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EVALUATION OF BRIDGE DECKS ON ROUTE I-64 AT HAMPTON, VIRGINIA

by

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(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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SUMMARY AND RECOMMENDATIONS

The testing of 15 bridges on Route I-64 just west of the Hampton Roads Bridge Tunnel marked the first major use of electrical potential readings and chloride analyses in evaluating the condition of bridge decks in Virginia. Two of the decks were also sounded with a chain drag to disclose any areas of delaminated concrete.

In general, the electrical potential readings were found to be of disappointing usefulness, probably because of poor connections between the deck reinforcement and the voltmeter. The chloride analyses appeared to yield reasonably reliable but highly variable results, and considerable differences were found in the chloride contents of various spans within some of the structures. The limited use of soundings provided valuable information to supplement the potential readings and chloride content data.

Several recommendations are presented in an effort to overcome the problems encountered in the Route I-64 bridge deck evaluations.

1. The role of corrosion of the reinforcement as a prime cause of spalling of concrete bridge decks is well established. Accordingly, it is recommended that the Department of Highways and Transportation utilize electrical potential readings, chloride analyses, and sounding of the decks in future evaluations of major bridges for deck repair. All three are required for a valid survey.

2. It is recommended that each construction district develop the capabilities of performing electrical potential measurements and obtaining chloride samples for analysis.

3. In obtaining measurements of electrical potentials to evaluate active corrosion, it is recommended that wherever possible a direct connection be made to the deck steel. The use of a direct connection is in keeping with the best current practice and would tend to avoid the generally disappointing results obtained in the subject study.

4. In obtaining samples for chloride analysis and evaluating the results, it is recommended that each span be considered as a unit. Based on limited data from the subject study it appears that 6 samples per span would allow a reasonably precise determination of the average chloride content. Should the chloride levels vary widely, it may be desirable to consider portions of the span, using additional samples to define the area to be repaired.

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INTRODUCTION

In the past it was common practice to sound a deteriorated bridge deck with a hammer to find delaminated areas around visible spalls in the concrete, cut out the areas, and patch them. Additional spalling of the concrete was often noted adjacent to the patches within a short time after the repairs were made. With the realization that spalling is a continuing process, considerable attention was devoted to the development of new, more sophisticated means of deck evaluation.

It is generally acknowledged,now, that a complete deck survey should include thorough sounding of the deck to locate delaminations in the concrete, the measurement of electrical potentials to define areas of active corrosion of the reinforcing steel, and the determination of the chloride content of the concrete to evaluate the likelihood of future corrosion of the steel.[1] Sounding alone will provide an indication of only those spalled areas in need of immediate repair; it will not disclose areas where active corrosion will lead to further delamination. However, the delaminated areas can extend beyond the points of active corrosion indicated by the electrical potential measurements. Chloride analyses provide an indication of whether or not active corrosion can begin, that is, if the chloride content is high enough to overcome the natural passivity of the steel. Active corrosion does not automatically begin when the chloride concentration is sufficiently high, but it can begin in previously passive concrete adjacent to a patch when the point of active corrosion has been repaired.[1] The chloride content is also used to verify the active corrosion indicated by the potential measurements. The procedures used in each of these three means of evaluating bridge decks are described in more detail later in this report.

Bridges Evaluated

The building of a second Hampton Roads Bridge Tunnel beside the existing crossing will require the upgrading of an adjacent portion of Route 64 opened to traffic in 1958 and 1959.

Before committing funds to the widening of several bridges along the route, the Federal Highway Administration directed, as a condition to their participation in the work, that the long-range prognosis of the existing decks be determined through electrical potential measurements and chloride analyses. Accordingly, the Research Council was asked by the Bridge Division to obtain the potential readings and samples for chloride analyses. The analyses were performed by the Council and, later, by the Materials Division in Richmond.

Fifteen bridges, described in Table 1, were evaluated. The other bridges in the affected portion of Route 64 were immediately scheduled for replacement because of inadequate structural capacity or geometric factors which did not allow widening without redecking.

Table 1

Bridges Evaluated on Route I-64 at Hampton

Bridge Contract Number*	Name	Date Opened to Traffic	Nominal Deck Area	Number of Spans
1) B603	EBL Rte I-64 over Mercury Boulevard	June 1959	46 x 180 ft.	4
2) B604	WBL Rte I-64 over Mercury Boulevard	June 1959	46 x 180 ft.	4
3) B606	WBL Rte I-64 over New Market Creek	June 1959	37 x 50 ft.	1
4) B613	EBL Rte. I-64 over LaSalle Avenue	June 1959	37 x 140 ft.	3
5)	WBL Rte I-64 over LaSalle Avenue	June 1959	37 x 140 ft.	3
6) B614	EBL Rte I-64 over Armistead Avenue	March 1958	46 x 230 ft.	4
7)	WBL Rte I-64 over Armistead Avenue	March 1958	37 x 230 ft.	4
8) B615	EBL Rte I-64 over Rip Rap Road	March 1958	37 x 140 ft.	3
9)	WBL Rte I-64 over Rip Rap Road	March 1958	37 x 140 ft.	3
10) B616	EBL Rte I-64 over King Street	March 1958	37 x 170 ft.	3
11)	WBL Rte I-64 over King Street	March 1958	37 x 170 ft.	3
12) B617	EBL Rte I-64 over Hampton River and E. Pembroke Avenue	March 1958	26 x 1440 ft.	17
13)	WBL Rte I-64 over Hampton River and E. Pembroke Avenue	March 1958	26 x 1440 ft.	18
14) B618	EBL Rte I-64 over East Branch and C & O Railroad	March 1958	26 x 720 ft.	7
15)	WBL Rte I-64 over East Branch and C & O Railroad	March 1958	26 x 720 ft.	7

*Numbers shown are those used on the project plans rather than those assigned within the highway system. As shown in the table, a single "B" number often indicated twin bridges.

