Deterioration of reinforced concrete structures has become a serious nationwide problem and threatens to become more severe as the use of deicing salts increases. At present, the primary problem is associated with bridge decks, but the future performance of continuously reinforced concrete pavements is also a matter of concern.

Because of the national interest in finding a solution to this problem, a Steel Corrosion Workshop was held in Federal Highway Administration (FHWA) headquarters on February 9 and 10, 1971. Attached is a summary of this workshop for the attention of all FHWA and State highway department personnel who have responsibility for the design, construction, and maintenance of reinforced concrete structures. Those responsible for research of concrete structures should take special notice of part VII of the summary which concerns existing practices requiring evaluation and other needed research.

The summary report describes the causes and effects of bridge deck deterioration. No totally effective method for preventing or correcting spalling of reinforced concrete structures was identified at the workshop, but present practices requiring immediate attention and further performance evaluation were identified. The results of investigations by several States are included in the discussion which focuses on the performance of continuously reinforced concrete pavements. A national cooperative program to evaluate the effectiveness of various bridge deck membranes was initiated as a result of the urgent need expressed at the workshop. We are hopeful that the attached report will stimulate additional interest.
Sufficient copies are attached for distribution to division offices, two each, and State highway offices, four each. Changes in distribution or questions concerning this report may be made by contacting the Construction Methods and Practices Branch, Office of Highway Operations.

M. F. Maloney
Acting Associate Administrator for Engineering and Traffic Operations

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I. Introduction

Concrete spalling and delamination of concrete at the level of the top mat of reinforcing steel is generally recognized as the most serious and troublesome kind of bridge deck deterioration. Corrosion of reinforcing steel has been identified as the primary cause for this type of distress. Spalls impair the riding quality, expose the reinforcement to the elements of the atmosphere, and ultimately could reduce structural capacity. The cost in highway funds to correct the problem is increasing at an alarming rate, and to date, no effective method is known which will correct spalling decks or prevent deterioration of new decks.

Because of the magnitude of the present and the potential bridge deck durability problem, Region 15 initiated a project to demonstrate a nondestructive device which is designed to detect corrosion of steel in concrete. This device was first applied to highway work by the California Division of Highways in an HPR study. It promises to be a valuable tool in evaluating new designs. Virtually all States have requested a demonstration of this device. In 1970, demonstrations were performed on 181 bridge decks in 16 States. An additional 30 States have asked for a demonstration of the corrosion detection equipment in 1971. Anyone desiring information about this equipment or the electrical resistance testing equipment for membranes should contact the Demonstration Projects Division, Region 15, 1000 North Glebe Road, Arlington, Virginia 22201.

As a result of the national corrosion problem, a workshop was organized and conducted on February 9 and 10, 1971, in the headquarters office. The workshop was challenged to consolidate the best design methods and construction techniques known that will effectively control corrosion and offer recommendations for needed research.

The workshop was attended by 81 persons. Invitations were sent to the 16 States which had been visited by the above-mentioned demonstration project. Thirteen of these States sent representatives. Also represented were six concrete or steel industries and personnel from our headquarters, regional, and division offices.
II. General Workshop Conclusions

1. Corrosion of steel in concrete has been identified as the primary cause of bridge deck delamination and subsequent spalling. Spalling is generally recognized as the most troublesome kind of bridge deck deterioration.

2. Steel in concrete is protected from corrosion by the natural alkalinity of the concrete. The pH factor of new concrete is usually between 12 and 13. When sufficient amounts of chlorides are added or absorbed by the concrete, the pH factor will decrease until the concrete can no longer protect the steel. If moisture, oxygen, and chlorides (in sufficient quantities) are present at the level of the steel, corrosion will take place. The increase in volume of the metal undergoing corrosion will exert an outward pressure causing cracking and spalling of concrete.

3. Chemical analysis of concrete from laboratory and field specimen has shown that chlorides in solution can penetrate sound concrete of excellent quality.

4. The corrosion process is accompanied by an electric current flow. The voltage that generates this current flow is due to variations in the amount of chlorides, oxygen, and moisture along the length of reinforcement. Areas of active corrosion (anodes) and passive areas (cathodes) exist, often close to each other. The steel corrosion detection device developed by the California Division of Highways will determine the activity level of the steel at any specific location by measuring the potential difference between this steel and a reference half-cell. When the electrical activity of the steel is known over a sizable area, such as a bridge deck, it is possible to locate the most active areas. This information has been useful in promoting a better understanding of bridge deck deterioration and should reduce the delay time for evaluating new materials and techniques for construction or repair of reinforced concrete structures.

