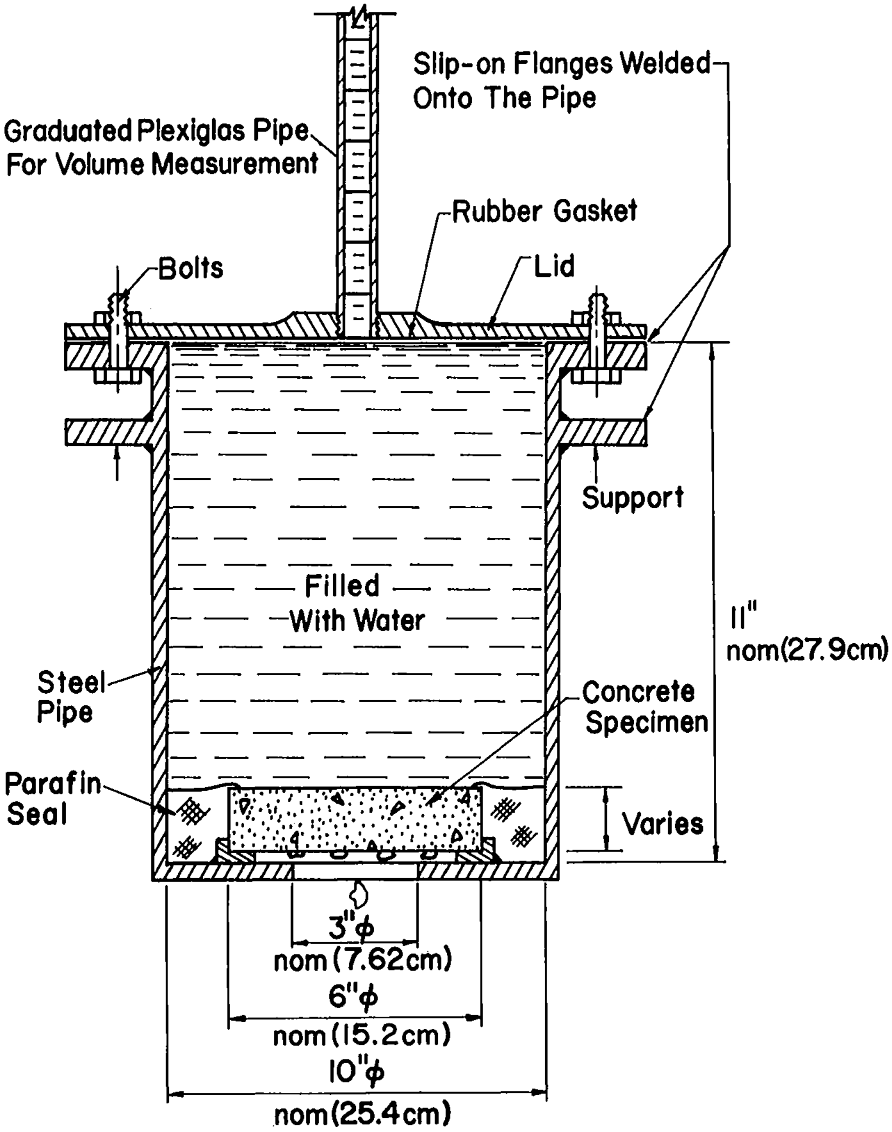

Fig. 4--Test apparatus for measuring permeability

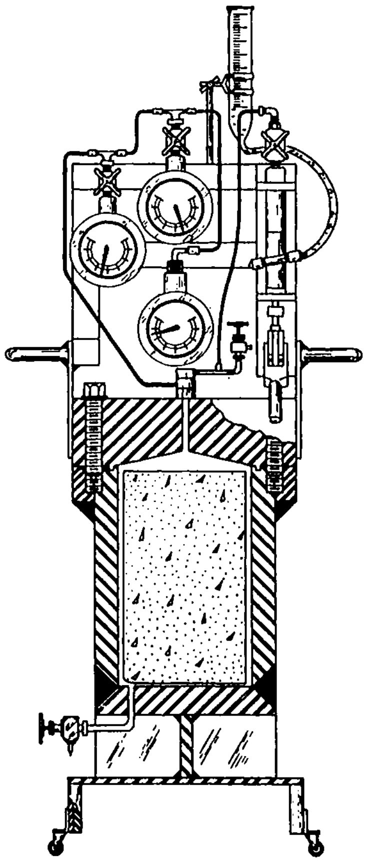

Fig. 5--Test apparatus for field testing (relative permeability)

