CHLORIDE PENETRATION INTO LSDC (IOWA SYSTEM) RESURFACING MIXES

PROJECT R-267

Division of Highways
Office of Materials and Research
Cement & Concrete Section

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Introduction

The Federal Aid Highway Program Manual[1] requires a system to protect the reinforcing steel from corrosion for all new and resurfaced bridge decks. The Federal Highway Administration Office of Research and Development has undertaken a study to determine which of the proposed methods are effective. (1, 2) Two methods used in Iowa have been found to be effective, the LSDC-Low Slump Dense Concrete overlay (Iowa system), and polymer modified concrete. Federal study discovered that the maximum threshold depth to which chlorides penetrated into Iowa system concrete was 1.4 inches after 830 daily salt applications. The one problem that appeared with the Iowa system approach concerned consolidation. When densities were 92 to 94 percent of rodded unit weight, the threshold depth for corrosion dropped to 3.4 inches.

To date, more than 340 bridges throughout Iowa have been, or are being, surfaced or resurfaced with Low Slump Dense Concrete (Iowa system). These bridges were let, for the most part, allowing either the latex modified or Iowa system. Although the service history of bridges let using the Iowa system has been good, it was felt that further investigation was warranted.

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1. U.S. Dept. of Transportation, FHWA, Federal Aid Highway Program Manual, Vol. 6, Ch. 7, Sect. 2, Subsection 7.

Based on preliminary reports, the Federal Highway Administration gave approval to use the Iowa system for the 1974 construction season, provided in-place densities would be checked with nuclear apparatus.[2] With the issuance of the Program Manual in April, 1976, the Iowa system became the first recommended procedure when reinforcing steel is not replaced on a restoration project. At the time this approval was given, it was suggested that Iowa conduct a laboratory study similar to that done by Federal Highway Administration researchers.

Purpose

The purpose of this investigation was to determine the comparative effectiveness of standard D-57 concrete and Iowa system Low Slump Dense Concrete in preventing threshold levels of chloride from penetrating the concrete slabs to the reinforcing steel.

Procedure

The test was composed of two slabs, each 4 ft. x 5 ft. x 5 in. thick. One slab was fabricated using D-57 concrete, the other using the Iowa system.

The exact proportioning and mixing are included in Appendix A.

Finishing the slabs consisted of leveling with a wood float and brooming. After loss of surface sheen, the slabs were subjected to a 72 hour wet burlap cure. Forms were stripped after eight days and edges were sealed with epoxy sealer between ten and thirteen days. Three percent sodium chloride (NaCl) applications

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2. Letter from Leon Larson, FHWA Div. Engr. to Mr. Joseph R. Coupal, Jr., Dir. of Highways, ISHC, ref. 07-195 dated Feb. 7, 1974.

were begun after 22 days. These applications, one per normal working day, were continued until 300 applications were complete.