5. Concrete scaling has been reduced in recent years due to use of air-entrained concrete, but air-entrainment apparently does not improve the resistance to spalling.

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6. The quantities of deicing chemicals used for highway maintenance have increased phenomenally in the last 8 years. Best available information indicates a 400 percent increase of salt usage during this period. The results of this increased salt usage can now be seen in the rising rate of bridge deck deterioration. The bridge deck environment is drastically more severe than it ever has been in the past.

7. Corrosion of steel in continuously reinforced concrete pavement (CRCP) has not shown itself to be a serious maintenance problem. Exception to this can be found in those pavements constructed with smooth reinforcing bars. Many of these pavements have experienced failures due to lack of bonding strength, which has resulted in excessive crack openings and subsequent corrosion at these locations. Deformed bars have not shown this type of failure, however, indications are that some corrosion at cracks is also occurring in pavements constructed with deformed bars. This could be a significant factor in future performance and will require close observation.

8. Although the actual cost associated with spalling decks is not known, estimated costs are alarming. Repairs are expensive, disruption of traffic can be serious, and repairs are often ineffective with problems recurring in a short time. In addition, there is no proven positive prevention known that can be incorporated into new construction.

9. The cooperative study report, "Durability of Concrete Bridge Decks," published by the Portland Cement Association in 1970, carefully outlines the types of bridge deck deterioration and makes recommendations for concrete bridge deck construction. The mechanisms which lead to failure of bridge decks are outlined in a recent publication, NCHRP Synthesis 4, "Concrete Bridge Deck Durability." These publications are considered to represent the most comprehensive information that is available on bridge deck deterioration. A bibliography is attached for additional reference material.

III. Construction of New Bridge Decks

1. The present policy of the Federal Highway Administration (IM 40-2-70), especially relating to a 2-inch cover and 7-sack mix, is a sound policy, however, it should be continually reviewed and supplemented as more information becomes available.
Both research and field observations show that increases in concrete cover and improvements in concrete quality are beneficial. Data is lacking, however, to predict actual increases in the service life of reinforced concrete decks due to changes in these features.

2. Some accelerated laboratory tests have been performed on galvanized reinforcement. These tests show that corrosion can occur with galvanized steel in concrete, but do not provide conclusive data on expected service life for structures using galvanized steel. Industry representatives have advised of 20 years successful experience with galvanized reinforcement on the island of Bermuda which has poor quality aggregates and a marine environment. Construction of a number of experimental bridge decks using galvanized steel to determine if there is an increase in maintenance-free time was recommended. Representatives of the International Lead Zinc Research Organization, Inc., and the American Hot-Dip Galvanizers Association will provide technical assistance to any State proposing to use galvanized reinforcement.

3. Cathodic protection is a promising method of preventing corrosion of reinforcing steel, but an economical cathodic design for bridge decks has not been developed. This problem is not insurmountable and research to develop an economical design for both new and existing structures is encouraged.

4. Protective membranes are now being used by some States and are being considered by others as a means to protect new bridge decks from deicing chemicals. Some membranes appear to offer effective protection, however, quality evaluation remains a problem. Electrical resistance testing appears to be the most promising method currently available. Research performed by the California Division of Highways under an HPR study indicates that the porosity of dielectric membranes is proportional to the resistance of the membrane to current flow.

5. Water cured concrete appears to be more resistant to chloride penetration than steam cured concrete. Tests performed by the California Division of Highways, with reinforced concrete specimens, indicate that steam cured specimen cracked from corrosion of the embedded steel prior to the water cured specimens.

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IV. Waterproof Membrane Protective Systems

1. An effective membrane waterproofing system would prevent deterioration on new structures and may halt or retard deterioration on existing structures. A concentrated effort is, therefore, underway to identify or develop an effective economical membrane waterproofing system. The Highway Research Board is currently conducting a comprehensive study of existing membrane systems under NCHRP Project 12-11. The Federal Highway Administration (FHWA) recently requested State highway departments to cooperate in a national experimental evaluation effort to evaluate various types of waterproofing treatments. In addition, many individual State highway departments and manufacturing firms are conducting research in this area. As a result of these efforts, many new developments can be expected in the next few years.

