

NCHRP Research on the Durability of Reinforced Concrete Bridge Components

An NCHRP staff digest of the progress and status of research on durability of reinforced concrete bridge components under the National Cooperative Highway Research Program

It was recently reported that nearly one-third of all highway bridge decks in the United States are seriously deteriorated due to corrosion of reinforcing steel. This corrosion is usually caused by chloride ions that have penetrated the concrete as a result of repeated application of deicing salts. Chlorides alter the normally protective alkaline environment, thus permitting the corrosion reaction to take place. Accumulation of corrosion products around the reinforcing steel causes cracks to develop in the concrete cover. This allows intrusion of additional chloride solution, thereby accelerating corrosion and causing spalling of the deck.

In addition to the problem of deterioration of bridge decks caused by deicing salts, there is growing concern that chloride penetration in a marine environment can affect all bridge components, including piling, piers, girders, and diaphragms, as well as decks. Deterioration is also often caused by faulty bridge deck drainage that permits contamination of structural members by deicing salts.

Numerous studies on the durability of reinforced concrete bridge components have been included in the National Cooperative Highway Research Program (NCHRP). In recent years, concurrently with a growing national awareness of bridge deterioration, a substantial number of research projects on this problem have been referred to NCHRP by the program sponsors, the American Association of State Highway and Transportation Officials (AASHTO). The purpose of this Digest is to outline the status of this research for easy reference. Information is included on all projects either completed or in progress (Table 1). All relevant NCHRP publications are listed, with directions for obtaining copies.

The studies discussed in this Digest represent only part of the research carried out on this subject in the United States in recent years. A more comprehensive listing of current and planned research, including Federal Highway Administration (FHWA) contracts and state Highway Planning and Research (HP&R) studies, can be

found in the documentation for FHWA's Federally Coordinated Program for Research and Development (FCP), which may be obtained from Mr. Kenneth C. Clear, Office of Research, HRS-22, Federal Highway Administration, U. S. Department of Transportation, Washington, DC 20590, 703/557-5211.

I. PUBLISHED REPORTS

The following publications are listed in chronological order. Some of the earlier reports, included for the sake of completeness, no longer constitute full, up-to-date treatments of the respective subjects.

Copies of these publications can be obtained from the Publications Office, Transportation Research Board, 2101 Constitution Avenue, NW, Washington, DC, 20418. A check or money order payable to Transportation Research Board must accompany orders totaling \$7.50 or less.

NCHRP Report 1 - "Evaluation of Methods of Replacement of Deteriorated Concrete in Structures" (Project 6-8), 56 pp., \$1.80, 1964.

This study included a search of available literature and a canvass of agencies known to have experience in repair of structural concrete. The researchers evaluated the economics and adequacy of various methods of repair and recommended areas requiring further study.

NCHRP Report 16 - "Protective Coatings to Prevent Deterioration of Concrete by Deicing Chemicals" (Project 6-3), 21 pp., \$1.60, 1965.

This research was aimed at evaluating materials for application to concrete surfaces to control deterioration caused by deicing agents. Consideration was given to fresh as well as hardened concrete.

NCHRP Report 23 - "Methods for Reducing Corrosion of Reinforcing Steel" (Project 6-4), 22 pp., \$1.40, 1966.

This project consisted of an appraisal of existing methods for inhibiting corrosion of reinforcing steel in concrete. Consideration was given to such methods as (1) coatings on reinforcing bars, (2) inhibitors in concrete mixtures, (3) inhibitors in deicing chemicals, and (4) cathodic protection.

NCHRP Report 165 - "Waterproof Membranes for Protection of Concrete Bridge Decks—Laboratory Phase" (Project 12-11), 70 pp., \$4.80, 1976.

Experience has shown that most waterproofing barriers used to date have not provided the desired degree of protection. This project was undertaken to identify improved waterproofing membrane systems and was carried out in two phases. Some 147 membrane systems were evaluated in Phase I: the findings are presented in this report. Five systems were recommended for in-service evaluation in Phase II. The findings of this field evaluation are presented in the unpublished report on Project 12-11 referenced in Section II of this Digest.

NCHRP Report 180 - Cathodic Protection for Reinforced Concrete Bridge Decks - Laboratory Phase" (Project 12-13), 135 pp., \$7.00, 1977.

The objective of this study was to develop one or more technically and economically feasible cathodic protection systems for reinforced concrete bridge decks. A sacrificial zinc anode galvanic protection

system was developed and recommended for field evaluation. Information on this field evaluation, now in progress (Project 12-13A), may be found in Section III of this Digest.

