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16. Abstract

This study evaluates the concretes in steam-cured prestressed piles and beams containing calcium nitrite as protection against chloride-induced corrosion of the steel strands and assesses their field performance over a 3-year period. Concretes containing slag were also included in the study to evaluate their permeability to chloride ions. It was found that concretes containing calcium nitrite (DCI) have satisfactory strengths and are expected to provide adequate resistance to cycles of freezing and thawing. The steam-cured slag concretes were found to have lower permeability than the similar portland cement concretes. Since the addition of DCI does not have an appreciable adverse affect on the properties of steam-cured concretes and has the potential to provide long-term protection against corrosion, its use is recommended in prestressed concrete subjected to severe exposure.

The limited time available for laboratory and field testing did not allow conclusions on the effectiveness of the corrosion inhibitor. Continuing evaluations are recommended.

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FINAL REPORT

EFFECT OF CALCIUM NITRITE ON THE PROPERTIES OF CONCRETE USED IN PRESTRESSED PILES AND BEAMS

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(A Cooperative Organization Sponsored Jointly by the
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the University of Virginia)

In Cooperation with the U.S. Department of Transportation
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ABSTRACT

This study evaluates the concretes in steam-cured prestressed piles and beams containing calcium nitrite as protection against chloride-induced corrosion of the steel strands and assesses their field performance over a 3-year period. Concretes containing slag were also included in the study to evaluate their permeability to chloride ions. It was found that concretes containing calcium nitrite (DCI) have satisfactory strengths and are expected to provide adequate resistance to cycles of freezing and thawing. The steam-cured slag concretes were found to have a lower permeability than the similar portland cement concretes. Since the addition of DCI does not have an appreciable adverse affect on the properties of steam-cured concretes and has the potential to provide long-term protection against corrosion, its use is recommended in prestressed concrete subjected to severe exposure.

The limited time available for laboratory and field testing did not allow conclusions on the effectiveness of the corrosion inhibitor. Continuing evaluations are recommended.

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INTRODUCTION

Corrosion of prestressed strands in piles and beams can cause cracking and spalling of concrete and, under severe conditions, can reduce the load-carrying capacity of a structure.[1] To prevent or minimize corrosion of the strands and bars, a number of protective systems can be used, such as epoxy-coating, increased cover depth, concretes with low permeability, and concretes with a corrosion inhibitor such as calcium nitrite.[2, 3] These systems vary in cost-effectiveness, depending somewhat on the conditions under which they are used.

In steam-cured prestressed piles and beams with uncoated strands, a concrete cover exceeding 2 in over the strands is commonly used. However, in marine environments, there is still some risk of corrosion and more effective protective systems are needed.

A frequently used method of protection is to use low-permeability concretes or provide for increased cover depth. Low-permeability concretes can be prepared using slag and pozzolanic materials (such as silica fume) and a low water-cement ratio (w/c).[4] However, if cracking or lack of consolidation occurs, much of the protection from low permeability is lost since the penetration of chlorides to the level of reinforcement is facilitated. The use of a corrosion inhibitor to protect reinforcement in cracked concretes needs to be investigated. Another method of protection is to use epoxy-coated strands. However, there is some concern that the epoxy coating will be damaged and lose effectiveness as a result of the high temperature resulting from steam curing. Creep is also a concern with epoxy-coated strands.

At present, calcium nitrite is a widely used inhibitor, and others are being made available. An inhibitor, such as calcium nitrite, can be added to freshly mixed concrete to induce a reaction that results in the formation of a protective oxide layer on the steel. In effect, the chloride ions and the nitrite ions engage in competing chemical reactions, and corrosion does not occur when the amount of chloride is low compared to the amount of nitrite (low chloride-to-nitrite ratios). To achieve continuing protection with the inhibitor at minimum costs, the amount of calcium nitrite added to freshly mixed concrete varies with the amount of chlorides expected to penetrate the concretes during the life of the structure.[5] Thus, it is important to prepare concretes that will significantly hinder the penetration of chlorides to the level of the steel so that minimum amounts of calcium nitrite can be used for cost-effectiveness.

Although the inhibition of corrosive reactions by calcium nitrite is well established,[3, 6] it is also important to determine if the addition of calcium nitrite adversely affects the properties of concretes.