PURPOSE AND SCOPE

The effort described in this report was not a complete research study. Instead, the primary objective was the evaluation of the potential durability of the decks of the Route 64 bridges. It was also desired to acquaint operating personnel with the use of two evaluation techniques — electrical potential measurements and chloride analyses — with which the Council had some experience, and to determine how the techniques would be applied in a practical situation.

Little was done beyond the work requested by the operating divisions. Only two of the structures, those carrying the eastbound and westbound lanes of Route 64 over Mercury Boulevard, were sounded to check for existing delaminations in the deck concrete. High traffic volumes discouraged the undertaking of purely research activities.

EVALUATION PROCEDURES USED

Electrical Potential Measurements

A detailed description of the equipment required to obtain electrical half cell potentials is available in the literature.[2,3] In the subject evaluation the electrical potentials were obtained through the use of a copper-copper sulfate half cell connected to a high input impedance voltmeter which was, in turn, connected to a part of the structure (called a ground) having electrical continuity to the deck reinforcing steel. The ground generally used on the Route 64 bridges was a handrail anchor bolt or, where available, an armored joint plate. Neither of these are of certain satisfaction as a ground, and errors were apparent in some of the final data. The reliability of the ground is difficult to assess, and it does influence the level of the potential readings.[4] The copper-copper sulfate half cell was placed at points on a 5 ft. x 5 ft. grid on the deck surface. This is a wider grid than the 4 ft. x 4 ft. spacing recommended by the California Department of Transportation and others, but its use was believed necessary to expedite completion of the work.[5,6] In interpreting the results, potentials in excess of 0.35 volt to the copper-copper sulfate electrode were considered to give a strong indication of active corrosion; those below 0-20 volts to indicate no active corrosion; and those in the mid-range to be indeterminate.[1,4,7,8] The electrical potential to the copper-copper sulfate half cell is negative, but, for convenience, the negative sign has been omitted.

Chloride Analyses

The samples for chloride analysis were obtained in accordance with a technique suggested by Clear,[1] and the determination of the chloride content followed a procedure developed by Berman.[9] These references contain fully detailed descriptions of both the procedures and the equipment required. In general, a powdered concrete sample was obtained through the use of a rotary hammer with a 2-in. diameter core bit, and leader bit. A pachometer was used at several points on each span to determine the average depth of the top steel and at each sampling point to locate the steel. Then, as shown in Figure 1, a 2-in. diameter hole was drilled between the reinforcing bars to a level 1/4 in. above the measured steel depth and the material in Volume A was vacuumed out and discarded. The sample retained for determination of the chloride content at the steel level, Volume B in Figure 1, was taken from a level 1/4 in. above the steel depth to a point 1/4 in. below it, and occasionally a sample from Volume A was also retained for comparative analysis.

The numbers of samples obtained from the bridges varied widely. Clear ties the number of chloride analysis samples to the result of the potential survey by grouping the decks into three categories as discussed below.[1]

