Evaluation of Rapid Determination of the Chloride Permeability of Portland Cement Concrete By AASHTO T277-83

Project No. MLR-86-11

Highway Division
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Iowa Department of Transportation

EVALUATION OF RAPID DETERMINATION OF THE CHLORIDE PERMEABILITY OF PORTLAND CEMENT CONCRETE BY AASHTO T 277-83

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TABLE OF CONTENTS

ABSTRACT

An Iowa D.O.T. Laboratory built machine was constructed for the chloride permeability testing of concrete by measuring electric current through a specimen between a salt solution and a base solution.

This study had two purposes. The first was to evaluate the machine's performance. To do this, three concrete mixes were made consisting of different cement factors and water/cement ratios. Each mix was tested for chloride ion content by the 90-day salt ponding method and for chloride permeability at a 28-day cure by the permeability machine. The results from each test were evaluated to see if there was correlation between chloride ion content and the chloride permeability. It was determined that there was a correlation and that the permeability machine was satisfactory for determining chloride permeability in concrete.

The second purpose of this study was to examine the effects that pozzolans have on the chloride permeability of concrete. Four mixes were made: one without any pozzolans as a control, one with class C fly ash, one with class F fly ash, and one with silica fume. Specimens from each mix were evaluated for chloride ion content by the 90-day salt ponding test and by the laboratory built machine for chloride permeability after curing 28 days. Specimens from these mixes were also taken from the salt ponding slabs after completion of the ponding test to examine the effect

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chloride ion content has on the operation of the chloride permeability machine. Specimens containing pozzolans were also examined for chloride permeability after a cure of 180 days. It was determined that the addition of pozzolans to concrete lowers the chloride permeability as measured by the permeability machine. Class F fly ash and silica fume in the concrete had a major effect in lowering the chloride permeability in concrete as measured by the permeability machine.

INTRODUCTION

In August of 1981 the Federal Highway Administration released a report by David Whiting of the Construction Technology Laboratories in Skokie, Illinois titled, FHWA/RD-81/119 "Rapid Determination of the Chloride Permeability of Concrete"(1). The report promoted the concept of measuring the direct electric current through a portland cement concrete specimen between a salt solution and a base solution to determine the chloride permeability of p. c. concrete. Since that time, a number of agencies and institutions have used this concept to study the permeability of portland cement concrete and AASHTO has adopted this procedure as a standard test, T 277-83 "Rapid Determination of the Chloride Permeability of Concrete"(2).

A machine was built based on specifications stated in Whiting's report in the Iowa D.O.T. Central Materials Lab to determine the chloride permeability of concrete. Data is needed to properly assess the viability and reliability of the Iowa D.O.T. lab built machine in determining the chloride permeability of concrete mixes. Research and data is also needed to analyze the effects of different characteristics such as cement content, water/cement ratio, curing, and pozzolans has on the chloride permeability of concrete.

OJBECTIVE

This study served two purposes. The first was to examine the reliability of the Iowa D.O.T. lab built chloride permeability machine on three concrete mixes (B-4, C-4, and O-4).

The second purpose was to analyze what effects different characteristics such as pozzolans, chloride content, and curing would have on the chloride permeability of a D-57 concrete mix.

SCOPE

For the first purpose, specimens of the B-4, C-4, and O-4 mixes were tested at 28 days for chloride permeability by the permeability machine and for chloride ion content by the 90-day salt ponding test (AASHTO T 259-80) (3) to determine if the chloride permeability test correlates with the 90-day salt ponding test.

For the second purpose, four concrete mixes were made, a D-57 mix without any pozzolans as a control mix, a D-57-C mix containing class C fly ash, a D-57-F mix containing class F fly ash, and a D-57 mix made with condensed silica fume. The D-57-C and D-57-F mixes were made with fly ashes conforming with ASTM C618. Specimens of these mixes were tested for chloride permeability at 28 days and 180 days.

The chloride ion content was also determined by the 90-day salt ponding test. Core specimens of each of the D-57 mixes were taken from the salt ponding slabs after completion of the 90-day salt ponding tests for chloride permeability testing to analyze the effects the chloride ion content of concrete might have on the chloride permeability test.

LABORATORY PROCEDURES

A. Materials

The following materials were used in this study:

1. Portland Cement: Type I, the standard laboratory blend of the eight portland cement sources commonly available in Iowa, was used to prepare the concrete specimens, Lab No. R-11-Z-86.
2. Water: City of Ames
3. Air Entraining Agent: Ad-Aire, Naturalized vinsol resin, Carter-Waters, single strength, Lab No. ACA6-110.
4. Fine Aggregate: Mississippi River Sand, Cordova, IL, Lab No. AAS6-201.
5. Coarse Aggregate: Martin Marietta Limestone, Ft. Dodge, Lab No. AAC6-647.
6. Water Reducing Admixture (Used in O-4): WRDA-82, W. R. Grace and Co. Dosage rate 3 fl. oz./100 lbs. of cement, Lab No. ACI6-36.

