TIME-TO-CORROSION OF REINFORCING STEEL IN CONCRETE VOL. 5

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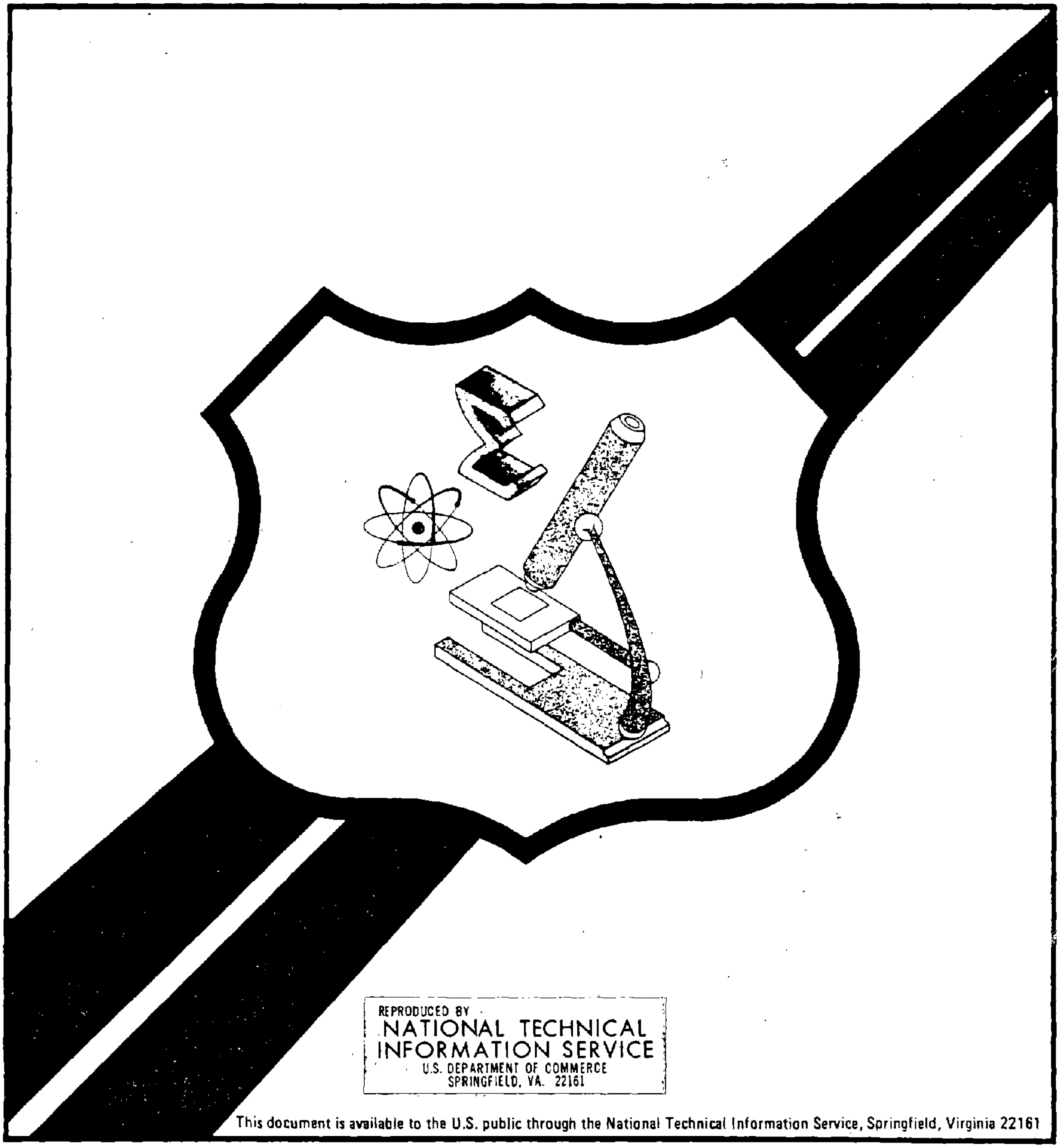

FOREWORD

This report presents the finding of an outdoor exposure study of concrete slabs containing either epoxy-coated rebars or calcium nitrite as a corrosion -inhibiting protective system. The tests were performed under conditions which simulated those found in typical highway bridge decks and the results are compared to those obtained on uncoated reinforcing steel. The concrete in the slabs contained 15 pounds per cubic yard of chloride ion admixed during mixing, to accelerate the initiation of the corrosion process. The report will be of interest to bridge engineers and designers of reinforced concrete structures exposed to deicing salts or to a marine environment.

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16. Abstract

Thirty-one relatively large reinforced concrete slabs were fabricated in 1980 using either non-specification epoxy-coated reinforcing steel or calcium nitrite admixture with black (uncoated) steel. Their performance is compared with uncoated steel in concrete without admixtures. The slabs were placed in two lifts: the bottom lift consisted of a bottom mat of reinforcing steel in chloride-free concrete; and a top lift consisting of the top-mat rebars in concrete contaminated with various quantities of sodium chloride. All the electrical connections between the reinforcing mats were made exterior to the slabs so that the corrosion current flow could be monitored. A worst case type of research design was used by specifying poor quality concrete, nonspecification epoxy-coated rebars, and good electrical coupling between the rebar mats.

After curing, the slabs were mounted above ground and exposed to the environment of the Washington, D.C. location. They were periodically subjected to additional chloride exposure while being monitored for about 1 year to determine the corrosion rate. Selected slabs were than demolished to confirm the findings of the nondestructive testing.

Findings of the study indicate that both epoxy-coated reinforcing steel and calcium nitrite can provide more than an order of magnitude reduction in the corrosion rate; and thus should provide long-term protection against corrosion-induced damage on properly engineered and constructed structures in severe salt environments.

Some of the variables which affected the performance of the slabs were the chloride content in the calcium nitrite experiment, and the selective coating of the upper mat only, versus the coating of both mats in the coated rebar experiment.

17. Key Words

concrete, corrosion, reinforcing steel, bridge deck corrosion rate, macrocell, galvanic cell, epoxy-coated reinforcing steel, corrosion inhibitor, calcium nitrite, rebars

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INTRODUCTION

This report presents the results of laboratory tests on two corrosion protection systems. The systems are different in the approaches to alleviate the problem. The one system involves the use of a calcium nitrite admixture to reduce the galvanic action, while the other system uses an epoxy-barrier coating on the reinforcing bars. The two dissimilar approaches are reported together because they were conducted over the same time span and are compared to the same specimens containing black steel in an unprotected system.

The purpose of this report is to provide the latest information on the corrosion protection properties of each of the above protective systems. The Federal Highway Administration initiated studies in 1980 on both systems, and since the research designs are quite similar, as is the outdoor exposure, examination of this interim data provides some valuable information.

Previous research has established the value of using epoxy-coated reinforcing bars in concrete to reduce the effects of corrosion damage. Briefly, the coating process consists of properly cleaning the bar and then applying an electrostatic spray of the powdered epoxy to the heated bar. Rebars coated with approved epoxies are very resistant to high rates of corrosion and thus early age deterioration of the surrounding concrete (due to the pressure generated by the expansive corrosion products) is minimized (1, 2, 3).

On the other hand, calcium nitrite is an anodic corrosion inhibiting admixture for concrete which has been shown in laboratory tests to effectively reduce the corrosion of uncoated steel in salty concrete. It has no adverse effect on the mechanical properties of the concrete.

RESEARCH DESIGNS AND SLAB FABRICATION

Philosophy

The research experiment design for these tests was based on the latest information on the process of steel corrosion in concrete(4). This information indicated that macroscopic corrosion cells (those in which large quantities of cathodic steel drive corrosion at the anodic steel) were the primary cause of early age bridge deck deterioration. This macroscopic concept is in contrast with previous research which had concentrated on microscopic corrosion cells (those which operate on a single small section of reinforcing steel) which are of much lesser importance. This concept explains why a few damaged areas on epoxy-coated reinforcing bars do not exhibit poor performance for the cases of electrically-isolated epoxy-coated bars. It also explains why, in a two-mat system of all epoxy-coated bars, a corrosion macrocell of significant magnitude cannot develop, since the properly coated portion of the bar cannot function as an oxygen-reducing cathode. The macrocell concept simultaneously raises the question as to what will be the effect of electrically coupling damaged epoxy-coated rebars to large quantities of black steel. Similarly, the concept says that for calcium nitrite to be effective, the electrical potentials of all rebar, regardless of the chloride content of the surrounding concrete, must be maintained at similar values.

Specifically, the previous research on uncoated bars without calcium nitrite had shown that a strong macroscopic corrosion cell developed between the top mat of reinforcing steel (in chloride-contaminated concrete) and the bottom mat of steel in chloride-free concrete. It further showed the corrosion rate was often controlled by the ability of the bottom mat reinforcing steel to reduce oxygen. A large quantity of bottom-mat steel and an outdoor exposure produced high corrosion rates and the rate depended on the electrical-resistance path between the mats.

Thus, a highly accelerated corrosion test for a simulated bridge deck situation could be attained by using:

(a) a relatively large slab of high permeability stored outdoors,
(b) a high level of chloride contamination in the concrete surrounding the top mat of reinforcing steel,
(c) a large quantity of bottom-mat reinforcing steel in chloride-free concrete, and
(d) a separation distance between rebar mats less than that typically used on bridge decks.

Of course, even in the above situation, a macrocell will not develop unless there is direct electrical contact (i.e., metal to metal contact) between the rebar mats. In a conventional black steel bridge deck such contact is normally provided by truss bars, tie wires, bar chairs, expansion dams and/or scuppers. Field observations indicated that in black steel decks such contact is available in virtually every instance and full coupling can be expected.

On the other hand, the extent of electrical coupling where epoxy-coated rebars are being used is indefinite. Hence, 17 bridge decks containing epoxy-coated rebars in Kentucky and Virginia were measured. The bridges contained epoxy-coated reinforcing steel for the top mat and black steel in the bottom mat. The data summarized in Table 1 indicated that some of the epoxy-coated reinforcing bars were in electrical contact with the bottom-mat steel. On two decks all the tested bars showed electrical contact, while no contact was found anywhere on four decks.

Partial contact was the most common situation on all other decks. The use of nonmetallically-coated tie wires and bar chairs seemed to minimize the amount of mat-to-mat coupling but did not always eliminate it. Apparently, the presence of truss bars, bar ends in contact with expansion dams and the presence of scuppers and associated positioning wires appeared to be the major cause of the electrical contact on the bridge decks.

Slab Design

The above information was used to create a worst case experiment design. Each slab was 2 ft. by 5 ft. by 6 in. and contained two mats of reinforcing steel (as shown in Figure 1). The top-mat reinforcing steel consisted of four 51-in. long bars and two 18-in. cross bars beneath them. The bottom mat consisted of seven 51-in. long bars and three 18-in. long cross bars beneath them. The clear concrete cover over the top mat was 3/4-in. and 1 3/8-in. between the two mats of the slab. All epoxy-coated rebars were No. 6 bars. Black steel of sizes No. 4, 5 and 6 was used. All rebars met AASHTO Specification M 31. Table 2 provides specifics on the reinforcing steel in each slab. The separation distance between the mats (longer bars) was 2 3/8 inches. The black steel bottom reinforcing steel mats were welded at each bar crossing point. Electrical leads were attached to each epoxy-coated rebar, to all top-mat black steel rebars and to two of the rebars in each black steel bottom mat in the following manner: The ends of the bars were sandblasted and a 1-in. wide area on one side of the bar was flattened, after which a 1/4-in. diameter hole was drilled through the bar. A 1/4-in. bolt was used to attach the lead wire to the bar with a closed ring crimp lug. The attachment area was then well coated with epoxy. All lead wires were No. 12 guage stranded, tinned copper with teflon insulation. Figure 2 shows the construction of the slabs.

Concrete

The concrete used in each slab had the following properties: water cement ratio of 0.53, cement content of 658 lbs/yd^3, air content of 7±1.5 percent, and sand by volume of total aggregate of 44 percent. The fine aggregate was White Marsh sand which has a specific gravity of 2.64 and a fineness modulus of 2.6. The coarse aggregate was Riverton Limestone which has a specific gravity of 2.77 and a 3/4-in. maximum size, graded to the midpoint of the AASHTO M43 size number 67 specification. All of the coarse aggregate was separated into four sizes which were then batched separately to insure gradation control. Details of the mixtures are shown in Tables 3 and 4.

The concrete was mixed in 9-ft.^{3} batches in an 11-ft^3 rotary drum mixer and placed in each slab in two lifts, 1 to 3 days apart. The lower lift (3.5 in.) was chloride-free while that in the top lift of each slab contained a specified amount of sodium chloride dissolved in a portion of the mix water. The lower lift was cured with wet burlap and then wire brushed prior to the placement of the top lift. The top lift was cured for 14 days using wet burlap and polyethylene and then the slab was mounted on 3-ft. posts at the FHWA outdoor exposure site.

Table 2 provides specifics on each slab. All slabs were fabricated between May 6 and September 28, 1980. Nine thermocouples (3 at the top-mat level, 3 at the slab mid-depth and 3 at the bottom-mat level) were placed in each slab to facilitate accurate measurement of the average slab temperature. All lead wires were brought outside the concrete to facilitate the taking of corrosion measurements.

Epoxy-Coated Bar Specimens

The epoxy-coated reinforcing steel was coated in 1977 for use in another study and had been stored outdoors for over 2 years. Holiday detection was used to identify those bars with more than 25 holidays per foot and only these bars were used in this study. Also, the epoxy-coated rebar did not pass the bend test. Upon being subjected to this test, it was very easy to peel the epoxy coating from the rebar. This test is used to detect poor surface preparation which will result in a poor bond between the epoxy coating and the steel. Consequently, the epoxy-coated rebar used in this study did not meet AASHTO or ASTM specifications (5, 6) for the finished product.

A small amount of shipping and storage chipping was present on the coated rebar (estimated at less than 0.05 percent of the rebar surface area and less than 1 visible chip per foot). All bars were cut to size from the 20-ft. lengths, lead wires were attached, and all ends were coated with liquid epoxy. The bars were then allocated for use in the various slabs using a random numbers table. Coating thickness measurements, made using a thumbwheel gauge calibrated on plates, average 12.8 mils with a range of 11.0 to 14.6 mils. This thickness is higher than normal because the bars were specially coated to this thickness at FHWA's request for an earlier planned bond study.

Damaged areas were created on the epoxy-coated bars for use in slabs 207 through 210 and 235. This was based on measurements taken in surveys by the States of Kentucky and Iowa in which epoxy-coated rebar installations were measured immediately prior to concrete placement to define the actual damaged bar areas. Kentucky Department of Transportation personnel surveyed 16 bridge decks after the steel had been placed. Visual standards (rebars with bare areas of 0.01, 0.1 and 1.0 percent of surface area) were used to compare and estimate the damaged areas on at least one 25-ft^2 representative area of the deck steel of each bridge. Several areas were studied on some bridges. All of these Kentucky bridges were built using epoxy-coated reinforcing steel in the top mat only, and nonmetallic-coated chairs and tie wires. On twelve decks the average damaged area was between 0 and 0.010 percent. The average damaged area on three other decks was between 0.011 and 0.04 percent while on a single deck a damaged area of 0.4 percent was found. In the latter case, the inspector indicated that he purposely chose that sampling location because it was the worst area on the deck.

Iowa surveyed thirty No. 11 and six No. 15 bars randomly chosen from three groups at a jobsite immediately prior to installation into columns as main column bars and hoop ties. The bars had been coated in North Carolina, fabricated as required, and shipped to Ames, Iowa via truck. This jobsite was chosen because of its close proximity to the office and because preliminary examination indicated the column bars were in general, more badly damaged than bridge deck reinforcing steel. In this study, the percentage of damaged area was defined in each 1-foot interval of each bar. The size of each damaged area was estimated by comparison with an area representation card. The card contained eighteen shaded squares or rectangles varying in area from 0.0039 to 0.094 in^2. The bars were most damaged on the ridges and most often near the ends. The maximum amount of defective area in 1-foot length was 1.08 percent for the No. 15 bars and 0.88 percent of surface area for the No. 11 bars. However, overall averages for the bars were 0.22 percent for the No. 15 hoop bars and 0.065 percent for the No. 11 bars.

Based on the above measurements, the damaged areas of 0.22 and 0.80 percent on the bars were specified for slabs in this study. The coating was removed in 0.25-in. by 0.50-in. areas (0.125-$in.^2$). A 0.22 percent damaged area involved the removal of the coating from an area that size every 18 inches along the No. 6 bars. A 0.80 percent bare area involved coating removal every 6 inches along the bars (10 and 36 individual damaged areas per top mat, respectively). The damaged areas on each bar were placed alternately on each side of the bar along its length. Figure 2 shows a typical damaged area on the coated reinforcing steel.

Calcium Nitrite Specimens

The variable used in the calcium nitrite study involved only the quantity of chloride in the concrete surrounding the top-mat reinforcing steel. All calcium nitrite slabs had 2.75 percent calcium nitrite by weight of cement in both the top and bottom lifts of concrete, while the control slabs had none. Nominal chloride contents of 0, 5, 10, 15, 20, 25 and 35 lbs. Cl^-/yd^3 were used in the top lift of the calcium nitrite slabs, while the control slabs were made with only four levels, 0, 5, 15 and 35 lbs Cl^-/yd^3.

The research with the calcium nitrite is considered a severe corrosion environment since the chloride was added initially, thus complicating initial passivation of the steel by the nitrite ion. In addition, the concrete quality (water-cement ratio = 0.53) was quite poor.

Environmental Conditioning

Overall, to insure that a highly corrosive environment existed, all epoxy bar, all calcium nitrite, and control slabs (except slabs 212 and 217) were continuously ponded with 3 percent sodium chloride solution for 46 days in the fall of 1980. The ponding was discontinued when corrosion was induced in a control slab which was initially chloride free. Upon termination of the ponding, the dams were removed and since then the slabs have been subjected to natural weathering only.

CORROSION TESTING

When the only mat-to-mat electrical contact is exterior to a slab, a direct measure of the corrosion current flowing between the mats can be obtained. Such a measurement provides direct evidence of corrosion and its magnitude. Such data can be used to calculate a variety of important parameters such as the oxygen consumption rate at the cathode. Also, by monitoring corrosion current versus time, a valid indication of the iron consumed by the action of the macroscopic corrosion cell can be obtained.

To facilitate these measurements, the wires were brought out of the slab, as shown in Figure 3, and mounted in an instrumentation interface box attached to each slab. Figure 4 shows a closeup of an interface box which allows the following:

(a) A switch couples or uncouples all the rebars in the top mat from all the rebars in the bottom mat.

(b) The corrosion current flowing between the two mats can be directly measured as the voltage drop across a 1.0 ohm precision resistor (switch coupled).

(c) The driving voltage of the corrosion cell can be measured (at switch instant OFF).

(d) The electrical potential between the top-mat and a half-cell placed at various positions on the slab surface can be measured (switch OFF).

(e) The electrical potential between the bottom mat and a half-cell placed at various positions on the bottom surface of the slab can be measured (switch OFF).

(f) The electrical resistance between rebar mats can be measured using a 1,000 cycle AC meter (switch OFF).

(g) The temperature indicated by the nine thermocouples within the slab can be recorded (switch ON or OFF).

Once a slab is under test, the mat couple switch is ON at all times, except as follows:

The typical measurement sequence is to make measurements (b) and (g) with the coupling switch ON, measurement (c) is made immediately upon uncoupling and then measurements (d), (e), and (f). The mats are then recoupled. It is essential that the corrosion current measurement be made first (before uncoupling) since depolarization of the corrosion cell after uncoupling is rapid. Testing showed that typically 1 to 2 days in the mats coupled mode were required for the corrosion cell to stabilize (polarize to a steady state condition) initially or after several days in the uncoupled mode. Shorter stabilization times (1 hr) were required for short uncoupled periods, such as that needed to obtain the measurements.

