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16. Abstract

Solution to the problem of deterioration of bridge decks due to the corrosion of embedded steel has been sought by engineers for a long time. The purpose of the study was to evaluate, under laboratory conditions, the properties of concrete using a commercially available corrosion inhibitor (Darex) as an additive to the concrete.

There was a limited scope to the study and evaluations were by means of a half-cell potential measurement system and visual observations. Generally the following conclusions were made: (1) Darex corrosion inhibitor does protect some against corrosion of steel embedded in concrete, but the extent has not been defined yet, (2) strength is higher for corrosion inhibitor treated concrete than for reference concrete (not treated), (3) Darex corrosion inhibitor does improve the general mix properties of air entrained concrete, (4) concrete using a corrosion inhibitor as an additive will cost approximately 22% more than conventional concrete, but will not be as expensive as other types of treatments and (5) it is not known at this time whether the protection advantages will offset the cost increases of the material.

The laboratory testing performed in this study is not fully corroborative of corrosion inhibiting qualities of calcium nitrite. More research is needed in this area of corrosion protection and also in correlating the laboratory results to actual field conditions.

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EVALUATION OF CORROSION INHIBITOR

Final Report

by

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MAY, 1980

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METRIC CONVERSION CHART

To convert U.S. Units to Metric Units (S.I.), the following conversion factors should be noted:

Multiply U.S. Units	By	To Obtain Metric Units
	LENGTH	
inches (in.)	2.5400	centimeters (cm.)
feet (ft.)	0.3048	meters (m.)
yards (yd.)	0.9144	meters (m.)
miles (mi.)	1.6090	kilometers (km.)
	AREA	
square inches (in^2)	6.4516	square centimeters (cm^2)
square feet (ft^2)	0.0929	square meters (m^2)
square yards (yd^2)	0.8361	square meters (m^2)
	VOLUME	
cubic inches (in^3)	16.3872	cubic centimeters (cm^3)
cubic feet (ft^3)	0.0283	cubic meters (m^3)
cubic feet (ft^3)	28.3162	liters (l.)
cubic yards (yd^3)	0.7646	cubic meters (m^3)
fluid ounces (fl. oz.)	29.57	milliliters (ml.)
gallons (gal.)	3.7853	liters (l.)
	MASS (WEIGHT)	
pounds (lb.)	0.4536	kilograms (kg.)
ounces (oz.)	28.3500	grams (g.)
	PRESSURE	
pounds per square inch (p.s.i.)	0.07030	kilograms per square centimeters (kg/cm^2)
pounds per square inch (p.s.i.)	0.006894	mega pascal (MPa)
	DENSITY	
pounds per cubic yard (lb/yd^3)	0.5933	kilograms per cubic meter (kg/m^3)
bags of cement per cubic yard (cement bags/yd^3)	55.7600	kilograms per cubic meter (kg/m^3)
	TEMPERATURE	
degrees fahrenheit (°F.)	5/9 (°F.-32)	degrees celsius (°C.) or centigrade

ABSTRACT

Durability of bridge decks and deterioration associated with the corrosion of embedded reinforcing steel bars has continued to be a problem over the years. Solution to this problem has been sought by engineers for a long time and several methods to solve this problem have been introduced and experimented with. Among these methods are: low slump dense concrete (the Iowa method), polymer (latex) modified concretes, internally sealed concretes (wax beads) and also waterproof membranes.

The purpose of this research study was to evaluate the properties of portland cement concrete using calcium nitrite (Darex), a corrosion inhibitor, as an additive in the concrete mix and to concentrate on the evaluation of the corrosion inhibiting qualities of this chemical. In this study, the corrosion of embedded steel bars in treated and reference (untreated) concrete was evaluated under laboratory conditions. Due to the limited scope of this study and the lack of specific procedures for corrosion detection under laboratory conditions, which we considered to be conclusive evidence of corrosion protection, definite conclusions were not given herein. However, limited conclusions were given from evaluations by means of half-cell potential measurements to determine the corrosion inhibiting qualities of calcium nitrite (Darex corrosion inhibitor).

Generally the following conclusions were made:

(1) Darex corrosion inhibitor does protect some against corrosion of steel embedded in portland cement concrete, but the extent of the protection has not been defined yet,

(2) the strength of corrosion inhibitor treated concrete is higher than that for reference concrete (not treated) at all ages,

(3) Darex corrosion inhibitor (calcium nitrite) improves the general mix properties of air entrained concrete,

(4) concrete using a corrosion inhibitor as an additive will cost approximately 22% more than conventional concrete, although it is not as expensive as other types of treatments for this purpose and

(5) even though there are strength increases in corrosion inhibitor treated concrete over conventional concrete, it is not known at this time whether this, or what protection advantage is attained, will be enough to offset the cost increases with the use of this additive.

The laboratory testing performed in this research study is not fully corroborative of corrosion inhibiting qualities of a corrosion inhibitor (calcium nitrite), such as Darex. More research is needed in the area of corrosion detection of embedded steel in concrete, tested under laboratory conditions, and also in the field with a simplified method to correlate this to the actual field conditions is needed.

Three (3) 3 in. x 4 in. x 16 in. concrete beams, each with a 1/2 - or 3/4-in. diameter steel bar placed in it, were poured, cured (normal curing for 28 days in the moist room) and then placed in the salt-fog chamber for testing. Cracks were intentionally induced in the blocks in order to accelerate the flow of the salt solution to the steel bars. The application of salt-fog lasted for intervals of 100 days, with half-cell potential measurements taken after each 100 day period. Also, one of the specimens was broken open and observations were made on the corrosion of the embedded steel bar.

Direct Coating of Steel

In order to determine what effect direct coating of the steel bars has on the corrosion inhibiting ability of the material, two (2) 1/2-in. diameter steel bars were coated twice with the calcium nitrite solution and were subjected to a corrosion environment (in an open air 100% relative humidity room). Pictures were taken of the resulting corrosion and observed details recorded. This testing was done as an extra effort for comparison purposes.

DISCUSSION OF RESULTS

General Discussion

As seen in Table 2 below, the data indicates that the slump was greatest for the reference mixes. It was seen by the technicians that the addition of Darex corrosion inhibitor to the mix tends to help stiffen up the mix with no apparent loss in workability. The air content using Darex was increased from 1% to 1.8% in the mixes with no air entraining agents used. The air content did not change significantly for mixes with Darex corrosion inhibitor added and air added.

TABLE 2

PLASTIC CONCRETE TEST DATA

Type Mix	Slump, Inches	Unit Weight, lbs./ft.^{3}	Air Content, %	W/C Ratio
Ref., no air	5 1/2	146.8	1.0	0.47
Darex, no air	2 1/4	147.2	1.8	0.45
Ref., air	4 1/4	142.4	5.0	0.42
Darex, air	3	142.0	5.2	0.42

*Note: All mixes had a fine to coarse aggregate ratio of 40/60 with a 6.5 bag cement factor.