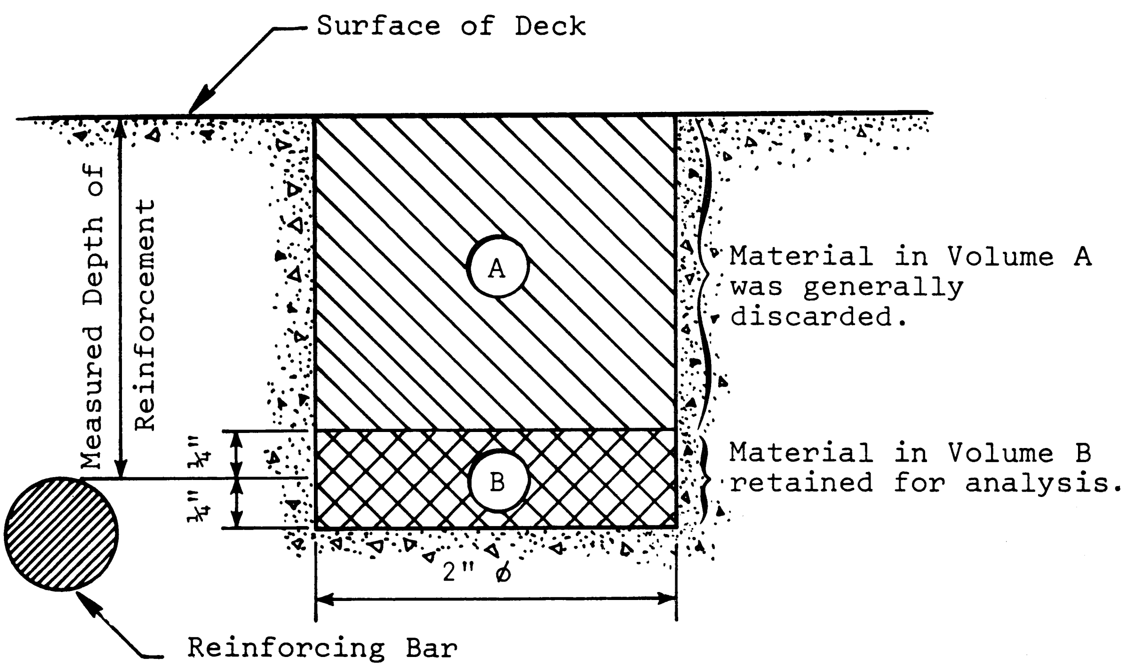

Figure 1. Location of concrete sample used in determination of chloride content at level of reinforcing steel.

Category 1

If 40% or more of the potentials indicate active corrosion, it is suggested that 5 to 10 chloride samples be taken from areas of sound concrete with potentials less than 0.35 volt.

Category 2

If 5% to 40% of the potentials indicate active corrosion, it is suggested that chloride samples be obtained on a 5-ft. grid pattern in those areas of structurally sound concrete with potentials less than 0.35 volt to define the concrete which must be removed.

Category 3

If less than 5% of the potentials indicate active corrosion, it is suggested that about 10 samples be taken from areas of sound concrete, several of which had potentials higher than 0.35 volt.

While the general philosophy of the chloride sampling followed these guidelines, it was initially determined that the large number of samples required by category 2 would not be obtained. The numbers of samples per bridge varied from 3 to 40 with the size of the structure.

In interpreting the meaning of the chloride contents, the corrosion threshold (the amount of chloride required to support active corrosion) was taken to be 1.00 lb./cu.yd., although slightly higher numbers have appeared in the literature.[1]

Sounding of Decks

Since sounding of the decks to determine the presence of deteriorated concrete was not originally requested, it was performed on only the two bridges crossing Mercury Boulevard. It is acknowledged, however, that sounding of the decks should be a part of the evaluations of the remaining structures. The two Mercury Boulevard bridges were sounded, using a chain drag, in less than one day.

RESULTS

The great volume of data obtained during this study was communicated directly to the Bridge Division to serve as a basis for the operational decision regarding the Route 64 bridges. Summaries of the results of the electrical potential tests and chloride analyses for each of the 15 bridges evaluated are appended to this report, and the complete data are available from the Research Council.

Depth of Reinforcement

Although the measurement of the thickness of the concrete over the reinforcing steel was peripheral to the main purpose of the Route 6 deck evaluations, the data were interesting enough to warrant presentation in Table 2. The average measured depth of cover was slightly less than the specified 1½ in. of clear cover for 8 of the 15 bridges, and slightly greater for 7. The average measured depth for all 15 bridges was 1.57 in., based on 969 measurements, and the average standard deviation was 0.27 in. A study by Newlon,[3] based on bridges of more recent construction, found that the actual cover was greater than the specified amount by 5/8 in. when 1.69 in. of cover was called for and 1/2 in. when 1.94 in. was specified. Newlon's conclusion that contractors are now allowing for the variability inherent in steel placement in order to attain proper cover seems to be verified. This advantage undoubtedly stems from the greater emphasis presently placed on deck construction.

Table 2

Pachometer Readings of Steel Depths

Bridge	Number of Measurements	Avg. Measured Depth of Cover (inches)	Standard Deviation
EBL Rte I-64 over Mercury Boulevard	10	1.45	0.23
WBL Rte I-64 over Mercury Boulevard	52	1.42	0.21
WBL Rte I-64 over New Market Creek	28	1.49	0.18
EBL Rte I-64 over LaSalle Avenue	67	1.74	0.32
WBL Rte I-64 over LaSalle Avenue	75	1.72	0.34
EBL Rte I-64 over Armistead Avenue	90	1.71	0.34
WBL Rte I-64 over Armistead Avenue	113	1.56	0.37
EBL Rte I-64 over Rip Rap Road	68	1.33	0.15
WBL Rte I-64 over Rip Rap Road	22	1.43	0.22
EBL Rte I-64 over King Street	79	1.38	0.20
WBL Rte I-64 over King Street	19	1.70	0.26
EBL Rte I-64 over Hampton River and E. Pembroke Avenue	76	1.34	0.20
WBL Rte I-64 over Hampton River and E. Pembroke Avenue	121	1.41	0.22
EBL Rte I-64 over East Branch and C & O Railroad	54	1.87	0.24
WBL Rte I-64 over East Branch and C & O Railroad	95	1.85	0.31

Note: Depth of cover was specified to be 1½ inches to top of bar for all structures.