The corrosion testing of slabs 201 through 210 (epoxy coated and controls) was initiated on August 7, 1980, by coupling the reinforcing-steel mats after a set of initial uncoupled data had been obtained. A similar procedure was used to initiate the testing of slabs 211 through 228 (calcium nitrite and controls) on October 8, 1980, and slabs 234 and 235 (epoxy bar and control) on October 28, 1980. The reinforcing steel then remained coupled throughout the test except when measurements were made.

RATE OF CORROSION FINDINGS

Table 5 summarizes the rate of corrosion data obtained on the slabs. Included are data on:

(1) Average Macrocell Corrosion Current - This is a direct measure of the electrons released by the corrosion process and flowing to the bottom rebar mat for oxygen reduction. As noted in the discussion above, concrete temperature has a significant effect on the corrosion current (rate). This effect has been shown to be due primarily to the effect of temperature on concrete resistivity. The corrosion current measured at any given field temperature can be adjusted to another temperature to compensate for differing concrete resistivities using the formula:

$$i_1 = \frac{i_2}{e^{2883\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}}$$

where i_1 = corrosion current at temperature T_1.

i_2 = corrosion current measured at temperature T_2.

T_2 = average temperature of the concrete between the macro-anode and macro-cathode (in degrees Kelvin).

T_1 = temperature (in degrees Kelvin) that one desires to know the corrosion current.

e = natural or naperian base of logarithms.

A temperature of 70 F (21 C) was chosen as the datum in these studies and all measured currents were adjusted to a concrete resistivity corresponding to that temperature.

Two averages are presented in Table 5: One is an arithmetic average obtained by adding all data and dividing by the number of readings; and the second is a weighted average which considers the variable time intervals between data points. The latter is considered the better indicator. (See Appendix for additional details.)

(2) Average Macrocell Driving Voltage - This is the polarized driving voltage of the corrosion cell measured in the instant-off mode (i.e., an instant after uncoupling the rebar mats) to eliminate iR drop errors. If no corrosion macrocell developed, the driving voltage would be zero. At constant corrosion circuit resistance, the higher the driving voltage, the higher the rate of corrosion.

(3) Mat-to-Mat AC Electrical Resistance (R) - This measurement is made using a 1,000 cycle AC signal after the mats are uncoupled and after the electrical potentials are measured. It provides an indication of concrete resistivity in a black-steel system. The mats are recoupled immediately after making this measurement. Tests in solutions of known resistivity gave conversion factors of 735 for the black steel slabs with all No. 4 and No. 5 bars, and 706 for the black steel slab with No. 6 bars. These conversion factors are used as multipliers for the measured resistance to obtain the approximate concrete resistivity. This approach was not used for the slabs containing epoxy-coated rebars. In general, the higher the concrete resistivity, the lower the corrosion current. As for the case of corrosion currents, field measurements are adjusted to 70 F (21 C) utilizing an experimentally defined equation. (See Appendix.)

(4) 70 F (21 C) Metal Consumed - This calculation is the amount of metal which would have been consumed during the test period if each concrete resistivity had constantly been at its 70 F (21 C) adjusted value. It is well known that each 1.0 amp-hr. of corrosion current consumes 1.04 gram of iron. The total amp-hr. of current passed is calculated by multiplying the average corrosion current for each two successive readings by the hours between readings and accumulating a total.

CHLORIDE ANALYSIS

In all the epoxy and calcium nitrite concrete slabs, a calculated amount of salt (sodium chloride) was admixed into the water used for mixing the concrete. All the slabs in the epoxy series contained 15 lbs. of Cl^-/yd^3.

Hardened concrete samples were analyzed after 28 days of curing for total and water soluble chloride ion content according to AASHTO T-260 procedure and FHWA-RD-77-85 procedures (7, 8).

		Measured Cl^- Content ($lbs./yd^3$)	
Batch No.	Used in Slab No.	Total	Water Soluble
2	201 and 203	15.0	13.4
6	202 and 206	12.7	11.9
9	207 and 209	13.2	12.2
10	208 and 210	11.9	11.0
	Average	13.2	12.1

In addition to the admixed salt, all of the slabs in the epoxy and calcium nitrite series, except 212 and 217, were ponded with a 3 percent sodium chloride solution to accelerate the corrosion of the top-reinforcing mat. Concrete samples were extracted from all the slabs at the end of the ponding. Four concrete samples from a single location at depths of 1/16 to 1/2-inch; 1/2 to 1 inch; 1 to 1 1/2 inches; and 1 1/2 to 2-inches were analyzed for the chloride content. The location of the sampling site was chosen to be away from any cracks, delamination and visible rust spots. This was done to insure that the measured chloride amounts were most representative of the actual concentration in the total slab. The results are summarized in Table 6. Since top-mat reinforcement is located from 3/4-in to about 2 inches from the surface, an average is also given in Table 6 for the three samples from each slab associated with that depth.

A few of the slabs in the calcium nitrite series have rust spots on the surface of the concrete which may be due to the corrosion of the top reinforced-mat embedded in the chloride-contaminated concrete. These slabs had moderate amounts of chloride at the top-mat level but the visible rust spots were more extensive than the duplicate slabs containing about equal amounts of chloride. Although most of the duplicate slabs containing the same concentration of admixed salt were cast at the same time and in the same manner, it is possible that some individual slabs might have developed shrinkage cracks. Since these slabs were ponded for 46 days with a 3 percent sodium chloride solution, it was conceivable that these slabs might have accumulated a localized higher concentration of chloride ions through the cracks. To explore the hypothesis, a second sample was obtained from a location site near the rust spot. Table 6 shows the extra sample collected from slabs 213, 218, 220, 223 and 225. From the chloride analysis data, it appears there is no significant localized higher concentration of chloride in the rust-stained areas as compared to the adjacent unstained surface areas.

DISCUSSION

The data collected and analyzed in this study indicate that both epoxy-coated reinforcing steel and calcium nitrite are quite effective in reducing the corrosion rate, although some corrosion did occur in all the highly-chloride bearing concrete. Table 7 shows the average weighted 70 F corrosion currents for the black steel slabs without nitrite at the various average top-level rebar chloride contents. Figure 5 shows a plot of these data which form a straight line approximated by the equation:

$$\text{Corrosion current (in } \mu A) = 473\ (Cl^- \text{ content in lbs/yd}^3\ -1.8)$$

Also shown in Figure 5 are the average data for the calcium nitrite and epoxy-coated rebar slabs. Tables 8 and 9 include this experimental data plus the corrosion currents for slabs having equal chloride concentration (black steel, no nitrite) obtained using the above equation. These data indicate that the corrosion rate of both the control (no nitrite) slabs and the slabs containing 2.75 percent calcium nitrite increased, as the chloride content of the hardened concrete increased. However, in all instances, the corrosion rates in the slabs containing nitrite were far lower, as indicated by Figure 5 and Table 9.

For chloride to nitrite ratios up to 1.25, reductions in corrosion rate by a factor of 10 or more were achieved using calcium nitrite. Thus, at least 10 years would be required to consume the same amount of iron as was consumed in 1 year in the concrete without nitrite. Further, even at chloride to nitrite ratios as high as 1.79 to 1, large reductions in corrosion rate were achieved (at least a factor of 5). Considering the severity of these tests (poor quality concrete with chloride added initially and by continuous ponding), the results are extremely favorable.

In the case of epoxy-coated reinforcing steel (all concrete had rebar level chloride in the range of 13 to 18 lbs Cl^-/yd^3), little differences in performance were found between bars with holidays only and those with holidays and visible bare areas. Therefore, the data have been grouped into three primary treatment variables (black steel, top-mat only epoxy coated, and both mats epoxy coated) and are given in Table 8.

The data show that the corrosion rate can be reduced greatly by using even poor quality epoxy-coated reinforcing steel and a severe situation in which all bars are electically coupled. When only one mat was coated, it would take on the average 12 years to consume an equal quantity of iron as was consumed in 1 year on uncoated steel. If all the rebar (both mats) is epoxy coated, 46 years would be required to consume equal iron.

Since calcium nitrite slabs were also tested in concrete containing a similar amount of chloride as the epoxy-coated rebars, a comparison is possible. Figure 5 provides such a comparison at 14 to 15 lbs Cl^-/yd^3 and indicates that the inclusion of 2.75 percent calcium nitrite provided corrosion protection closest to that provided by coating only the top-mat rebar. Refinements in conclusions will require additional studies because of the relatively small number of slabs and the severe conditions used herein. Suffice it to say that both epoxy-coated reinforcing steel and calcium nitrite (at a Cl^-/NO_2 ratio of up to 1.25) provide at least an order of magnitude reduction in corrosion rate; and thus should provide long-term protection against corrosion-induced damage on properly engineered and constructed structures in severe salt environments.

MEANS OF PROTECTION (Or Lack of It)

The electrical half-cell potential, macrocell driving voltage data and electrical resistance data provide valuable insights into the manner in which the protective systems are functioning (See Tables 5 to 10 and the Appendix.)

Calcium Nitrite

The mat-to-mat resistance measurements indicate that the resistivity of the concrete used in these tests averaged about 7600 ohm-cm (at 70 F) for the concrete without nitrite and about 6400 ohm-cm at 70 F for the concrete containing 2.75 percent calcium nitrite. (Interestingly, the amount of chloride in the top lift of the concrete had no large effect on mat-to-mat resistance.) Thus, a resistance effect is not part of the means in which the calcium nitrite protects against corrosion.

The macrocell driving voltage data, on the other hand, are far lower for those slabs containing nitrite than for those without it. In general, the driving voltage increased as the corrosion rate increased for all slabs. Thus, it would appear that calcium nitrite is functioning by reducing the difference between macro-anode and macro-cathode polarized potentials. This is in line with data from others. Only a few electrical half-cell potential readings are available for slabs in the calcium nitrite series. (See Appendix.) They substantiate the other corrosion rate data and indicate that the calcium nitrite functions by passivating the anode. (See data for calcium nitrite slabs with zero and very low corrosion rates.) As the chloride content increases, the ability of a given amount of calcium nitrite to maintain complete passivity is reduced, the anode potentials become more negative and a corrosion macrocell develops. When its magnitude becomes relatively large, cathodic polarization begins, whereas, at lower corrosion rates, no cathodic polarization is noticeable (probably due to the excess of oxygen at the cathode; note how the bottom-mat potentials become more negative as the corrosion rate increases).

Thus, to characterize control of the corrosion process by calcium nitrite, both the quantities of nitrite and chloride are important. At low chloride to nitrite ratios, the potentially anodic rebar is completely passivated, preventing corrosion. At high chloride to nitrite ratios, anodic, cathodic and resistance effects are all involved.

Epoxy-Coated Reinforcing Steel

The mat-to-mat resistance data indicate that epoxy-coated reinforcing steel owes its success largely to the increased macro-corrosion cell resistance path. For example, the average mat-to-mat resistance for the uncracked slabs equals 82.5 ohms and 50.3 ohms for both mats coated and one mat coated, respectively, versus 10.8 ohms for all black steel. Further, the macrocell driving voltages and half-cell potential differences are far lower for all epoxy-bar slabs than for the black steel controls. The fact that the top-mat potentials in the one mat of epoxy-coated rebars did not become highly negative indicates that sufficient oxygen was available at the top-mat rebar level to support microcell action at holidays and bare areas without micro-cathode polarization. Had this not been the case, it would have induced higher macrocell corrosion rates by driving top mat potentials more negative.

From the above, one would expect better performance from the both mats coated situation by virtue of the higher mat-to-mat resistance and lower macrocell driving voltage (both mats coated average=21 mV while the top-mat only coated average = 32mV). There is, however, a major difference in electrical half-cell potentials (polarized) for these two situations which should be highlighted: Both top- and bottom-mat polarized potentials are much more negative for the case when both mats were coated than for the situation of only the top-mat coated. This indicates that macro-cathode polarization is occurring in the both-mats coated situation, undoubtedly because of the limited bare steel area on the bottom-mat for oxygen reduction. Note the potential data (both mats coated) obtained prior to mat coupling indicate that the unpolarized bottom-mat potentials were substantially more positive than the polarized values.

Thus, control of the corrosion rate for the case of one-mat epoxy-coated is best characterized as resistance control with the absence of top-mat micro-cathodic polarization, while that for the both-mats coated system involves both resistance effects and macro-cathodic polarization.

Slabs Debonded Between Lifts

Several slabs debonded between concrete lifts (i.e., between the mats) during curing. Angle iron clamps were placed on each end of each slab and were electrically isolated from the slabs using 0.25-inch thick plexiglass strips. Electrical potential, resistance and corrosion current measurements on slabs with and without the clamps confirmed that they had no effect on the corrosion evaluation. Although the data collected on these slabs are presented, they were not included in average calculations for the variables under test.

Examination of the data, in comparison to that for well-bonded slabs show that resistivity effects are playing an important role in the debonded slabs and that cathodic polarization is generally reduced, resulting in higher macro-cell driving voltages and mat-to-mat electrical potential differences. Thus, the cracking between lifts in the black steel slabs caused a shift in the balance of corrosion rate control from predominantly cathodic control to predominantly resistance control.

VISUAL EXAMINATION FOR CONFIRMATION

In August and December 1981, selected slabs were demolished to allow the visual examination of the reinforcing steel. W. R. Grace analyzed the calcium nitrite slab in December while the FHWA studied the others in August. All slabs were those containing 15 lb. Cl^-/yd^3 (plus ponding) and included one black steel control, three epoxy-bar slabs and one calcium nitrite slab. Chloride contents at various depths within the concrete were determined using rotary hammer sampling and the procedure defined in AASHTO T-260. The demolition process was photographed and a few photographs are presented in Figure 6. A discussion on the findings for each slab is given below.

Slab 201 - Black steel, Both Mats.

Partially debonded between lifts, but nevertheless subsequently badly cracked due to corrosion and 70 F metal loss (from macro-cell measurements)=28.3g/yr. Average Cl^- at the rebar level (2 samples)=15.0 lbs Cl^-/yd^3. Widespread rebar corrosion was on all bars, with (as usual) some uncorroded (cathodic) areas. Corrosion-induced cracking was throughout (see photographs). Metal loss at some spots was significant.

Slab 204 - Epoxy-Coated with Holidays, Top-Mat Only

Macro-cell 70 F metal loss = 8.0g/yr. Minor surface scaling occurred (due to freeze-thaw action immediately after ponding). Very fine hairline cracks occurred since fabrication. Average Cl^- at rebar level (2 samples)=14.9 lbs/ Cl^-/yd^3. Little corrosion was found (see photographs); hairline cracking is not corrosion related. Several "spots" of rusting at holidays were observed.

Slab 205 - Epoxy-coated with Holidays, Both Mats.

Macro-cell 70 F metal loss=1.2g/yr. Average Cl^- at the rebar level (2 samples)=14.9 lbs Cl^-/yd^3. Very little corrosion on bars or corrosion product in the concrete were found. No corrosion-induced cracking was observed.

Slab 209 - Epoxy-coated with Holidays and 0.22 Percent Bare Area, Top Mat only.

Macro-cell 70 F metal loss=2.8g/yr. Minor surface scaling occurred. Average Cl^- at rebar level (2 samples) = 14.5 lbs Cl^-/yd^3. No corrosion-induced cracking was observed.

Slab WRG - Black Steel, 2.75 percent calcium nitrite, 15 lbs Cl^-/yd^3

Macro-cell 70 F metal loss=6.6g/yr. Average rebar level chloride content=17.3 lbs Cl^-/yd^3. Several rust stains observed, but no surface cracking observed. Removal of the concrete in the rust-stained areas revealed light rebar corrosion while cores from other areas showed corroded areas to be most often associated with voids in the concrete. Bar corrosion is neither widespread nor as deep as in control slab 201. (See photographs.)

Thus, the slab demolition in general confirmed the findings of the rate of corrosion studies and verified the test technique. The epoxy-coated rebar and calcium nitrite slabs experienced much less steel corrosion than the black steel slab. Corrosion in the black steel slab had corrosion-induced widespread cracking, while no corrosion-induced cracking was found in the epoxy-coated rebar or 2.75 percent calcium nitrite slabs.

APRIL 1982 SLAB CONDITION

The condition of each of the remaining slabs as of April 2, 1982, is documented by the photographs in Figure 7. The salt-free slabs (212 and 217) have, of course, exhibited no distress. The control slabs with an average top-rebar level chloride of 15.6 lbs Cl^-/yd^3, black steel, and no nitrite are badly corrosion damaged; none of the epoxy bar slabs shows corrosion-induced distress; and the calcium nitrite slabs at that chloride content also show no significant distress. Black steel slabs (no nitrite) with 7.6 lbs/yd^3 of chloride are rust stained with small surface cracking. The black steel slab with 26.1 lb Cl^-/yd^3 is badly cracked due to corrosion, whereas, the companion with nitrite exhibits only rust staining. Calcium nitrite slab 218 with 7.7 Cl^-/yd^3 is an outlier, exhibiting widespread rust staining on the concrete over one bar which may have developed a crack in the concrete during curing. Calcium nitrite slab 226 with 16.8 lb Cl^-/yd^3 is very severely rust stained, as would be expected by the corrosion rate measurements which indicated the highest weighted average corrosion current of all nitrite slabs. The additional rust staining and higher corrosion rates of the nitrite slabs with chloride contents in excess of 15 lbs/yd^3 were the major factors involved in making the recommendation that the expected chloride to nitrite ratio not exceed 1.25.

In general, the slab condition in April 1982 indicates that the previous findings of the rate of corrosion studies are valid.

CONCLUSIONS

The testing of the 31 large reinforced concrete slabs for over 2 years to determine the effects of either a calcium nitrite admixture or epoxy-coated reinforcing steel on the measured corrosion rates/distress, leads to the following conclusions:

1. The corrosion process can be accelerated to produce comparative results in a relatively short time (2 years) by using the criteria delineated earlier in the report.

2. Measured damage found on epoxy-coated reinforcing bars in place on structures was considerably less than the 2 percent allowed by the specifications.

3. Slabs with all black steel and no initial admixed chloride nor any corrosion-inhibiting systems have measureable corrosion current and showed rust stains on the surface (through 3/4-in. clear cover) after 46 days of continuous ponding with a 3 percent NaCl solution.

4. The rate of corrosion is greatly affected by temperature, with higher temperatures yielding higher corrosion rates when other conditions are equal. But, means are available to convert all temperatures (and consequent rates) to that which would occur at a selected datum for temperature (70 F was used herein).

5. The measurement of electrical current flowing between steel in salty concrete and steel in salt-free concrete, with time, can be used to monitor the rate of corrosion. This can be used to estimate the amount of iron consumed.

6. Epoxy-coated reinforcing steel which did not meet specifications (failed the bend tests, had excessive holidays and had surface damage) was very effective in reducing corrosion of rebar in salty concrete. The relative effectiveness, compared to black steel in conventional concrete without nitrite, can be estimated as the relative time to consume equal iron in the worst case situation of complete electrical continuity between bars. If black steel is assigned a life of 1 year, then 12 years would be required to consume equal iron if only the rebar in the salty concrete was coated and the rebar in salt-free concrete was uncoated. When all of the reinforcing steel is epoxy coated, 46 years would be required to consume equal iron.