Discussion of Strength Results

There will be no extensive discussion of strength results here because the prime discussion should be on the corrosion inhibiting abilities of calcium nitrite (Darex corrosion inhibitor), and not other properties. However, strengths (both compressive and flexural) were generally increased on the treated concrete over the reference concrete.

Test data included strengths at 1, 7 and 28 days. Tables 3 and 4 on the following page give the strength test data (both compressive and flexural strength) on reference concrete and on treated concrete (calcium nitrite). Table 3 gives test results for the non-air entrained concrete mixes while Table 4 gives test results on the air entrained concrete mixes.

As seen in Figures 2 and 3, pages 13 and 14, the compressive strengths of the treated concrete were much higher generally than the reference concrete, both in non air-entrained concrete and air-entrained concrete. Generally, the percentage increase in strength is higher at 1 day, decreasing proportionately at later ages. The percentage of increase in strength for the treated concrete over the non-treated concrete is generally the same regardless of whether the concrete is air-entrained or not. Increased strength gain (over the reference concrete) associated with the use of a corrosion inhibitor as an additive to concrete was probably due to the certain chemical composition of the material found in Darex (calcium nitrite) and its reaction with the cement.

The flexural strength of concrete is not as greatly affected by the addition of calcium nitrite as the compressive strength. In comparing flexural strengths, some of the results on the non air-entrained mixes appeared to be out of line; therefore, more emphasis was put on the air entrained mixes.

Usually, strength of concrete is reduced when air-entraining agents are introduced into the concrete mix. However, when calcium nitrite and an air agent were both present, the strength properties of the concrete improved considerably. The 28-day compressive strength of treated air-entrained concrete was 26% higher than the same concrete without the calcium nitrite. Additionally, it was surprising 5% higher than the reference concrete with no air-entrainment, which should have been higher than air entrained concrete. Flexural strength of treated air-entrained concrete at 28 days improved approximately 19% over the reference air-entrained concrete. The loss of strength which is normally associated with the addition of air-entraining agents is therefore compensated for with the addition of calcium nitrite. This could be useful, if strength is needed for a mix that has air-entrainment in it, regardless of what other benefits may be present in the mix.

TABLE 3

STRENGTH TEST DATA
NON-AIR MIXES

Type of Concrete	Age, days	Compressive Strength, p.s.i.	Flexural Strength, p.s.i.
Reference	1	1620 ------	300 ------
Darex (C.I.)	1	2774 (171%)*	425 (142%)*
Reference	7	3490 ------	666 ------
Darex (C.I.)	7	4914 (141%)*	550 (83%)*
Reference	28	4814 ------	783 ------
Darex (C.I.)	28	5919 (123%)*	706 (90%)*

*Percentage of reference.

TABLE 4

STRENGTH TEST DATA
AIR MIXES

Type of Concrete	Age, days	Compressive Strength, p.s.i.	Flexural Strength, p.s.i.
Reference	1	1596 ------	292 -----
Darex (C.I.)	1	2404 (151%)*	411 (142%)*
Reference	7	2930 -----	489 -----
Darex (C.I.)	7	4096 (140%)*	536 (110%)*
Reference	28	3999 -----	556 -----
Darex (C.I.)	28	5044 (126%)*	662 (119%)*

*Percentage of reference.

