers...), as well as temperature changes and cover cracking contributions during the initiation time of corrosion. The increase of the initial chloride concentration is defined on the basis of the capillary pore volume and the quantity of salt crystals that can fill the pores in different environmental conditions. For the same environmental loads, a corrosion propagation period is calculated. A well-known experimental expression for corrosion rate is adopted (Andrade) and modified with the coefficient which enlarges corrosion current density because of sulfates, carbonation and real cracking contribution. Corrosion rate is additionally enlarged by the safety factor which takes into account contribution of all the other relevant influences that can also enlarge the probability of bearing capacity reduction such as: significance of the object, adopted calculation model, type of the structural element, designed section, construction technology, errors in design and construction, characteristics of the material, special environmental conditions and influences of other environmental loads. The safety factor is calculated on the basis of the fuzzy set analysis. A propagation period is calculated from the condition of calculated and limited diameter equality. In addition to the diameter verification, it is necessary to prove that the sum of initiation and propagation periods is not less than the required. If this condition is not satisfied, it is necessary to repeat the calculation changing the material characteristics or cross section dimensions. For the quick estimate of concrete quality requirements, nomographs (cover- initiation time-coefficient of diffusion) are created.