7. The use of a calcium nitrite corrosion inhibiting admixture at chloride to nitrite ratios up to 1.79 was also a very effective means of reducing the rate of corrosion of uncoated reinforcing steel in poor quality salty concrete. In this worst case situation in which sodium chloride of various amounts was also admixed in the concrete, the calcium nitrite (added at a rate of 2.75 percent by weight of cement) proved very effective. In concrete with 3.6 lbs Cl^-/yd^3 at the top rebar level, (0.3 chloride/nitrite ratio) the corrosion rate in the calcium nitrite slabs was zero

while corrosion occurred in the no-nitrite slabs. In the slabs with 8.4 to 13.4 lbs Cl^-yd^3, corrosion rate in the slabs with nitrite was reduced to 1/11.5 and 1/29 of the controls (except for one outlier). At rebar level chlorides between 16.4 and 22.6 lbs Cl^-/yd^3 , corrosion in the nitrite slabs was 1/5 to 1/9 that of the controls. Thus, if black steel without nitrite is assigned a value of 1 year, it would require between 5 and 29 years for the same rebar in concrete containing 2.75 percent calcium nitrite solids by weight of cement and chlorides in the range of 22.6 to 8.4 lbs Cl^-/yd^3 to undergo equal iron consumption. At chloride -to-nitrite ratios equal to or less than 1.25, the data indicate that 10 or more years would be required to consume the same amount of iron as that consumed in 1 year in the equal chloride, no-nitrite black steel slabs.

8. The performance of either protective system, non-specification epoxy-coated reinforcing steel or calcium nitrite can be compared at a chloride content of about 15 lbs/yd^3 at the rebar level using the developed data. The calcium nitrite provided a level of protection closest to that provided by coating only the top-mat rebar.

9. Calcium nitrite appears to be effective primarily because it does not allow a large electrical potential difference to develop between areas of steel, which, without the nitrite, would be highly anodic and cathodic to each other. In other words, the electrical potential of all rebar is maintained at similar values at or near the passive range.

10. Epoxy-coated reinforcing steel appears to be effective because its use increases the electrical resistance between the macro-anode and macro-cathode (i.e. the top- and bottom-rebar mats in this study). Also, when all rebar is epoxy-coated, macro-cathode polarization occurs due to the inability of the small cathodic areas to reduce sufficient oxygen, further minimizing the corrosion rate at bare areas in the salty concrete.

11. Destruction of the concrete slabs and examination of the retrieved rebar mats corroborated the electrical corrosion measurements and the visual distress.

The choice as to whether to coat all rebar or only that portion which will be exposed to critical amounts of chloride should be made by the user/owner based on the extended life data herein and information on each specific structure, its desired maintenance-free life and the effect of corrosion on structural integrity.

Calcium nitrite, if chosen as the protective system, should be admixed so that the chloride-to-nitrite ratio at the steel level closest to the exposed surface does not exceed 1.25 during the expected life of the structure. This criteria can be relaxed if improved performance levels of less than 10 times that expected with no protection are deemed adequate or other data are developed to indicate a higher chloride-to-nitrite ratio is adequate when the chloride accumulates slowly by the environmental exposure.

A closure discussion on each protective system is provided below.

Epoxy-Coated Rebar Slabs

Concrete structures constructed in salt environments using epoxy-coated reinforcing steel should be many times more resistant to corrosion-induced concrete damage than those constructed with uncoated rebar and conventional concrete. This is true even though the epoxy-coated rebars did not meet either the holiday (pin holes not discernable to the unaided eye) requirement or the bend test as specified by AASHTO M 284 or ASTM D 3963. A 6-inch diameter mandrel was used to perform the bend test on Number 6 epoxy-coated rebar utilized in the above study.

However, this should not be construed as support to permit relaxation of these requirements but rather to reinforce the validity of these specification requirements. Over the very long term, the development of corrosion beneath the epoxy-coated rebars that would not pass the bend test (bend test identifies poorly cleaned bars prior to coating) might become detrimental. These bend and holiday requirements are in the quality control portion of the specifications in order to obtain the same quality field product as that evaluated during laboratory prequalification testing. The fusion bonded epoxy coating functions well, primarily, because of the high electrical resistance of the coating and by greatly reducing the steel surface area available for cathodic oxygen reduction. This results in large reductions in total metal consumed, the major item leading to concrete disruption, even though the corrosion current density at local coating breaks may be quite high. Such localized high current density areas are not believed to be of great concern, since rebar metal loss is not normally a critical factor. For example, studies (Reference 2) have indicated that corrosion-induced concrete cracking occurred after only 0.5 to 1 percent of the bar steel was consumed, whereas, reinforcing steel production specifications typically allow a production variation of at least 6 weight percent. Further, no deep pitting was found at bare areas when select slabs were demolished.

The best situation is one in which all the bars are epoxy-coated or the coated bars are electrically isolated from other metal in the structure. But, even when non-specification epoxy-coated bars in salty concrete were all electrically coupled to large amounts of uncoated steel in salt-free concrete, total metal consumed was no more than 1/12 that for the situation of all uncoated bars.

Calcium Nitrite Slabs

The presence of chloride ion in concrete at the black steel level facilitates the formation of Fe^{++} ions which are responsible for the formation of expansive corrosion products. The rust products exert forces which cause damage to the concrete. Calcium nitrite as an admixture inhibits/interferes with removal of Fe^{++} by the following reaction which averts further corrosion:

$$2\ Fe^{++} + 2OH^- + 2NO_2^- \rightarrow 2\ NO\uparrow + Fe_2O_3 + H_2O$$

In this oxidation reduction process, nitrite ion is reduced to nitric oxide gas which causes a net reduction in the nitrite concentration.

Chloride and nitrite ions are engaged in competing reactions. (Chloride is accelerating and nitrite inhibiting.) The relative rates of the formation of Fe^{++} by chloride ion and back to Fe^{++} by nitrite ions are unknown. The experimental data suggest that Cl^-/NO_2 ratios of up to 1.25 would provide a protection level at least ten times greater than that of ordinary iron rebars, based on the corrosion values measured herein. Additional investigation is needed on the corrosion/inhibition process in the presence of chloride and nitrite ions with increasing time. It would provide a valuable guideline for the addition of nitrite ions based on the expected concentration of chloride ions during the useful life of the structure.

However, it must be remembered that most chloride in these studies was added initially and thus represented a worst case situation. It may be that for the more common situation of nitrite addition to the fresh concrete and the accumulation of chloride relatively slowly in hardened concrete, that higher chloride to nitrite ratios might be tolerable. Future research should be concentrated in this area.

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TABLE 1
Electrical Resistance Between Epoxy-Coated Top- and Uncoated Bottom-Mat Rebars in Bridge Decks

State	Project	Number of Measurements	Measured Resistance Uncoated Bottom-Mat to Top-Mat Epoxy Bars, Ohms		Distribution of Measurement	
			Average	Range	No.	Resistance (ohms)
Kentucky	1	7	4	0-10	All	Low
	2	16	-	8-∞	13	∞
					3	8-15
	3	12	∞	∞	All	∞
	4	21	-	0-∞	14	∞
					4	0
					3	10-100
	5	36	-	4-∞	29	00
					7	4-100
	6	24	-	0-∞	18	∞
					6	0
	7	12	-	10-∞	10	∞
					2	10&15
	8	20		∞	All	∞
	9	20	-	9-∞	18	∞
					2	9&10
	10	20	-	9-∞	19	∞
					1	9
	11	12		∞	All	∞
	12	36	-	5-∞	23	∞
					13	5-50
	13	12		∞	All	∞
	14	12	-	9-∞	10	∞
					2	9&10
	15	16	15	9-20	All	Low
Virginia	GWP 1	20	-	<10-∞	5	∞
					15	10
	GWP 2	20	-	10-∞	3	∞
					17	<10

Table 2. Research Design and Slab Fabrication Data

A. Epoxy-Coated Rebars and Controls

							Reinforcing Mat					
								Transverse		Longitudinal		Mat
Slab No.	Lift	Date Made in 1980	Temp. of Mix F	Cl^- lb/yd^3	Unit Wt. lbs/ft^3	Air %	Coating	Bar Size	% Bare Area	Bar Size	% Bare Area *	% of Total Bare Area *
201	Top	5-9	68	15	139	6.8	None	4	-	5	-	-
	Bot	5-6	79	0	137	6.9	None	4	-	5	-	-
202	Top	5-12	82	15	-	7.0	None	4	-	5	-	-
	Bot	5-10	77	0	142	5.6	None	4	-	5	-	-
234	Top	9-28	79	15	141	7.8	None	6	-	6	-	-
	Bot	9-27	77	0	133	9.0	None	4	-	5	-	-
203	Top	5-9	68	15	139	6.8	Epoxy	6	-	6	-	-
	Bot	5-6	79	0	137	6.9	None	4	-	5	-	-
204	Top	5-12	79	15	142	6.4	Epoxy	6	-	6	-	-
	Bot	5-10	77	0	142	5.7	None	4	-	5	-	-
205	Top	5-12	79	15	142	6.4	Epoxy	6	-	6	-	-
	Bot	5-10	77	0	142	5.7	Epoxy	6	-	6	-	-
206	Top	5-12	82	15	-	7.0	Epoxy	6	-	6	-	-
	Bot	5-10	77	0	142	5.6	Epoxy	6	-	6	-	-
207	Top	5-15	72	15	139	7.3	Epoxy	6	0.09	6	0.71	0.80
	Bot	5-13	84	0	141	6.0	None	4	-	5	-	-
208	Top	5-16	69	15	145	6.1	Epoxy	6	0.09	6	0.71	0.80
	Bot	5-13	89	0	142	5.5	None	4	-	5	-	-
209	Top	5-15	72	15	139	7.3	Epoxy	6	0.04	6	0.18	0.22
	Bot	5-13	84	0	141	6.0	None	4	-	5	-	-
210	Top	5-16	69	15	145	6.1	Epoxy	6	0.04	6	0.18	0.22
	Bot	5-13	89	0	142	5.5	None	4	-	5	-	-
235	Top	9-28	79	15	141	7.8	Epoxy	6	0.09	6	0.71	0.80
	Bot	9-27	77	0	133	9.8	Epoxy	6	0.09	6	0.71	0.80

* 0.80 percent comprised of 1/4 in. X 1/2-in. at every 6 inches.

* 0.22 percent comprised of 1/4-in. X 1/2-in. at every 18 inches.

Degree C = 5/9(Degree F-32)
1 lb/cy = 0.6 kg/m^3
1 lb/cf =16.02 kg/m^3

Table 2. Research Design and Slab Fabrication Data (Cont.)

B. Calcium Nitrite and Controls 1/

Slab No.	Lift	Date Made in 1980	Temp Of Mix °F	Cl^- 2/ lbs/ cu yd	$Ca(NO_2)2$ %Solids by wt of cement	Unit Wt lbs/ cu ft	Air %
211	top	5-25	81	0	0	140	6.9
	bot	5-24	79	0	0	145	5.5
212	top	5-25	81	0	0	145	6.9
	bot	5-24	79	0	0	145	5.5
213	top	5-25	84	5	0	140	6.4
	bot	5-24	80	0	0	141	6.3
214	top	5-25	84	5	0	140	6.4
	bot	5-24	80	0	0	141	6.3
215	top	6-12	-	35	0	144	5.5
	bot	6-0	83	0	0	140	7.7
216	top	5-30	86	0	2.75	141	6.0
	bot	5-28	0	0	2.75	145	5.2
217	top	5-30	86	0	2.75	141	6.0
	bot	5-28	-	0	2.75	145	5.2
218	top	5-30	87	5	2.75	142	6.8
	bot	5-28	86	0	2.75	141	6.6
219	top	5-30	87	5	2.75	142	6.8
	bot	5-28	86	0	2.75	141	6.6
220	top	6-8	86	10	2.75	142	7.0
	bot	6-7	86	0	2.75	145	5.5
221	top	6-8	86	10	2.75	142	7.0
	bot	6-7	86	0	2.75	145	5.5
222	top	6-8	89	15	2.75	143	6.0
	bot	6-7	94	0	2.75	145	5.8
223	top	6-8	89	15	2.75	143	6.0
	bot	6-7	94	0	2.75	145	5.8
WRG	top	6-27	96	15	2.75	144	6.0
	bot	6-25	89	0	2.75	-	5.5
224	top	6-19	84	20	2.75	146	7.5
	bot	6-18	85	0	2.75	145	6.0
225	top	6-19	84	20	2.75	146	7.5
	bot	6-18	85	0	2.75	145	6.0
226	top	6-19	86	25	2.75	-	7.3
	bot	6-18	85	0	2.75	147	8.2
227	top	6-19	86	25	2.75	-	7.3
	bot	6-18	85	0	2.75	147	8.2
228	top	6-27	90	35	2.75	-	5.5
	bot	6-25	80	0	2.75	-	5.5

NOTES: 1/ All Table 2B slab reinforcing steel was Number 4 black steel transverse and Number 5 black steel longitudinal.

2/ Chloride contents shown are theoretical, based on the amount of NaCl added to the concrete mixing water (1.0 lb Cl^-/yd^3 is approx. 255 ppm).

Conversion:
$C = 5/9 (F - 32)$
$1 \text{ lb/cy} = 0.6 \text{ kg/m}^3$
$1 \text{ lb/cf} = 16.02 \text{ kg/m}^3$

TABLE 3

Concrete Mixture Design 1/, 2/

Cement	7.0 sks/cy
Water to Cement Ratio	0.53
Fine Aggregate	1160 lbs/cy
Coarse Aggregate	1550 lbs/cy
Darex AEA	290 ml/cy
Unit Weight	138 lb/cf
Air Content	7±1.5 percent
Slump	2.0 to 3.0 inches

1/ Made in 9 cubic foot batches.

2/ Calcium nitrite slabs contain 18.09 lbs of calcium nitrite dissolved in 43.2 lbs of water. This amount is subtracted from the total water added in the concrete mixture.

Conversions

1 in = 25.4mm

1 cf = $0.028m^3$

1 sk/cy = 94 lbs/cy = $56.4kg/m^3$

1 lb/cy = $0.6kg/m^3$

1 ml/cy = $1.3ml/m^3$

1 lb/cf = $16.02kg/m^3$

TABLE 4

Aggregate Properties

Type	Fine	Coarse
Source	White Marsh River Sand Harry Campbell Sons Towson, Maryland	Riverton Limestone Riverton, Virginia
Los Angeles Abrasion Loss	-	Approx: 23 percent loss 1/
Sodium Sulfate Soundness Loss	-	Approx: Less than 2.0 percent 1/
Dry Rodded Weight	-	Approx: 105 lb/cf 1/
Nominal Max. Size	3/8-inch	3/4-inch
Gradation Sieve Size Pass - Retained		
3/4-in. - 1/2-in.		38
1/2 - 3/8		24.5
3/8 - No. 4		32.5
4 - Pan		5
3/8 - 4	5	
4 - 8	13	
8 - 16	15	
16 - 30	19	
30 - 50	26	
50 - 100	16	
100 - 200	4	
200 - Pan	2	
Absorption	0.56	0.45
Fineness Modulus	2.6	-
Specific Gravity (Bulk Dry)	2.644	2.757
(SS Dry)	2.659	2.769
Apparent	2.684	2.790

1 inch equals 25.4mm

1/ (Based on History)

TABLE 5. Corrosion Rate Data
A. Epoxy Coated Rebar and Control Slabs at 15 lbs Cl$^-$/yd^3 plus Ponding

Slab #	Variable	Ave. Driving Voltage mV	Ave. 70°F Corrosion Current, µA	Weighted Ave. 70°F Corrosion Current, µA	Ave. 70°F Mat to Mat Resistance, ohms	70°F metal consumed per year, grams
PONDED SLABS						
201*	Black Steel	141	2958	3102	42.0*	28.3
202	Black Steel	87	6089	6478	11.0	59.0
234	Black Steel	92	6521	6663	10.5	60.7
205	Epoxy, Both Mats	18	106	135	100.5	1.23
206	Epoxy, Both Mats	22	115	140	90.3	1.28
235	Epoxy, Both Mats with 0.80% Damage	22	122	139	56.6	1.26
203	Epoxy, Top Only	25	301	362	53.0	3.29
204	Epoxy, Top Only	43	722	876	43.5	7.98
207*	Epoxy, Top Only and 0.80% Bare	75	516	534	100.5*	4.86
208	Same as 207	29	477	518	36.3	4.71
209	Epoxy, Top Only and 0.22% Bare	28	273	311	54.8	2.84
210	Same as 209	36	334	381	63.7	3.47

* Slabs 201 and 207 are debonded between lifts, and therefore, were not included in the averages.

Table 5

B. Calcium Nitrite and Control Slabs (Black (uncoated) Steel)

Slab No.	2.75% Calcium Nitrite	No. Cl^-/yd^3 in Fresh Concrete	Ave. Driving Voltage mV	Ave. 70 F Corrosion Current µA	Weighted Ave. 70 F Corrosion Current µA	Ave. 70 F Mat-to-Mat Resistance ohms	70 F Metal Consumed Per Year, grams
(A) PONDED SLABS							
211	NO	0	16	498	898	10.0	8.2
216	YES	0	0	0	0	7.3	0.0
213	NO	5	61	2537	3558	10.5	32.4
214	NO	5	26	1248	2072	10.5	18.9
218*	YES	5	13	719*	863*	8.3	7.9*
219	YES	5	2	176	272	8.2	2.5
220	YES	10	2	152	209	8.1	1.9
221	YES	10	2	88	158	8.1	1.4
222	YES	15	2	147	188	9.4	1.7
223**	YES	15	12	147	200	32.8**	1.8
WRG	YES	15	12	638	729	7.9	6.6
224	YES	20	14	571	661	11.2	6.0
225	YES	20	18	944	891	10.2	8.1
226	YES	25	26	1522	1,832	8.3	16.7
227	YES	25	17	1,071	1,299	8.0	11.8
215	NO	35	112	10,502	10,360	9.3	94.4
228	YES	35	22	1,246	1,448	9.0	13.2
(B) SLABS NOT PONDED							
212**	NO	0	0	0	0	28.0**	0.0
217	YES	0	0	0	0	8.6	0.0

* Slab may have contained surface cracks (over rebar) before ponding.

** Resistance measurements indicate these slabs are at least partially debonded between the top and bottom lifts.

TABLE 6.

Total Chloride at Various Depths

A. Epoxy-Coated Rebars and Control Slabs Admixed Chloride Plus Ponding

Slab		Cl^- - Lbs/Yd^3					
No.	Coating	1/16-1/2 inch	1/2-1 inch	1-1½ inch	1½-2 inch	Ave.1/2-2 inch	Variable (average)
201*	None Black Steel	15.3	16.3	15.0	11.0	14.1	15.6
202		15.5	17.9	15.2	11.0	14.7	
234		20.2	15.4	19.0	13.4	16.6	
205	Epoxy Both Mats	17.7	14.5	14.9	14.0	14.5	15.2
206		15.7	14.8	14.2	10.8	13.3	
235		18.1	18.9	19.6	14.8	17.8	
203	Epoxy Top Mat Only	14.0	14.5	14.5	13.0	14.0	14.3
204		14.2	15.5	14.9	10.5	13.6	
207*		15.8	16.2	17.6	13.4	15.7	
208		13.0	15.7	15.6	15.6	15.6	
209		15.9	16.0	14.5	12.5	14.3	
210		11.5	14.2	14.7	13.3	14.1	
Avg. w/ponding		15.6	16.0	14.6	12.8		
Avg. Without Ponding		13.2	13.2	13.2	13.2		
Avg. Salt Due to Ponding		2.4	2.8	1.4	-0.4		

* Not included in variable average because slabs are partially debonded between lifts.

TABLE 6.