PURPOSE AND SCOPE

The objective of this study was to conduct a field evaluation of steam-cured concretes containing calcium nitrite in prestressed piles in two bridges and beams. The evaluation included (1) the properties of the concrete, i.e., strength, permeability, and resistance to deterioration resulting from freezing and thawing; (2) the effectiveness of calcium nitrite in preventing corrosion; (3) the effectiveness of the addition of slag in preventing or minimizing the penetration of chlorides into the concrete; and (4) the condition of the structures after specified intervals of service.

METHODOLOGY

The bridges are located on Rte. 258 over Mill Creek in the city of Hampton, Virginia, in the Suffolk District. In one (longer) bridge, piles were made of portland cement concrete without other cementitious admixtures, and concrete beams were prepared that consisted of 60 percent portland cement and 40 percent slag. No corrosion inhibitor was used. In the second (shorter) bridge, located 400 ft to the east of the first bridge, calcium nitrite (marketed under the trade name DCI) was added to the portland cement concretes in both the piles and the beams. The piles and the beams for the bridges were prepared and steam cured at the prestressing plant (Plant 1). In addition, test specimens using concretes made with portland cement from a different source were prepared and tested at another plant (Plant 2). These were tested to investigate the effects of cements from different sources on the resistance to cycles of freezing and thawing.

To determine the properties of concrete at Plant 1, control and experimental concretes containing calcium nitrite were prepared using Type II cement that was finely ground and had a C_3A content of 5.6 percent. The characteristics of the cement are given in Table 1. The mixture proportions are given in Table 2. Control beams contained slag equaling 40 percent by weight of the cementitious material. Additional control samples for beams were prepared at the plant using portland cement only, since portland cement was the only cementitious material in all of the experimental concretes with DCI. The corrosion inhibitor contained 30 percent by weight calcium nitrite.

Table 1
CHEMICAL AND PHYSICAL ANALYSES OF CEMENTS

Analysis	Plant 1 Type II	Plant 2 Type III
Chemical (%)		
SiO_2	21.1	20.7
Al_2O_3	4.3	4.7
Fe_2O_3	3.4	3.9
CaO	63.0	62.9
MgO	3.7	2.7
SO_3	2.8	3.2
Na_2O equivalent	0.57	0.72
Ignition loss	1.0	0.79
C_3S	54.4	53.0
C_3A	5.6	6.0
Physical		
Fineness, Blaine (m^2/kg)	511	480

Table 2
MIXTURE PROPORTIONS FOR CONCRETES FROM PLANT 1 (LB/FT^3)

	For Beams			For Piles	
Ingredient	Control	Control with Slag	DCI Concrete	Control	DCI Concrete
Cement[a]	705	423	705	658	658
Slag	—	282	—	—	—
Maximum w/c[b]	0.40	0.35	0.40	0.40	0.40
Coarse aggregate[c]	1,820	1,850	1,820	1,900	1,840
Fine aggregate[d]	989	1,030	989	1,076	1,026
HRWR	Yes	Yes	Yes	Yes	Yes
DCI (gal/yd^3)			3.5		5.4

[a] Modified Type II Atlantic cement with a Blaine fineness of 511 m^2/kg.
[b] Specifications: maximum w/c = 0.49.
[c] 1-in maximum size siliceous river gravel.
[d] Natural siliceous sand.

At Plant 2, the cement used was Type III with a C_3A content of 6 percent. The characteristics of the cement are given in Table 1. The mixture proportions are given in Table 3. One control and two DCI mixtures were prepared. The second DCI mixture did not contain a high-range water-reducing admixture (HRWR), but all the other concretes did. All the concretes contained an air-entraining admixture, and the air requirement was 4-1/2 ± 1-1/2 percent, which was raised to 5-1/2 ± 1-1/2 percent when HRWR was used. All the concretes were steam cured.

Table 3
MIXTURE PROPORTIONS FOR CONCRETE FROM PLANT 2 (LB/FT^3)

Ingredient	Control	DCI 1	DCI 2
Cement[a]	635	705	752
Maximum w/c[b]	0.40	0.40	0.45
Coarse aggregate	1,820	1,820	1,820
Fine aggregate	1,252	1,071	904
DCI (gal/yd^3)	—	5.4	5.4
HRWR	Yes	Yes	No

[a] Lone Star Type III modified with 6% C_3A.
[b] Water from the DCI is included.

Eight batches of concretes, four with and four without DCI, were prepared and tested at the freshly mixed stage for air content (ASTM C 231) and slump (ASTM C 143). Specimens were prepared for tests at the hardened stage for strength, resistance to deterioration from freezing and thawing, and chloride ion penetration. The number and size of specimens and the age of the test are given in Table 4.