NCHRP Report 190 - "Use of Polymers in Highway Concrete" (Project 18-2), 77 pp., \$5.60, 1978.

This project demonstrated the feasibility of polymer impregnation to depths sufficient to encase the upper layer of steel reinforcement (about 4 in.) as a possible means of arresting or preventing corrosion in salt-contaminated but structurally sound bridge decks. A field manual describing the techniques that were developed and recommending safety precautions and acceptance criteria is included in the final report.

NCHRP Synthesis of Highway Practice 4 - "Concrete Bridge Deck Durability" (Project 20-5, Topic 3), 28 pp., \$2.20, 1970.

The nature, causes, and solutions of bridge deck deterioration in the form of spalling, sealing, and cracking were collected and evaluated based on information available in the late 1960s.

NCHRP Synthesis of Highway Practice 57 - "Durability of Concrete Bridge Decks" (Project 20-5, Topic 9-01), 61 pp., \$6.00, 1979.

Virtually all protective systems currently in use to prevent corrosion of bridge deck reinforcing steel were developed after publication of Synthesis 4 (1970). In addition, methods of evaluation and rehabilitation have changed significantly since then. This report is, therefore, intended to supplement Synthesis 4.

NCHRP Research Results Digest 85 - "Bridge Deck Repairs" (Project 12-16), 22 pp., \$1.00, 1976.

This digest contains the findings of a survey of preventive and remedial solutions to bridge deck deterioration. This survey, which was carried out as a first step in Project 12-16, included both personal and telephone contacts with numerous individuals and highway agencies, a mailed questionnaire (returned by all 50 states), and a search of available published information. The results indicate a great diversity in bridge deck repair practices. The complete findings from Project 12-16 are included in the unpublished final report discussed in Section II of this Digest.

II. UNPUBLISHED REPORTS

Copies of uncorrected agency reports on the following studies may be obtained on a loan basis by request to the NCHRP Program Director. A limited number of copies are available to NCHRP sponsors for permanent retention, and others may purchase copies from University Microfilms International, 300 North Zeeb Road, Ann Arbor, MI, 48106.

NCHRP Project 12-11 - "Waterproof Membranes for Protection of Concrete Bridge Decks - Phase II Field Evaluation," Sept. 1968.

This is the follow-up phase to the study carried out under NCHRP Project 12-11 and described in NCHRP Report 165. The five waterproofing

membrane systems selected as most promising in Phase I were each installed experimentally on new decks at sites in four states. The report contains an evaluation based on semiannual observations of the installed systems, all of which were judged to have functioned effectively during the monitoring period. In October 1978, one copy of this report was forwarded to the TRB Representative in each state highway or transportation department for circulation to personnel in the areas of bridge design, construction, and maintenance.

NCHRP Project 12-16 - Final Report - Influence of Bridge Deck Repairs on Corrosion of Reinforcing Steel," June 1979.

The objective of this research was to determine the relative effectiveness of various repair methods in arresting corrosion of reinforcing steel, both within and outside the repaired areas. The study also sought to determine whether some of these methods actually aggravate the corrosion problem. An extensive laboratory program was carried out to test and rank the performance of repair methods. A number of material and process variables were included in the laboratory specimens to simulate realistic corrosion phenomena and repair methods. Some 160 slabs (28X28X8 in.) were ponded with a chloride solution and monitored for more than 18 months. The experimental program was both innovative and ambitious, and some of the researchers' conclusions have been disputed by members of the Project Panel. It is recommended that anyone considering use of the results of this study also consider the panel's review comments, a summary of which may be obtained by request to the NCHRP Program Director.

NCHRP Project 12-19 - Interim Report - "Corrosion Control and Repair of Concrete Bridge Structures," Apr. 1979.

This state-of-the-art report is based on a thorough survey of methods, materials, and criteria that have been used to control corrosion in reinforced concrete bridge members other than the top portion of decks. Corrosion-related deterioration of the bottom of bridge decks, girders, piers, and other reinforced concrete structural components was found to be a serious and growing problem in many states. Based on a questionnaire survey of state highway agencies, the annual cost of maintenance related to this problem is estimated at \$15 million. It was found that various methods are being used, and the benefits and disadvantages of each are discussed in this report. In May 1979, one copy was forwarded to each TRB State Representative for circulation to personnel working in related areas.

NCHRP Project 18-2(2) - Final Report - "Polymer Concrete in Highway Bridge Decks," Sept. 1978.