Total Chloride at Various Depths

B. Calcium Nitrite and Control Slabs (Black Steel)
Admixed Chloride Plus Ponding

Slab No.	2.75% Calcium Nitrite	Amount Admixed in the Concrete	1/16-1/2 inch	1/2-1 inch	1-1½ inch	1½-2 inch	Ave. 1/2-2 inch	Variable (average)
		Cl⁻ - Lbs/Yd³						
(A) Ponded								
211	No	0	6.2	5.7	3.7	1.4	3.6	3.6
216	Yes	0	5.4	5.8	3.6	1.6	3.7	3.7
213*	No	5	10.4	10.2	8.2	6.4	8.3	7.5
213		5	9.9	8.2	8.4	5.7	7.4	
214		5	7.6	7.0	7.0	6.8	6.9	
218*	Yes	5	8.1	8.8	7.7	6.1	7.5	8.4
218*		5	12.2	11.7	9.7	7.8	9.7	
218		5	10.4	9.6	8.5	6.2	8.1	
219		5	9.2	9.3	9.2	6.8	8.4	
220*	Yes	10	11.9	12.0	11.6	9.6	11.1	11.4
220		10	14.2	13.5	13.2	10.3	12.3	
221		10	11.2	12.6	10.2	9.9	10.9	
222*	Yes	15	16.8	15.6	13.1	11.6	13.4	13.4
223		15	16.2	12.7	14.8	13.9	13.8	-
223		15	15.7	14.3	14.8	15.4	14.8	-
224	Yes	20	15.6	18.1	16.8	15.2	16.7	16.4
225*		20	17.8	18.5	17.1	14.7	16.8	
225		20	20.9	17.3	16.0	13.7	15.7	
226	Yes	25	20.9	15.2	19.8	15.3	16.8	18.5
227		25	25.6	23.1	21.6	15.8	20.2	
215	No	35	35.6	26.0	26.1	17.7	23.3	23.3
228	Yes	35	24.9	24.2	22.1	21.6	22.6	22.6
(B) Not Ponded								
212		0	-	-	-	-		
217		0	0.7	0.3	0.2	0.3		

* Concrete samples taken at locations near the rust spots.

** Cracked between lifts, therefore not included in variable average.

TABLE 7

Summary of Corrosion Currents-Control (Black Steel) Slabs

Control Slab No.	Ave. Cl^- At Top Rebar Level, Lbs Cl^-/yd^3	Weighted Ave. 70 F Corrosion Current, μA
211	3.6	898
213, 214	7.5	2,815
202, 234	15.6	6,570
215	23.3	10,360

TABLE 8

Summary of Corrosion Currents - Epoxy Rebar Vs. Control (Black Steel) Slabs

Epoxy Bar Slabs	Variable	Ave. Cl^- At Top-Rebar Level Lbs Cl^-/yd^3	Weighted Ave. 70 F Corrosion Current, μ A		Ratio Control/ Epoxy
			Epoxy Bar	Black Steel*	
205, 206, 235	Both Mats Coated	15.2	138	6340	46 to 1
203, 204, 208, 209, 210	Top Mat Coated Only	14.3	490	5920	12 to 1

* From Figure 5

TABLE 9

Summary of Corrosion Currents - Nitrite Slabs Vs. Control (Black Steel) Slabs

Nitrite Slabs	Ave. Cl$^-$ At Top Rebar Level lbs Cl$^-$/yd^3	Theo. Cl$^-$ to NO$_2^-$ Ratio	Weighted Ave. 70 F Corrosion Current µA**		Ratio No Nitrite/ Nitrite
			Nitrite Slabs	No Nitrite	
216	3.7	0.29	0	900	∞ to 1
219	8.4	0.67	272*	3120	11.5 to 1*
220, 221	11.4	0.90	184	4540	24.5 to 1
222	13.4	1.06	188	5490	29 to 1
224, 225	16.4	1.30	776	6910	9 to 1
226, 227	18.5	1.47	1566	7910	5 to 1
228	22.6	1.79	1488	9850	7 to 1

* Slab 218 which appears to be an outlyer has been excluded. If it is included, the nitrite average = 568 µA and Ratio = 5.5 to 1.

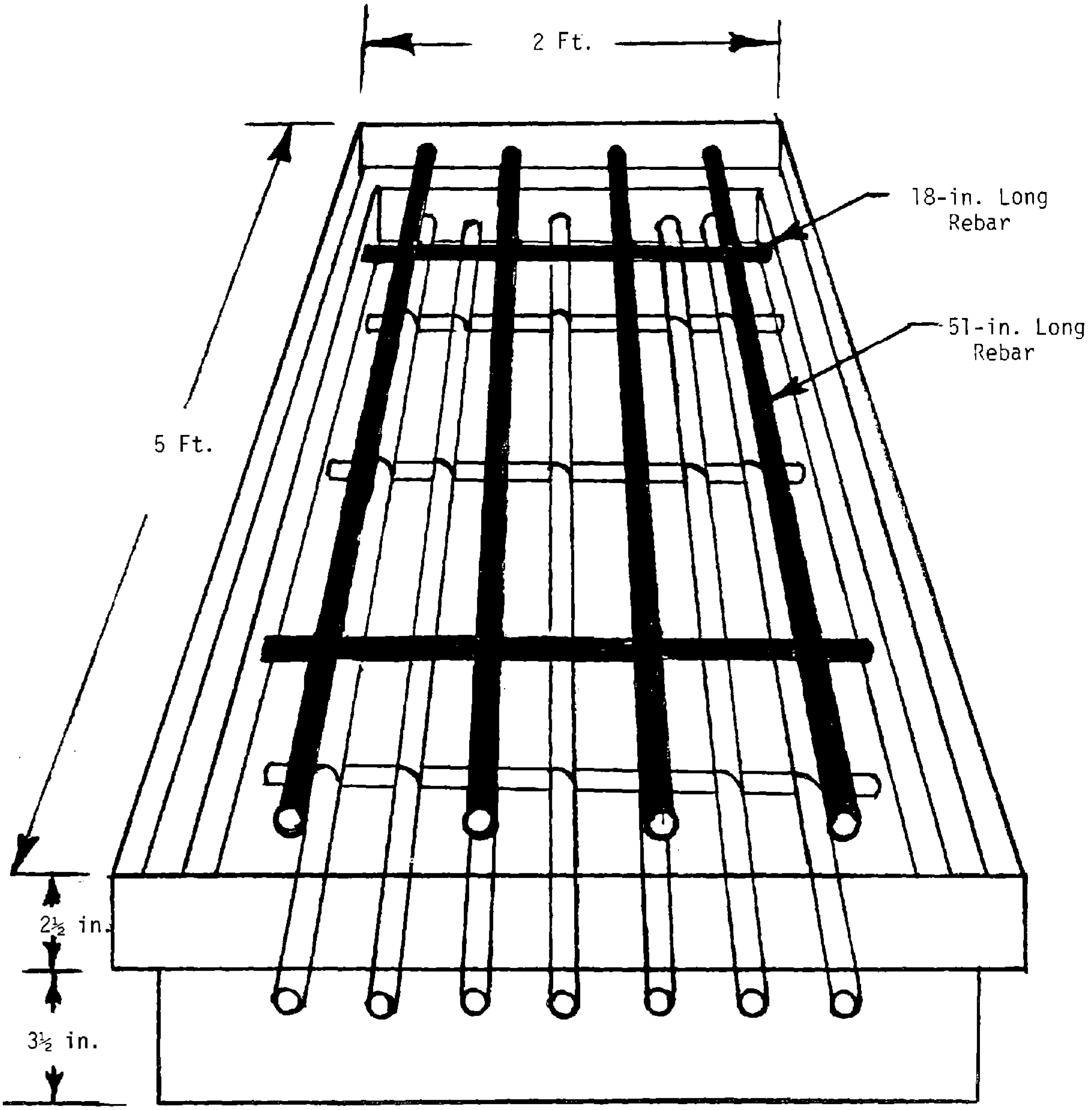
** From Figure 5.

Table 10. Average Electrical Half Cell Potentials

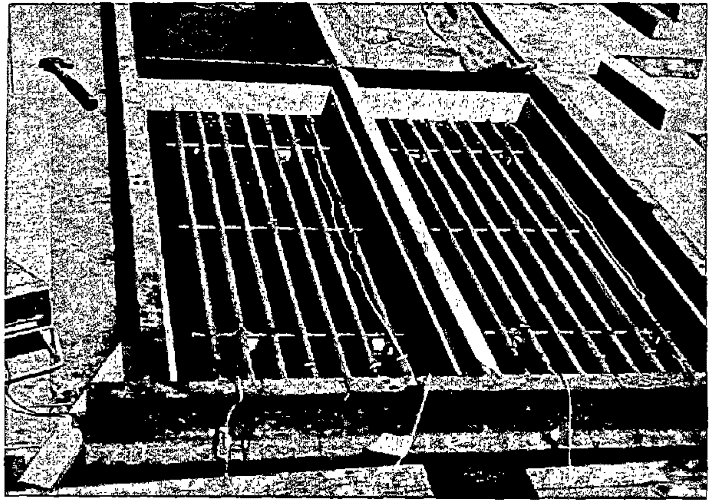
Slab Number	Variable	Ave. Electrical Potentials mV CSE Top Mat	Ave. Electrical Potentials mV CSE Bottom Mat	Average Potential Difference, mV	
201*	Black Steel	-503	-216	-287	
202	Black Steel	-479	-243	-236	-231
234	Black Steel	-532	-307	-225	
203	Epoxy, Top only	-251	-140	-111	-120
204	Epoxy, Top Only	-297	-154	-143	
207 *	Epoxy, Top only & 0.86% bare	-364	-173	-191	
208	Same as 207	-263	-140	-123	
209	Epoxy, Top only & 0.24% bare	-269	-160	-109	
210	Same as 209	-248	-133	-115	
205	Epoxy, Both Mats	-342	-244	-98	-122
206	Epoxy, Both Mats	-383	-263	-120	
235	Epoxy, Both Mats & 0.86% bare	-465	-316	-149	

* Slabs 201 and 207 are debonded between lifts, and therefore, were not included in averages.

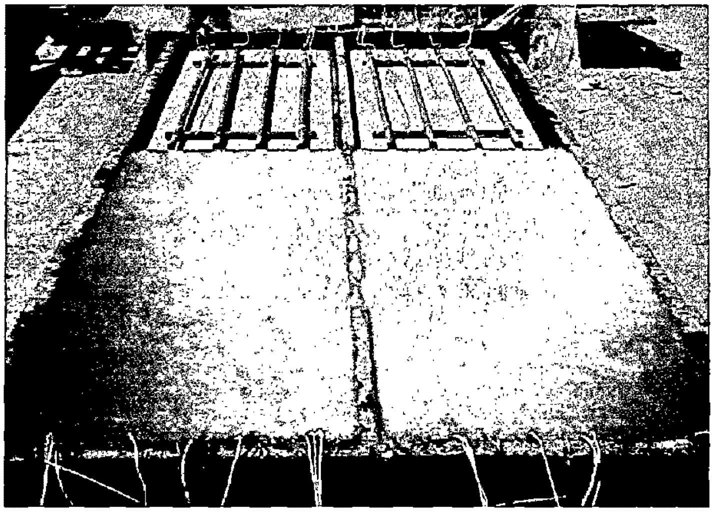
Figure 1. Standard Slab Design



Bottom-Rebar Mats



Top-Rebar Mat and Completed Slab



Bare Area on Epoxy Coated Rebar

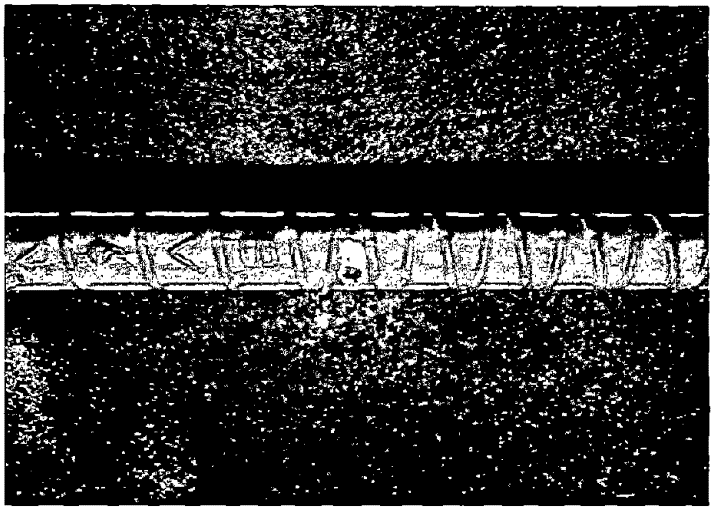
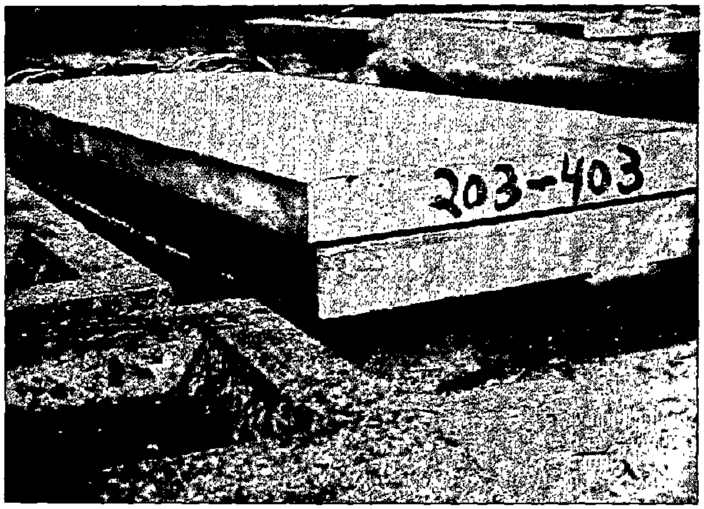
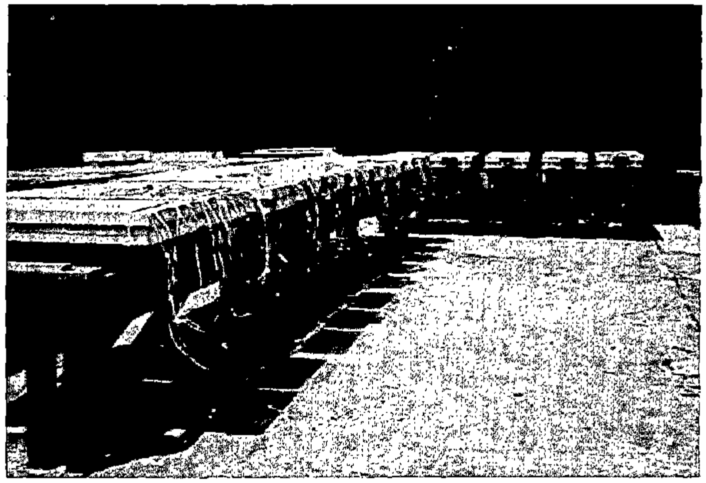


Figure 2. Slab Fabrication

Finished Slab



Slabs at Outdoor Test Yard Before Wiring



Slabs at Outdoor Test Yard After Wiring

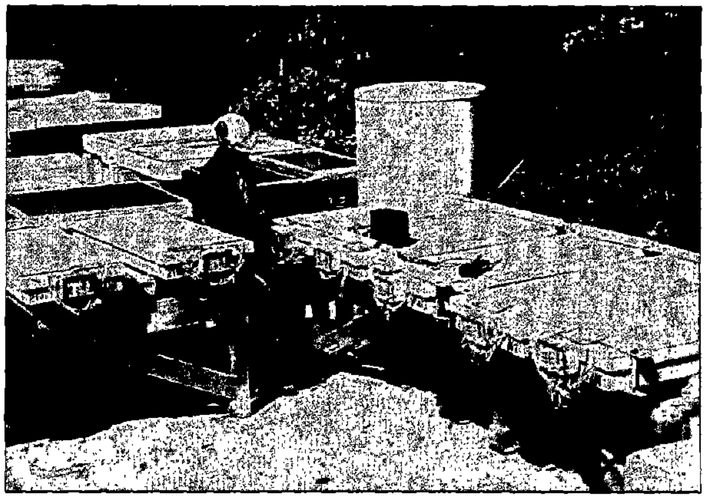
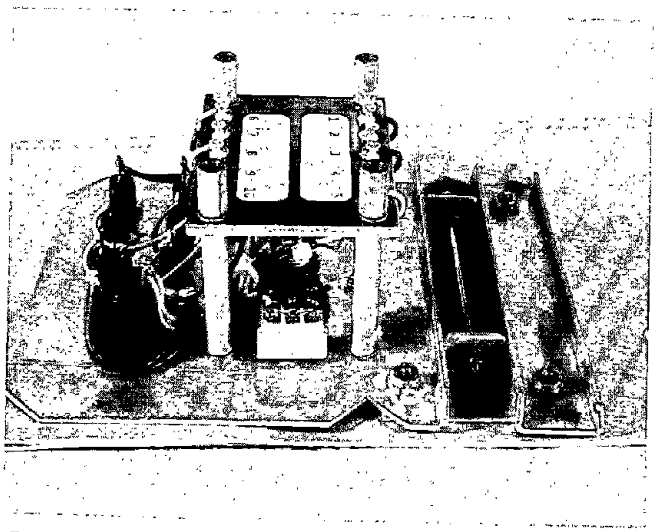
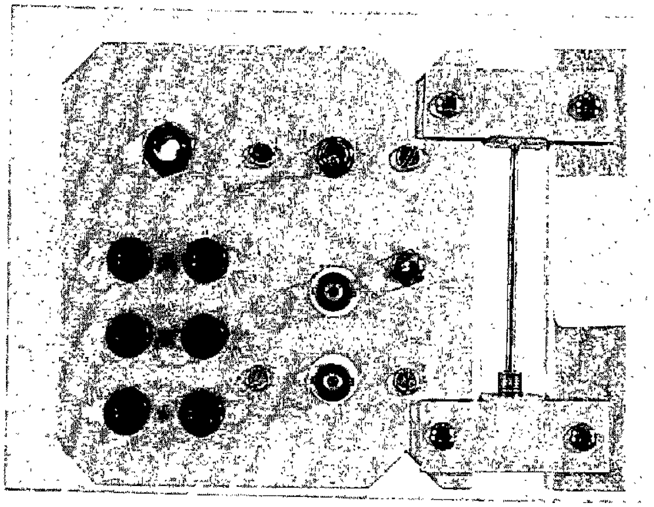


