NISTIR 6327

Modelling Service Life and Life-Cycle Cost of Steel-Reinforced Concrete

Report from the NIST/ACI/ASTM Workshop held in Gaithersburg, MD on November 9-10, 1998

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William M. Daley, *Secretary*
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Gary R. Bachula, *Acting Under Secretary for Technology*
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Ray Kammer, *Director*

In regard to the subject of the workshop, questions to be asked include: What is the required performance? What is meant by service life? Is reduced load-carrying capacity acceptable?

It was pointed out that many reports will issue from the three-year European project that is developing the Duracrete Chloride Penetration Model and will end soon.

2.4 CHLORIDE EXPOSED RC-STRUCTURES: CHLORIDE INGRESS AND LIFETIME PREDICTION BY THE HETEK MODEL

Ervin Poulsen, AEC Laboratory, Denmark

In the design, construction, and maintenance of marine reinforced concrete structures different persons have different needs for information. The structural engineer needs an estimate in which the basic parameters of chloride ingress are based on a knowledge of the concrete, reinforcement, and the environment in order to plan and design marine structures. The entrepreneur (i.e., the contractor) needs the concrete to be accepted or rejected by pre-testing and trial casting before the construction of a marine structure starts. The building owner needs to be warned, on the basis of inspection and examination of the marine structure, in due time before corrosion starts,. The basic HETEK model can assist the structural engineer and the entrepreneur in obtaining the information they need from knowledge of the concrete composition, the rebar cover, and the environment, but owners of structures also need field data which differs depending on whether the structure is new or old. The HETEK model is based on observations at the Träslövsläge Marine Exposure Station in Sweden. It is the result of cooperation between the University of Gothenberg's Department of Materials and the Cementa Company in Sweden, and the AEC Laboratory and the Department of Mathematics of the Technical University of Denmark in Denmark. The model uses data obtained with the Scandinavian NT Build 443 test method. The main result of the work is a model for chloride ingress into concrete and prediction of the initiation period before corrosion of the steel reinforcement begins. The model applies to marine structures of reinforced concrete, as well as to reinforced concrete structures exposed to traffic splash containing chlorides. Inputs to the model are: the mixture proportions of the concrete; the class of chloride environment; and the thickness of the cover over the reinforcement bar in question. The outputs are the chloride profile at any time and the initiation period. Prediction of service lives is being addressed, but it is complicated by the need to know the criterion for initiation of corrosion (i.e., the threshold value of chloride in concrete) and the failure criterion, and the difficulty in predicting corrosion rates.

In marine environments chloride ingress has to be considered in a) submerged sections, b) sections in the splash zone, and c) sections exposed in the marine atmosphere above the splash zone. If proper care is taken, useful data on chloride distribution can be obtained from profile grinding of concrete cores. Chloride profiles can also be obtained from *insitu* measurements on drilled dust or by use of the CorroWatch* multiprobe [9] embedded in field

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* Certain trade names and company products are mentioned in the text or identified in an illustration to adequately specify the experimental procedure and equipment used. In no case does such an identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the products are necessarily the best available for the purpose.

concrete. The probe has four anodes at different distances from the surface; using the time for corrosion observed at each anode, the model can estimate the chloride profile at any time and predict the initiation period if the thickness of cover is known. For existing concrete, required information about the ingress of chloride can be obtained by the method of inverse cores [10]. In this method, a core cut from the concrete is put back in place with the virgin part exposed to the environment; the ingress into the virgin surface is followed by measurements made at suitable intervals.

The chloride profile is characterized by four parameters – exposure time, t; surface ordinate (i.e., the chloride concentration at the surface), C_s; the initial chloride content of the concrete, C_i; and the diffusion coefficient, $D = a^2 / \pi t$, where a is the distance that chloride would have penetrated if the chloride concentration gradient was constant and had the value of the gradient at the concrete surface. The surface chloride content changes with time and the distribution depends on the direction of the prevailing wind and the distance above sea level. Also, for structures on the seashore, distance from the shore influences chloride ingress.

Penetration of chloride ions into concrete is affected by the heterogeneity of the material; it occurs through defects and the cement matrix. The potential diffusion coefficient can be determined as a function of. *w/c* ratio and concrete maturity using the NT Build 443 test method. For supplementary binding materials such as fly ash and blastfurnace slag, the binder's *factor of efficiency* is the mass of cement that can replace 1 kg of the binder without changing the chloride diffusivity of the concrete.

Examination of concrete specimens exposed to seawater at the Träslövsläge Marine Exposure Station provided data on chloride ingress; the parameters were: environments (marine atmosphere, splash zone, submerged), concrete composition (4 types of cement; 2 types of silica fume; 2 types of fly ash; $0.25 \leq w/b \leq 0.75$), and exposure periods from about 6 months to 5 years.

Service lifetime prediction by the HETEK method involves a 10-step spread-sheet calculation. It is described, and examples of initiation time predictions are given, in Reference [11]. The predicted initiation times were comparable to those made by Clifton's model [12] (e.g., Clifton, 30 years; HETEK, 25 years). Estimates of the parameters of the HETEK model were made using Mejlbro's Lambda functions [13].

Some other references to the work of Poulsen and his colleagues are [14,15,16].

2.5 MODELLING CHLORIDE INGRESS BY THE COMBINED PROCESSES OF DIFFUSION AND CONVECTION

Michael Thomas, University of Toronto, Canada (with Evan Bentz)

The University of Toronto (U of T) model [17] was developed by Bentz and Thomas. Their purpose was to provide a model that would be useful to engineers. The specific application was for reinforced concrete tunnel lining sections. The WINDOWS-based model addresses chloride ingress by diffusion, wicking, and permeability, with positive pressure heads, evaporation, convection, and chloride binding being taken into account. For wicking, the Buenfeld model [18] was adopted.