2. There are many factors which enter into the design and construction of a good waterproofing system. Insufficient consideration given to a relatively minor detail may render a membrane useless. Performance may also be related to the type of structures. Some important design and installation details are as follows:

a. Bleeders at weepholes should be provided between the membrane and the bituminous surface.

b. A fine aggregate mix should be used for bituminous concrete overlays. Course aggregate can, and often does, puncture membranes.

c. Sharp projections or ridges on the decks surface may puncture a membrane.

d. Flashing at joints between the membrane and curb should be provided. Similar protection should be provided at parapets and expansion dams.

e. Membranes must be protected from damage by construction equipment.

V. Maintenance of Existing Bridge Decks

1. Several highway departments have recently initiated a practice of restoring spalled bridge decks and then adding a membrane waterproof system over the deck. The effectiveness of these waterproofing systems over concrete which is already contaminated with chlorides is speculative. A concentrated research effort is needed immediately to determine if this work will provide permanent and economical repair.

- more -
2. The Iowa Highway Commission has initiated a procedure which consists of removing all the deck concrete down to and around the reinforcing steel. This assures removal of contaminated concrete from contact with the steel and reduces the chance of recurring "hot" spots. The deck is then repaired with a low slump, 8.75 bag concrete mix. This mix has been designed to minimize shrinkage. The concrete cover is carefully controlled during the construction of this overlay. Some of the overlays have been in service for 5 or 6 years with good results.

3. Many of the patching materials presently used on bridge decks include additives that are designed for rapid strength gain, but many of these additives are highly corrosive to steel. This may be due to the presence of chloride accelerators or other chemicals in the mixes.

4. Concrete used to repair bridge decks does not have the same concentration of chlorides, moisture, oxygen, etc., as the existing concrete. These variations along the length of the reinforcing steel can create a very active corrosion cell. As a result, repairs may accelerate corrosion at other locations, particularly immediately around the patched area. An electrical insulator, such as a nonporous coating of epoxy, applied to the reinforcing steel in the repair area, can help prevent this problem.

5. At least one maintenance engineer feels that benefits greater than cost can be attributed to washing or flushing decks with fresh water after a salt application has served its purpose. This would only be appropriate in areas where ambient temperatures lend themselves to do this type of operation.

6. A cathodic protection system has been designed for the reinforced concrete piling of an existing highway bridge in Florida. The cost of this system appears to be nominal. Similar protection, especially in marine environments, may be economically advantageous.

7. Salt application practices should be carefully reviewed to be sure that salt is prudently used. Present research indicates that a trace of salt, when applied at the proper time, is sufficient to break the bond that exists between the snow and pavement allowing easy and complete removal of the snow. With strong management control, it

- more -
should be possible to significantly reduce application rates by timely application of a carefully metered amount of salt.

VI. Continuously Reinforced Concrete Pavements

1. Corrosion problems in CRCP are not as obvious as those problems now found on bridge decks. While the same principles and mechanisms are applicable, the problem has not manifested itself to date. It is generally believed that the extended service life of CRCP is due to the depth of concrete cover over the reinforcement. Several concrete samples, taken from both pavements and bridge decks, have been analyzed for chloride content. The results indicate that the rate of chloride absorption is approximately equal. It is the opinion of many that when sufficient chlorides penetrate to the depth of steel, corrosion will occur. Unknown, however, is the time required for the chlorides to accumulate in sufficient quantities to cause corrosion.

2. Although there does not appear to be an immediate spalling problem, corrosion of steel at cracks is causing concern about future pavement performance. Cores at cracks from continuously reinforced concrete pavement in Illinois were analyzed. All cores indicated that moisture infiltrates in various amounts. It was interesting to note that the amount of infiltration could not be correlated with crack width and that the infiltration in some cores was occurring from both the top and the bottom of the pavement. It is conceivable that in areas of heavy salt application, field conditions may simulate an exposed steel bar dipped in a brine solution. These conditions are accelerated in locations of high deflections and thereby strengthens the concept of using a high type stabilized base. After observing corrosion of steel at cracks on relatively new pavement, one State discontinued construction of CRCP in areas of high salt application.