Figure 3. Completed Slabs

Rear



Front



Front After Wiring

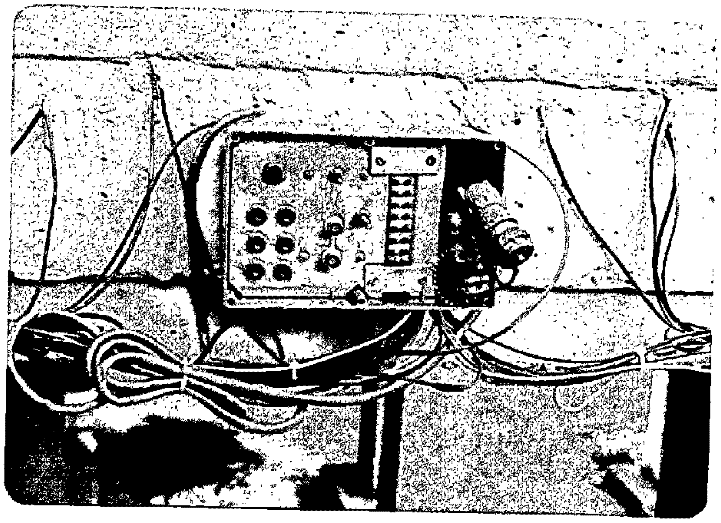
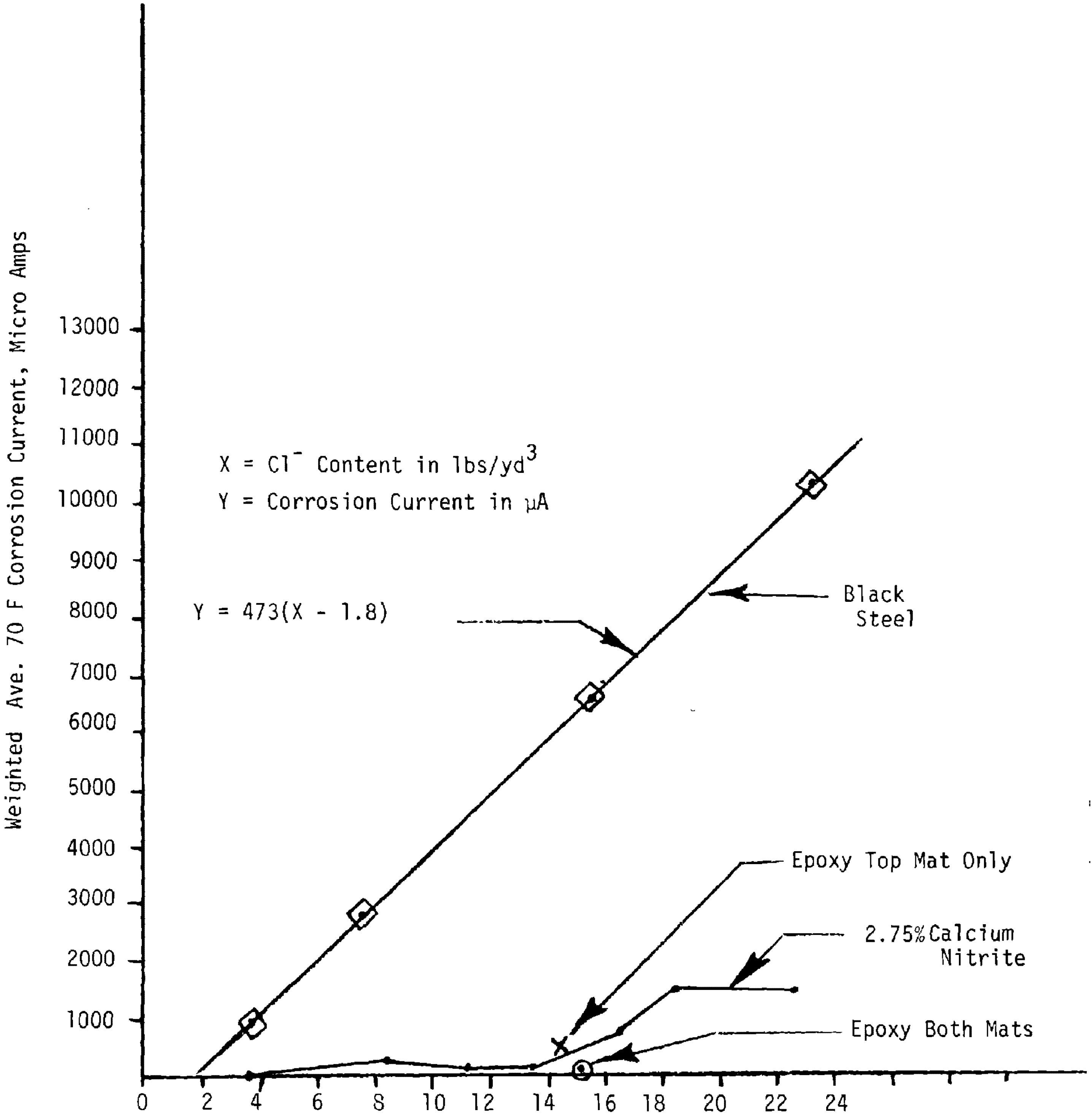


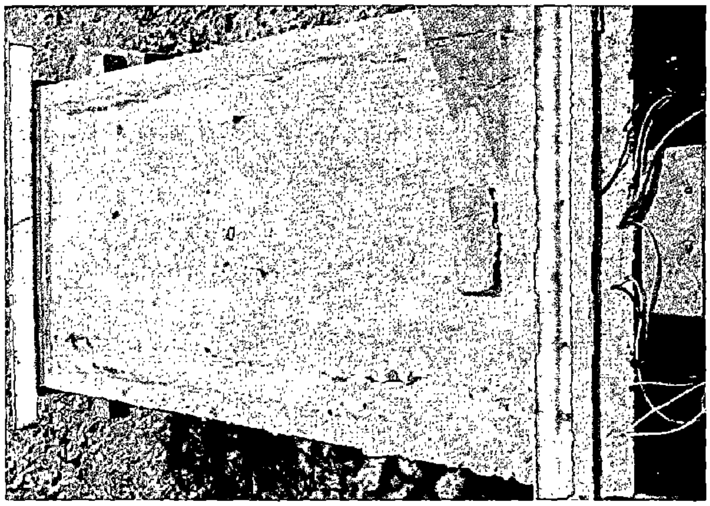
Figure 4. Instrumentation Interface Box

FIGURE 5
Corrosion Current VS. Chloride in Concrete Slabs
At Reinforcing Steel Level

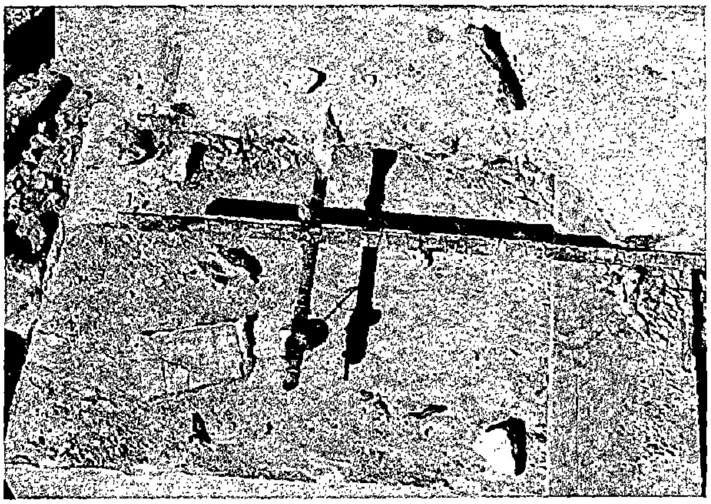


Rebar Level Chloride Content, lbs Cl^-/yd^3

Slab 201: Black Steel Both Mats, 15.0 lbs Cl^-/yd^3



Slab 201: Demolished, Visible Rust on Iron Rebar Mat



Slab 201: Demolished, Concrete With Rebar Rust Imprint

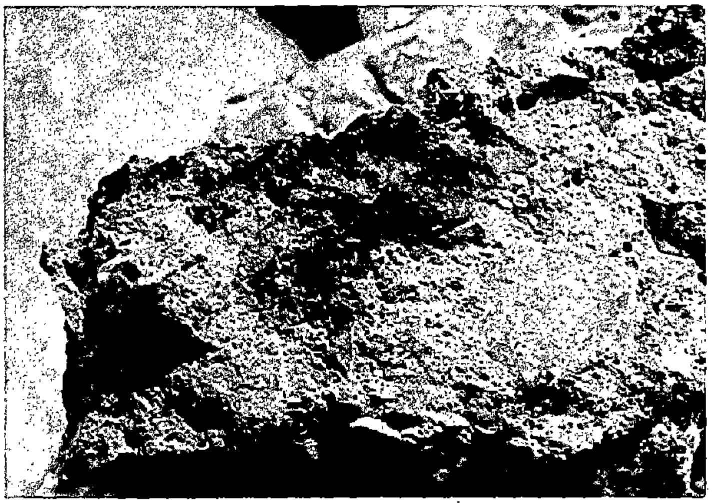
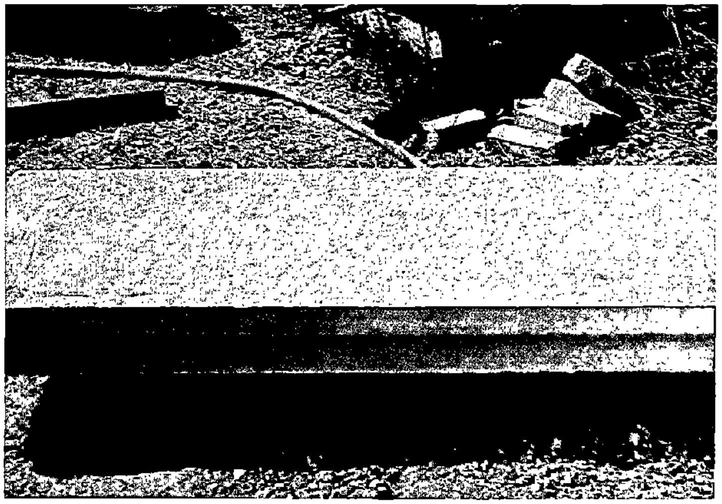
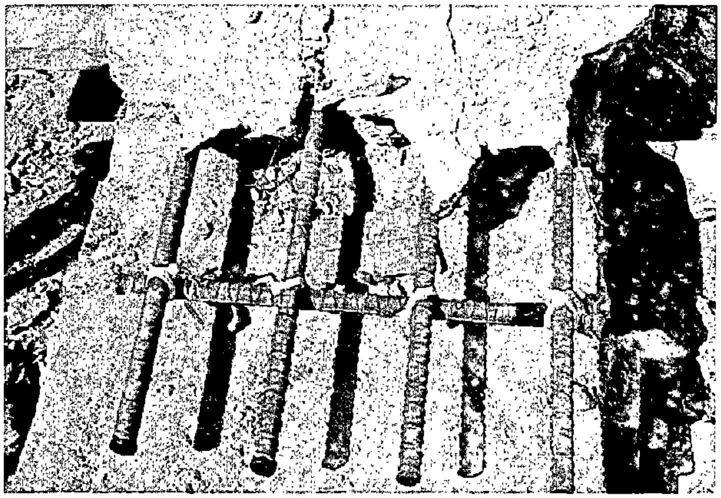


Figure 6. Slab Demolition and Findings

Slab 204: Epoxy-Coated With Holidays,
Top Mat Only, 14.9 lbs Cl^-/yd^3



Slab 204: Demolished, No Visible Rust on
Epoxy-Coated Rebars



Slab 204: Demolished Concrete With Rebar
Imprint But No Corrosion Except
at a Single Bare Area

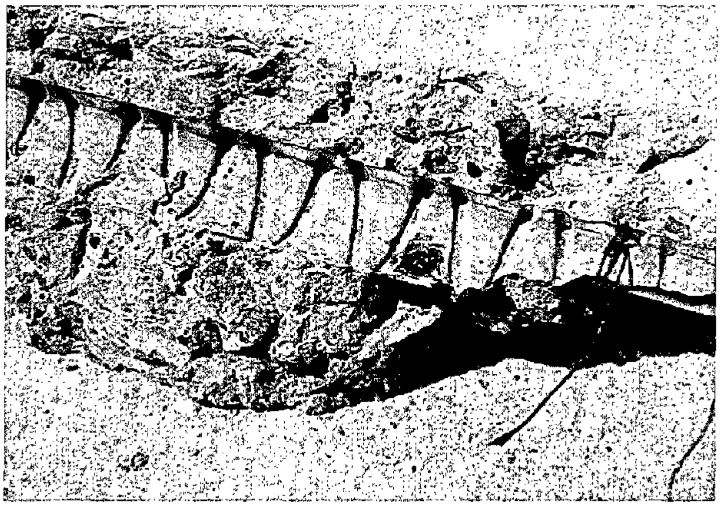
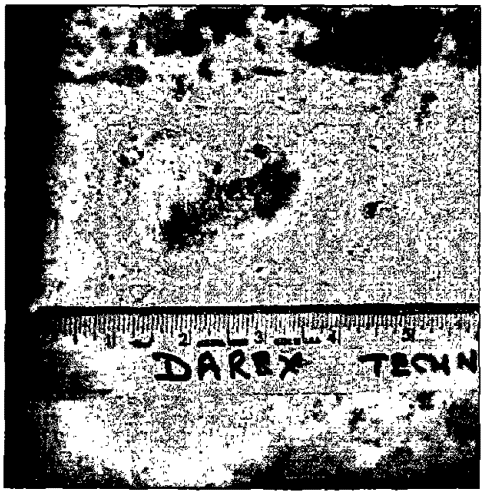


Figure 6. Slab Demolition and Findings

Slab WGR: Black Steel, Both mats, 2.75 percent Calcium Nitrite, 15.0 Cl^-/yd^3

Slab WRG: Visible Rust Spot on Top of Concrete Surface



Slab WRG: Exposed Rebar Below Rust Spot

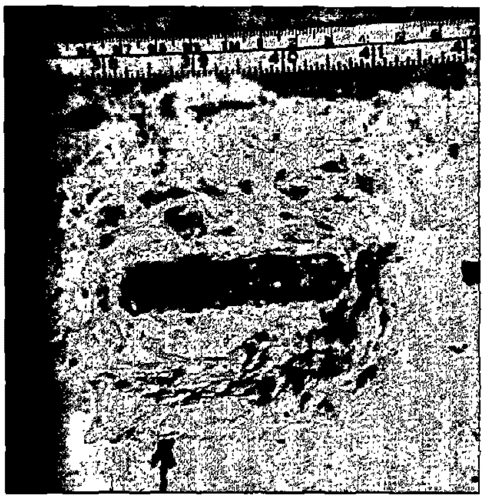
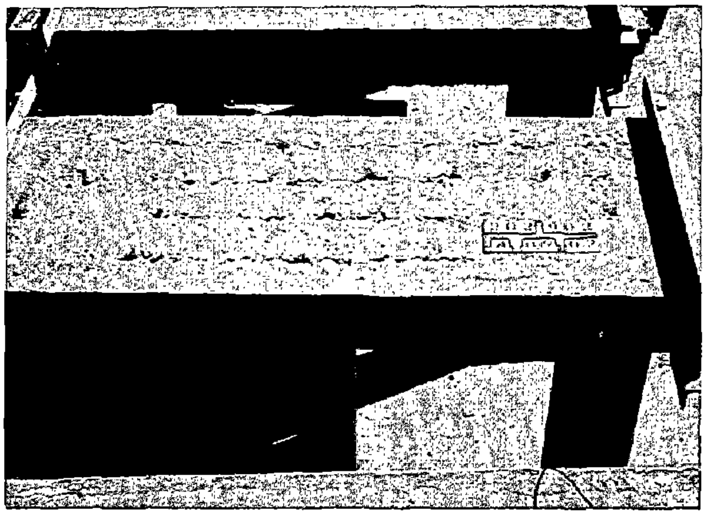
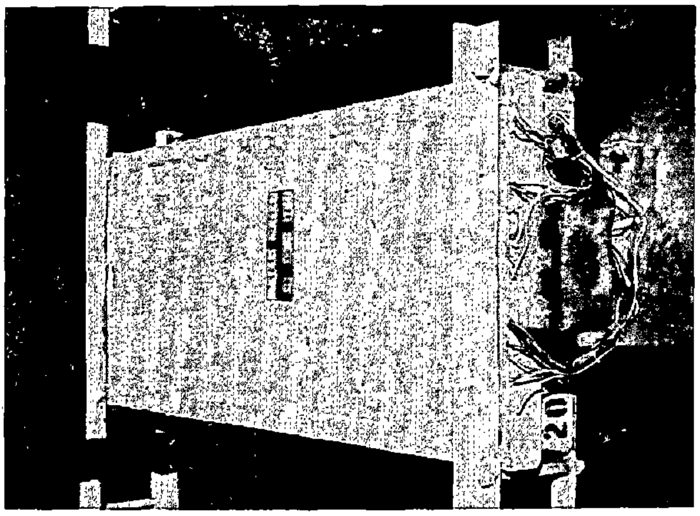


Figure 6. Slab Demolition and Findings

Slab 202: Black Steel, Both Mats, 15.2 lbs Cl^-/yd^3



Slab 206: Epoxy-Coated With Holidays, Both Mats, 14.2 lbs Cl^-/yd^3



Slab 235: Epoxy-Coated With Holidays, 0.80 Bare Area, Both Mats, 19.6 lbs Cl^-/yd^3

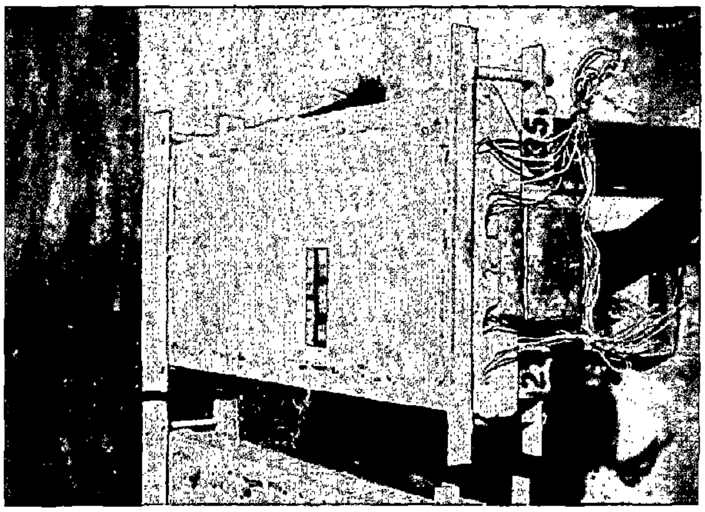
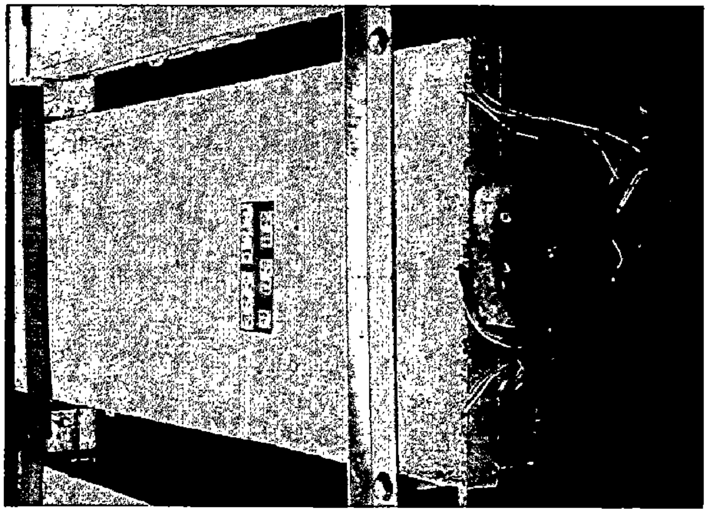
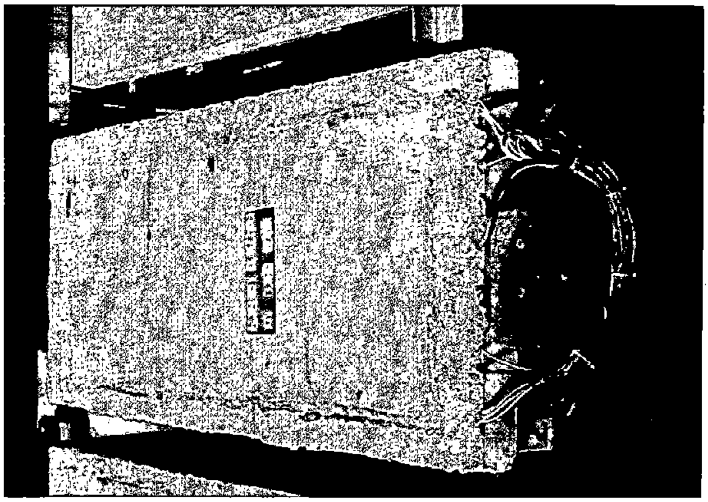


Figure 7. Condition of Few Remaining Slabs in April 1982

Slab 222: Black Steel, Both Mats, 2.75 percent Calcium Nitrite, 13.1 lbs Cl$^-$/yd^3



Slab 224: Black Steel, Both Mats, 2.75 percent Calcium Nitrite, 16.8 lbs Cl$^-$/yd^3



Slab 226: Black Steel, Both Mats, 2.75 percent Calcium Nitrite, 19.8 lbs Cl$^-$/yd^3

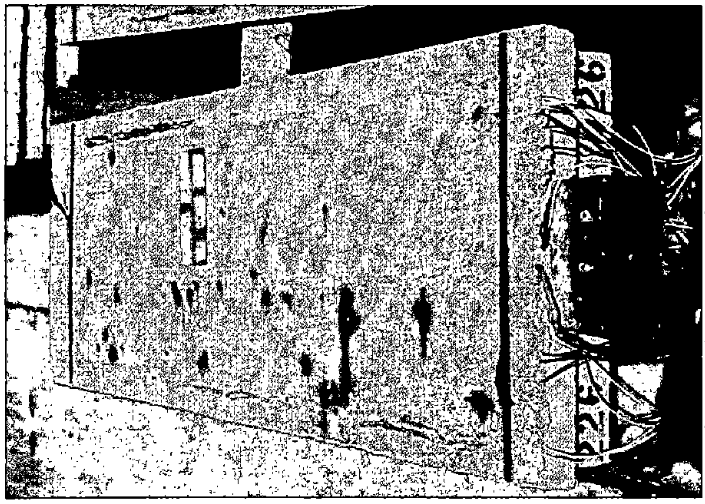


Figure 7. Condition of Few Remaining Slabs in April 1982

Appendix

Corrosion Rate and Electrical Potential Data

A complete listing of the corrosion rate and electrical potential data collected during these studies is contained in the tables which follow for each test slab, the corrosion rate tables contained the following information.