The effectiveness of calcium nitrite in inhibiting corrosion was determined using a new proposed ASTM test method, G 109. Concretes were prepared and tested in the laboratory.

The effectiveness of the addition of slag on the chloride permeability of both the steam-cured and moist-cured concretes were evaluated at various w/c.

To evaluate the conditions of the control and the adjacent experimental piles and beams, surveys were made the same year the members were cast and after the first and third winters. Also, copper leads were attached to four beams (two control and two DCI beams) at the plant to enable the measurement of electric half-cell potentials for corrosion activity at the job site. Each lead was soldered to the strand, and the area of connection was isolated from the environment by coating with an epoxy resin to prevent corrosion at the joint. Six leads for four control piles in 2 of the 10 bents and 12 leads for six piles with DCI in both bents were attached to pile ends at the job site after the piles were driven. Visual observations of the beams and piles were made.

Table 4
NUMBER OF SPECIMENS AND TESTS FROM EACH BATCH

Test	Specimens		Age (days) Tested
	No.	Size (in)	
Compressive strength	6	4 x 8	1, 28
Flexural strength	3	3 x 3 x 11 1/4	28
Rapid permeability	2	4 x 2	28
Freeze-thaw	6	3 x 4 x 16	
Air voids	1	4 x 8	28

RESULTS AND DISCUSSION

Properties of Concretes

Freshly Mixed Concretes

The results of tests for air content and slump are given in Table 5 along with w/c. The air content ranged from 4.5 to 8.4 percent, and the slump from 1.8 to 6.8 in. All the values were within the specifications except for the 8.4 percent air content.

Table 5
CONCRETE CHARACTERISTICS AT FRESHLY MIXED STAGE

Batch	w/c	Air Content (%)	Slump (in)
Plant 1			
Beams			
Control	0.37	6.6	3.8
Control (slag)	0.33	4.7	2.8
DCI	0.39	4.5	1.8
Piles			
Control	0.38	6.4	5.0
DCI	0.43	5.1	2.0
Plant 2 Piles			
Control	0.39	8.4	6.8
DCI 1	0.40	5.0	3.5
DCI 2	0.45	6.0	3.8

Hardened Concretes

Strength

The compressive strengths given in Table 6 were determined in accordance with AASHTO T 22 using 4-in x 8-in cylinders except that neoprene pads in steel end caps were used for capping. The concretes were steam cured at the plant. The 1-day results shown were determined at the end of the steam-curing period, about 16 ± 2 hr. Some of the steam-cured specimens were kept in the laboratory air and tested at 28 days. The flexural strength tests were conducted in accordance with ASTM C 78. The test results indicated satisfactory compressive and flexural strengths.

Table 6
STRENGTH AND CHLORIDE PERMEABILITY DATA

Batch	Compressive Strength (psi) 1-Day[a]	Compressive Strength (psi) 28-Day	28-day Flexural Strength (psi)	28-day Chloride Permeability (C)
Plant 1				
Beams				
Control	4,600	5,960	685	6,305 (high)
Control slag	6,600	8,860	835	891 (very low)
DCI	5,330	7,490	790	6,562 (high)
Piles				
Control	5,100	6,810	690	3,112 (moderate)
DCI	5,120	6,470	580	6,691 (high)
Plant 2 Piles				
Control	—	8,860	—	4,582 (high)
DCI	5,150	9,390	—	3,385 (moderate)

[a] At the end of the steam-curing period.

Permeability

The permeability to chloride ions was determined using both the rapid permeability test (AASHTO T 277) and the 90-day ponding test (AASHTO T 259). In the rapid permeability test, the charge passing through the specimen in a 6-hr period is determined and expressed in coulombs. These values are related to the chloride permeability. After the steam-curing period, the rapid permeability samples were stored in the laboratory air until tested at 28 days. The results given in Table 6 indicate that all of the portland cement concretes without slag had a moderate or high chloride permeability rating. However, a very low chloride permeability rating was indicated for the concrete containing slag. This observation prompted further testing of steam-cured slag concretes.