Electrical Potential Measurements

In general, the half cell potential measurements obtained on the Route 64 bridges were of disappointing usefulness. While in some instances, such as span 1 of the westbound bridge over Mercury Boulevard, high electrical potential readings were supported by chloride contents above the corrosion threshold, more often they were not. Thus, in cases like the westbound bridges over LaSalle Avenue and Armistead Avenue, and in a portion of span 3 of the eastbound bridge, the potential measurements were misleading in that they indicated active corrosion at points with low chloride contents. There are reasons why the potential readings might have been erroneous. They can be significantly influenced by the location of the ground,[4,8] and it is also possible to obtain high readings over a short duration, as in a single test of a deck, when there is no active corrosion.[4] The only readily available ground on the bridges, in most instances, was the anchor bolts of the metal handrail, which may not have provided proper electrical continuity to the deck reinforcement. Certainly the reliability of the connection is suspect in the case of span 3 of the eastbound bridge over Rip Rap Road, where low readings were found in the right shoulder and driving lane and high readings in the passing lane and left shoulder. It is likely that exposure of a portion of the deck reinforcement may be required to provide a reliable circuit for the half cell potential evaluations.

A complete correlation between the potential measurements and the chloride contents was not to be expected. As mentioned previously, the presence of sufficient chloride in the concrete does not automatically initiate the corrosion process. Furthermore, since the electrical potential indicates the presence of active corrosion rather than the rate or amount of corrosion, no correlation with the chloride contents can be expected beyond the corrosion threshold value.

In the majority of the decks evaluated low electrical potential measurements were supported by chloride contents well below the corrosion threshold level, and the potential tests can be considered valid. The occasional high potential readings found near the joints in the decks may be due to localized active corrosion, a result of leakage of the joint seals. It was not possible to obtain chloride samples at the joints because of the presence of reinforcement at the ends of the slabs, but the soundings of the two Mercury Boulevard bridges disclosed instances of delamination at the joints.

It is the consensus of the literature cited previously that the half cell electrical potential test can be a valuable tool in the evaluation of bridge decks. However, the test must be properly performed and interpreted. Citing the problems inherent in the procedure, Clear and Hay warn against the use of a single set of potential measurements as a sole evaluation technique and the strict adherence to a 0.35 volt corrosion versus no corrosion rule.[8] The potential test should be used in conjunction with chloride analyses and sounding of the deck if a true evaluation of a deck is to be obtained. A proper ground connection, difficult to determine in the field, must be used, and it appears advisable to verify high potentials with a second set of measurements. The ASTM's Committee C09.03.15 is developing a "Standard Method of Test for Determining Half Cell Potentials of Reinforcing Steel in Concrete,"[6] which, when adopted, should provide a useful guide for field personnel. It requires connection to the deck reinforcement or verification that the ground is valid.

Chloride Analyses

The chloride analysis, performed in accordance with Berman's procedure,[9] was very useful in the evaluation of the decks. The test appears to be reasonably reliable; the results of the analyses of two samples taken from different depths at a single point on the deck showed, with few exceptions, a decrease in chloride content with depth, as reported by Spellman and Stratfull.[7] Chloride contents were regarded as a means of verifying the electrical potential readings.

Considerable variation was seen between the chloride contents obtained from different points on the decks of the Route 64 bridges. Other agencies have also found the distribution of chloride in concrete to be highly variable; coefficients of variation of 30% to 36% have been reported, and it has been recommended that no less than 6 samples be obtained for a valid survey.[5,7] Except for the single span New Market Creek Bridge, this requirement was met in the subject study in that more than 6 samples per bridge were obtained. However, based on the standard deviations for samples from the individual bridges shown in Table 3, the coefficients of variation (the standard deviation divided by the mean) usually far exceed 36%. One reason for this great variability is that large differences were apparent in the chloride contents of various spans within a single bridge, which are described in the written summaries appended to this report. A second reason, of course, is the variation within a single span. Testing error is apparently quite small.

Unfortunately, a sufficiently large number of samples to allow an evaluation of the variability within an individual span was seldom taken. The variability within the 4 spans of the eastbound bridge over Mercury Boulevard is shown in Table 4.

Table 3

Summary of Chloride Contents

Bridge	Number of Samples	Range (lb./cu.yd.)	Mean (lb./cu.yd.)	Standard Deviation
EBL Rte I-64 over Mercury Boulevard	28	0.235-1.527	0.660	0.339
WBL Rte I-64 over Mercury Boulevard	14	0.157-2.153	0.906	0.721
WBL Rte I-64 over New Market Creek	3	0.160-0.530	0.294	0.205
EBL Rte I-64 over LaSalle Avenue	7	0.420-0.504	0.450	0.040
WBL Rte I-64 over LaSalle Avenue	14	0.118-0.756	0.335	0.192
EBL Rte I-64 over Armistead Avenue	15	0.042-0.630	0.445	0.133
WBL Rte I-64 over Armistead Avenue	21	0.059-0.735	0.262	0.155
EBL Rte I-64 over Rip Rap Road	14	0.155-1.373	0.437	0.409
WBL Rte I-64 over Rip Rap Road	7	0.256-1.575	0.665	0.429
EBL Rte I-64 over King Street	10	0.227-1.642	0.671	0.537
WBL Rte I-64 over King Street	10	0.113-2.839	0.875	0.997
EBL Rte I-64 over Hampton River and E. Pembroke Avenue	39	0.088-1.163	0.373	0.257
WBL Rte I-64 over Hampton River and E. Pembroke Avenue	40	0.008-1.487	0.353	0.311
EBL Rte I-64 over East Branch and C & O Railroad	13	0.105-0.723	0.362	0.221
WBL Rte I-64 over East Branch and C & O Railroad	14	0.084-1.474	0.377	0.419