1. Date the data were obtained.
2. Days under test in this study (i.e., days the rebar mats have been coupled).
3. The measured driving voltage of the corrosion macrocell, ΔV in mV (millivolts).
4. The measured macrocell corrosion current, i_{ACTUAL} in μA (microamperes).
5. The measured corrosion current adjusted to 70 F (21 C) using the temperature data listed and the formula listed in the text, i_{70} in μA.
6. The measured top mat to bottom mat 1000 cycle AC electrical resistance adjusted to 70 F (21 C), R_{70} in ohms.

Note: The lead wires which electrically connect the two rebar mats are uncoupled prior to this measurement. The formula utilized to adjust the measured resistance to 70 F (21 C) is:

$$R_{70} = R_2 e^{2883\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}$$

where:

R_2 = measured resistance at field temperature.

T_1 = 70 F (21 C) expressed in degrees Kelvin (294.1K)

T_2 = average field temperature in degrees Kelvin.

e = natural or naperian base of logarithms

The actual measured resistance can be calculated by solving the above equation for R_2. Also, the concrete resistivity for uncoated rebar slabs can be calculated by multiplying the resistance values by experimentally defined cell constants (735 for slabs with No. 4 and No. 5 bars and 706 for the slab with No. 6 bars). These constants were determined by placing duplicates of the entire rebar system (in the exact configuration used in the slab) in solutions of known resistivity and then measuring the resistance. The constants are not valid for slabs with epoxy-coated rebars.

7. The approximate temperature of the concrete between the two mats of reinforcing steel.

   Note: Nine thermocouples were contained in each slab. The average concrete temperature between the rebar mats is the average top mat temperature plus the average bottom slab temperature plus two times the average slab mid-depth temperature divided by four.

8. Cumulative amp-hrs of corrosion. This is the area under a plot of I_{70} in amps and time in hours in which all data points are connected by straight lines. It is calculated by multiplying the average 70 F (21 C) corrosion current for each two successive readings by the time between the readings, and accumulating a total. For the initial calculation (that between zero time and data point 1) the corrosion current is assumed to be constant at the data point one measured value. When more than one data point was available for a single day, that day's data were averaged prior to the cumulative amp-hrs calculation.

   The actual average corrosion current (called the weighted average) during the test period can be calculated by dividing the total cumulative amp-hours by the test time in hours and multiplying by 1 million to convert to micro-amps. This value is more representative than the arithmetic average of the measured values since the time between measurements was not constant.

9. 70 F (21 C) metal consumed, grams. These data are obtained by multiplying cumulative amp-hours by 1.04 grams/amp-hour when iron corrosion is occurring.

Following the tabulation of the data for each slab, the data are reduced to averages to allow easier comparison. The chloride contents shown are the study design chloride values. See the main report for actual measured chloride values.

The electrical potential data obtained during the study are presented in the tables following the corrosion rate data and are discussed in the body of this report. All half-cell potentials are referenced to the copper-copper sulfate electrode.

Slab No: 201-401

Variable Black Steel, Both Mats, 15 lb Cl$^-$/yd^3 1/ Top Lift

Days	ΔV mV	i actual μA	i_{70} 2/ μA	R_{70} Ω	Approx. Actual Temp. °C	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (8/7/80)				19.2	22.9		
21		5380	3322	14.9	36.3	1.674	1.74
28		2970	2767	14.8	23.2	2.185	2.27
54		1520	1862	49.2	15.1	3.629	3.77
61		1140	1748	58.4	8.8	3.932	4.09
81		1370	1947	74.0	10.9	4.819	5.01
91		1980	3182	47.9	7.5	5.424	5.64
119	140	2650	4363	30.4	6.9	7.959	8.28
167	140	3230	4382	27.8	12.2	12.996	13.52
202	138	1370	2689	46.9	2.2	15.966	16.60
229	123	940	1941	57.3	0.8	17.466	18.16
256	138	2020	3051	40.8	9.2	18.365	19.10
271	132	1370	2272	54.3	6.7	19.323	20.10
295	145	5390	5689	22.1	19.5	20.852	21.69
350	175	3100	2202	71.9	31.7	26.060	27.10
AVERAGE	141	2459	2958	42.0	14.3		
Weighted Ave.			3102				

Note: This slab is cracked between lifts.

1/ C = 5/9 F - 32

2/ lb/yd^3 = 0.5933 Kg/m^3

Slab No: 202-402

Variable: Black Steel, Both Mats, 15 lb Cl$^-$/yd^3 Top Lift

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (8/7/80)				10.6	23.3		
21		8300	4996	12.4	37.2	2.518	2.62
28		4400	4082	11.9	23.4	3.281	3.41
54		3940	4663	11.5	16.1	6.009	6.25
61		3150	4641	11.5	9.9	6.791	7.06
81	80	4030	5686	11.0	11.1	9.269	9.64
91		5220	8399	9.8	7.5	10.959	11.40
119	100	5570	9045	9.3	7.2	16.820	17.49
167	100	6220	8456	9.5	12.2	26.901	27.98
202	83	3330	6402	10.2	2.7	33.141	34.47
229	71	2610	5088	10.9	2.4	36.864	38.34
256	80	4080	5804	10.8	10.9	40.393	42.01
271	69	3170	5066	11.4	7.7	42.350	44.04
295	102	6870	7228	11.1	19.6	45.891	47.73
350	95	8240	5692	12.6	32.6	54.418	56.59
AVERAGE	87	4938	6089	11.0	14.9		
Weighted Ave.			6478				

Slab No: 234-434

Variable: Black Steel, Both Mats, 15 lb Cl^-/yd^3 Top Lift

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/28/20)				8.4	11.1		
1		2610	4667	8.8	4.6	0.063	0.07
9		6430	8062	8.5	14.5	1.285	1.34
37	80	4710	7236	9.0	8.8	5.425	5.64
85	90	5650	7438	9.2	13.1	13.877	14.43
120	81	3980	6858	9.5	5.6	19.881	20.68
147	83	4980	5934	10.4	15.9	24.026	24.99
160		9510	6742	11.2	30.8	26.003	27.04
174	84	4590	5636	11.4	15.1	28.083	29.21
189	71	3380	5202	11.5	8.7	30.034	31.21
203	131	12330	8140	12.6	34.1	32.275	33.5
228	118	10200	5817	15.3	39.0	36.462	37.9
AVERAGE	92	6188	6521	10.5	16.8		
Weighted Ave.			6663				

Slab No: 203-403

Variable: Epoxy Coated with holidays, Top mat only

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (8/7/80)				87.1	23.5		
21		270	162	59.6	37.3	0.082	0.09
28		90	83	72.5	23.5	0.102	0.11
54		70	82	61.9	16.5	0.154	0.16
61		50	73	58.0	10.0	0.167	0.17
81	11	90	127	53.4	11.2	0.215	0.22
91		130	205	40.5	8.0	0.254	0.26
119	20	300	485	29.7	7.3	0.486	0.51
167	40	590	811	35.4	11.8	1.232	1.28
202	34	310	606	34.6	2.3	1.827	1.90
229	32	240	467	39.1	2.4	2.175	2.26
256	26	270	383	40.9	11.0	2.450	2.55
271	19	170	266	47.1	8.3	2.567	2.67
295	23	270	284	52.0	19.6	2.725	2.83
350	22	260	182	82.5	32.3	3.033	3.15
AVERAGE	25.2	222	301	53.0	15.0		
Weighted Ave.			362				

Slab No: 204-404

Variable: Epoxy coated with holidays, Top mat only

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (8/7/80)				56.3	23.8		
21		640	368	61.1	38.7	0.185	0.19
28		220	204	66.9	23.4	0.233	0.24
54		170	195	57.9	17.0	0.358	0.37
61		140	207	53.5	9.8	0.397	0.41
81	13	190	262	50.3	11.7	0.510	0.53
91		230	353	37.5	8.8	0.584	0.60
119	40	950	1473	22.1	8.5	1.198	1.25
167	70	1270	1760	26.1	11.6	3.060	3.18
202	55	680	1302	30.1	2.8	4.346	4.52
229	49	510	951	34.4	3.5	5.076	5.28
256	48	650	903	35.6	11.6	5.677	5.90
271	40	470	738	39.2	8.2	5.972	6.21
295	40	860	879	38.0	20.5	6.438	6.70
350	31	760	512	44.0	33.5	7.356	7.65
AVERAGE	43	553	722	43.5	15.6		
Weighted Ave.			876				

Slab No: 205-405

Variable: Epoxy Coated with Holidays, both mats

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (8/7/80				98.8	23.7		
21		60	35	109.9	38.3	0.018	0.019
28		30	28	119.7	23.7	0.023	0.024
54		30	34	119.1	17.9	0.042	0.044
61		20	28	115.2	11.4	0.047	0.049
81	16	70	88	107.9	14.3	0.075	0.078
91		60	91	89.2	9.2	0.096	0.10
119	30	210	323	70.3	8.7	0.235	0.24
167	40	280	387	61.6	11.7	0.644	0.67
202	22	110	212	80.0	2.7	0.896	0.93
229	12	30	55	90.4	4.0	0.983	1.02
256	12	50	70	100.1	11.6	1.024	1.06
271	8	10	16	112.8	7.6	1.039	1.08
295	14	60	62	107.7	20.4	1.061	1.10
350	12	80	54	124.6	33.7	1.138	1.18
AVERAGE	18	79	106	100.5	15.9		
Weighted Ave.			135				

Slab No: 206-406

Variable: Epoxy coated with holidays, Both mats

Days	ΔV mV	i actual µA	i_{70} µA	R_{70} Ω	Approx. Actual Temp. °C	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (8/7/80)				109.3	24.0		
21		60	34	120.9	38.9	0.017	0.018
28		40	37	127.0	23.9	0.023	0.024
54		40	44	110.7	18.6	0.048	0.050
61		40	53	105.0	13.1	0.056	0.058
81	16	70	86	96.2	14.9	0.089	0.093
91		70	98	79.7	11.4	0.111	0.12
119	40	210	310	60.6	9.9	0.248	0.26
167	40	240	316	67.3	13.1	0.609	0.63
202	26	110	212	62.2	2.6	0.831	0.86
229	18	50	82	77.6	7.0	0.926	0.96
256	17	60	86	77.2	10.6	0.980	1.02
271	11	30	49	86.6	7.0	1.004	1.04
295	16	100	101	82.5	20.7	1.047	1.09
350	17	150	101	91.8	33.6	1.180	1.23
AVERAGE	22.3	91	115	90.3	16.6		
Weighted Ave.			140				

Slab No: 235-435

Variable: Epoxy coated with holidays and 0.80% Bare area, both mats

Days	ΔV mV	i actual µA	i_{70} µA	R_{70} Ω	Approx. Actual Temp. °C	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/28/80)				48.1	11.0		
1		30	54	51.0	4.7	0.001	0
9		70	87	44.1	14.6	0.014	0.015
37	20	100	150	46.5	9.4	0.094	0.098
85	30	160	213	47.0	12.8	0.303	0.32
120	21	70	119	49.7	6.0	0.442	0.46
147	26	110	127	55.6	16.8	0.522	0.54
160		230	172	56.6	30.2	0.569	0.59
174	22	100	123	61.9	15.0	0.619	0.64
189	14	40	64	65.5	7.8	0.653	0.68
203	25	250	167	65.2	33.8	0.692	0.72
228	18	120	70	87.8	38.3	0.763	0.79
AVERAGE	22	116	122	56.6	16.7		
Weighted Ave.			139				

Slab No: 207-407

Variable: Epoxy coated with holidays and 0.80% bare area top mat only

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (8/7/80)				54.2	24.2		
21		1270	716	44.7	39.4	0.361	0.38
28		550	502	46.0	23.9	0.463	0.48
54		530	567	57.1	19.1	0.797	0.83
61		420	526	76.8	14.5	0.889	0.92
81	70	360	443	104.7	15.0	1.122	1.17
91		290	410	106.7	11.1	1.224	1.27
119	70	410	602		10.0	1.564	1.63
167	80	620	817	71.6	13.1	2.381	2.48
202	83	350	652	101.6	3.5	2.998	3.12
229	73	390	603	85.2	8.6	3.405	3.54
256	80	360	491	110.9	12.1	3.759	3.91
271	71	200	316	167.8	8.0	3.904	4.06
295	78	350	356	159.9	20.6	4.097	4.26
350	70	340	229	219.8	33.5	4.483	4.66
AVERAGE	75	460	516	100.5	17.1		
Weighted Ave.			534				

Note: This slab is cracked between lifts.

Slab No: 208-408

Variable: Epoxy coated with holidays and 0.80% bare area top mat only

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (8/7/80)				41.0	24.6		
21		860	523	43.7	36.8	0.264	0.27
28		360	325	49.8	24.2	0.335	0.35
54		320	354	38.7	18.1	0.547	0.57
61		270	287	40.8	19.3	0.601	0.63
81	16	290	335	42.1	16.9	0.750	0.78
91		230	338	35.6	10.0	0.831	0.86
119	30	390	647	28.9	6.6	1.162	1.21
167	40	540	747	31.8	11.7	1.965	2.04
202	31	330	636	32.9	2.7	2.546	2.65
229	29	350	522	36.0	9.6	2.921	3.04
256	31	410	517	38.9	14.3	3.258	3.39
271	25	290	453	39.3	8.3	3.433	3.57
295	26	460	457	40.4	21.3	3.695	3.84
350	35	860	535	43.2	36.1	4.350	4.52
AVERAGE	29	401	477	36.3	17.4		
Weighted Ave.			518				

Slab No: 209-409

Variable: Epoxy coated with holidays and 0.22% bare areas, Top mat only.

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (8/7/80)				67.8	24.9		
21		280	165	61.8	37.9	0.083	0.086
28		100	89	74.9	24.5	0.104	0.11
54		100	96	66.3	22.3	0.162	0.17
61		90	91	61.7	20.8	0.178	0.19
81	15	130	146	62.5	17.8	0.235	0.24
91		140	202	53.6	10.5	0.277	0.29
119	20	190	313	39.9	6.8	0.450	0.47
167	30	290	395	41.1	12.1	0.858	0.89
202	33	260	489	39.7	3.3	1.229	1.28
229	39	350	452	45.5	13.6	1.534	1.60
256	27	260	330	50.7	14.1	1.787	1.86
271	25	210	327	49.9	8.4	1.905	1.98
295	32	590	450	47.8	29.4	2.129	2.21
350	29	450	283	58.4	35.7	2.613	2.72
AVERAGE	28	246	273	54.8	18.8		
Weighted Ave.			311				

Slab No: 210-410

Variable: Epoxy coated with holidays and 0.22% bare area, top mat only

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (8/7/80)				60.6	25.6		
21		310	178	69.6	38.7	0.090	0.09
28		120	106	81.4	24.8	0.114	0.12
54		140	133	73.3	22.6	0.189	0.20
61		170	162	71.1	22.5	0.214	0.22
81	19	180	199	70.0	18.2	0.301	0.31
91		160	221	51.3	11.6	0.351	0.37
119	30	290	472	43.4	7.2	0.584	0.61
167	40	410	567	53.9	11.7	1.182	1.23
202	43	290	537	51.6	3.7	1.646	1.71
229	43	400	490	58.7	15.1	1.979	2.06
256	40	350	439	65.9	14.5	2.280	2.37
271	33	250	383	64.6	8.9	2.428	2.53
295	42	670	489	61.9	30.9	2.679	2.79
350	31	490	299	77.8	36.8	3.199	3.33
AVERAGE	36	302	334	63.7	19.5		
Weighted Ave.			381				

Data On Slab No.: 211-411

Variable : Black Steel, no calcium nitrite, 0 Cl^-/yd^3, Ponded

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/8/80)				15.4	13.6	0	
2		0	0	10.3	15.0	0	
8		0	0	9.3	11.7	0	
14		0	0	9.0	7.8	0	
30		0	0	9.1	15.0	0	
44		0	0	8.9	11.1	0	
61	0	0	0	8.4	10.1	0	
106	30	140	299	8.0	0.0	0.323	0.34
141	8	580	746	8.7	13.8	0.762	0.79
169	12	720	863	9.4	15.8	1.303	1.355
201	14	840	1114	9.8	12.9	2.062	2.14
272	30	2900	1805	11.7	36.0	4.549	4.73
366	19	1000	1153	12.6	16.9	7.886	8.20
AVERAGE	16	515	498	10.0	13.8		
Weighted Ave.			898				

Slab No.: 216-416

Variable: Black Steel. 2.75% calcium nitrite, 0 Cl^-/yd^3 Ponded

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/8/80)				8.5	19.1	0	0
2	0	0	0	8.8	14.7	0	0
8		20	25	7.4	14.9	0	0
14		0	0	6.9	11.1	0	0
30		0	0	6.4	20.2	0	0
44	0	0	0	6.0	13.2	0	0
61	0	0	0	6.0	18.7	0	0
106	0	0	0	5.4	3.3	0	0
141	0	0	0	6.0	15.4	0	0
169	0	0	0	6.7	19.0	0	0
201	0	0	0	7.4	16.5	0	0
272	0	0	0	9.8	43.3	0	0
366	0	0	0	9.6	22.4	0	0
AVERAGE	0	0	0	7.3	17.8	0	0
Weighted Ave.			0				

Slab No.: 213-413

Variable : Black Steel, no nitrite, 5 lb Cl^-/yd^3 top lift

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/8/80)				12.0	14.1	0	0
2		20	25	10.7	14.8	0.001	0
8		120	160	10.0	12.8	0.014	0.02
14		320	491	9.8	8.8	0.061	0.063
30		1140	1353	9.7	16.1	0.415	0.43
44	100	1130	1536	9.4	12.2	0.900	0.94
61	30	1740	2266	9.8	13.4	1.676	1.74
106		2120	4154	8.7	2.2	5.143	5.35
141	58	3720	4439	9.8	15.9	8.752	9.10
169	57	3140	3563	10.4	17.4	11.441	11.90
201	54	3040	3935	10.4	13.6	14.320	14.89
272		8620	4652	13.0	40.8	21.636	22.50
366	65	3660	3874	12.8	19.4	31.253	32.50
AVERAGE	61	2398	2537	10.5	15.5		
Weighted Ave.			3558				

Slab No.: 214-414

Variable : Black Steel, no nitrite, 5 lb Cl^-/yd^3
top lift

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/8/80)				18.6	15.8	0	0
2		0	0	10.1	14.7	0	0
8		0	0	9.7	13.1	0	0
14		20	30	9.5	9.3	0.002	0
30		40	48	9.4	16.0	0.017	0.02
44	10	70	95	9.3	12.4	0.041	0.04
61		180	231	9.3	13.8	0.108	0.11
106	20	760	1414	8.5	3.6	0.996	1.04
141	25	1700	2065	9.3	15.4	2.457	2.56
169	27	1780	1958	9.9	18.3	3.809	3.96
201	34	2020	2520	9.9	14.6	5.529	5.75
272	18	6580	3501	10.5	40.4	10.744	11.17
366	48	2960	3008	12.5	20.6	18.199	18.93
AVERAGE	26	1343	1248	10.5	16.0		
Weighted Ave.			2072				

Slab No.: 218-418

Variable : Black Steel, 2.75% calcium nitrite, 5 lb Cl^-/yd^3
top lift

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/8/80)				9.7	21.0	0	0
2	0.0	0	0	8.8	14.7	0	0
8		0	0	8.1	16.3	0	0
14		200	279	7.4	11.4	0.020	0.02
30		680	701	7.2	20.2	0.208	0.22
44	20	530	524	8.7	21.4	0.414	0.43
61	20	1180	1210	6.8	20.4	0.768	0.80
106	20	1120	1765	6.2	8.1	2.375	2.46
141	15	1280	1437	6.8	17.7	3.720	3.87
169	12	920	832	8.1	24.2	4.482	4.66
201	11	720	783	8.2	18.6	5.102	5.30
272	12	1300	678	10.7	42.0	6.347	6.60
366	7	460	419	11.2	24.0	7.584	7.89
AVERAGE	13	699	719	8.3	20.0		
Weighted Ave.			863				

Note: This slab exhibited cracking over several top mat rebars <u>before</u> ponding. Therefore, the rebar level chloride content after ponding is undoubtly quite high.