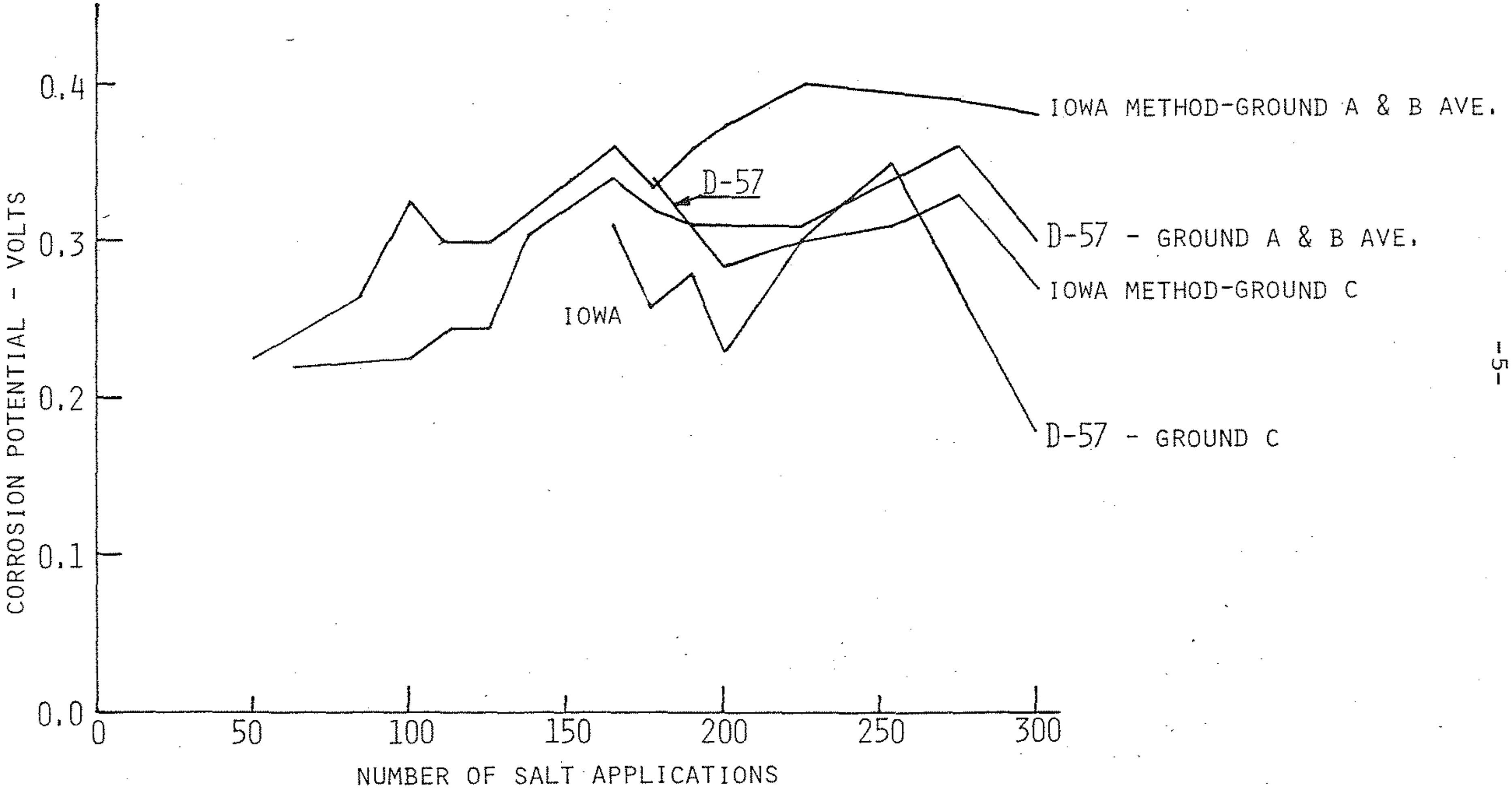
Corrosion detection ($CuSO_4$ ½ cell) readings were taken in accordance with Iowa Test Method 1008A at approximate 25 cycle intervals. Concrete cores were taken at approximate 25 cycle intervals for chloride content determination.(3) These cores were further separated into half inch thick segments to determine chloride ion penetration.

Results

Nuclear density measurements were not taken of the slabs at the time of fabrication. To determine the density of the plastic concrete, cores were taken and their density was determined using a water displacement method. From the density of these cores and the actual mix design measurements, the density of the D-57 mix was determined to be 103.9% of the rodded unit weight. That of the Iowa mix was determined as 102.9% of the rodded unit weight. For further verification that a minimum density of 98% of the rodded unit was obtained, exact duplicates of the original mixes were recreated. Two inch direct transmission nuclear densities were then obtained for these companion mixes. The results were 99.4% and 99.5% of the rodded unit weights for the D-57 and Iowa mixes, respectively.