Table 4

Chloride Contents of Deck Concrete in the Four Spans of the Eastbound Bridge Over Mercury Boulevard

Span	Number of Samples	Range (lb./cu.yd.)	Mean (lb./cu.yd.)	Standard Deviation
1	10	0.235-1.096	0.606	0.286
2	6	0.352-0.822	0.548	0.184
3	6	0.313-0.666	0.489	0.138
4	6	0.548-1.527	1.031	0.444
All	28	0.235-1.527	0.660	0.339

It is evident that the coefficients of variation remain high even when individual spans are considered, but the variance is reduced somewhat. These findings suggest that the individual span be the largest unit for which samples are averaged in an evaluation, as opposed to using the average data for an entire deck. It seems logical to assume that any major repair requirements based on the evaluations would be considered on a span by span basis.

Based on the average standard deviations for individual spans on those bridges from which 4 or more samples per span were taken, it appears that the average of 6 samples would allow a determination of the chloride content to a tolerance of ± 0.25 lb. at the 95% confidence level. This value can only be regarded as an estimate, and it would not be true in those cases where the range of the data was large. In such instances, computation of the standard deviation may be advisable to evaluate the accuracy of the mean. The wide variation in the chloride contents within a span also suggests that the locations from which the samples are taken should be logged in case it becomes necessary to consider the replacement of only a portion of a span.

The chloride contents of the concrete also may have been influenced to an undetermined degree by the chloride contents of the aggregate. There are results from another study at the Research Council that indicate Virginia aggregates can have relatively high chloride contents, which influence the interpretation of the results of Berman's analysis, although these chlorides would contribute little to the corrosion of the steel.* The effect of

*Personal correspondence, John Reynolds to S. S. Tyson, June 17,1975.

chlorides in the aggregate on the results of the test should be considered in those evaluations where the chloride content is at a critical level.

Obtaining the samples through drilling of the concrete is considered an acceptable technique, and it proved expeditious.[1,5] The use of a pachometer to determine the depth at which the sample must be taken and to locate the top reinforcing steel is essential. Contact with the steel will rapidly destroy the expensive core bit used to obtain the samples. The hard river gravel used in the deck concrete of the bridges also wore the bits more than was expected.

Sounding of the Decks

Sounding of the decks was not requested in the case of the Route 64 bridges, because the long-term durability of the concrete was a primary question. Nevertheless, sounding is a valid part of the evaluation process. Sounding of the two Mercury Boulevard bridges disclosed a minor amount, 25 sq. ft., of delaminated concrete, which must be repaired. Some delaminations were discovered in spans where the average chloride content was below the threshold level. It would, therefore, seem advisable to sound the decks of those other structures which will be widened as part of the Route 64 upgrading. The results of the soundings, in conjunction with the electrical potential and chloride analysis results, would present a complete picture of any immediate repair requirements and an assessment of the prospects for long-term durability.

EQUIPMENT AND MANPOWER REQUIREMENTS

Adoption of the electrical potential and chloride analysis procedures as deck evaluation tools would involve equipment purchases by the Department of Highways and Transportation. Among the major items required would be the voltmeter and half cell and the rotary hammer with bits, which would be needed in each construction district. Suitable generators to power the rotary hammer are generally available and the chain drag sounding device is easily fabricated.

A two-man crew can easily perform any of the evaluation techniques with acceptable speed. Since judgment is required in the proper application of the procedures, it would be desirable to assign these tasks to members of the district bridge crew. The most time-consuming part of the Route 64 evaluations lay in the establishment of proper traffic control.

DISPOSITION OF THE ROUTE 64 BRIDGES

The operational decision as to the handling of the Route 46 bridges was made by members of the Bridge Division and representatives of the FHWA. Factors such as the handling of traffic during repairs or widening were considered along with the results of the deck evaluations.

In view of the low chloride contents determined over most of the spans, it was determined to widen the bridges without redecking. The addition of a third lane to the bridges will also greatly facilitate the handling of traffic during any future repairs.

While the chloride contents indicate that future repairs can be expected on three spans (span 4 eastbound and span 1 westbound over Mercury Boulevard, and span 2 westbound over King Street) and, possibly, others, only the King Street span had an average content of over 2 lb./cu.yd., a figure beyond which field engineers often favor the removal of the concrete over the reinforcing steel. Thus the decision to proceed with widening appears to present the best course of action.

CONCLUSIONS

Several conclusions can be drawn regarding the implementation of the use of half cell electrical potential measurements and chloride analyses as operational tools for bridge deck evaluations on the basis of the Route 64 project.

1. A complete bridge deck evaluation should include sounding, electrical potential readings, and chloride analyses. The sounding of those structures to be widened as part of the Route 64 upgrading is advisable.

2. The electrical potential procedure can yield misleading results unless it is performed properly, but it is difficult to assess the suitability of the connection to the reinforcing steel unless a portion of the deck steel is exposed. Experience gained with the Route 64 bridges verifies the recommendation of other agencies that the electrical potential measurements are not suitable as the sole means of deck evaluation.

3. The chloride analysis of the deck concrete appears to be reliable, relatively easily performed, and useful in bridge deck evaluations.