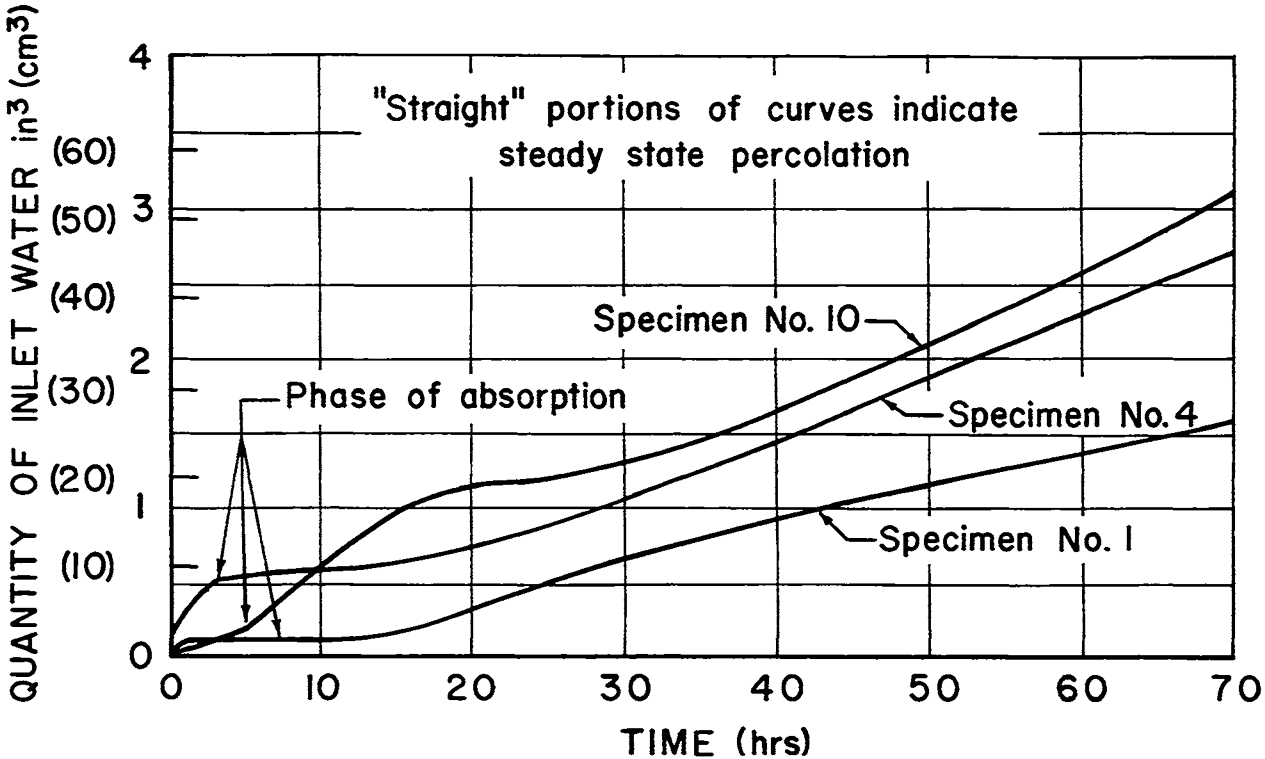

Fig. 6--Typical permeability curves

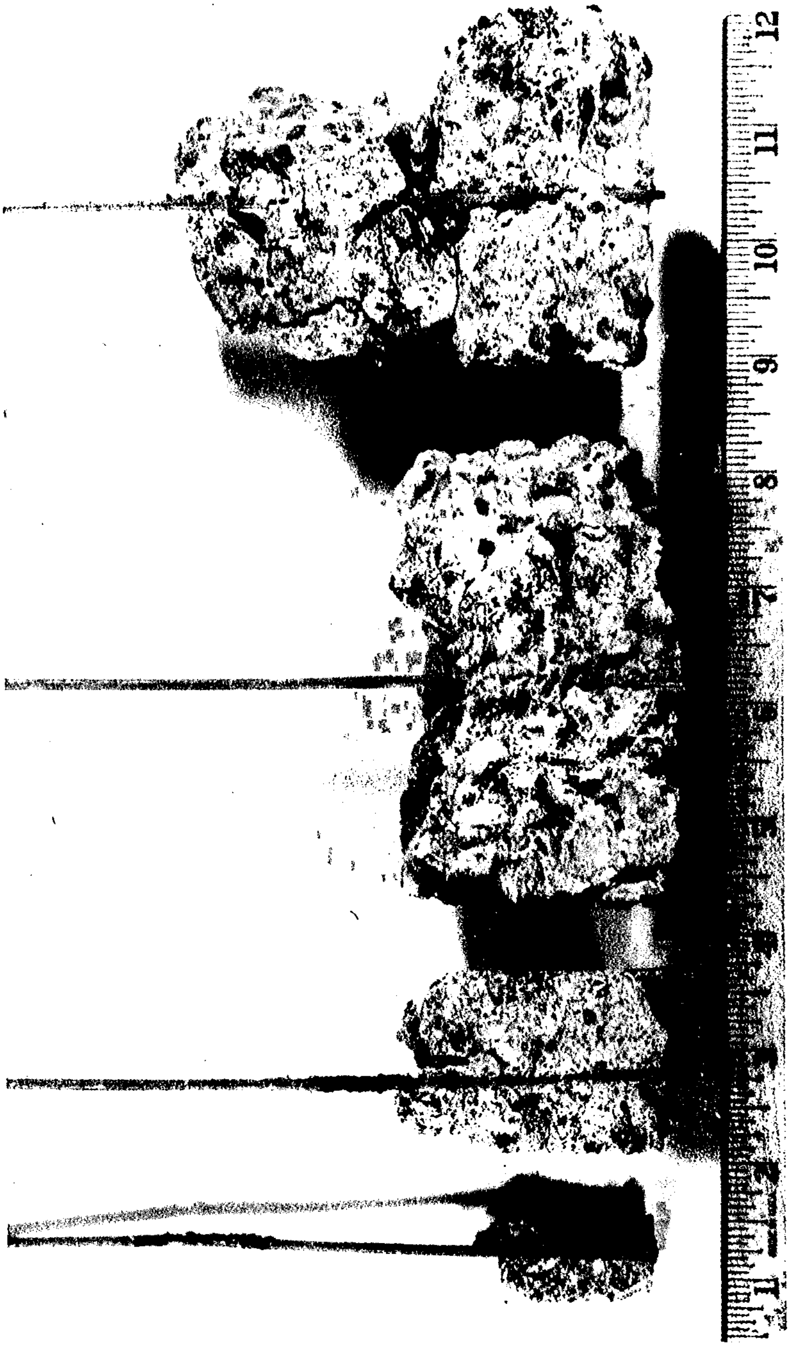

Fig. 8--Typical results of accelerated corrosion tests

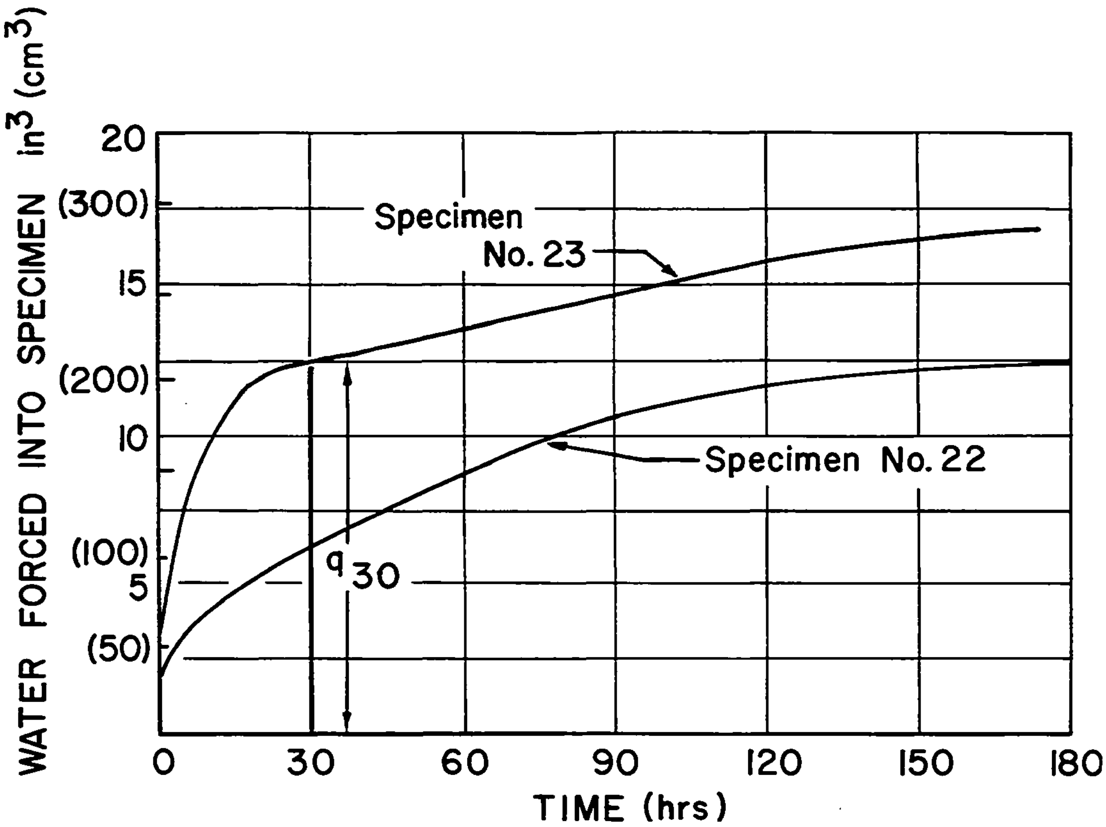

Fig. 7--Typical results of "relative" permeability (absorption) tests

SP 49-6

REINFORCING BAR CORROSION IN CONCRETE: EFFECT OF SPECIAL TREATMENTS

By
Kenneth C. Clear

Synopsis: This paper is a partial summary of data obtained in an FHWA study designed to provide administrators and designers with factual data on which to base decisions as to types of protection for bridge decks constructed in corrosion environments. Reinforced concrete slabs 4 ft x 5 ft x 6 in. (1.22 x 1.52 x 0.152 m) were fabricated using various mixes and special treatments. These slabs being subjected to daily ponding to a 1/16 in. (1.6 mm) depth with a 3 percent sodium chloride solution. Visual examination, weekly electrical half-cell potential surveys, and coring with subsequent chloride analysis of rebar level concrete, are used for performance evaluation.