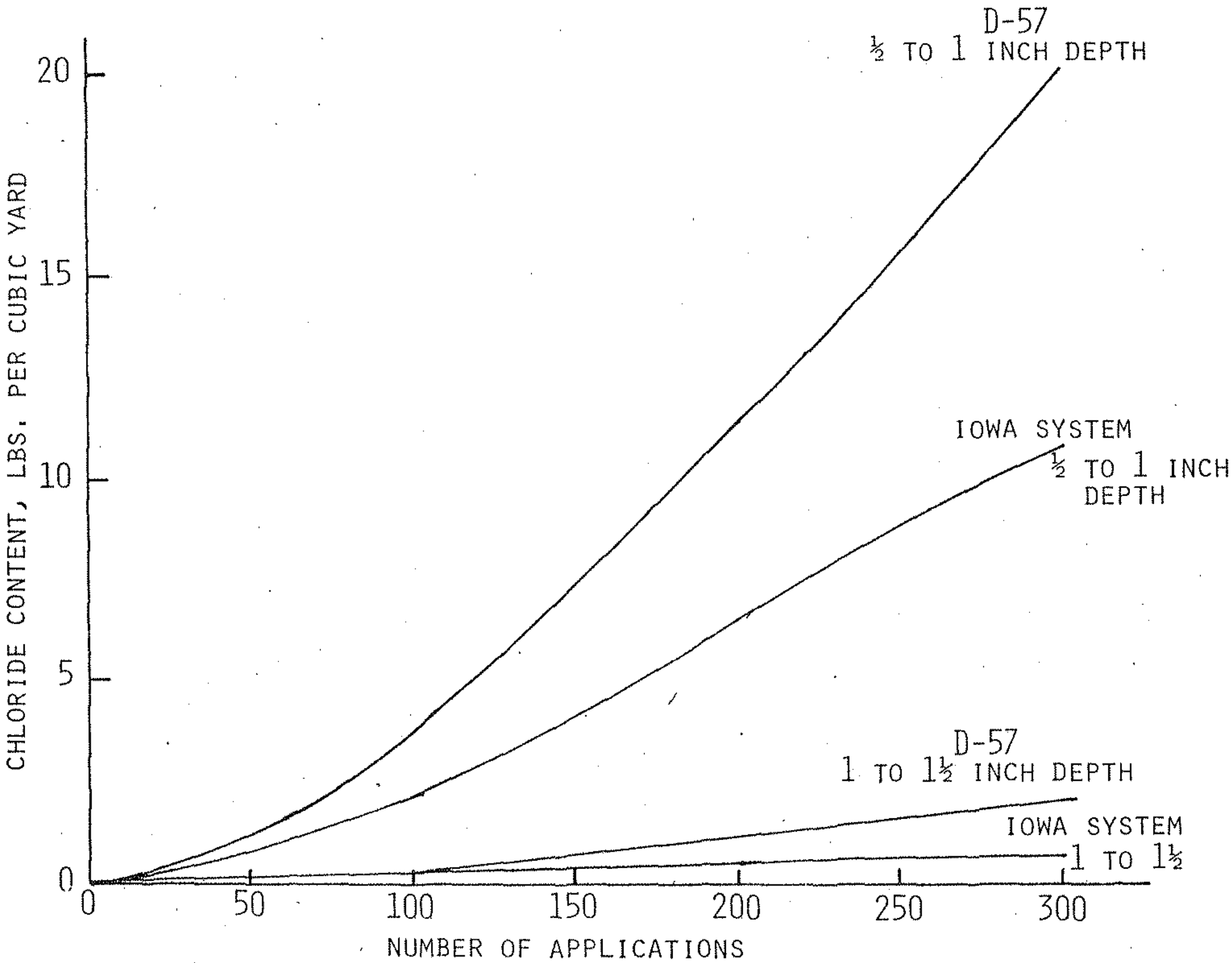
Copper sulfate half-cell corrosion detection readings were taken in accordance with Iowa Test Method 1008A at approximate 25 cycle intervals. Due to various problems encountered with the integrity of the grounding technique, the readings were not considered necessarily representative. After 300 cycles, the Iowa mix had an average reading of 0.34 volts and the D-57, an average of 0.26 volts. Both these averages are in the 'inconclusive' range for active corrosion determinations. Complete corrosion readings are included in Appendix B. As could be expected, the potential increased with repeated salt solution applications. This is displayed in Figure 1, Comparison of Mean Corrosion Potentials. This graph displays the average of readings at ground points A and B. Ground point C readings are more representative, due to the integrity of the ground at this point. The erratic nature of the increase lends further credence to the 'inconclusive' determination.

Cores for chloride analysis were taken at 25, 50, 100, 200, and 300 applications. Work by the Federal Highway Administration (4) has shown that the threshold level of corrosion varies with the cement factor. This is because total chloride present must be computed on a cement basis. This study showed that a total chloride content of 0.20% Cl on a cement basis was sufficient to initiate corrosion. For the particular mix designs evaluated in this study, the cement factor was 7.55 for the D-57 and 8.75 for the Iowa mix. From this information the threshold level of corrosion for the D-57 mix was calculated to be 1.42 pounds Cl-per cubic yard. The threshold corrosion level for the Iowa mix is 1.65 pounds Cl-per cubic yard. As will be noted from Figure 2, Chloride Penetration vs. Applications, the Iowa mix was well below the threshold level for its cement factor, whereas the D-57 was above its threshold level. Complete chloride penetration analysis is presented in Appendix C.