Slab No.: 219-419

Variable : Black Steel, 2.75% calcium nitrite, 5 lb Cl^-/yd^3
top lift

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/8/80)				8.4	21.6	0	0
2	0	0	0	7.8	14.7	0	0
8		0	0	7.6	16.6	0	0
14		0	0	7.0	11.8	0	0
30		0	0	6.6	20.1	0	0
44		110	143	6.1	13.4	0.024	0.02
61		280	289	6.2	20.1	0.112	0.12
106		220	359	5.6	7.1	0.462	0.48
141	3	200	226	15.9	17.5	0.708	0.74
169	3	160	157	9.2	21.6	0.837	0.87
201	3	220	241	7.4	18.4	0.990	1.03
272	1	880	474	9.4	40.9	1.599	1.66
366	.4	240	223	9.8	23.3	2.385	2.48
AVERAGE	2.3	193	176	8.2	19.0		
Weighted Ave.			272				

Slab No.: 220-420

Variable : Black Steel, 2.75% calcium nitrite, 10 lbs Cl^-/yd^3
Top lift

Days	ΔV mV	i actual µA	i_{70} µA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/8/80)				9.6	21.9	0	0
2	0.5	0	0	7.9	14.6	0	0
8		0	0	8.0	17.9	0	0
14		140	193	7.4	11.8	0.014	0.01
30		0	0	7.5	20.2	0.051	0.05
44		130	171	7.1	13.1	0.080	0.08
61		220	226	7.1	20.3	0.161	0.17
106		200	310	6.7	8.5	0.450	0.47
141	1	100	110	7.1	18.3	0.626	0.65
169	3	160	157	7.4	21.7	0.716	0.74
201	3	120	130	8.0	18.8	1.826	0.86
272	1	680	362	10.4	41.3	1.245	1.29
366	3	180	164	11.4	23.8	1.838	1.91
AVERAGE	1.9	161	152	8.1	19.4		
Weighted Ave.			209				

Slab No.: 221-421

Variable : Black Steel, 2.75% calcium nitrite
10 lb Cl^-/yd^3, top lift

Days	ΔV mV	i actual µA	i_{70} µA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/8/80)				8.4	24.2	0	0
2	0.4	0	0	7.9	14.7	0	0
8		0	0	8.0	17.9	0	0
14		0	0	7.6	12.7	0	0
30		0	0	7.5	20.0	0	0
44	0	0	0	7.3	13.2	0	0
61		40	40	7.3	21.2	0.008	0.01
106		100	157	6.6	8.2	0.114	0.12
141	2	100	107	7.2	19.2	0.225	0.23
169	2	80	77	7.4	22.1	0.287	0.30
201	2	140	147	7.9	19.7	0.373	0.39
272	1	680	347	10.4	42.8	0.794	0.83
366	4	200	180	11.3	24.4	1.388	1.44
AVERAGE	1.6	112	88	8.1	20.0		
Weighted Ave.			158				

Slab No.: 222-422

Variable : Black Steel, 2.75% calcium nitrite,
15 lb Cl^-/yd^3, top lift

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/8/80)				9.8	22.0	0	0
2		0	0	8.9	14.7	0	0
8		0	0	9.1	17.6	0	0
14		40	54	8.8	12.6	0.004	0.00
30		180	189	8.6	19.6	0.051	0.05
44		80	108	8.4	12.4	0.101	0.10
61	0	160	165	8.4	20.2	0.157	0.16
106	0	120	185	8.2	8.7	0.346	0.36
141	1	120	137	8.7	17.3	0.481	0.50
169	4	160	162	9.1	20.8	0.581	0.60
201	3	140	151	9.6	18.8	0.701	0.73
272	1	880	467	11.3	41.5	1.228	1.28
366	4			12.9	23.4		
AVERAGE	1.9	171	147	9.4	19.2		
Weighted Ave.			188				

Slab No.: 223-423

Variable : Black Steel, 2.75% calcium nitrite,
15 lb Cl^-/yd^3 Top lift

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/8/80)				24.3	23.3	0	0
2	11	50	61	23.1	15.4	0.003	0
8		40	44	32.8	18.2	0.010	0.01
14		70	92	31.6	13.1	0.02	0.02
30		150	159	29.1	19.4	0.068	0.07
44	10	55	75	28.3	12.3	0.108	0.11
61	10	160	163	19.9	20.7	0.156	0.16
106	10	110	169	28.6	8.8	0.335	0.35
141	7	140	158	31.7	17.6	0.472	0.49
169	3	140	135	23.1	22.3	0.570	0.60
201	11	160	170	38.4	19.3	0.687	0.72
272	27	730	377	49.4	42.4	1.153	1.20
366	15	170	160	66.3	23.1	1.758	1.83
AVERAGE	11.6	165	147	32.8	19.7		
Weighted Ave.			200				

Note: This slab is probably cracked between lifts (based on resistance measurements).

Slab No.: WRG

Variable : Black Steel, 2.75% calcium nitrite, 15 lb Cl^-/yd^3
Top lift

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0	(10/8/80)			7.9	7.8	0	0
2	23	200	256	7.7	13.9	0.012	.01
8		360	317	8.3	25.0	0.053	0.05
14		220	275	7.8	14.5	0.096	0.10
30		400	523	7.2	13.3	0.249	0.26
58	10	460	670	6.8	10.2	0.650	0.68
106	10	500	657	6.8	13.1	1.414	1.47
141	6	240	395	6.4	6.9	1.856	2.01
168	8	480	552	7.5	17.0	2.163	2.25
196	10	720	875	8.1	15.4	2.642	2.75
212	8	660	1055	8.0	7.7	3.013	3.13
240	17	1780	1137	9.3	35.2	3.750	3.90
292	16	1680	942	11.4	39.5	5.047	5.25
AVERAGE	12	642	638	7.9	16.9		
Weighted Ave.			720				

Slab No.: 224-424

Variable : Black Steel, 2.75% calcium nitrite, 20 lb Cl^-/yd^3
top lift

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0	(10/8/80)			10.5	24.4	0	0
2	39	340	423	10.4	14.7	0.020	0.02
8		360	392	10.6	18.6	0.079	0.08
14		320	420	10.4	13.2	0.137	0.14
30		640	670	10.2	19.7	0.346	0.36
44	10	240	315	10.4	13.2	0.511	0.53
61	10	780	776	10.2	21.3	0.734	0.76
106	10	400	609	9.5	9.0	1.482	1.54
141	10	560	590	10.4	19.5	1.986	2.07
169	13	820	760	10.6	23.4	2.440	2.54
201	7	460	470	10.7	20.4	2.912	3.03
272	20	2100	1030	13.1	44.2	4.190	4.36
366	10	540	401	18.1	30.4	5.804	6.04
AVERAGE	14	630	571	11.2	20.9		
Weighted Ave.			661				

Slab No.: 225-425

Variable : Black Steel, 2.75% calcium nitrite, 20 lb Cl^-/yd^3
top lift

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/8/80)				9.7	25.5	0	0
2		660	821	9.7	14.7	0.039	0.04
8		820	859	9.6	19.7	0.160	0.17
14		660	840	9.6	14.1	0.282	0.29
30		1200	1203	9.6	21.0	0.674	0.70
44	20	430	555	9.4	13.6	0.969	1.01
61	20	1400	1331	9.4	22.6	1.354	1.41
106	10	640	934	8.8	10.2	2.576	2.68
141	15	1140	1138	9.8	21.1	3.446	3.58
169	22	1440	1311	10.0	23.9	4.269	4.44
201	18	1160	1142	10.1	21.6	5.211	5.42
272	25	700	339	12.3	44.6	6.473	6.73
366	16	1000	859	14.1	25.8	7.824	8.14
AVERAGE	18	938	944	10.2	21.4		
Weighted Ave.			891				

Slab No.: 226-426

Variable : Black Steel, 2.75% calcium nitrite, 25 lb Cl^-/yd^3
top lift

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/8/80)				8.3	8.0	0	0
2		440	539	8.4	15.1	.026	.03
8		680	710	8.4	19.8	0.116	0.12
14		660	853	8.0	13.6	0.229	0.24
30		1600	1625	7.6	20.6	0.705	0.73
44	30	690	881	7.3	13.9	1.126	1.17
61	30	1880	1801	7.3	22.4	1.673	1.74
106	20	1440	2034	6.8	11.1	3.744	3.89
141	24	1900	2152	7.1	17.4	5.502	5.72
169	27	2500	2207	7.8	24.9	6.967	7.25
201	23	1840	1757	8.3	22.5	8.489	8.83
272	32	4980	2267	10.9	46.8	11.917	12.39
366	25	1680	1438	12.0	25.8	16.096	16.74
AVERAGE	26	1691	1522	8.3	20.1		
Weighted Ave.			1832				

Slab No.: 227-427

Variable : Black Steel, 2.75% calcium nitrite, 25 lb Cl^-/yd^3 top lift

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0	(10/8/80)			7.9	8.4	0	0
2		340	415	7.9	15.3	0.020	0.02
8		480	505	8.0	19.6	0.086	0.09
14		600	773	7.8	13.7	0.178	0.19
30		1060	1091	7.4	20.2	0.536	0.56
44	10	430	562	7.2	13.3	0.814	0.85
61	20	1400	1339	7.2	22.5	1.202	1.25
106	10	820	1176	6.7	10.7	2.560	2.66
141	17	1340	1425	7.1	19.3	3.652	3.80
169	19	1700	1526	7.4	24.4	4.644	4.83
201	18	1580	1488	8.0	22.9	5.801	6.03
272	26	3740	1716	10.1	45.5	8.531	8.87
366	13	940	834	11.3	24.7	11.407	11.86
AVERAGE	17	1203	1071	8.0	20.1		
Weighted Ave.			1299				

Slab No.: 215-415

Variable : Black Steel, no nitrite, 35 lb Cl^-/yd^3 top lift

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0	(10/8/80)			10.5	17.7	0	0
2		6300	7885	9.8	14.5	0.378	0.39
8		8320	10520	9.3	14.2	1.703	1.77
14		8260	12354	9.0	9.5	3.350	3.48
30		13320	13835	8.8	20.0	8.378	8.71
44	140	5190	6879	8.2	12.9	11.858	12.33
61	120	9100	11383	8.2	14.5	15.583	16.20
106	130	7060	12810	7.9	4.3	28.647	29.79
141	148	12340	14633	7.9	16.1	40.173	41.78
169	119	9600	10264	8.8	19.1	48.538	50.48
201	103	7640	9252	8.9	15.5	56.032	58.27
272	43	19360	10323	12.2	41.3	72.710	75.62
366	92	6040	5890	11.8	21.9	90.998	94.64
AVERAGE	112	9378	10502	9.3	17.0		
Weighted Ave.			10360				

Slab No.: 228-428

Variable : Black Steel, 2.75% calcium nitrite, 35 lbs Cl^-/yd^3 top lift

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/8/80)				8.6	8.2	0	0
2		580	708	8.6	15.2	.034	.04
8		1000	914	8.6	23.8	0.151	0.16
14		620	793	9.2	13.9	0.274	0.28
30		1460	1496	8.2	20.4	0.713	0.74
44	20	510	672	8.1	13.1	1.077	1.12
61	30	1760	1694	8.1	22.3	1.560	1.62
106	20	960	1304	7.8	12.2	3.179	3.31
141	17	1380	1491	8.1	18.8	4.353	4.53
169	19	1640	1485	8.6	24.1	5.353	5.57
201	17	1280	1211	9.1	22.8	6.388	6.64
272	32	4340	2000	11.4	46.3	9.124	9.49
366	20	1260	1185	13.1	22.9	12.717	13.22
AVERAGE	22	1399	1246	9.0	20.3		
Weighted Ave.			1448				

Slab No.: 217-417 No Ponding

Variable : Black Steel, 2.75% calcium nitrite, 0 Cl^-/yd^3

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/8/80)				13.7	19.4	0	0
2	0	0	0	7.8	14.6	0	0
8		0	0	7.8	14.0	0	0
14		0	0	7.7	10.7	0	0
30		0	0	8.1	19.8	0	0
44	10	0	0	7.5	11.3	0	0
61	0	0	0	7.3	17.6	0	0
106	0	0	0	6.7	3.6	0	0
141	0	0	0	7.0	15.2	0	0
169	0	0	0	8.2	20.0	0	0
201	0	0	0	8.1	16.2	0	0
272	0	0	0	10.8	42.9	0	0
366	0	0	0	10.9	21.9	0	0
AVERAGE	0	0	0	8.6	17.5		
Weighted Ave.			0				

Slab No.: 212-412 No Ponding

Variable : Black Steel, no calcium nitrite, 0 Cl^-/yd^3

Days	ΔV mV	i actual μA	i_{70} μA	R_{70} Ω	Approx. Actual Temp. °C.	Cumul. Amp-hrs.	70°F Metal Consumed grams
0 (10/8/80)				21.7	13.9	0	0
2		0	0	19.7	14.9	0	0
8		0	0	22.0	11.7	0	0
14		0	0	24.3	8.5	0	0
30		0	0	25.3	14.9	0	0
44		0	0	26.1	10.8	0	0
61	0	0	0	24.4	12.1	0	0
106	0			23.5	0.9	0	0
141	0	0	0	27.3	13.7	0	0
169	0	0	0	24.7	15.2	0	0
201	0	0	0	30.1	12.0	0	0
272		0	0	43.6	38.2	0	0
366	0	0	0	51.6	17.5	0	0
AVERAGE	0	0	0	28.0	14.2		
Weighted Ave.			0				

Note: This slab may be cracked between lifts.

Potentials for Slab No: 201-401

Variable : Black Steel, both mats, 15 lb Cl^-/yd^3 top lift

Days	Top Mat Potentials 1	2	3	AVE	Bottom Mat Potentials 1	2	3	AVE	Ave. Potential Diff.
0 (8/7/80)	-510	-490	-470	-490	-130	-140	-120	-130	-360
54	-460	-460	-470	-463	-180	-180	-160	-173	-290
61	-480	-480	-470	-477	-210	-190	-180	-193	-284
81	-520	-520	-520	-520	-210	-190	-180	-193	-327
229	-470	-460	-500	-477	-160	-170	-160	-163	-314
298	-570	-570	-590	-577	-400	-340	-250	-330	-247
AVERAGE OVERALL				-501				-197	-304
AVERAGE 10/1/80 to 8/2/81				-503				-216	-287

Note: All potentials are mV to the copper sulfate electrode. The positive meter lead was connected to the reinforcing steel.

Measurements taken after uncoupling mats (within 3 minutes).

This slab is cracked between lifts.

Potentials for Slab No: 202-402

Variable : Black Steel, both mats, 15 lb Cl^-/yd^3 top lift

Days	Top Mat Potentials 1	2	3	AVE	Bottom Mat Potentials 1	2	3	AVE	Ave. Potential Diff.
0 (8/7/80)	-480	-470	-460	-470	-110	-110	-130	-117	-353
54	-470	-470	-480	-473	-250	-240	-260	-250	-223
61	-430	-440	-450	-440	-190	-180	-210	-193	-247
81	-460	-490	-490	-480	-360	-240	-240	-280	-200
229	-470	-430	-470	-457	-190	-180	-170	-180	-277
298	-550	-530	-560	-547	-320	-300	-320	-313	-234
AVERAGE OVERALL				-478				-222	-256
AVERAGE 10/1/80 to 6/2/81				-479				-243	-236

Note: All potentials are mV to the copper sulfate electrode. The positive meter lead was connected to the reinforcing steel.

Measurements taken after uncoupling mats (within 3 minutes).

Potentials for Slab No: 234-434

Variable : Black Steel, both mats, 15 lb Cl^-/yd^3 top lift

Days	Top Mat Potentials 1	2	3	AVE	Bottom Mat Potentials 1	2	3	AVE	Ave. Potential Diff.
0 (10/28/80)	-500	-510	-510	-507	150	180	160	-163	-344
2	-480	-460	-460	-467	-340	-350	-350	-347	-120
147	-510	-530	-520	-520	-220	-240	-350	-270	-250
216	-630	-620	-580	-610	-300	-290	-320	-303	-307
AVERAGE OVERALL				-526				-271	-255
AVERAGE 10/30/80 to 6/2/81				-532				-307	-225

Note: All potentials are mV to the copper sulfate electrode. The positive meter lead was connected to the reinforcing steel.

Measurements taken after uncoupling mats (within 3 minutes).

Potentials for Slab No: 203-403

Variable : Epoxy coated with holidays, Top mat only

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (8/8/80)	-400	-390	-390	-393	-140	-130	-140	-137	-256
54	-250	-240	-240	-243	-160	-150	-140	-150	-93
61	-250	-240	-240	-243	-140	-110	-130	-127	-116
81	-220	-230	-230	-227	-100	-70	-100	-90	-137
229	-300	-280	-260	-280	-180	-160	-190	-177	-103
298	-270	-270	-260	-263	-170	-150	-150	-157	-106
AVERAGE OVERALL				-275				-140	-135
AVERAGE 10/1/80 to 6/2/81				-251				-140	-111

Note: All potentials are mV to the copper sulfate electrode. The positive meter lead was connected to the reinforcing steel.