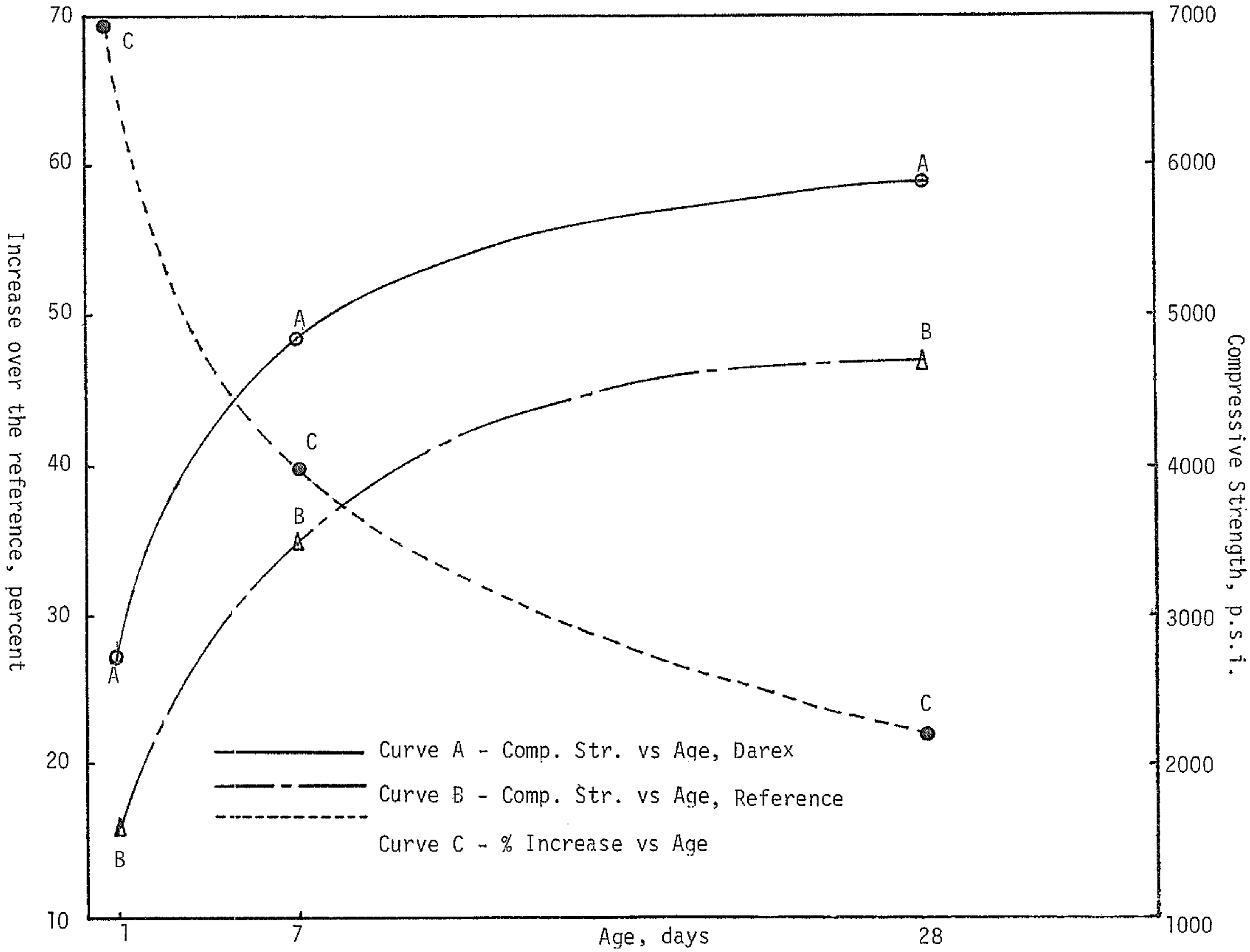

FIGURE 2

Compressive Strength vs Age: No Air Mix

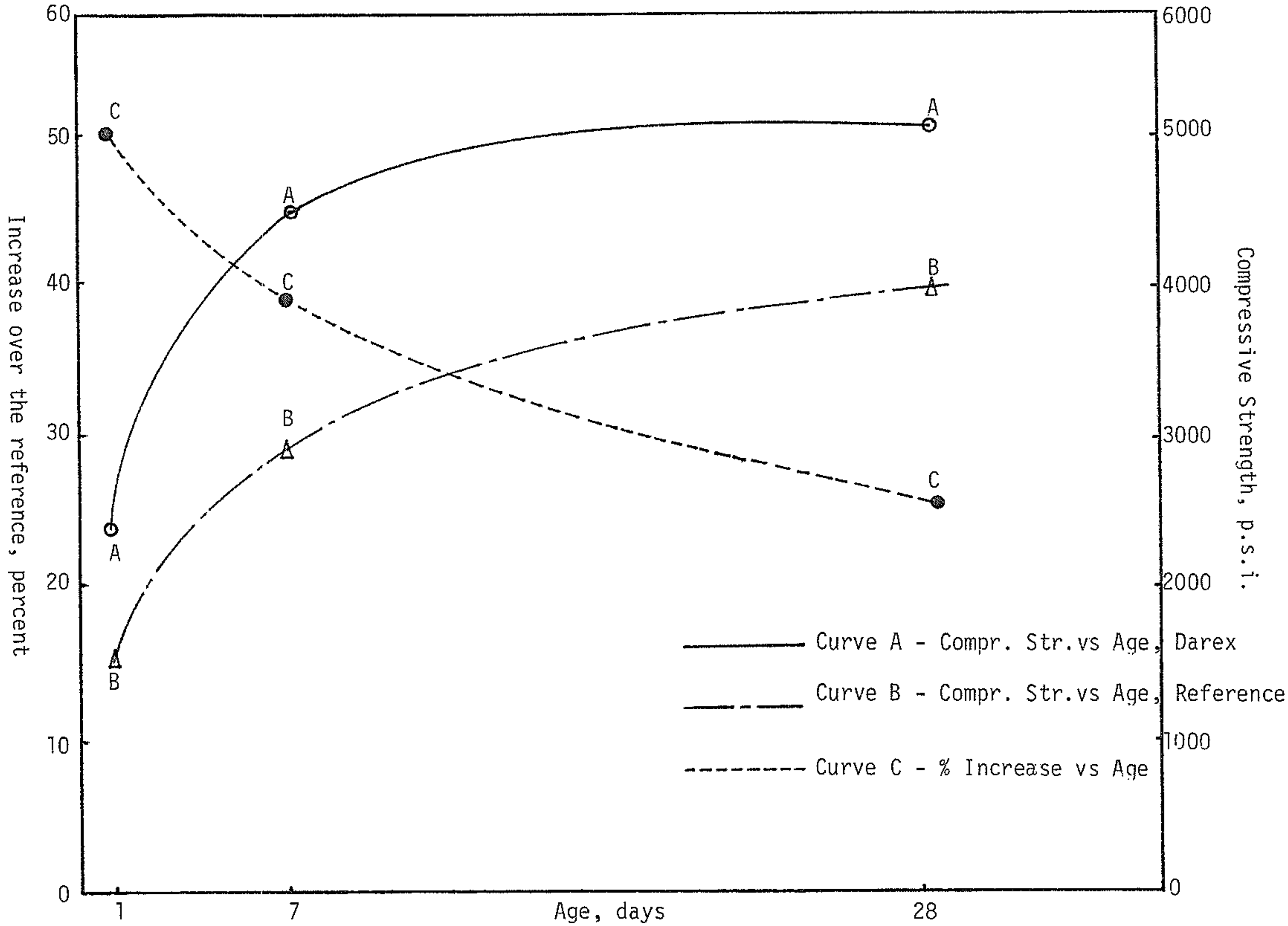

FIGURE 3

Compressive Strength vs. Age: Air-Entrained Mix

Discussion of Durability Results

As can be seen in Table 5, freeze and thaw durability of corrosion inhibited concrete was not greatly improved over the conventional non-treated concrete when no air-entraining agent was used. However, when there is an addition of an air-entraining agent to the treated (calcium nitrite added) concrete a more durable concrete than the conventional non-treated concrete was produced. The conventional concrete with air had a durability factor of 33 after 165 cycles of freezing and thawing. In conjunction with the air-entraining, the addition of a corrosion inhibitor (calcium nitrite) resulted in a durability factor of 48 after 242 cycles of freezing and thawing.

There are no established criteria for acceptance or rejection of concrete in terns of durability factors; however, durability factors and number of cycles of freezing and thawing are values which can be used for comparison purposes for different types of concretes, types of aggregates used in the mixes or other mix property comparisons. These values are thus primarily used in a comparison when one variable (e.g. admixture, aggregate) is changed. However, some guidance in interpretation can be obtained from the following: a factor smaller than 40 means that the concrete is probably unsatisfactory with respect to frost resistance; 40-60 is the range for concrete with doubtful performance, and above 60 is probably satisfactory.

There is no doubt, however, that some accelerated freezing and thawing tests result in the destruction of concrete that in practice would be satisfactory and durable. While the number of cycles of freezing and thawing in a test and in actual concrete are not related, it may be interesting to note that in most of the U.S. there are more than 50 such cycles per year (11).

The abrasion resistance of concrete is not greatly affected by the addition of the corrosion inhibitor. Table 5 gives the abrasion resistance data obtained on the study.

TABLE 5

DURABILITY TEST RESULTS

Type of Concrete	Freeze and Thaw Test Results: Durability Factor	Freeze and Thaw Test Results: No. Cycles	Abrasion Test Results: Abrasion Loss, cm^3/cm^2
Reference, no air	11	53	0.01
Darex, no air	9.4	47	0.02
Reference, air	33	165	0.03
Darex, air	48	242	0.02

Discussion of Length Change Test Results

As shown in Table 6 on the following page, the specimens with Darex corrosion inhibitor and air showed the greatest amount of shrinkage, but only slightly more than the shrinkage of the specimens (reference) with no air and no corrosion inhibitor. Over all, no significant changes could be attributed to the use of corrosion inhibitor for the shrinkage properties in portland cement concrete.