COMPARISON OF MEAN CORROSION POTENTIALS

FIGURE 1



CHLORIDE PENETRATION VS. NUMBER SALT APPLICATIONS

FIGURE 2

Summary and Conclusions

Iowa contractors show a definite preference for the LSDC (Iowa system) method of preventing corrosion in bridge deck reinforcing steel. This method appears to be a valid system, as long as the reinforcing steel has a minimum of 1½ inches of cover. Iowa Department of Transportation Standard Specifications[3] require a minimum of 2 inches of cover. This laboratory study indicates that is sufficient to prevent corrosion for a limited number of salt applications.

A minimum plastic concrete density of 98% of the standard rodded density does not appear to be especially hard to achieve under laboratory conditions. Field application of these overlays has verified that 98% density is not difficult to obtain with the proper equipment.

Active corrosion determinations using a copper sulfate reference voltage were not conclusive in this study. Some of the contributing factors to this were:

1. Steel too deep. The Iowa system reinforcing steel was under 3¼ inches of clear cover to the top bar and the D-57 under 3½ inches.
2. Improper ground. Ground points A and B are actually hooks placed in the plastic concrete during fabrication to facilitate handling. Some question exists as to their electrical continuity with the reinforcing mat.

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3. Iowa Dept. of Transportation Standard Specifications, 798, 800.

Ground point C had mill scale present at the time of connection, again leaving doubt as to the electrical intregity of the ground.

3. Varying amounts of moisture in the slabs at the time of electrical potential measurements.
4. It is recognized that for steel embedded in concrete to corrode, the environment cannot be basic. Since the test slabs were cast and tested indoors, it was doubtful that this neutral environment was ever obtained. To verify this, cores were taken to include a small section of reinforcing steel within the core, and pH determinations were made on the concrete immediately adjacent to the steel. The pH readings on both the Iowa System and D-57 mixes were 12.3. This very basic pH verifies the existence of a non-corrosive environment.

The potential for steel corrosion, based on chloride content at varying depths, appears to be effectively prevented by the Iowa System. The chlorides present in the Iowa System at 1- to 1½-inch depth were less than one third the value needed to induce corrosion, whereas the D-57 concrete at the same depth had more than enough chloride present to induce corrosion.

References

(1) Clear, K. C. and Hay, R. E., "Time-to-Corrosion of Reinforcing Steel in Concrete Slabs, Vol. 1 Effect of Mix Design and Construction Parameters," Report FHWA-RD-73-72, Federal Highway Administration, April, 1973,

(2) Clear, K. C., "Time to Corrosion of Reinforcing Steel in Concrete Slabs, Vol. 3 Performance After 830 Daily Salt Applications," Report No. FHWA-RD-76-70, Federal Highway Administration, April, 1976.

(3) Berman, H. A. "Determination of Chloride in Hardened Portland Cement Paste, Mortar, and Concrete," Report No. FHWA-RD-72-12, Federal Highway Administration, September, 1972, 22 pp.

(4) Clear, K. C., "Evaluation of Portland Cement Concrete for Permanent Bridge Deck Repair," Report No. FHWA-RD-74-5, Federal Highway Administration, February, 1974, pp. 5-6.

Appendix A

Test Slab Fabrication Data

Mix Design

D-57 Concrete

Coarse Aggregate - Chapin Montour Oolite
Basic Chemical Composition - CaO 2%; $CaCO_3$ 98%
Chloride as free chloride - 0.0090%
Specific Gravity - 2.63

Coarse Aggregate Gradation	
Size	% Passing
1/2	100.0
3/8	43.0
4	4.0
8	1.0

Fine Aggregate - Booneville Sand and Gravel
Specific Gravity - 2.66

Actual Absolute Volumes	
Cement	0.136345
Water	0.172748
Fine Aggregate	0.307707
Coarse Aggregate	0.315200
Air	0.068000

Slump - 2-1/2"

Actual w/c - 0.365

Air Entraining Agent - 3.8 oz./yd^3

Retarder - 22.02 oz./yd^3

Unit Weight - 142.8 lbs./ft^3

Mix Design Data

Iowa System

Low Slump Dense Concrete Overlay (LSDC)

Coarse Aggregate - Chapin Montour Oolite
Basic Chemical Composition - CaO 2%; $CaCO_3$ 98%
Chloride as free chloride - 0.0090%
Specific Gravity - 2.63

Gradation	
Size	% Passing
3/4	100
1/2	98.5
3/8	65
4	17.5
8	0.5
200	1.0

Fine Aggregate - Booneville Sand and Gravel
Specific Gravity - 2.66

Actual Absolute Volumes	
Coarse Aggregate	0.314804
Fine Aggregate	0.311348
Air	0.058000
Water	0.160277
Cement	0.155571

