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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Gary R. Bachula, *Acting Under Secretary for Technology*
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costs should also be included in the analyses. If these costs were included, only systems without repairs would make economical sense.

2.8 CREATING A STANDARD CORROSION SERVICE LIFE PREDICTION METHOD

Matthew A. Miltenberger, Master Builders Inc., Cleveland, Ohio

In order to model chloride diffusion, it is necessary to select appropriate boundary conditions and to have the necessary input parameters. The input parameters are the effective diffusion coefficient, the chloride loading, the depth of cover over the reinforcement and, perhaps, a temperature correction. Insight into the boundary conditions can be obtained by studies of buildup of chlorides at the concrete surface and by ponding experiments. Solutions to Fick's second law have been obtained for cases of buildup and constant chloride content.

In research at Master Builders, a chloride flux test cell, a chloride migration test cell, and ponding experiments have been used in the determination of diffusion coefficients for concretes with and without silica fume. (With the chloride flux test cell, it takes two to three years to obtain data for high-performance concrete.) For conductivity measurements in the migration test cell, the specimens were saturated with chloride solution prior to making the measurements. Plots of measured versus predicted diffusion coefficients showed reasonably good agreement. Among the comparisons made were: a) typical ponding test results – chloride content vs. depth from surface (measured and Fick's 2^{nd} law); b) complete chloride profile -- chloride content vs. depth from surface (measured and Fick's 2^{nd} law); c) combined transport mechanisms -- chloride content vs. depth from surface (measured and Fick's 2^{nd} law using D from flux test).

Standardization issues -- The standardization of a model, or models, for service life prediction will be a complex problem. Among matters that need to be addressed are: a) establishment of a common terminology, b) definition of calculation procedures, c) identification of applicable transport mechanisms, d) standardization of test methods, and e) provide guidance to all who need it. Ultimately the standard, or standards, to be drafted should help designers.

Standardization of terminology is important for improving communication and reducing confusion and, in this connection, units of measurement should be standardized and not left as they are, e.g., m^2/s, cm^2/s, mm^2/yr, in^2/yr.

As for the model calculations, among the issues are:

- Should the L-R (Load-Resistance) format be adopted?
- Should a model incorporate reduction factors to account for other distresses (e.g., cracking)?
- Should corrosion propagation be included?
- Should equation(s) for multiple chloride transportation modes be included?
- How should the model(s) be validated?

- If a Nernst-Einstein temperature correction is to be used, is an activation energy (U) determined from studies on cement paste applicable to concrete?

Among the transport issues are those relating to the definition of the environmental loads, i.e., the driving force(s) behind chloride ingress:

- Diffusion -- The effective surface concentration
- Wicking – Relative humidity and the moisture gradient
- Sorption – Wet/dry cycle frequency
- Hydraulic permeation – Pressure head

Other transport issues concern definition of corrosion resistance parameters (such as the chloride threshold) and parameters related to the pore structure and its connectivity (such as the diffusion coefficient, water vapor diffusivity, sorptivity, and the hydraulic permeability). Then there is the question of identification of appropriate test methods and whether values should be estimated from mixture proportions.

In connection with model inputs, designers will need guidance to select reasonable values for diffusion coefficients, surface concentrations, buildup coefficients, and environmental factors. In connection with environmental factors, Master Builders has developed a chloride loading map for the United States based on data obtained from the Salt Institute [22], publications from the Strategic Highway Research Program [e.g., 20], and the Florida Department of Transportation [23], and measurements on concrete in parking garage structures.

In summary, a service life standard(s) should define common nomenclature, follow the familiar L-R format, include multiple chloride transport mechanisms, identify appropriate test methods, provide graphical guidance where appropriate, and be validated with data from real structures.

2.9 PREDICTING SERVICE LIFE OF CHLORIDE-EXPOSED STEEL-REINFORCED CONCRETE

Dale Bentz, National Institute of Standards and Technology

A computer-integrated knowledge system (CIKS) provides a means of combining a wealth of information into a coherent system useful to both the academic and commercial communities. For the concrete community, a subject of vital interest is the service life of concrete structures. For corrosion of reinforcing steel, the diffusion rate at which chloride can reach the steel is one of the controlling factors in determining how long a structure will last. A prototype CIKS for use in predicting the service life of steel-reinforced concrete exposed to chloride ions has been developed [24]. Starting from the mixture proportioning process, the system proceeds to predict chloride ion diffusivity coefficients and finally to predict the ingress profiles and the time-to-initiation of corrosion for a reinforced concrete exposed in a specific environment. The CIKS integrates into a single coherent system a number of computer models -- some previously developed, some new.