Measurements taken after uncoupling mats (within 3 minutes).

Potentials for Slab No: 204-404

Variable : Epoxy Coated with holidays, Top mat only

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (8/7/80)	-420	-430	-440	-430	-100	-100	-100	-100	-330
54	-280	-270	-280	-277	-130	-140	-150	-140	-137
61	-280	-260	-280	-273	-140	-130	-130	-133	-140
81	-250	-250	-250	-250	-130	-120	-120	-123	-127
229	-380	-320	-330	-343	-200	-180	-170	-183	-160
298	-360	-330	-330	-340	-210	-180	-180	-190	-150
AVERAGE OVERALL				-319				-145	-174
AVERAGE 10/1/80 to 6/2/81				-297				-154	-143

Note: All potentials are mV to the copper sulfate electrode. The positive meter lead was connected to the reinforcing steel.

Measurements taken after uncoupling mats (within 3 minutes).

Potentials for Slab No: 205-405

Variable : Epoxy coated with holidays, both mats

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (8/7/80)	-390	-390	-390	-390	-220	-170	-190	-193	-197
54	-340	-350	-350	-347	-250	-210	-240	-233	-114
61	-300	-320	-320	-313	-270	-240	-250	-253	-60
81	-360	-360	-350	-357	-260	-220	-230	-237	-120
229	-350	-330	-350	-343	-250	-240	-240	-243	-100
298	-370	-350	-340	-353	-280	-230	-250	-253	-100
AVERAGE OVERALL				-350				-235	-115
AVERAGE 10/1/80 to 6/1/81				-342				-244	-98

Note: All potentials are mV to the copper sulfate electrode. The positive meter lead was connected to the reinforcing steel.

Measurements taken after uncoupling mats (within minutes).

Potentials for Slab No: 206-406

Variable : Epoxy coated with holidays, both mats

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (8/7/80)	-380	-380	-380	-380	-120	-130	-130	-127	-253
54	-370	-370	-360	-367	-270	-260	-250	-260	-107
61	-350	-360	-360	-357	-250	-250	-230	-243	-114
81	-380	-380	-380	-380	-250	-250	-240	-247	-133
229	-410	-410	-400	-407	-260	-280	-230	-257	-150
298	-420	-410	-380	-403	-340	-290	-290	-307	-96
AVERAGE OVERALL				-382				-240	-142
AVERAGE 10/1/80 to 61/81				-383				-263	-120

Note: All potentials are mV to the copper sulfate electrode. The positive meter lead was connected to the reinforcing steel.

Measurements taken after uncoupling mats (within 3 minutes).

Potentials for Slab No: 235-435

Variable : Epoxy coated with holidays and 0.86%
bare area, both mats

Days	Top Mat Potentials 1	2	3	AVE	Bottom Mat Potentials 1	2	3	AVE	Ave. Potential Diff.
0 (10/28/80)	-430	-430	-440	-433	-230	-230	-230	-230	-203
2	-410	-440	-420	-423	-330	-330	-320	-327	-96
147	-480	-490	-480	-483	-250	-250	-280	-260	-223
216	-500	-500	-470	-490	-350	-370	-360	-360	-130
AVERAGE OVERALL				-457				-294	-163
AVERAGE 10/30/80 to 6/1/81				-465				-316	-149

Note: All potentials are mV to the copper sulfate electrode. The positive meter lead was connected to the reinforcing steel.

Measurements taken after uncoupling mats (within 3 minutes).

Potentials for Slab No: 207-407

Variable : Epoxy coated with holidays and 0.86%
bare area, top mat only

Days	Top Mat Potentials 1	2	3	AVE	Bottom Mat Potentials 1	2	3	AVE	Ave. Potential Diff.
0 (8/7/80)	-470	-470	-470	-470	-120	-120	-120	-120	-350
54	-360	-380	-380	-373	-240	-240	-240	-240	-233
61	-370	-380	-380	-377	-140	-150	-170	-153	-224
81	-330	-350	-350	-343	-150	-140	-150	-147	-196
229	-380	-380	-370	-377	-150	-130	-150	-143	-234
298	-370	-350	-330	-350	-190	-170	-180	-180	-170
AVERAGE OVERALL				-382				-164	-218
AVERAGE 10/1/80 to 6/1/81				-364				-173	-191

Note: All potentials are mV to the copper sulfate electrode. The positive meter lead was connected to the reinforcing steel.

Measurements taken after uncoupling mats (within 3 minutes).

This slab is cracked between lifts.

Potentials for Slab No: 208-408

Variable : Epoxy coated with holidays and 0.86%
bare area, top mat only

Days	Top Mat Potentials 1	2	3	AVE	Bottom Mat Potentials 1	2	3	AVE	Ave. Potential Diff.
0 8/7/80)	-420	-410	-400	-410	-140	-110	-100	-117	-293
54	-270	-270	-280	-273	-180	-150	-140	-157	-116
61	-250	-260	-270	-260	-140	-140	-130	-137	-123
81	-230	-240	-240	-237	-120	-130	-110	-120	-117
229	-250	-280	-270	-267	-110	-120	-120	-117	-150
298	-270	-290	-280	-280	-170	-170	-170	-170	-110
AVERAGE OVERALL				-288				-136	-152
AVERAGE 10/1/80 to 6/1/81				-263				-140	-123

Note: All potentials are mV to the copper sulfate electrode. The positive meter lead was connected to the reinforcing steel.

Measurements taken after uncoupling mats (within 3 minutes).

Potentials for Slab No: 209-409

Variable : Epoxy coated with holidays and 0.24%
bare areas, top mat only

Days	Top Mat Potentials 1	2	3	AVE	Bottom Mat Potentials 1	2	3	AVE	Ave. Potential Diff.
0 (8/3/80)	-460	-470	-470	-467	-130	-130	-150	-137	-330
54	-270	-270	-270	-270	-160	-150	-140	-150	-120
61	-260	-260	-250	-257	-140	-150	-150	-147	-110
81	-210	-220	-240	-223	-120	-120	-130	-123	-100
229	-280	-290	-310	-293	-110	-110	-230	-150	-143
298	-300	-290	-310	-300	-200	-200	-290	-230	-70
AVERAGE OVERALL				-302				-156	-146
AVERAGE 10/1/80 to 6/1/81				-269				-160	-109

Note: All potentials are mV to the copper sulfate electrode. The positive meter lead was connected to the reinforcing steel.

Measurements taken after uncoupling mats (within 3 minutes).

Potentials for Slab No: 210-410

Variable : Epoxy coated with holidays and 0.24% bare area, top mat only

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (8/7/80)	-380	-390	-380	-383	-130	-130	-110	-123	-260
54	-230	-240	-250	-240	-190	-120	-110	-140	-100
61	-230	-240	-250	-240	-110	-120	-120	-117	-123
81	-210	-220	-220	-217	-110	-100	-100	-103	-114
229	-250	-260	-280	-263	-120	-110	-110	-113	-150
298	-280	-270	-290	-280	-200	-180	-200	-193	-87
AVERAGE OVERALL				-271				-132	-139
AVERAGE 10/1/80 to 61/81				-248				-133	-115

Note: All potentials are mV to the copper sulfate electrode. The positive meter lead was connected to the reinforcing steel.

Measurements taken after uncoupling mats (within 3 minutes).

Potentials for Slab No: 211-411

Variable : Black Steel, no calcium nitrite, 0.Cl$^-$/yd^3, Ponded

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (10/7/80)	-50	0	+10	-13	0	+10	+50	+20	-36
2	0	-80	+30	-17	-60	-90	-80	-77	+60
14					0	+40	+60	+33	
30					-10	+20	0	+3	
169	-190	-270	-330	-263	-60	-120	-150	-110	-153

Potentials for Slab No: 216-416

Variable : Black Steel, 2.75% calcium nitrite, 0 Cl$^-$ /yd^3, Ponded.

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (10/7/80)	-30	-20	-10	-20	-130	-130	-110	-123	+103
2	-60	-70	-60	-63	-150	-140	-150	-147	+84
14					-120	-120	-110	-117	
30					-120	-110	-100	-110	
169	-190	-140	-170	-167	-180	-180	-170	-177	+10

Potentials for Slab No: 213-413

Variable :Black Steel, no Nitrite, 5 lbCl$^-$/yd^3, top lift

Days	Top Mat Potentials 1	2	3	AVE	Bottom Mat Potentials 1	2	3	AVE	Ave. Potential Diff.
0 (10/7/80)	-30	-30	-50	-67	0	0	0	0	-67
2	-50	-60	-50	-53	-20	-60	-10	-30	-23
14					-40	-20	-40	-33	
30					-100	-70	-90	-87	
169	-430	-390	-410	-410	-150	-150	-130	-143	-267

Potentials for Slab No: 214-414

Variable : Black Steel, no nitrite, 5 lb Cl$^-$/yd^3, top lift

Days	Top Mat Potentials 1	2	3	AVE	Bottom Mat Potentials 1	2	3	AVE	Ave. Potential Diff.
0 (10/7/80)	-70	-70	-70	-70	0	-20	-20	-13	-57
2	-70	-70	-70	-70	-70	-80	-80	-77	+7
14					-10	+10	0	0	
30					-20	+10	0	-3	
169	-340	-420	-370	-377	-150	-130	-140	-140	-237

Potentials for Slab No: 218-418

Variable : Black Steel, 2.75% calcium nitrite, 5 lb Cl$^-$/yd^3, top lift

Days	Top Mat Potentials 1	2	3	AVE	Bottom Mat Potentials 1	2	3	Ave	Ave. Potential Diff.
0 (10/7/80)	-70	-30	-40	-47	-90	-120	-110	-107	+60
2	-110	-90	-90	-97	-140	-140	-140	-140	+43
14					-200	-200	-180	-193	
30					-210	-240	-230	-227	
169	-370	-330	-330	-343	-270	-240	-230	-247	-96

Potentials for Slab No:219-419

Variable :Black Steel, 2.75% calcium nitrite, 5 lb Cl$^-$/yd^3 top lift

Days	Top Mat Potentials 1	2	3	Ave	Bottom Mat Potentials 1	2	3	AVE	Ave. Potential Diff.
0 (10/7/80)	-70	-50	-60	-60	-120	-120	-110	-117	+57
2	-70	-70	-70	-70	-140	-120	-120	-127	+57
14					-100	-100	-90	-97	
30					-110	-110	-110	-110	
169	-260	-230	-240	-243	-200	-200	-190	-197	-46

Potentials for Slab No: 220-420

Variable :Black Steel, 2.75% calcium nitrite, 10 lbs Cl^-/yd^3, Top lift

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (10/7/80)	-150	-130	-210	-163	-130	-130	-130	-130	-33
2	-140	-140	-140	-140	-160	-170	-160	-163	+23
14					-250	-230	-220	-233	
30					-160	-160	-170	-163	
169	-260	-290	-220	-257	-230	-210	-210	-217	-40

Potentials for Slab No: 221-421

Variable : Black Steel, 2.75% calcium nitrite, 10 lb Cl^-/yd^3, Top lift

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (10/7/80)	-120	-110	-90	-107	0	0	0	0	-107
2	-140	-130	-140	-137	-150	-160	-150	-153	+16
14					-130	-200	-210	-180	
30					-120	-130	-130	-127	
169	-250	-300	-260	-270	-200	-200	-200	-200	-70

Potentials for Slab No: 222-422

Variable : Black Steel, 2.75% calcium nitrite, 15 lb Cl^-/yd^3, top lift

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (10/7/80)	-210	-170	-160	-180	-190	-210	-180	-193	+13
2	-200	-190	-200	-197	-240	-240	-220	-233	+36
14					-190	-210	-200	-200	
30					-230	-230	-230	-230	
169	-280	-230	-260	-257	-270	-240	-200	-237	-20

Potentials for Slab No: 223-423

Variable : Black Steel, 2.75% calcium nitrite, 15 lb Cl^-/yd^3 top lift

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (10/7/80)	-210	-180	-180	-190	-110	-100	-100	-103	-87
2	-210	-200	-200	-203	-250	-240	-240	-243	+40
14					-190	-190	-180	-187	
30					-220	-250	-230	-233	
169	-270	-270	-270	-270	-230	-230	-240	-233	-37

Potentials for Slab No:WRG

Variable :Black Steel, 2.75% calcium nitrite, 15 lb Cl^-/yd^3 top lift

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (10/7/80)	-250	-240	-240	-243					
2	-260	-250	-250	-253	-260	-240	-240	-247	-6
14					-250	-240	-230	-240	
30					-260	-260	-240	-253	
168	-340	-340	-330	-337	-250	-260	-250	-253	-84
240	-410	-430	-410	-417	-340	-340	-330	-337	-80

Potentials for Slab No:224-424

Variable :Black Steel, 2.75% calcium nitrite, 20 lb Cl^-/yd^3 top lift

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (10/7/80)	-270	-270	-310	-283	-100	-70	-70	-80	-203
2	-270	-260	-280	-270	-280	-270	-230	-260	-10
14					-240	-240	-240	-240	
30					-260	-240	-230	-243	
169	-340	-340	-380	-353	-220	-250	-250	-240	-113

Potentials for Slab No: 225-425

Variable : Black Steel, 2.75% calcium nitrite 20 lbs Cl^-/yd^3, top lift

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (10/7/80)	-360	-290	-280	-310	-120	-90	-120	-110	-200
2	-300	-280	-290	-290	-290	-270	-280	-280	-10
14					-270	-250	-250	-257	
30					-250	-270	-250	-257	
169	-380	-360	-360	-367	-260	-240	-220	-240	-127

Potentials for Slab No: 226-426

Variable : Black Steel, 2.75% calcium nitrite 25 lb Cl^-/yd^3, top lift

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (10/7/80)	-320	-320	-320	-320	-100	-100	-100	-100	-220
2	-320	-310	-320	-317	-270	-280	-260	-270	-47
14					-250	-270	-240	-253	
30					-270	-290	-270	-277	
169	-420	-450	-420	-430	-310	-320	-300	-310	-120

Potentials for Slab No: 227-427

Variable : Black Steel, 2.75% calcium nitrite
25 lb Cl^-/yd^3, top lift

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (10/8/80)	-320	-300	-300	-307	-100	-100	-90	-97	-210
2	-320	-280	-300	-300	-290	-270	-280	-280	-20
14					-260	-260	-260	-260	
30					-260	-270	-300	-277	
169	-400	-420	-490	-437	-280	-320	-300	-300	-137

Potentials for Slab No: 228-428

Variable : Black Steel, 2.75% calcium nitrite,
35 lb Cl^-/yd^3, top lift

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (10/8/70)	-330	-320	-320	-323	-120	-120	-120	-120	-203
2	-340	-330	-340	-337	-340	-300	-300	-313	-24
14					-290	-290	-280	-287	
30					-310	-340	-300	-317	
169	-380	-430	-390	-400	-310	-330	-300	-313	-87

Potentials for Slab No: 215-415

Variable : Black Steel, no nitrite,
35 lb Cl^-/yd^3, top lift

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (10/7/80)	-510	-480	-500	-497	-250	-200	-250	-233	-264
2	-500	-490	-500	-497	-230	-220	-140	-230	-267
14					-210	-130	-180	-173	
30					-130	-180	-200	-177	
169	-570	-590	-580	-580	-200	-190	-180	-190	-390

Potentials for Slab No: 217-417 No Ponding

Variable : Black Steel, 2.75% calcium nitrite, 0 Cl^-

Days	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
	1	2	3	AVE	1	2	3	AVE	
0 (10/7/80)	-30	0	0	-10	-120	-120	-120	-120	+110
2	-40	-60	-40	-47	-150	-140	-130	-140	+93
14					-100	-110	-100	-103	
30					-100	-110	-90	-100	
169	-140	-130	-140	-137	-110	-120	-110	-113	-24

Potentials for Slab No: 212-412 No Ponding

Variable : Black Steel, no calcium nitrite, 0 Cl^-/yd^3

	Top Mat Potentials				Bottom Mat Potentials				Ave. Potential Diff.
Days	1	2	3	AVE	1	2	3	AVE	
0 (10/7/80)	-50	-10	+20	-13	0	0	0	0	-13
2	-10	+20	+10	+7	+10	-40	+20	-3	+10
14					+70	+70	+50	+63	
30					+70	+50	+40	+53	
169					-30	-40	-40	-37	

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FEDERALLY COORDINATED PROGRAM (FCP) OF HIGHWAY RESEARCH AND DEVELOPMENT

The Offices of Research and Development (R&D) of the Federal Highway Administration (FHWA) are responsible for a broad program of staff and contract research and development and a Federal-aid program, conducted by or through the State highway transportation agencies, that includes the Highway Planning and Research (HP&R) program and the National Cooperative Highway Research Program (NCHRP) managed by the Transportation Research Board. The FCP is a carefully selected group of projects that uses research and development resources to obtain timely solutions to urgent national highway engineering problems.*

The diagonal double stripe on the cover of this report represents a highway and is color-coded to identify the FCP category that the report falls under. A red stripe is used for category 1, dark blue for category 2, light blue for category 3, brown for category 4, gray for category 5, green for categories 6 and 7, and an orange stripe identifies category 0.

FCP Category Descriptions

1. Improved Highway Design and Operation for Safety

Safety R&D addresses problems associated with the responsibilities of the FHWA under the Highway Safety Act and includes investigation of appropriate design standards, roadside hardware, signing, and physical and scientific data for the formulation of improved safety regulations.

2. Reduction of Traffic Congestion, and Improved Operational Efficiency

Traffic R&D is concerned with increasing the operational efficiency of existing highways by advancing technology, by improving designs for existing as well as new facilities, and by balancing the demand-capacity relationship through traffic management techniques such as bus and carpool preferential treatment, motorist information, and rerouting of traffic.

3. Environmental Considerations in Highway Design, Location, Construction, and Operation

Environmental R&D is directed toward identifying and evaluating highway elements that affect the quality of the human environment. The goals are reduction of adverse highway and traffic impacts, and protection and enhancement of the environment.

4. Improved Materials Utilization and Durability

Materials R&D is concerned with expanding the knowledge and technology of materials properties, using available natural materials, improving structural foundation materials, recycling highway materials, converting industrial wastes into useful highway products, developing extender or substitute materials for those in short supply, and developing more rapid and reliable testing procedures. The goals are lower highway construction costs and extended maintenance-free operation.

5. Improved Design to Reduce Costs, Extend Life Expectancy, and Insure Structural Safety

Structural R&D is concerned with furthering the latest technological advances in structural and hydraulic designs, fabrication processes, and construction techniques to provide safe, efficient highways at reasonable costs.

6. Improved Technology for Highway Construction

This category is concerned with the research, development, and implementation of highway construction technology to increase productivity, reduce energy consumption, conserve dwindling resources, and reduce costs while improving the quality and methods of construction.

7. Improved Technology for Highway Maintenance

This category addresses problems in preserving the Nation's highways and includes activities in physical maintenance, traffic services, management, and equipment. The goal is to maximize operational efficiency and safety to the traveling public while conserving resources.

0. Other New Studies

This category, not included in the seven-volume official statement of the FCP, is concerned with HP&R and NCHRP studies not specifically related to FCP projects. These studies involve R&D support of other FHWA program office research.

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* The complete seven-volume official statement of the FCP is available from the National Technical Information Service, Springfield, Va. 22161. Single copies of the introductory volume are available without charge from Program Analysis (HRD-3), Offices of Research and Development, Federal Highway Administration, Washington, D.C. 20590.