Interim study findings indicate that a total polymer impregnation with methyl methacrylate, a styrene-butadiene latex-modified concrete overlay and properly-consolidated, low water-cement ratio (0.32) portland cement concrete overlay are effective in preventing substantial chloride migration to a 1-in. (25 mm) depth. An epoxy-modified concrete (amido-amine curing agent) was not effective because of the presence of large, localized channels.

Keywords: cathodic protection; chlorides; coatings; concretes; corrosion; corrosion resistance; deterioration; epoxy resins; methyl methacrylate; mix prportioning; reinforced concrete; reinforcing steels; styrene butadiene resins; water-cement ratio.

ACI member Kenneth C. Clear has been active in the materials research field, with particular emphasis on solutions to concrete bridge deck deterioration problems, since joining the Federal Highway Administration as a highway research engineer in 1971. He has a Master of Science degree in civil engineering from the Pennsylvania State University.

INTRODUCTION

One of the most severe problems facing the highway industry is chloride deicer induced reinforcing steel corrosion and the subsequent deterioration of concrete bridge decks. The Federal Highway Administration, Offices of Research and Development, consider elimination of bridge deck deterioration as one of their highest priority efforts. The problem and the approach to the solution of the problem are defined in Task 4B1 of the Federally Coordinated Program of Transportation Research (FCP) under the title, "Elimination of Spalling and Delamination of Structural Concrete." One work unit within that task is the FHWA staff research study, "Time-to-Corrosion of Reinforcing Steel in Concrete Slabs versus Various Parameters of Design and Construction."