In the ponding tests, slabs were steam cured, air dried, and ponded with 3% NaCl for 2.5 years rather than the standard 90 days to provide sufficient time for chloride penetration. Three concretes from Plant 1 were tested. One was a control pile mixture, one was a control beam mixture with slag, and the third was a beam

Table 7
CHLORIDE CONTENTS OF VARIOUS CONCRETES FROM PLANT 1
SUBJECTED TO PONDING TESTS (LB/YD^3)

Concrete	w/c	At 1/2 in	At 1 in	At 1-3/4 in
Control piles	0.38	19.53	13.55	3.72
Control (slag) beams	0.33	9.06	0.82	0.24
DCI beams	0.39	21.96	19.14	6.14

mixture with DCI. The results given in Table 7 indicated that the control concrete without DCI and the experimental concrete with DCI had a high chloride content exceeding the threshold value[7] of 1.3 lb/yd^3 at all depths even though the chloride content decreased with depth. The chloride content of the concrete with slag also decreased with depth. However, the threshold value was exceeded only at the 1/2-in depth.

The results of the ponding test are consistent with the results of the rapid permeability test. Both indicate that low-w/c steam-cured slag concrete provides high resistance to chloride ion penetration.

Resistance to Freezing and Thawing

The resistance of concretes to damage from cycles of freezing and thawing was determined using ASTM C 666, Procedure A, in which the beams are moist cured for 2 weeks, including the initial steam-curing period, and then tested by freezing and thawing in water. In addition, specimens were tested with modifications to this procedure. In the modified procedure, a 2% NaCl solution is used as the test water and curing was extended by 1 week in a dry condition. These modifications are expected to simulate the actual field conditions more closely than the standard test. The results given in Table 8 indicate that almost all the concretes tested in salt water met the acceptance criteria based on an average of three beams having a weight loss (WL) of 7.0 percent or less, a durability factor (DF) of 60 or more, and a surface rating (SR) of 3.0 or less. The exceptions are that the DCI concrete for beams from Plant 1 had a high WL and SR but a satisfactory DF and the DCI 1 from Plant 2 failed all the criteria.

Table 8
FREEZE-THAW DATA

	In Water[a]			In Salt[b]		
Batch	WL (%)	DF	SR[c]	WL (%)	DF	SR
Plant 1						
Beams						
Control[c]	2.4	65	1.7	1.2	93	1.4
Control (slag)	0.0	82	0.7	1.5	82	1.5
DCI	10.8*	65	3.3*	12.7*	80	3.3*
Piles						
Control	60[d]*	33*	5.0*	6.8	95	2.5
DCI	58[d]*	42*	5.0*	5.9	92	2.6
Plant 2 Piles						
Control	1.4	88	1.5	1.6	93	1.9
DCI 1	e*	e*	e*	f*	f*	f*
DCI 2	—	—	—	3.1	94	1.5

[a] Standard ASTM C Procedure A with 14-day moist curing and tested in water.
[b] Modified test using 2% NaCl in test water and an additional 1-week dry cure. WL = weight loss, DF = durability factor, SR = surface rating (ASTM C 672 rating scale).
[d] Projected from 155 cycles.
[e] Broke in pieces at second and third reading (at an average of 113 cycles).
[f] Broke in pieces at first reading of 50 cycles.
*Failed test.

Tested in water, concrete prepared in Plant 1 for piles with or without DCI failed and the DCI 1 from Plant 2 failed. The DCI concrete for beams also had a high WL and SR but a satisfactory DF. The results indicate that one additional week of drying following 2 weeks of moist curing provides a better resistance to internal deterioration. Based on limited data, it appears that beams with DCI will be internally sound as long as the concrete is allowed to dry before it freezes in service, although they may show more scaling.

Air-Void Parameters

The air-void system in the hardened concretes was determined in accordance with the linear traverse method of ASTM C 457. All the concretes tested for freeze-thaw resistance were also tested for the air-void parameters except that a test specimen was not available for the control concrete from Plant 2. The specimens were moist cured at least 1 month, and a vertical slab was cut, lapped, and tested. The values for small, large, and total voids; specific surface; and spacing factor are given in Table 9. For adequate protection of critically saturated concretes exposed to extreme conditions, specific surface values of 600 in^2/in^3 or more and spacing factor values of 0.008 in or less are generally required. The test results indicate that the spacing factors were in the acceptable range except those for the slag concrete from Plant 1 and the DCI 1 concrete from Plant 2. Thus, the failure of DCI 1 concrete in the freeze-thaw test can be attributed to the lack of a proper spacing factor. However, even though the spacing factor of the control concrete with slag was high, the concrete performed satisfactorily in the freeze-thaw test. This is attributed to its very low permeability. The results of the petrographic examination and the freeze-thaw tests indicate that concretes with DCI can be prepared with proper air-void systems and are expected to provide the needed resistance to cycles of freezing and thawing even though they may exhibit more surface scaling.