TABLE 6

LENGTH CHANGE OF HARDENED CONCRETE TEST RESULTS

Type of Concrete	Initial Reading, inches	Final Reading, @ 32 wks, in.	Length Change, inches	% Length Change
Reference, no air	0.19706	0.19296	(-) 0.00410	(-) 0.041
Darex, no air	0.19063	0.18690	(-) 0.00373	(-) 0.037
Reference, air	0.19020	0.18650	(-) 0.00370	(-) 0.037
Darex, air	0.18643	0.18223	(-) 0.00420	(-) 0.042

(-) denotes the decrease in length

Discussion of 90-Day Chloride Permeability Test Results

This test was performed to provide data and information for the evaluation of the ingress of chloride ions into the corrosion inhibitor concrete. When no air-entraining agents were used in the calcium nitrite treated concrete mix, the concrete did not perform well. However, when air-entraining agents were used in conjunction with the calcium nitrite, a reduction in accumulated chloride occurred. This reduction, which is indicated by the 95%* chloride level, ranged from 35% for the 1/16 to 1/2 in. depth to 70% for the 1/2 to 1 in. depth. 90-day chloride permeability test results are shown in Table 7 on the following page and the modified FHWA procedures used here are included in the appendix. The values shown in Table 7 exceed the FHWA chloride content limits** recommended for polymer modified concretes (1), which is our only reference. Although this concrete (calcium nitrite concrete mix) is not a polymer modified concrete, the FHWA limits are some indication of permeability resistance.

*Note: The 95% chloride level given here is generally considered an appropriate measure of overall permeability since it is a single, statistically obtained chloride level which indicates that 95% of the chloride content at a particular depth encountered in the sample will be less than or equal to that value. It is based on the sample mean, standard deviation and the assumption that the data is normally distributed (1).

**Note: For depth range of 1/16 to 1/2 in., the limit is 12.5 lbs. chloride per cubic yard of concrete, while the depth range of 1/2 to 1 in., the limit is 2.5 lbs. chloride per cubic yard of concrete (1).

TABLE 7

90-DAY CHLORIDE PERMEABILITY
TEST RESULTS

Type of Concrete	Depth Sample, inches	Air Entrainment	Average Chloride Content, lbs/yd^3	95% Chloride Level, lbs. cl^-/yd^3
Reference	1/16 to 1/2	No	14.92	22.5
	1/2 to 1	No	8.40	19.0
Darex (C.I.) Treated	1/16 to 1/2	No	25.50	35.5
	1/2 to 1	No	10.76	25.0
Reference	1/16 to 1/2	Yes	32.85	37.3
	1/2 to 1	Yes	14.00	21.4
Darex (C.I.) Treated	1/16 to 1/2	Yes	17.87	24.4
	1/2 to 1	Yes	4.11	6.1

Discussion of Corrosion Detection Test Results

As mentioned in the Methodology, the detection of corrosion in the embedded steel of these concrete blocks was principally by the means of a half-cell potential measurement device, with comparisons made in voltage readings. Methods of corroding the steel at an accelerated pace in these concrete blocks and then measuring the amount of corrosion through the use of voltage readings by the half-cell potential measurement system were tried on this research study and are described as follows:

Discussion of Continuous Salt-Ponding Test Results

Figure 4 on page 21 shows the ponded blocks. From the data as shown in Figure 5 on page 22, the level of corrosion taking place is greater in the untreated blocks than the treated blocks. In other words, half-cell potential measurements were generally lower in the treated blocks. After 160 days of ponding, the reference blocks, however, showed an average reading of 0.57 volts (active corrosion level is presumed to be at 0.35 volts), while the reading on the untreated blocks averaged 0.28 volts.

One block from the reference group and one block from the treated group were broken to expose the embedded steel bar. As seen in Figures 6 and 7 on page 23, the steel bar in the calcium nitrite treated concrete block showed very little sign of corrosion, while the steel bar in the reference block was considerably corroded. None of these blocks were cracked to accelerate the flow of the solution to the steel.

Chloride content taken from these blocks after 160 days of ponding showed an accumulation of 9.1 lbs. chloride per cubic yard of concrete at 1/2-in. depth for the untreated block and 8.9 lbs. chloride per cubic yard of concrete at a 1/2-in. depth for the treated block. The remaining blocks will be evaluated for longer periods of time and although not reported herein will be useful information for in-house purposes and later reporting. This type of testing is highly accelerated, and it is difficult to establish a relationship between the laboratory time of testing and the time element for corrosion in the field.