The purpose of this investigation is to provide administrators and designers with factual data on which to base decisions as to the type of protection to provide for bridge decks constructed in corrosive environments. The specific study objective is: to determine the relative time-to-corrosion of reinforcing steel embedded in concrete slabs, fabricated from various mix designs and construction procedures, when the slabs are subjected to periodic wetting with a 3 percent sodium chloride solution. Interim findings, covering research performed on 120- 4 ft. by 5 ft. by 6 in. (1.22 m by 1.52 m by 0.152 m) and four smaller reinforced concrete slabs, formed the basis of a two-volume interim report coauthored by K. C. Clear and R. E. Hay. (1,2)

Data obtained from the test slabs and used to document the effect of special mix designs and treatments are presented in this report. Specifically, the effectiveness of a polymer-impregnated concrete, two polymer modified concretes, and a low water-cement ratio portland cement concrete are discussed. Brief descriptions of slab fabrication and testing procedures are also presented.

FABRICATION AND TESTING

The test slabs in the outdoor exposure yard are shown in figure 1. All slabs are 4 ft. by 5 ft. by 6 in. (1.22 m by 1.52 m by 0.152 m) except for the four polymer-impregnated concrete slabs shown in the lower right.

The 20 sq. ft. (1.86 m^2) slabs were molded in watertight molds having a grid of No. 4 reinforcing bars positioned at the required depth. The concrete was vibrated to 99 ± 1 percent of the rodded unit weight using a direct transmission nuclear density apparatus to control consolidation. The nuclear apparatus was a commercially-available, moisture-density gauge of the type commonly used to monitor soil compaction. Screeding was accomplished using a reproducible manual finishing process. The appropriate curing procedure was applied immediately after loss of surface sheen and remained on the concrete for 7 days.

After removal from the molds, the sides of all slabs were coated with epoxy resin to prevent water loss during testing. A small dike was placed around each slab to permit ponding of the sodium chloride solution. Following 7 days of on ground curing, the slabs were placed and leveled in the outdoor exposure yard. The surfaces were wire-brushed to remove the membrane curing compound before the initial sodium chloride application (applied at 6 weeks of age).

The top surface of each slab is subjected to ponding to a depth of 1/16-inch (1.6 mm) with a 3 percent sodium chloride solution each afternoon. Three evaluation techniques are used to determine the ability of each variable in preventing chloride migration to the level of the reinforcing steel and subsequent rebar corrosion:

(1) The electrical half-cell potential of the reinforcing steel is monitored with time by weekly measurement of the rebar potentials at six predetermined positions on the surface of each slab. Analysis yielded the following meaning of the potentials (referenced to the copper-copper sulfate half-cell, CSE).

(a) Potentials consistently greater than 0.35 volts CSE
High probability of rebar corrosion.

(b) Potentials consistently less than 0.20 volts CSE
High probability of no rebar corrosion.

(c) Potentials in the range of 0.20 to 0.35 volts CSE
Uncertain area with regard to the condition of the reinforcing steel: may be active or passive. Use of another detection technique is indicated.

(2) The chloride content of rebar level concrete is determined at select times by dry coring and analysis following the procedure described by H. A. Berman. (3) Work by Lewis and studies in the FHWA laboratory have shown the chloride content corrosion threshold (i.e., the minimum quantity of chloride required to initiate rebar corrosion in a bridge deck portland cement concrete when sufficient moisture, oxygen and other necessary factors are present) to be approximately 0.20 percent Cl^- per gram of cement. This corresponds to 330 parts per million, ppm, chloride on a concrete basis (i.e., about 1.3 pounds of

chloride ion per cubic yard of concrete) for a concrete with a cement content of 658 lbs/yd^3 (390 kg/m^3) and a unit weight of 145 lbs/ft^3 (2322 kg/m^3). (3,4) All chloride contents presented in this paper are in parts per million, ppm, chloride ion (by weight) in the concrete. For conversion to pounds Cl per cubic yard of concrete, multiply Cl^- in ppm by 0.003915.

(3) Visual and delamination surveys are frequently made to locate cracking, rust stains and hollow planes. Through 1 year of testing (i.e., through November 1972) no cracking or delamination is observable although surface rust stains are present on many slabs.

Brief descriptions of the fabrication parameters associated with the special treatments are presented below.