Table 9
AIR-VOID PARAMETERS OF HARDENED CONCRETE

	Voids				
Batch	<1 mm	>1 mm	Total	Specific Surface (in^{-1})	Spacing Factor (in)
Plant 1					
Beams					
Control	4.5	1.6	6.1	582	0.0075
Control slag	2.4	1.2	3.6	404	0.0140
DCI	3.4	1.4	4.8	655	0.0075
Piles					
Control	5.6	1.3	6.9	843	0.0046
DCI	6.0	0.8	6.8	578	0.0069
Plant 2 Piles					
DCI 1	1.9	1.0	2.9	404	0.0153
DCI 2	4.2	0.7	4.9	785	0.0062

Effectiveness of Calcium Nitrite in Inhibiting Corrosion

A test method (ASTM G 109) is being developed to provide a means of predicting the effectiveness of corrosion inhibitors. Tests were made using this proposed procedure on control concretes and concretes with 3.5 gal/yd^3 and 5.4 gal/yd^3 DCI. In this test, the specimens are repeatedly ponded with 3% NaCl solution for 2 weeks and allowed to dry for an additional 2 weeks. The tests are further explained in a related report.[8] For the normal test procedure, three specimens were cast for each concrete. For concretes with 3.5 gal/yd^3 DCI, three more specimens were prepared for special testing. These were cracked by loading in flexure prior to ponding with the NaCl solution. The cracks varied from 0.15 to 0.30 mm; thus, most are wider than the tolerable crack widths given in ACI 224 (0.18 mm when deicing chemicals are used and 0.15 mm when exposed to sea water or sea water spray with wetting and drying). The results show that corrosion began in the cracked specimens at an early age even though 3.5 gal/yd^3 DCI was present. No indication of corrosion was observed for the uncracked DCI concretes after 2.5 years of ponding. The average test results for control specimens did not indicate corrosion. Since more time is needed to determine the potential value of DCI, the tests are continuing.

Effectiveness of Slag Additions on Permeability

The low chloride permeability obtained with the steam-cured concrete containing slag prompted further evaluation of these concretes. Subsequently, concrete specimens with and without slag were prepared at Plant 1. Four sets of concrete specimens were furnished by Plant 1. The w/c, slump, air content, and strength of these concretes are given in Table 10. In each set, there was a control concrete and concrete in which 40 percent by weight of the cementitious material was slag. For each concrete, four cylinders measuring 4 in x 8 in were made and two were steam cured and allowed to dry in the laboratory. The other two were moist cured for 2 weeks and then air dried for an additional 2 weeks for the rapid permeability test of the top 2 in at the age of 28 days. The results are given in Table 11. The remaining lower 6 in of the moist-cured cylinders from the first three sets were soaked in lime water prior to testing in compression, and the values are given in Table 12. Only the top 2 in was furnished from the fourth set; therefore, 28-day compressive strengths were not determined for that set.

The results indicate that the permeability values for slag concretes were lower when the concretes were steam cured than when they were moist cured. This does not appear to be the case for the control samples, which had a higher permeability when steam cured in two of the batches and an equivalent or lower permeability in the remaining two batches. All the steam-cured concretes with slag and three of the four moist-cured concretes with slag had a lower permeability than the regular concretes.

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Table 10
CONCRETE CHARACTERISTICS AT THE FRESHLY MIXED STAGE
FOR SUBSEQUENT SPECIMENS PREPARED AT PLANT 1

Batch	Variable	Slump (in)	Air Content (%)
1	Control	2.2	4.2
1A	Slag	3.5	3.8
2	Control	1.8	3.5
2A	Slag	1.5	3.5
3	Control	3.2	4.5
3A	Slag	5.0	5.2
4	Control	3.2	4.8
4A	Slag	3.2	4.2

Table 11
28-DAY CHLORIDE PERMEABILITY OF SLAG CONCRETES (C)

Batch	Variable	w/c	Steam Cured	Moist Cured
1	Control	0.36	1,950	2,020
1A	Slag	0.38	710	1,670
2	Control	0.37	4,367[a]	2,295
2A	Slag	0.37	460	1,041
3	Control	0.35	713	1,077
3A	Slag	0.36	636	1,531
4	Control	0.47	7,580	5,200
4A	Slag	0.48	2,690	3,500

[a] Large variation was obtained between the two cylinders tested. One cylinder had 1,170 C, and the other 7,560 C.