Actual w/c = 0.3248031

Slump = 3/4"

Cement - Iowa DOT Laboratory blend R-112

Air Entraining Agent - 4.375 oz./yd^3

Water reducer - 24.96 oz./yd^3

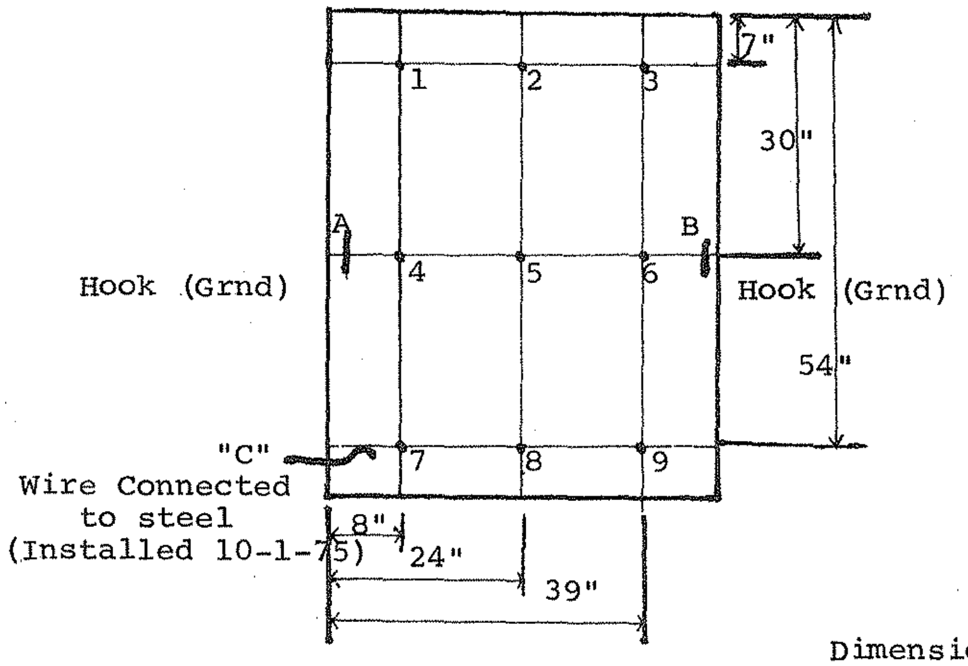
Appendix B

Electrical Potential Data

HALF - CELL CORROSION READINGS

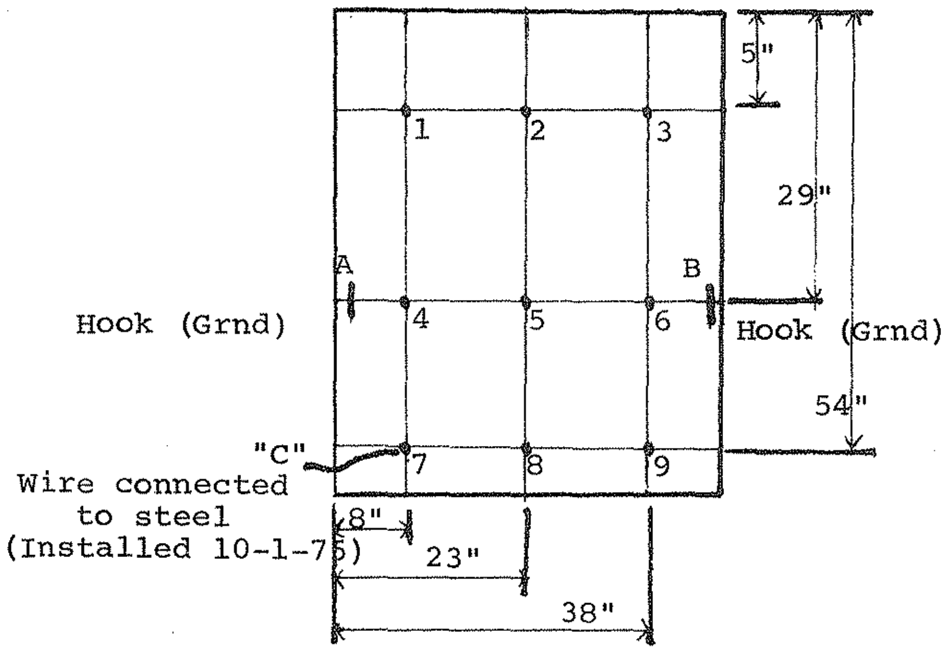
Placement of Probes

D-57



Dimensions Approximate (± 1")