4. The chloride content of the deck concrete can vary widely within a structure and between the spans of a given bridge. A single span should be considered as the unit to be evaluated, and it appears that 6 samples per span should provide a reasonable estimate of the chloride content of the deck concrete.

5. Little or no correlation between the magnitude of the electrical potential readings and the chloride content at a point on the deck is likely to be apparent.

ACKNOWLEDGMENTS

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REFERENCES

1. Clear, K. C., "Evaluation of Portland Cement Concrete for Permanent Bridge Deck Repair," Report No. FHWA-RD-74-5, U. S. Department of Transportation, Federal Highway Administration, Offices of Research and Development, Washington, D. C., February 1974.

2. Federal Highway Administration, Region 15, "Demonstration of a Steel Corrosion Detection Device in Virginia," U. S. DOT, September 1971.

3. Newlon, H. H., Jr., "A Survey to Determine the Impact of Changes in Specifications and Construction Practices on the Performance of Concrete in Bridge Decks," Report No. VHRC 73-R59, Virginia Highway and Transportation Research Council, Charlottesville, Virginia, June 1974.

4. Stratfull, R. F., "Half Cell Potentials and the Corrosion of Steel in Concrete," Report No. CA-HY-MR-5116-7-72-42, California Department of Transportation, 1973.

5. Stratfull, R. F., W. J. Jorkovich, and D. L. Spellman, "Corrosion Testing of Bridge Decks," Report No. CA-DOT-TL-5116-12-75-03, California Department of Transportation, 1975.

6. Committee C09.03.15, "Standard Method for Determining Half Cell Potentials of Reinforcing Steel in Concrete," Draft, under Committee review, American Society for Testing and Materials.

7. Spellman, D. L., and R. F. Stratfull, Chlorides and Bridge Deck Deterioration," Report No. M & R 635116-4, California Department of Transportation, 1969.

8. Clear, K. C., and R. E. Hay, "Time-to-Corrosion of Reinforcing Steel in Concrete Slabs, Vol. 1. Effect of Mix Design and Construction Parameters," Report No. FHWA-RD-73-32, Federal Highway Administration, Offices of Research and Development, Washington, D. C., 1973.

9. Berman, H. A., "Determination of Chloride in Hardened Portland Cement Paste, Mortar, and Concrete," Report No. FHWA-RD-72-12, Federal Highway Administration, Offices of Research and Development, Washington, D. C., 1972.

APPENDIX

SUMMARY OF RESULTS — HALF CELL ELECTRICAL POTENTIALS AND CHLORIDE ANALYSES

RTE. 64 BRIDGES AT HAMPTON

B603-EBL Rte 64 over Mercury Boulevard

Span 1 — Potential readings gave no indication of active corrosion except at areas adjacent to the transverse expansion joint and at 3 grid points in the span. Readings at the joints ranged from 0.40 - 0.64 volt CSE; those in the span from 0.37 - 0.40 volt CSE. The results of 10 chloride analyses were generally low; the chloride contents ranged from 0.235 lb./cu.yd. to a high of 1.096 lb./cu.yd., the only value above the assumed corrosion threshold. The average chloride content was 0.606 lb./cu.yd. Concrete samples taken as near as possible to the joints did not indicate a high chloride content, but it was not possible to obtain samples close to the joint because of the presence of reinforcing steel. Subsequent sounding of the span showed one delaminated area near midspan at the curb in the general vicinity of the high chloride sample.

Span 2 — Electrical potential readings were low except for 4 points near a joint where potentials ranging from 0.37-0.44 volt CSE were obtained. These higher readings could not be verified by chloride analyses, and sounding disclosed no delamination. Six chloride analyses showed contents from 0.352-0.822 lb./cu.yd., with an average of 0.548 lb./cu.yd.

Span 3 — High electrical potential readings were found near both expansion joints, but readings in the interior of the span generally ranged from 0.15-0.25 volt CSE. Chloride contents from 6 samples taken at the level of the top steel were all below 1 lb./cu.yd., averaging 0.489 lb./cu.yd. One value of 1.096 lb./cu.yd. was obtained from a sample of concrete above the top steel. The average chloride content from 6 samples of the concrete above the steel was 0.815 lb./cu.yd. No delaminated concrete was found.

Span 4 — Electrical potential readings indicated 3 points of active corrosion, 2 at the joints and 1 in the span. Of 6 samples taken for chloride analyses, 3 had chloride contents above the corrosion threshold (1.175, 1.527 and 1.527 lb./cu.yd.). The first 2 of these samples were taken near the joint; the third was from the interior of the span, but at a point where active corrosion was not indicated. The average of 6 chloride contents was 1.0310 lb./cu.yd., a higher level than those found in the other spans, but no delamination of the concrete was apparent.

B604 - WBL Rte 64 over Mercury Boulevard

Span 1 — Electrical potential readings indicated a strong possibility of active corrosion over approximately 50% of the deck surface. This was supported by the results of 4 chloride analyses which disclosed contents ranging from 1.605 to 2.153 lb./cu.yd., with an average of 1.850 lb./cu.yd. Sounding with a chain drag indicated the presence of 2 delaminated areas, the first 2 ft. by 3 ft. in area in the interior of the span and the second 3 ft. by 3 ft. in area at the joint. All indications were that the concrete should be removed from span 1 to a level below the top reinforcement and replaced.