The objective of this study was to synthesize available information on the use of polymers in concrete bridge decks. It did not involve extensive investigations to develop new knowledge but was intended to outline what is already known, what additional information is needed, and what new research needs to be undertaken. The final report represents a comprehensive review of the state of current practice and provides guidance for decisions on future research in this area. The possibility of a continuation to this study is now under consideration by NCHRP Project Panel D18-2. A decision will be made during the second half of 1979.

III. RESEARCH IN PROGRESS

Loan copies of the agency's final reports will be available upon completion of the following studies:

NCHRP Project 12-13A - "Field Evaluation of Galvanic Cathodic Protection for Reinforced Concrete Bridge Decks."

This study, which is being conducted by the Portland Cement Association, is scheduled for completion in January 1981. It includes design, installation, and three years of monitoring of two variations of the sacrificial-anode, cathodic protection system developed in NCHRP Project 12-13 and described in NCHRP Report 180. Nearly two years of monitoring the systems, which have been installed on a bridge deck in Illinois, indicate promising performance.

NCHRP Project 12-19 - "Cathodic Protection of Concrete Bridge Structures."

The objective of this study, which is being conducted by Corrosion Engineering and Research Company of Concord, Calif., is to develop one or more cathodic protection systems to control corrosion of steel in chloride-contaminated structural members (excluding top reinforcement in decks and steel in members below water or soil). Two conductive concrete mixtures and a conductive paint have been developed and appear to show promise for use in cathodic protection systems. Results of the laboratory evaluation phase of this study should be available early in 1981. However, it is expected that field evaluation will be needed before the systems developed in this study can be recommended for widespread use.

NCHRP Project 12-19A - "Concrete Sealers for Protection of Bridge Structures."

The objective of this study is to establish the efficacy of sealers used to protect reinforced concrete bridges exposed to chloride contamination and to provide guidance for their use on bridge members. The research will concentrate on the protection of structural elements other than the top surface of the deck.

Evaluation of sealers will reflect consideration of economic feasibility, including materials and application costs; compatibility with the structure, including repaired areas; pollution problems; esthetics; potential safety hazards; durability; and resistance to various environments, such as freezing and thawing, leaching, and marine conditions. Particular attention will be given to penetrants that are impermeable to liquid but are vapor-permeable, thereby permitting drying of the concrete while preventing chloride intrusion. This 24-month study started on August 1, 1979, and is being conducted by Wiss, Janney, Elstner and Associates of Northbrook, Ill.

Additional details may be found in the NCHRP Summary of Progress Through 1978 or obtained by contacting Robert J. Reilly, NCHRP Projects Engineer, at 202/389-6741.

TABLE 1
NCHRP PROJECTS

Project No.	Title	Research Agency	Status
6-3	Development and Evaluation of Protective Coatings to Prevent Deterioration of Concrete Structures by Deicing Agents	Battelle Memorial Institute	Completed 1965 See Section I
6-4	Evaluation and Development of Methods for Reducing Corrosion of Reinforcing Steel	Battelle Memorial Institute	Completed 1965 See Section I
6-8	Evaluation of Methods of Replacement of Deteriorated Concrete in Structures	Bertram D. Tallamy	Completed 1964 See Section I
12-11	Waterproof Membranes for Protection of Concrete Bridge Decks (Laboratory Phase)	Materials Research and Development	Completed 1973 See Section I
12-11	Waterproof Membranes for Protection of Concrete Bridge Decks (Field Evaluation Phase)	Materials Research and Development	Completed 1978 See Section II
12-13	Cathodic Protection for Reinforced Concrete Bridge Decks	USS Engineers and Consultants	Completed 1974 See Section I
12-13A	Field Evaluation of Galvanic Cathodic Protection for Reinforced Concrete Bridge Decks	Portland Cement Association	In progress See Section III
12-16	Influence of Bridge Deck Repairs on Corrosion of Reinforcing Steel	Battelle Columbus Laboratories	Completed 1979 See Sections I & II
12-19	Cathodic Protection of Concrete Bridge Structures	Corrosion Engineering and Research Co.	In progress See Section III
12-19A	Concrete Sealers for Protection of Bridge Structures	Wiss, Janney, Elstner and Associates	In progress See Section III
18-2	Use of Polymers in Highway Concrete	Lehigh University	Completed 1975 See Section I
18-2(2)	Polymer Concrete in Highway Bridge Decks	Lehigh University	Completed 1979 See Section II
20-5 Topic 3	Concrete Bridge Deck Durability	Transportation Research Board	Completed 1970 See Section I
20-5 Topic 9-01	Durability of Concrete Bridge Decks	Transportation Research Board	Completed 1979 See Section I

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