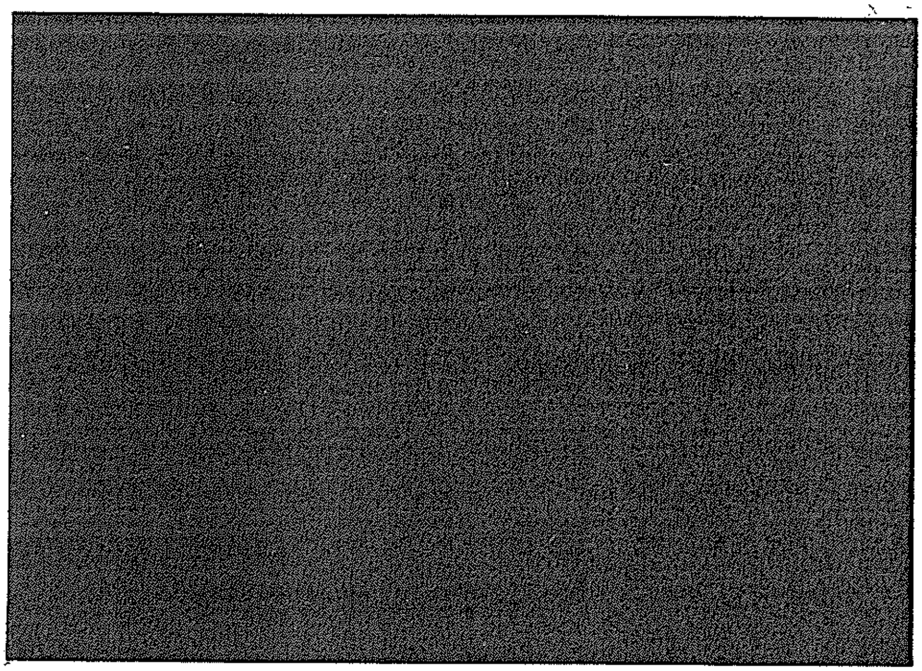

FIGURE 4

Ponded Concrete Blocks

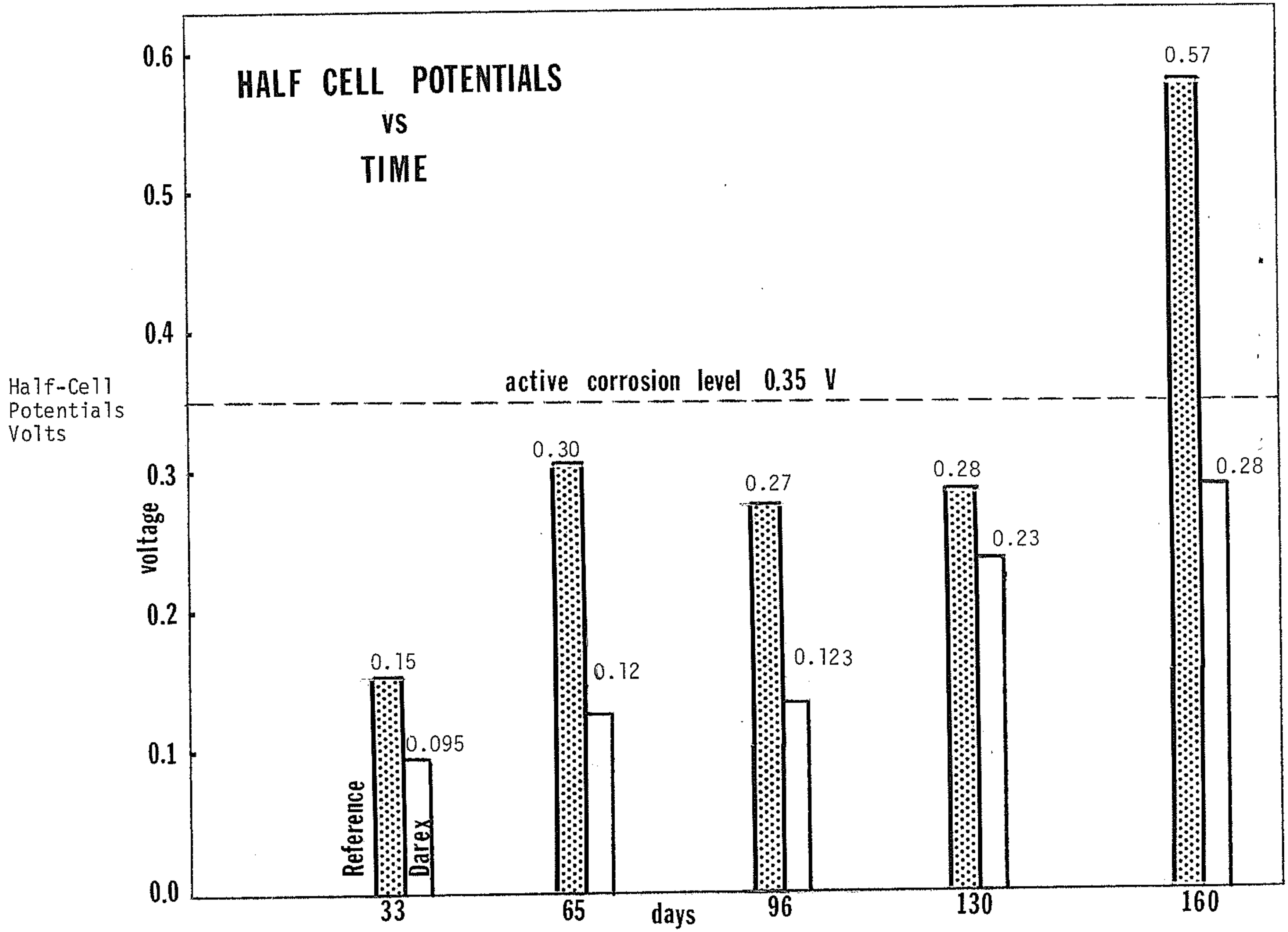

FIGURE 5

Half Cell Potentials vs Time

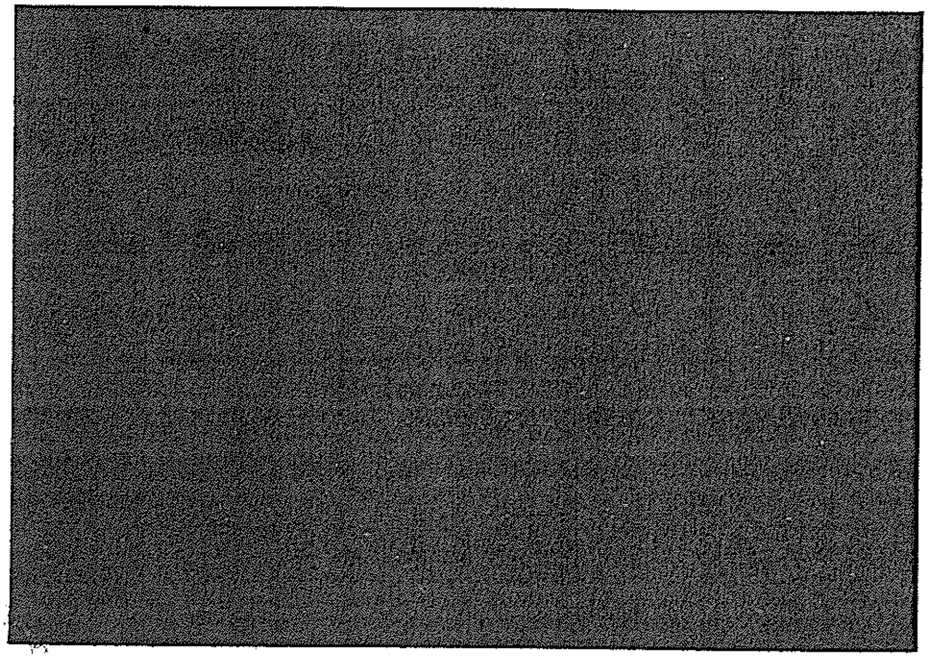

FIGURE 6

Exposed Steel, Reference Block
(160 days of ponding)

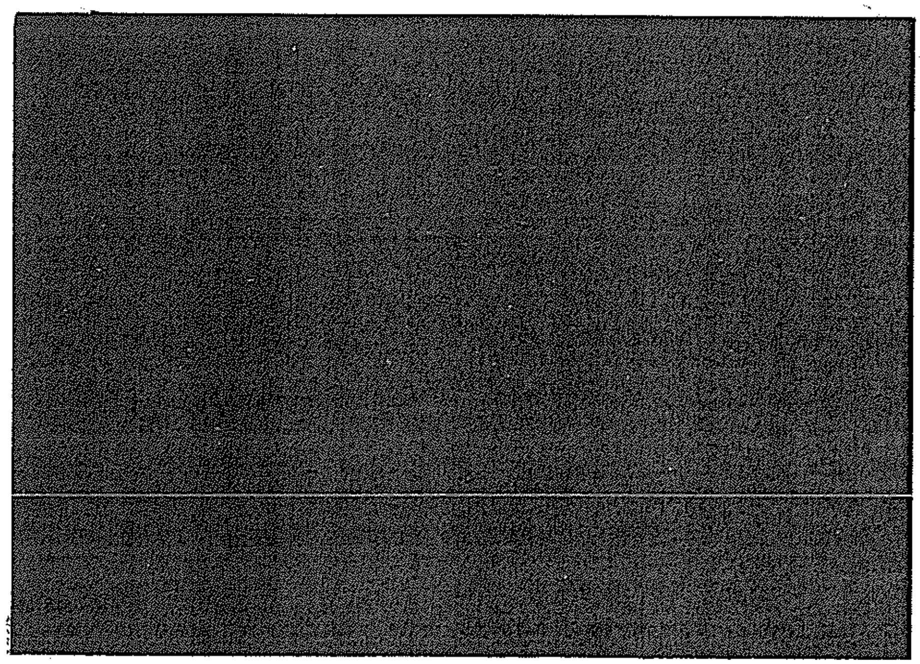

FIGURE 7

Exposed Steel, Darex Treated Block
(160 days of ponding)

Discussion of Salt-Fog Chamber Test Results

As described in the Methodology, after 100 days in the salt-fog chamber certain blocks were taken out and split longitudinally to expose the steel bar for observation. Results obtained on these specimens indicated that both the treated and reference blocks showed approximately the same level of corrosion. While there was some corrosion taking place around the vicinity of the induced cracks, the rest of the bars were corrosion free. Anywhere there are cracks in the concrete, corrosion will usually take place no matter what type of concrete (treated or not) is used.