Polymer-Impregnated Concrete

Impregnation of hardened portland cement concrete with a monomer and subsequent polymerization with radiation or heat has shown promise as a method of preventing deicer intrusion. The reinforced concrete specimens, 27-in. by 32-in. by 6-in. (690 mm by 810 mm by 152 mm) were fabricated in the FHWA laboratory in McLean, Virginia and shipped to Brookhaven National Laboratory, Upton, New York, for total impregnation with methyl methacrylate. Polymer loadings and pertinent impregnation data are given in table 1. These slabs are smaller than the other specimens because, at the time of fabrication, Brookhaven did not have the capability to impregnate 4 ft. by 5 ft. (1.22 m by 1.52 m) specimens.

Portland Cement Concrete Overlay Following Iowa Specifications

This overlay utilizes a very low water-cement ratio (0.32) and a high cement content (823 lbs. per cubic yard, 486 kg/m^3) as a means of reducing concrete permeability. The mix design, given in table 2, results in a very stiff mixture that must be pounded into place. Severe balling occurred when mixed in a rotary drum mixer.

Modification of Concrete

The use of latex and epoxy as additives to portland cement concrete has been recommended. Two such modifications were studied:

Latex-modified concrete--This polymer modified concrete utilizes a latex additive as a possible means of achieving an impermeable concrete. The latex additive is a water-styrene butadiene emulsion, 46 percent solids, and was added at a rate of 198 lbs. per cubic yard (117 kg/m^3) of concrete. The resultant modified portland cement concrete had a total water-cement ratio (water in latex emulsion plus mixing water) of 0.40. This low water-cement ratio concrete was easily placed although finishing problems due to the mixture's tendency to quickly skin-over were evident.

Epoxy-modified concrete--The epoxy-modified portland cement concrete was achieved by mixing a blend of water-dispersible epoxy resin and converter with the conventional components of portland cement concrete. The water-dispersible epoxy binder system is furnished as two components. Part A is a totally reactive, liquid epoxy resin, and Part B is a totally reactive, amido-amine type curing agent. The ratio of epoxy binder to cement was 0.20 (i.e., 142 lbs. epoxy per cubic yard, 84 kg/m^3, of concrete). As recommended by the manufacturer, the reinforcing steel was painted with the epoxy immediately prior to concrete placement. This procedure did not result in a rebar coating since the epoxy was still liquid when the concrete was placed. Its purpose was to provide an epoxy rich concrete layer around the rebars.

These modified concretes were used as 3-inch (76 mm) overlays on 3-inches (76 mm) of fresh portland cement concrete. The reinforcing mats are completely encased by the modified concretes. The modified concrete mix designs are presented in table 2.

EFFECT OF SPECIAL MIX DESIGNS AND TREATMENTS

The effects of the special mix designs and treatments studied are documented in figure 2 and table 3. Chloride migration data for conventional portland cement concretes (mix designs in table 2) of two water-cement ratios, 0.40 and 0.50, are presented for comparison.

Total impregnation of hardened portland cement concrete with methyl methacrylate and subsequent polymerization appears to be one method of preventing chloride migration within the concrete. Negligible chloride was found at all core locations (1-in., 25 mm, depth) within the polymer-impregnated concrete after 267 daily salt applications. By utilizing polymer impregnation, the typical bridge deck concrete (W/C = 0.50) was rendered virtually impermeable (for at least the field equivalency of the 267 salt applications in this test). The maximum chloride content found at a 1-in. (25 mm) depth within the polymer-impregnated, 0.50 water-cement ratio, portland cement concrete was 74 ppm cloride. Additionally, negligible moisture (loss at 110 C) was found at this level within the concrete.

The portland cement concrete overlay, (W/C = 0.32, cement content = 823 lbs/yd^3 = 486 kg/m^3, slump = 0.5-in. = 13 mm and average 28-day compressive strength = 6420 psi = 451 kgf/cm^2), presented mixing and consolidation problems during slab fabrication. Chloride analysis data show that if proper consolidation was obtained during fabrication, the resulting concrete does not permit the penetration of substantial quantities of chloride to a 1-in. (25 mm) depth. The average chloride content at the 1.0-inch (25 mm) depth, after 313 salt applications, was