3. Many miles of in-place continuously reinforced concrete pavements are relatively new. In 1969, CRCP constituted about 25 percent of all concrete pavements constructed on the Interstate and primary system. It should be noted that new pavements are being exposed to heavy salt applications shortly after construction. Performance of older pavements, not subjected

- more -
to these early salt application, may be a poor indicator of anticipated performance. This trend towards more use of the CRCP, in addition to the increasing use of deicing salts, warrants close observation for signs of deterioration caused by corrosion.

4. The representatives at the workshop indicated some concern about interpreting corrosion detection readings obtained on CRCP. On exposed bridge decks, visual observation of the surface condition will usually confirm the readings. Similar readings indicating active corrosion have been found on CRCP, but surface deterioration was not evident. Further correlation studies are necessary and are recommended for research.

VII. Existing Practices that Require Evaluation and Other Needed Research

1. Research to determine the economic feasibility of cathodic protection of new and existing structures.

2. The use of metallic or nonmetallic coatings on reinforcement steel, such as:
   a. Galvanized steel.
   b. Epoxy coatings.

3. Research to determine the effectiveness of concrete densification in reducing the rate of chloride penetration, such as:
   a. Additives to reduce absorption.
   b. Absorptive form liners.
   c. Vacuum processing of concrete.
   d. Increased cement content.

4. A national evaluation of existing membranes which are now in use.

5. Development of a recommended effective procedure to patch spalling decks by utilizing readings obtained from the corrosion detection device or other equipment.

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6. Research to determine time to failure for known rate of salt application for both continuously reinforced concrete pavements and bridge decks.

7. Research to evaluate the effect of stray currents on existing structures. States should be alerted that the number of pipelines using cathodic protection will increase as a result of the Pipeline Safety Act. Stray currents from this cathodic protection may cause corrosion of steel in reinforced concrete structures and continuously reinforced concrete pavements.

8. A national evaluation of extended service life of bridge decks when membranes are placed after the deck has been exposed to salt.

9. Research to determine the economic feasibility of increased service life resulting from increasing cover.

10. Research to determine how structure life can be extended in a marine environment.

11. Correlation studies of corrosion detection readings on continuously reinforced concrete pavements and bridge decks with the actual condition of the steel.

12. Possible benefits that may be derived from the use of precast slabs to obtain better quality control and allow easier replacement.

13. A program to determine a year's expenditure for bridge deck repair in the United States and an estimated projected annual cost.

14. Research to determine if commercial additives for asphalt mixes are available which will develop a nonporous surface.
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October 26, 1971

R. S. Martin

Concrete Structure Deterioration Due to Corrosion of Reinforcing Steel

On April 15, File 8-3-11, we wrote you to report on a performance study of CRC pavements in Minnesota. On February 9 and 10 of this year the FHWA played host to a steel corrosion workshop in Washington, D.C. PCA was represented at this workshop by Ross Martin of this department and Jerry Monfore from R&D. Attached is a report on this workshop prepared by the FHWA.

While they did not feel that CRCP corrosion was too serious at this time, they did consider corrosion of steel in bridge decks a serious problem and they will be expanding their non-destructive testing program. Ross has summarized this problem as follows:

-- The non-destructive testing program initiated by FHWA Region 15, to detect rather than measure the amount of corrosion, will probably involve each state to some extent.

-- Corrosion is of more concern in bridges than pavement.

-- The ever increasing use of deicing salts may ultimately create problems in CRCP particularly if traffic is heavy and the temperature range to which the slab is subjected is relatively large.

As you know, Ross himself has inspected many CRC pavements and has discussed CRC design with many engineers in highway departments, the FHWA and with steel companies and the CRC pavement group. He feels that while the corrosion problem has not been a source of pavement deterioration to date consideration should be given in design to prevent corrosion in those areas where deicing salts are used. He suggests
using 1.0 percent longitudinal steel in conventional CRCP or the use of CRCP with elastic joints. Ross discussed elastic joint CRCP in his HRB resurfacing paper and listed a reference on this pavement design. He would be glad to provide more details if you find a need for this information.

GORDON K. RAY
Paving and Transportation

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enclosure

Codes 9, 16