Span 2 — Electrical potential readings showed points indicative of active corrosion at the joints and in a portion of the right-hand lane in the interior of the span. A delaminated area 2 ft. by 2 ft. in area was found in the left-hand lane in a region where electrical potential readings generally had been in the 0.20-0.30 volt CSE range. Chloride contents from 4 samples ranged from 0.157 to 0.940 lb./cu.yd., with an average of 0.529 lb./cu.yd.

Span 3 — Only a few potential readings above 0.20 volt CSE and only 2 points indicative of active corrosion, near the joint, were found. The chloride content from 1 sample at the level of the top steel was 1.566 lb./cu.yd., which was higher than the content of a sample from the concrete over the steel. Similar discrepancies in the chloride content pattern from that which is logical had been noted in research studies of earlier bridges, but the cause cannot be explained. As a result, the average chloride content at the steel level, based on 3 samples, was higher, 0.743 lb./cu.yd., than the average from the layer of concrete nearer the surface, 0.423 lb./cu.yd. No delaminations were found in the deck.

Span 4 — Electrical potential readings indicated the presence of active corrosion in the right corner of the driving lane and across the joint at the opposite end of the span. Other readings did not indicate active corrosion. Chloride analyses from the corner of the span did not reveal contents above the corrosion threshold; the average of 3 samples taken at the level of the steel throughout the span was 0.313 lb./cu.yd. As would be expected higher chloride contents were found in the concrete above the steel; the average of 3 analyses was 0.770 lb./cu.yd. Although the chloride contents were below the threshold level, 1 delaminated area 2 ft. by 3 ft. in size was found in the traffic lane, but not in the vicinity of high potential readings.

B606 - WBL Rte 64 over Newmarket Creek

Electrical potential readings taken at 5 ft. grid points on this single span bridge indicated no problems with active corrosion of the reinforcing steel, as no values of 0.20 volt CSE or higher were obtained. Only 3 chloride analysis samples were obtained, and the average chloride content at the level of the steel was determined to be 0.294 lb./cu.yd.

B613 - EBL Rte 64 over LaSalle Avenue

Span 1 — Electrical potential readings did not include the presence of active corrosion in this span, although there were 3 readings in the doubtful range, between .20 and .35, near one joint. The average of 3 chloride analyses was 0.434 lb./cu.yd.

Span 2 — As in span 1, relatively high readings, including one value of .36, were taken near the joints. The other readings did not indicate any active corrosion. Two chloride analyses, which indicated an average chloride content of 0.462 lb./cu.yd., were performed.

Span 3 — High electrical potential readings, some between .20 and .30, were again found at the joints, but, overall, no active corrosion was indicated. The average of 2 chloride analyses at the level of the top steel was 0.462 lb./cu.yd. Two samples taken from the level above the steel had a slightly lower average chloride content of 0.441 lb./cu.yd. However, the validity of the comparison is weakened by the small number of samples.

B613 - WBL Rte 64 over LaSalle Avenue

Electrical potential readings taken on all 3 spans strongly indicated the presence of active corrosion at all grid points. These were not verified by the chloride analyses shown below.

Span 1, 4 samples, 0.399 lb./cu.yd.

Span 2, 6 samples, 0.334 lb./cu.yd.

Span 3, 4 samples, 0.273 lb./cu.yd.

All Spans, 14 samples, 0.335 lb./cu.yd.

It is considered likely that the electrical potential readings, which were uniformly much higher than those obtained on any of the other Rte 64 bridges, were in error. The readings ranged from a low of .38 volt to a high of .90 volt, with many values in the .50-.70 range. It is difficult, however, to assign a cause to the high values.

B614 - EBL Rte 64 over Armistead Avenue

Span 1 — Electrical potential readings were low, giving no indication of active corrosion. This was verified by chloride contents below the corrosion threshold level. The average of 3 chloride samples at the level of the top steel was 0.350 lb./cu.yd. The average of 3 chloride analyses of samples from the concrete above the steel was 0.686 lb./cu.yd.

Span 2 — No evidence of active corrosion was given by the electrical potential readings, and this was verified by chloride analyses. The average of 4 chloride contents at the steel level was 0.493 lb./cu.yd.

Span 3 — As in spans 1 and 2 there was no evidence of active corrosion based on the potential readings. Chloride contents were low; the average content of 4 samples was 0.441 lb./cu.yd.

Span 4 — Electrical potential readings were low except for some high values at the joints, and chloride contents were low. The average of 4 samples was 0.441 lb./cu.yd.

B614 - WBL Rte 64 over Armistead Avenue

Spans 1 and 2 — Electrical potential readings indicated the presence of active corrosion over virtually all of spans 1 and 2. However, the chloride contents obtained from 5 samples in each span averaged only 0.255 lb./cu.yd. in span 1 and 0.230 lb./cu.yd. in span 2.

Spans 3 and 4 — Electrical potential readings taken in spans 3 and 4 were slightly lower than those taken in spans 1 and 2, but the presence of widespread active corrosion was still strongly suggested. Twenty-five percent of the points in span 3 and 38% of the points in span 4 were in the range indicating active corrosion, and most of the remainder were between .20 and .35. However, the average of 5 chloride contents from span 3 and 6 from span 4 were only 0.221 lb./cu.yd., and 0.328 lb./cu.yd., respectively.