At this time it was decided not to crack the additional blocks but test them for a longer period of time. Steel bars exposed from the concrete blocks which were not originally cracked showed no sign of corrosion after 200 days in the salt-fog chamber. The steel bar in the cracked block (fractured over the full length of the beam) was badly corroded, as shown in Figure 8, while the steel bar in the original uncracked blocks, after 200 days in the salt-fog chamber, showed no apparent corrosion (Figure 9). Both of these blocks were broken at the end of the designated period for observation. The steel bar extracted from the reference block is shown in Figure 10 on page 26.

Corrosion on the cracked block left in the salt-fog chamber for 300 days, as shown in Figure 11 on page 26, was considerable. A half-cell reading on this block was 0.47 volts, which shows active corrosion (start of active corrosion estimated at 0.35 volts). However there was some inconsistency in the half-cell readings. The readings are dependent on how wet or dry the specimens are when they are tested. Also they are dependent on how much copper sulfate solution (at the end of the testing rod) penetrates into the concrete block when testing. Considerable

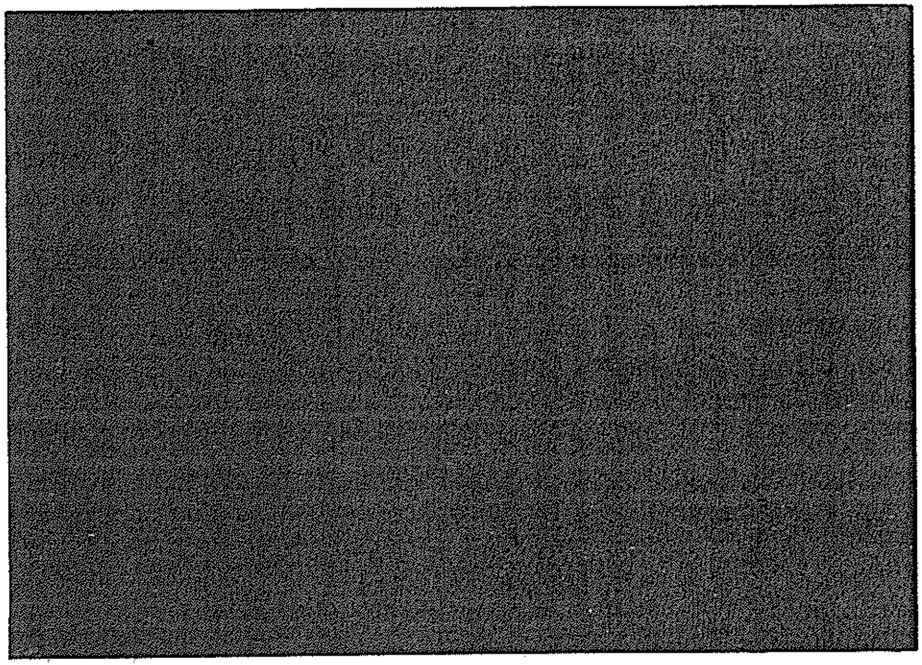

FIGURE 8

Exposed Steel in a Cracked Beam
(after 200 days in salt-fog chamber)

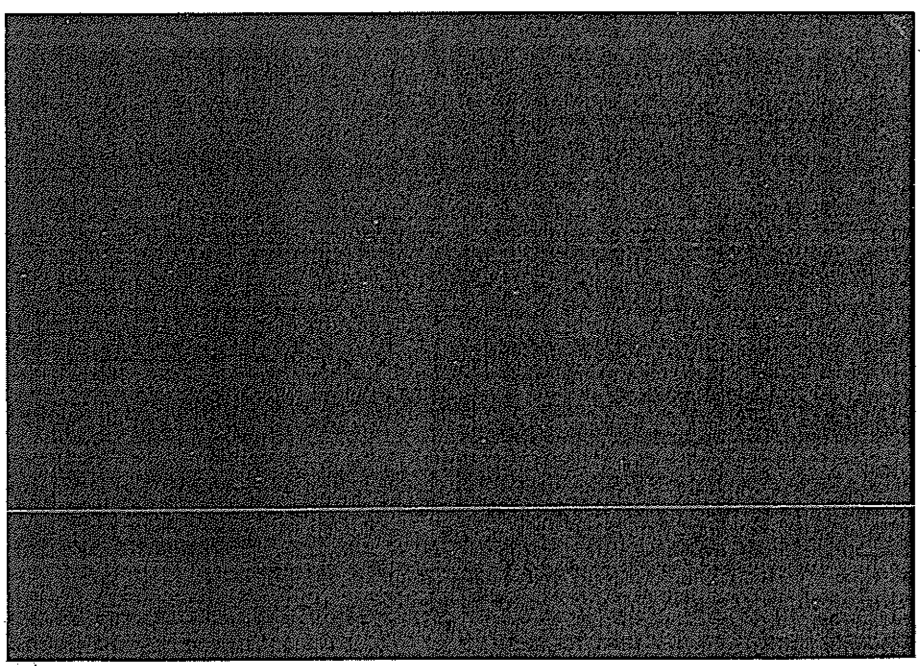

FIGURE 9

Exposed Steel in a Beam (Not Cracked)
(after 200 days in salt-fog chamber)

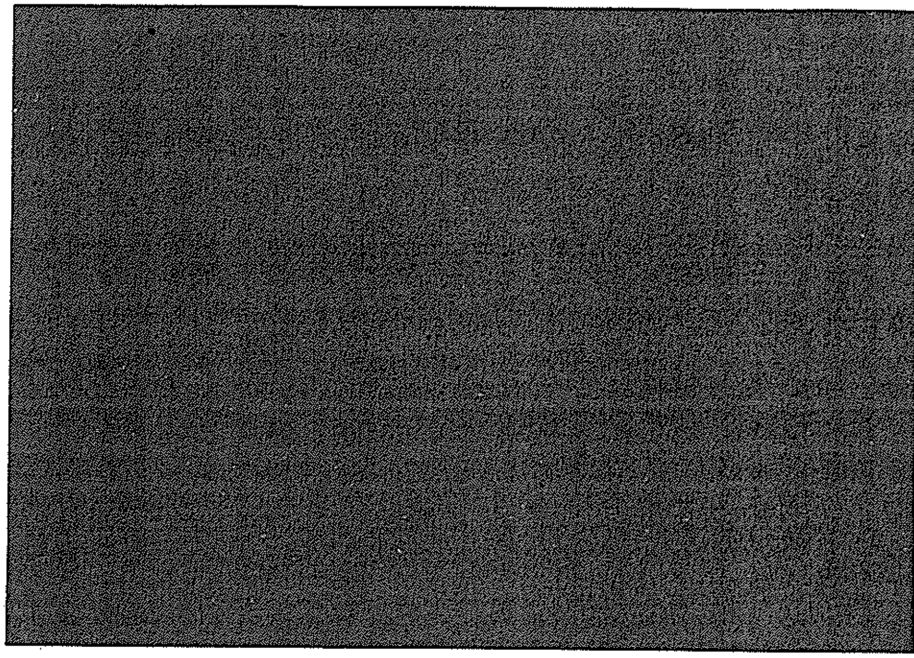

FIGURE 10

Corroded Steel Bars
(Extracted from Beam)