Iowa Method Mix



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HALF-CELL CORROSION READINGS

SUMMARY

	Iowa			D-57		
	Ground			Ground		
CYCLES	A	B	C	A	B	C
50	.26	.19				
63				.21	.23	
84	.32	.23				
100	.35	.29		.19	.28	
113	.33	.27		.26	.23	
125	.31	.29		.20	.29	
138				.25	.36	
151	.36	.31				
164	.38	.34	.31	.28	.40	
177	.35	.32	.26	.24	.40	.34
189	.37	.35	.28	.22	.40	.31
200	.38	.37	.23	.22	.40	.28
225	.40	.40	.30	.22	.42	.30
253	.40	.39	.31	.25	.43	.35
275	.39	.39	.33	.29	.43	.27
300	.38	.38	.27	.20	.40	.18

	D-57		Iowa		D-57		Iowa	
No. of Cycles	63		50		100		84	
	Ground		Ground		Ground		Ground	
Grid No.	A	B	A	B	A	B	A	B
1	.22	.24	.27	.20	.20	.29	.33	.23
2	.21	.23	.24	.18	.20	.28	.31	.21
3	.20	.22	.23	.17	.19	.28	.28	.19
4	.21	.23	.25	.19	.19	.29	.33	.23
5	.21	.24	.27	.20	.19	.28	.32	.22
6	.21	.24	.27	.21	.18	.27	.32	.23
7	.20	.22	.26	.19	.18	.26	.34	.25
8	.21	.23	.26	.20	.18	.27	.34	.24
9	.20	.23	.27	.21	.18	.27	.34	.25
Mean	.21	.23	.26	.19	.19	.28	.32	.23

No. of Cycles	113		100		125		112	
Grid No.	A	B	A	B	A	B	A	B
1	.27	.24	.36	.30	.21	.30	.36	.29
2	.26	.22	.36	.31	.20	.29	.34	.28
3	.27	.23	.34	.29	.20	.29	.31	.25
4	.26	.22	.34	.29	.21	.30	.33	.26
5	.27	.23	.34	.29	.22	.30	.32	.26
6	.27	.23	.35	.30	.20	.29	.33	.27
7	.26	.22	.34	.29	.19	.28	.34	.28
8	.26	.23	.34	.28	.20	.28	.34	.27
9	.25	.22	.35	.29	.19	.29	.34	.28
Mean	.26	.23	.35	.29	.20	.29	.33	.27

No. of Cycles	138		125		164		151	
Grid No.	A	B	A	B	A	B	A	B
1	.26	.37	.32	.29	.30	.43	.36	.31
2	.28	.39	.30	.28	.31	.43	.37	.32
3	.29	.40	.28	.26	.27	.39	.35	.30
4	.24	.35	.31	.28	.29	.42	.35	.30
5	.25	.35	.30	.29	.28	.40	.36	.30
6	.24	.35	.31	.28	.26	.39	.36	.31
7	.23	.33	.33	.30	.27	.39	.36	.31
8	.23	.34	.32	.29	.26	.39	.35	.30
9	.23	.33	.32	.30	.25	.37	.37	.31
Mean	.25	.36	.31	.29	.28	.40	.36	.31

	D-57			Iowa		
No. of Cycles	177			164		
	Ground			Ground		
Grid No.	A	B	C	A	B	C
1	0.28	0.45	0.39	0.42	0.38	0.34
2	0.25	0.42	0.35	0.41	0.38	0.34
3	0.24	0.41	0.34	0.38	0.35	0.31
4	0.24	0.40	0.34	0.38	0.35	0.32
5	0.25	0.42	0.34	0.37	0.34	0.30
6	0.22	0.38	0.32	0.35	0.31	0.28
7	0.23	0.40	0.34	0.38	0.33	0.29
8	0.22	0.38	0.35	0.36	0.34	0.29
9	0.20	0.36	0.31	0.36	0.32	0.29
Mean	0.24	0.40	0.34	0.38	0.34	0.31