Table 12
28-DAY COMPRESSIVE STRENGTH OF SLAG CONCRETES (PSI)

Batch	Variable	After Steam Curing	28-Day Steam Cured	28-Day Moist Cured
1	Control	—	8,330	8,850
1A	Slag	4,700	7,920	9,050
2	Control	—	6,200[a]	8,650
2A	Slag	4,930	7,630	8,530
3	Control	—	7,560	9,010
3A	Slag	4,930	7,250	9,480
4	Control	3,300	—	—
4A	Slag	3,260	—	—

[a] Large variation was obtained between the two cylinders tested. One cylinder had 7,440 psi, and the other 4,970 psi.

The strength of the concretes were higher when they were moist cured for 28 days compared to those steam cured and then stored in the laboratory until 28 days.

Evaluations of the Structure

First Evaluations

The first evaluation was conducted in September 1988, the same year the members were cast and soon after placement at the job site. During the survey, it was noted that the piles were coated with epoxy resin. The 6 leads in the control piles were located, but only 1 lead in the DCI piles could be found. The remaining 11 leads in the DCI piles had been cut off during height adjustment. Ten half-cell potential readings were taken directly above the epoxy coating, and two above a chipped bare section in the controls. The single DCI pile was also tested at several points. All the readings were more negative than –0.35 V CSE, which under normal circumstances is an indication that corrosion is occurring. However, the epoxy coatings and the tidal zone keep the piles saturated, and half-cell potential values are expected to be high for saturated reinforced concrete members, which is the case with these piles. Thus, for this situation, the high negative values do not necessarily indicate corrosion and are related to the moist conditions of the members. Under these field conditions, the test is not considered applicable, and further testing of piles was discontinued.

All the leads in the beams were located except for one in a control beam. Half-cell potential values were determined at 4-ft intervals, and all the readings were found to be more positive than –0.20 V CSE, indicating a greater than 90 percent probability that no corrosion of reinforcing steel was occurring.

Second and Third Evaluations

The second evaluation was conducted in July 1989 after 1 year of exposure, and the third evaluation after 3 years of exposure in August 1991. The half-cell potentials on one control and two DCI beams available were determined as more positive than –0.20 V CSE, indicating a greater than 90 percent probability that no corrosion of the reinforcing steel was occurring. There was no evidence of corrosion on the outside of any beam or pile that was visible from the shore or the snooper. Also, no discernible scaling was occurring on the members.

CONCLUSIONS

Based on the laboratory tests conducted and the evaluation of piles and beams after 3 years, it is concluded that:

1. Concretes containing DCI can yield satisfactory compressive and flexural strengths and can provide adequate resistance to cycles of freezing and thawing, even though more scaling in some of the concretes with DCI was observed in the concretes tested in the laboratory.
2. The chloride permeability of concretes containing slag is lower than that of the comparable regular concretes. Also, steam curing results in better resistance to chloride penetration for slag concretes than similar concretes cured at room temperature.
3. The 2.5-year duration of tests in the laboratory was not sufficient to demonstrate the effectiveness of calcium nitrite.
4. The field performance of the control and experimental elements has been similar for the first 3 years. However, sufficient time has not passed for definite conclusions regarding the level of protection provided by calcium nitrite.

RECOMMENDATIONS

Since the addition of calcium nitrite does not have an appreciable adverse affect on the properties of steam-cured concretes and has the potential to provide long-term protection against corrosion, the following are recommended:

1. Specifications for steam-cured prestressed concretes with uncoated strands, other than those over tidal waters, should have a minimum of 3.5 gal/yd^3 of calcium nitrite in the mixtures (as recommended by the manufacturer) unless slag (minimum 40 percent of cementitious material) or silica fume (minimum 7 percent of the cementitious material) is used.
2. For structures with uncoated strands over tidal waters, specifications for beams and slabs should require a minimum of 5.4 gal/yd^3 of calcium nitrite for ordinary portland cement concretes (as recommended by the manufacturer) or 2.0 gal/yd^3 of calcium nitrite when slag (minimum 40 percent of cementitious material) or silica fume (minimum 7 percent of cementitious material) is used.

The exclusion or reduction in the amount of calcium nitrite for steam-cured concretes with slag or silica fume is permissible because of the very low permeability obtained with these concretes.

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