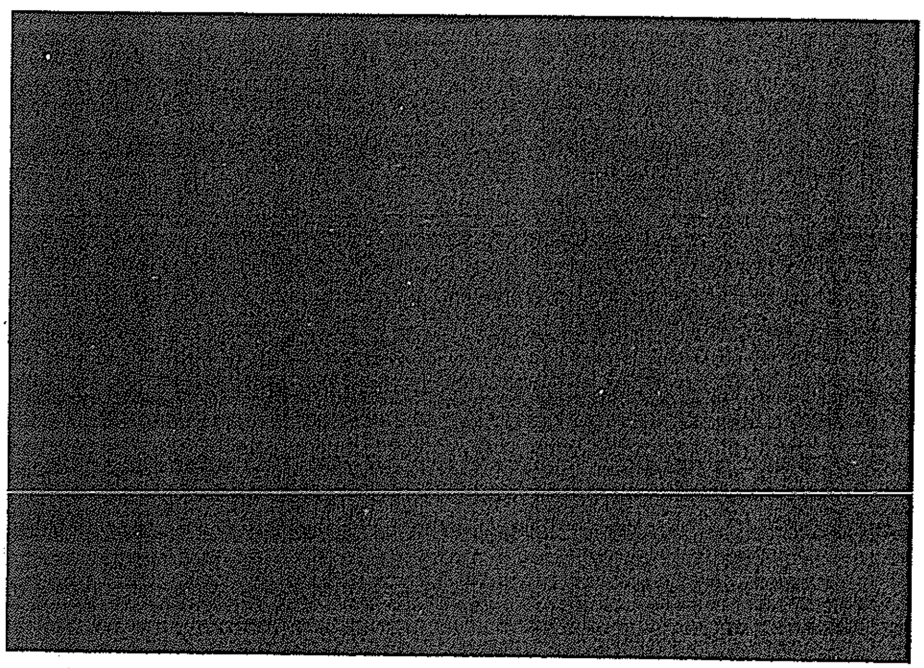

FIGURE 11

Corroded Steel Bar,
300 days of Testing

variations were seen in the readings on the specimens within the same group. An uncracked block was left in the salt-fog chamber for further evaluation. This was done in order to evaluate the penetration of salt for longer periods of time.

Discussion of Direct Coating of Steel Results

This test was performed as an extra effort for comparison purposes. The intended use of calcium nitrite corrosion inhibitor (Darex) is not as a direct coating of steel bars, but as an additive to concrete mixes for their corrosion inhibiting qualities. This test was performed in order to study the effect of the corrosion environment on plain steel bars that were coated with calcium nitrite. The steel bars were coated twice, with each application taking approximately 24 hours to dry. Then, the steel bars were placed in a 100% relative humidity (moist) room for the corrosion evaluation.

The results showed that the coated bars started to rust 21 days later than the uncoated bars. This was the only difference noted. Observations made approximately 10 days later indicated the same level of corrosion for both coated and uncoated bars. As mentioned earlier, this test was only added effort in the research study. Possibly coating the steel bars and placing in concrete might help out in the prevention of corrosion of the steel but this was not tried.

Discussion of Cost-Effectiveness

According to the manufacturer's recommendations, the dosages of Darex Corrosion Inhibitor (calcium nitrite) that should be used range from two to four percent, by weight of cement, in the concrete mix. As the manufacturer states, the protection level against any corrosion increases and also the strength development increases as the dosage rate increases toward four percent. It is also stated that this is an easy system to use and an inexpensive corrosion control system for use in structural concrete.

The material cost for Darex Corrosion Inhibitor, as quoted by the manufacturer, is approximately $6.00 per gallon, depending on the quantity purchased. For a 7 in. bridge deck, assuming a 6.5 sack cement per cubic yard concrete mix design, the material cost for treatment would be from $4 to $5 per square yard or a rough estimate of from $21 to $25 per cubic yard of concrete. The concrete with treatment would cost from $13 to $15 per square yard, or roughly from $67 to $77 per cubic yard. All costs quoted for corrosion inhibitor in this discussion include a dosage of two percent, by weight of cement, in the concrete mix design.

The treatment cost to coat rebars (epoxy coated rebars) is approximately $8.58 per square yard for a new bridge deck, which corresponds to a treatment cost for corrosion inhibitor of approximately $4.50 per square yard. Therefore, a savings of $4.08 per square yard for material cost is achieved through the use of a corrosion inhibitor, which amounts to a 48% savings in respect to this form of epoxy coated rebars.

A polymer modified concrete cost, including the steel, would be approximately $36.64 per square yard; while the corrosion inhibitor concrete cost, including the steel, would be approximately $24.79; and the concrete cost using an epoxy coated rebars (top mat only) would be approximately $28.97 per square yard. Therefore, polymer modified concrete would cost approximately 27% more than concrete using epoxy coated rebars, or 48% more than concrete using a corrosion inhibitor. In comparison, the cost of low slump dense concrete should be approximately in the same range as the polymer modified concrete per square yard. Some of the comparative costs can be found in Tabe 8 on page 29.

As can be seen from these cost comparisons, concrete using a corrosion inhibitor is competitive in cost, with some of the other types of corrosion protection systems (e.g. epoxy coated rebars, low slump dense concrete or polymer modified concrete). However, the concrete using the corrosion inhibitor is still approximately 22% more expensive than conventional concrete, the costs including the steel. It all comes down to the bottom line, that is, how effective is a corrosion inhibitor in concrete? Is it effective enough to offset what additional cost there is?

A definite conclusion was not obtained on this study regarding the protection effectiveness of Darex corrosion inhibitor (calcium nitrite). More research is needed in the establishment of a more satisfactory and feasible method of measuring the protection effectiveness of corrosion inhibiting materials against corrosion of steel in portland cement concrete, when tested under laboratory conditions, and to correlate with actual field conditions.