B615 - EBL Rte 64 over Rip Rap Road

Spans 1 and 2 — Electrical potential readings obtained on spans 1 and 2 indicated no active corrosion. This was verified by 4 chloride analysis samples from each span, which averaged 0.288 lb./cu.yd. in span 1 and 0.303 lb./cu.yd. in span 2.

Span 3 — The electrical potential readings taken in the right shoulder and driving lane areas of span 3 indicated that there was no active corrosion. Those taken in the passing lane and left shoulder were very high, indicating, if the values are correct, that active corrosion was present. However, the latter values were noted as "doubtful" by the technician. All available grounds were used, and all gave high readings. The 6 chloride samples taken from span 3 included 2 with chloride samples above the threshold value of 1.0 lb./cu.yd., 1.373 and 1.365 lb./cu.yd. However, these samples were taken from the portion of the span in which the potential readings were low. The average chloride content from all 6 samples was 0.624 lb./cu.yd.

B615 - WBL Rte 64 over Rip Rap Road

All Spans — With the exception of 8 high readings near the joints, all electrical potential readings on all 3 spans were low, indicating no active corrosion. Two samples for chloride analysis were taken from spans 1 and 2 and 3 samples were taken from span 3. One of the samples from span 2 had a chloride content of 1.575 lb./cu.yd.; all others were below 1 lb./cu.yd. The average values were: span 1, 0.664 lb./cu.yd.; span 2, 0.916 lb./cu.yd.; span 3, 0.498 lb./cu.yd.; and overall, 0.665 lb./cu.yd.

B616 - EBL Rte 64 over King Street

Although high, but not definitive, electrical potential readings were obtained near the joints, there was no evidence of active corrosion within the spans. Two concrete samples having contents higher than the 1.0 lb./cu.yd. corrosion threshold were obtained, 1.638 lb./cu.yd. from span 1 and 1.642 lb./cu.yd. from span 3. The averages are shown below for all spans.

Span	No. Samples	Average Chloride Content lb./cu.yd.
1	4	0.749
2	3	0.372
3	3	0.867
All	10	0.671

B616 - WBL Rte 64 over King Street

Span 1 — High electrical potential readings, indicative of active corrosion, were obtained at the joints and adjacent to the right curb, and interior readings were often in the .20-.30 volt CSE range. However, chloride contents were below the corrosion threshold; the average of 3 samples was 0.262 lb./cu.yd.

Span 2 — As in span 1, some high electrical potential readings were found along the joints and at the curb. Most of the readings in the interior of the span were in the range of 0.10-0.30 volt CSE. The 3 chloride analysis samples taken from the span showed very high chloride contents, 2.839, 1,604, and 2.281 lb./cu.yd. Interestingly, these were much higher than the chloride contents encountered in the other spans. No examination of the deck concrete has been made at this writing, but it is believed that variation in the concrete characteristics could account for the differences in chloride content. There was no correlation between the magnitudes of the chloride contents and the electrical potential readings at the sampling points.

Span 3 — High electrical potential readings were found at the joints, but the interior readings showed no evidence of active corrosion. The average of 4 chloride analyses was 0.310 lb./cu.yd.

B617 - EBL Rte 64 over Hampton River and E. Pembroke Avenue

The deck of this long bridge composed of a series of continuous spans had many transverse cracks, typical of continuous structures. A few high electrical potential readings were found adjacent to the curbs, but, overall the decks showed no evidence of active corrosion of the reinforcing steel. Thirty-nine samples for chloride analysis were obtained from the deck throughout the bridge. Only 1 of the chloride contents was above the threshold at 1.163 lb./cu.yd. The grand average chloride content of the 39 samples was 0.373 lb./cu.yd. It appears that the cracks in the deck had been effectively sealed.

B617 - WBL Rte 64 over Hampton River and E. Pembroke Avenue

A few high electrical potential readings were obtained at points where the deck appeared to be wet. These were noted by the technician as being of dubious accuracy. Otherwise there was no evidence of active corrosion. This was verified by the results of chloride analyses performed on 40 samples from the deck. Two tests yielded values, 1.487 and 1.147, above the assumed corrosion threshold of 1.0 lb./cu.yd. The grand average chloride content from the 40 samples was 0.353 lb./cu.yd.

B618 - EBL Rte 64 over East Branch and C & O Railroad

High electrical potential readings were obtained at the joints but the interior of the spans showed no evidence of active corrosion. The average of 13 chloride analyses, all of which disclosed chloride contents below the corrosion threshold, was 0.362 lb./cu.yd.

B618 - WBL Rte 64 over East Branch and C & O Railroad

A very few high electrical potential readings were found at the joints, but there was no sign of active corrosion within the spans. Fifteen samples for chloride analysis were taken from the 7 placement areas on the continuous span bridge. The 2 samples obtained from 1 area indicated high chloride contents, 1.474 and 0.974 lb./cu.yd. All others had both values below 1.0 lb./cu.yd., and the overall average for the deck was 0.383 lb./cu.yd.