No. of cycles	189			176		
Grid No.	A	B	C	A	B	C
1	0.24	0.43	0.34	0.33	0.30	0.24
2	0.23	0.41	0.32	0.35	0.31	0.25
3	0.21	0.39	0.30	0.33	0.30	0.24
4	0.23	0.40	0.32	0.34	0.31	0.25
5	0.22	0.40	0.31	0.35	0.32	0.26
6	0.21	0.39	0.30	0.35	0.32	0.26
7	0.22	0.40	0.31	0.37	0.35	0.29
8	0.20	0.38	0.30	0.37	0.34	0.28
9	0.20	0.38	0.29	0.37	0.34	0.28
Mean	0.22	0.40	0.31	0.35	0.32	0.26

No. of cycles	200			189		
Grid No.	A	B	C	A	B	C
1	0.24	0.42	0.30	0.34	0.32	0.26
2	0.23	0.41	0.29	0.36	0.34	0.27
3	0.22	0.40	0.28	0.35	0.34	0.27
4	0.23	0.41	0.29	0.36	0.34	0.27
5	0.22	0.40	0.28	0.37	0.34	0.28
6	0.21	0.39	0.27	0.37	0.35	0.29
7	0.22	0.40	0.28	0.39	0.37	0.31
8	0.20	0.38	0.27	0.38	0.36	0.30
9	0.20	0.38	0.26	0.39	0.37	0.30
Mean	0.22	0.40	0.28	0.37	0.35	0.28

	D-57			Iowa		
No. of Cycles				200		
Grid No.	Ground A	B	C	Ground A	B	C
1				0.38	0.35	0.22
2				0.36	0.36	0.23
3				0.36	0.35	0.22
4				0.37	0.35	0.22
5				0.38	0.37	0.23
6				0.38	0.37	0.24
7				0.40	0.39	0.25
8				0.39	0.38	0.24
9				0.39	0.38	0.24
Mean				0.38	0.37	0.23

No. of Cycles	225			225		
Grid No.	A	B	C	A	B	C
1	0.23	0.44	0.31	0.39	0.39	0.29
2	0.23	0.45	0.32	0.40	0.40	0.30
3	0.23	0.44	0.31	0.38	0.39	0.29
4	0.22	0.42	0.30	0.39	0.39	0.29
5	0.21	0.41	0.29	0.37	0.38	0.28
6	0.20	0.41	0.28	0.37	0.38	0.28
7	0.21	0.42	0.29	0.43	0.43	0.33
8	0.22	0.42	0.29	0.41	0.42	0.31
9	0.21	0.41	0.28	0.42	0.41	0.32
Mean	0.22	0.42	0.30	0.40	0.40	0.30

No. of Cycles	253			253		
Grid No.	A	B	C	A	B	C
1	0.27	0.44	0.37	0.36	0.36	0.29
2	0.25	0.43	0.36	0.38	0.38	0.30
3	0.24	0.42	0.35	0.39	0.38	0.31
4	0.26	0.44	0.36	0.39	0.39	0.31
5	0.24	0.42	0.35	0.39	0.38	0.30
6	0.24	0.43	0.35	0.38	0.38	0.30
7	0.26	0.43	0.36	0.44	0.44	0.36
8	0.24	0.42	0.35	0.42	0.41	0.34
9	0.22	0.40	0.33	0.41	0.41	0.32
Mean	0.25	0.43	0.35	0.40	0.39	0.31

	D-57			Iowa		
No. of Cycles	275			275		
Grid No.	Ground A	B	C	Ground A	B	C
1	0.32	0.46	0.30	0.36	0.36	0.30
2	0.30	0.44	0.28	0.36	0.36	0.30
3	0.30	0.44	0.28	0.35	0.35	0.29
4	0.31	0.43	0.27	0.40	0.40	0.33
5	0.30	0.43	0.26	0.38	0.38	0.33
6	0.27	0.41	0.25	0.37	0.37	0.32
7	0.29	0.43	0.27	0.49	0.49	0.42
8	0.30	0.44	0.27	0.44	0.44	0.38
9	0.26	0.40	0.24	0.40	0.40	0.34
Mean	0.29	0.43	0.27	0.39	0.39	0.33