TABLE 8

COMPARATIVE COST DATA

Type of Material	Approximate Average Material Costs		
	Unit	Per Sq. Yd.	Per Cu. Yd.
Conventional Concrete	-	$ 9.50	$ 49.00
Concrete + Steel	-	$20.29	$104.50
Corrosion Inhibitor	$6.00/gal.	$ 4.50	$ 23.00
Corrosion Inhibitor + Concrete	-	$14.00	$ 72.00
Corrosion Inhibitor + Concrete + Steel	-	$24.79	$127.50
Polymer Modifier	$3.70/gal.	$16.40	$ 84.17
Polymer Modified Concrete + Steel	-	$36.69	$189.00
Epoxy Coated Rebars (top mat only)	$0.68/lb.	$14.97	-
(Cost to Coat Rebars)	$0.39/lb.	$ 8.58	-
Bare Steel (top mat only)	$0.29/lb.	$ 6.39	-
Additional Steel	$0.20/lb.	$ 4.40	-
Bare Steel + Additional Steel	$0.49/lb.	$10.79	-
Epoxy Coated Rebars + Additional Steel	$0.88/lb.	$19.37	-
Epoxy Coated Rebars + Additional Steel + Concrete	-	$28.87	-

CONCLUSIONS

The following conclusions have been established on this research study:

(1) Darex corrosion inhibitor does protect some against corrosion of steel embedded in portland cement concrete, but the extent of protection has not been defined in this study.

(2) Strength of corrosion inhibitor treated concrete is higher than for reference concrete (not treated) at all ages; however, at later ages, the percentage difference in strength between the treated and untreated concrete decreases, which is to be expected, even though the strength increase stays approximately the same.

(3) Darex corrosion inhibitor (calcium nitrite) improves the general mix properties of air-entrained concrete.

(4) Concrete using a corrosion inhibitor as an additive will cost approximately 22% more than conventional concrete, although it is not as expensive as polymer modified concrete, low slump dense concrete or the use of epoxy coated rebars in concrete. Even though there are strength increases in corrosion inhibitor treated concrete over conventional concrete, it is not known at this time whether the small corrosion inhibiting qualities that have been attained are enough to offset the cost increases with the use of this additive.

(5) More research is needed in the establishment of a more satisfactory and feasible method of measuring the protection effectiveness of corrosion inhibiting materials against corrosion of steel embedded in portland cement concrete, when tested under laboratory conditions, and effectively correlating it to actual field conditions.

RECOMMENDATIONS

The laboratory testing performed on specimens in this research study is not fully corroborative of corrosion inhibiting qualities of a corrosion inhibitor (calcium nitrite) such as Darex. More research in the area of corrosion detection of embedded steel in concrete, under laboratory conditions, and a simplified method to correlate this to actual field conditions is needed.

BIBLIOGRAPHY

1. Clear, K. C. and Choller, B. H., "Stryene-Butadiene Latex Modifiers for Bridge Deck Overlay Concrete." Federal Highway Administration, Report No. FHWA-RD-78-35, Interim Report, April 1978.
2. Craig, R. J. and Wood, L. E., "Effectiveness of Corrosion Inhibitors and Their Influence on the Physical Properties of Portland Cement Mortars." Highway Research Record No. 328, 1970, pp 77-88.
3. Griffin, D. F., "Corrosion Inhibitors for Reinforced Concrete." Corrosion of Metals In Concrete, American Concrete Institute Publications SP-49, 1975, pp 95-102.
4. Rosenberg, A. M., et. al., "A Corrosion Inhibitor Formulated with Calcium Nitrite for Use in Reinforced Concrete." Chloride Corrosion of Steel in Concrete, D. E. Tonini and S. W. Dean, Jr., Eds., ASTM STP 629, American Society for Testing and Materials, 1977, pp. 89-99.
5. Berman, H. A., "Determination of Chloride in Hardened Cement Paste, Mortar and Concrete." Report No. FHWA-RD-72-12, FHWA, 1972.
6. Stratfull, R. F., Jurkovich, W. J. and Spellman, D. L., "Corrosion Testing of Bridge Decks." Transportation Research Record No. 539, 1975, pp. 50-59.
7. Morrison, G. L., et. al., "Rapid In-Situ Determination of Chloride Ion in Portland Cement Concrete Bridge Decks." Report No. FHWA-KS-RD-75-2, FHWA, 1976.
8. Stratfull, R. F., "Half-Cell Potentials and the Corrosion of Steel in Concrete." Highway Research Record No. 433, 1973, pp. 12-21.
9. National Cooperative Highway Research Program, Synthesis of Highway Practice, Report No. 57, "Durability of Concrete Bridge Decks." Transportation Research Board, National Research Council, Washington, D.C.
10. ASTM Special Technical Publication 169 B, "Significance of Tests and Properties of Concrete and Concrete-Making Materials." 1619 Race Street, Philadelphia, Pa. 19103.
11. Neville, A. M., Properties of Concrete, New York: John Wiley and Sons, 1973.

APPENDIX

MODIFIED 90-DAY CHLORIDE PERMEABILITY TEST FOR CONCRETE

(a) Four 9 in. x 15 in. x 3 in. treated or plain concrete slabs shall be made from the concrete mix of the required design.

(b) Slabs shall be cured with wet burlap for 24 hours after molding, then cured thirteen days in the moist room and 21 days in laboratory air (73.4 ± 3°F., 50 ± 4% rh).

(c) 1-inch high x 1-inch wide dams shall be placed around 3 of the specimens. All 4 slabs shall then be placed in a 73.4° ± 3°F., 50 ± 4% rh environment for 90 days. Three of the slabs shall be subjected to continuous ponding with a 1/2-inch deep, 3 percent sodium chloride solution during the 90 days. Glass plates shall be placed over the 3 ponded specimens to retard evaporation of the solution, and additional solution shall be added when necessary to maintain the 1/2-inch depth.

(d) After 90 days of ponding, the solution shall be removed from the slabs, and after drying, the surfaces shall be wire brushed until all salt crystal buildup is completely removed.

(e) Samples for chloride analysis shall then be taken from all 4 slabs, in accordance with the rotary hammer procedure described in report FHWA-RD-74-5 or by dry coring (1.5-inch minimum diameter cores) and dry sawing. Three samples shall be obtained from each slab at each of the following depths:

1/16-inch to 1/2-inch
1/2-inch to 1-inch

(f) The baseline chloride content for the overlay concrete shall be determined as the average chloride content of samples obtained from the 1/16-inch to 1/2-inch and 1/2-inch to 1-inch depths within the slab that was not ponded with 3 percent NaCl solution.

(g) The absorbed chloride content of each sample from the 3 ponded slabs shall be determined as the difference between the total chloride content of that sample and the baseline value calculated in item (f) above. If the result is less than zero, the result shall be reported as 0.0. The average chloride absorbed at each sampling depth shall be calculated.

(h) Reporting shall include:

(1) Each total chloride value determined in item (e).

(2) The average and maximum baseline chloride in item (f).

(3) Each calculated absorbed chloride value determined in item (g).

(4) The average and maximum absorbed chloride values calculated in item (g) for each depth.