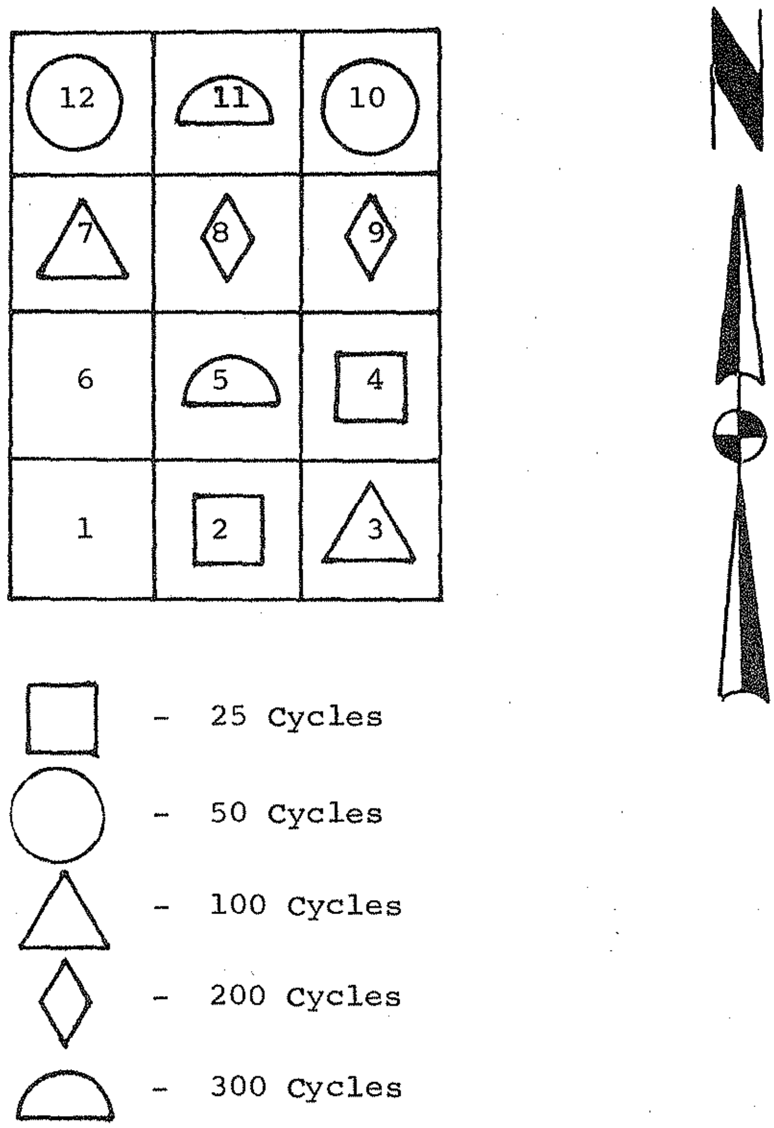
No. of Cycles	300			300		
Grid No.	A	B	C	A	B	C
1	0.21	0.42	0.18	0.35	0.35	0.24
2	0.22	0.41	0.19	0.35	0.35	0.23
3	0.21	0.41	0.18	0.34	0.34	0.22
4	0.20	0.40	0.18	0.39	0.39	0.28
5	0.21	0.41	0.18	0.38	0.37	0.26
6	0.20	0.40	0.18	0.37	0.37	0.25
7	0.19	0.40	0.17	0.46	0.46	0.35
8	0.19	0.40	0.17	0.41	0.41	0.29
9	0.19	0.40	0.17	0.38	0.38	0.27
Mean	0.20	0.40	0.18	0.38	0.38	0.27

Appendix C

Chloride Analysis

DRILL PATTERN FOR SLABS

(Determined by Lots)



		25 Cycles		50 Cycles		100 Cycles		200 Cycles		300 Cycles	
	Depth	Iowa	D-57	Iowa	D-57	Iowa	D-57	Iowa	D-57	Iowa	D-57
A	½	13.6	14.5	19.5	18.0	25.4	23.7	29.1	19.0	29.2	28.5
B	1	0.4	0.9	1.0	0.9	1.8	3.1	6.5	11.4	10.8	20.1
C	1½	0.3	0.4	0.4	0.4	0.2	0.4	0.5	1.2	0.5	2.0
D	2	0.5	0.5	0.5	0.4	0.2	0.4	0.6	0.4	0.6	0.4
E	2½	0.5	0.5	0.5	0.4	0.2	0.4	0.4	0.4	0.3	0.5
F	3	0.3	0.6	0.3	0.6	0.2	0.3	0.5	0.3	0.5	0.3
G	3½	0.5	0.5	0.7	0.4	0.3	0.2	0.5	0.4	0.5	0.6
H	4	0.4	0.6	0.5	0.5	0.3	0.3	0.4	0.4	0.5	0.3
I	4½	0.3	0.5	0.4	0.4	0.3	0.5	0.3	0.3	0.6	0.7
J	5									0.5	0.5

CHLORIDE CONTENT - LB./CU. YD.

Each result is an average value of specimens from each of two cores.