7. Superwater Reducing Admixture (Used in D-57 with silica fume): Daracem 100, W. R. Grace and Co. Dosage rate 14.0 fl. oz./100 lbs. of cement.

8. Condensed Silica Fume (Used in D-57 with silica fume): Force 10,000, W. R. Grace and Co. Dosage rate 1 gal./100 lbs. of cement.

9. Class C Fly Ash (self-cementing) (Used in D-57-C): Ottumwa fly ash, Chillicothe, IA Lab No. ACF6-88.

10. Class F Fly Ash (non-cementing) (Used in D-57-F): Clinton fly ash, Clinton, IA Lab No. ACF7-1.

B. Mixes

The following seven p.c.c. mixes were used in this study:

Mix No.	Mix Type	Cement Lb/Yd.3	Fly Ash Lb./Yd.3	Water/Cement Ratio
1A	B-4	492	---	0.538
2A	C-4	624	---	0.429
3A	O-4 (overlay)	825	---	0.340
1B	D-57 (control)	709	---	0.389
2B	D-57-C	603	104	0.366
3B	D-57-F	603	133	0.365
4B	D-57 with Silica Fume	709	39	0.343

The mix designs and properties of each mix are listed in Table 1 of Appendix A.

C. Aggregate Gradations

Both coarse aggregate and fine aggregate gradations complied with current Iowa DOT Specifications.

D. Procedure

90-Day Salt Ponding Test

For each mix, a 12" x 12" x 2" ponding slab was made. Each slab was made and tested in accordance to the requirements of AASHTO T 259-80, "Resistance of Concrete to Chloride Ion Penetration"(3). After the procedures in AASHTO T 259-80 were completed, three holes were drilled in the slab. At each hole, powdered concrete samples were taken at depths of 1/16" to 1/2", 1/2" to 1", and 1" to 1-1/2" to determine the chloride content by AASHTO T 260-84, "Sampling and Testing for Total Ion in Concrete and Concrete Raw Materials"(4). A four inch diameter core was also drilled from each slab to test for rapid chloride permeability.

The Chloride Permeability Test

The procedure for the chloride permeability was in accordance to AASHTO T 277-83. A 3" x 6" x 20" beam was made for each mix. Four-inch diameter cores were drilled from each beam and sawed to two-inch high specimens (see figure 1). Each core was then transferred to a moisture room and cured at a 100% humidity and at a temperature of 73 degrees F. +/- 3 degrees. After a designated period of cure, the core was taken out of the moisture room and the sides were coated with rapid setting epoxy. After the epoxy dried the core was placed in a sealed desicator (see figure 2). A vacuum pump was attached and allowed to

Figure 1

Two-inch by 4-inch diameter core epoxy coated and ready for vacuum saturation.

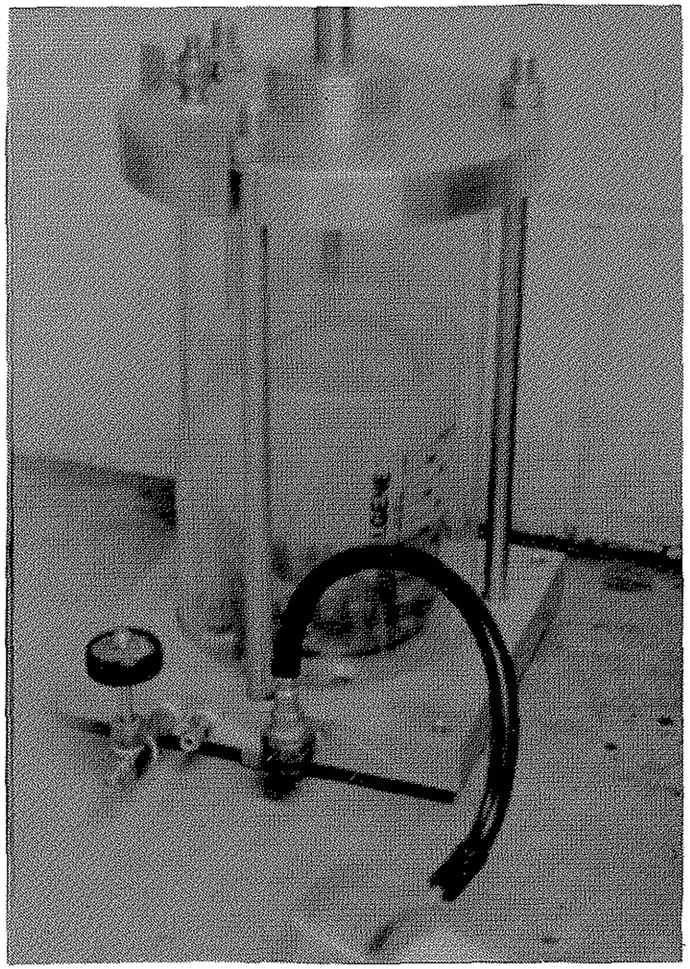
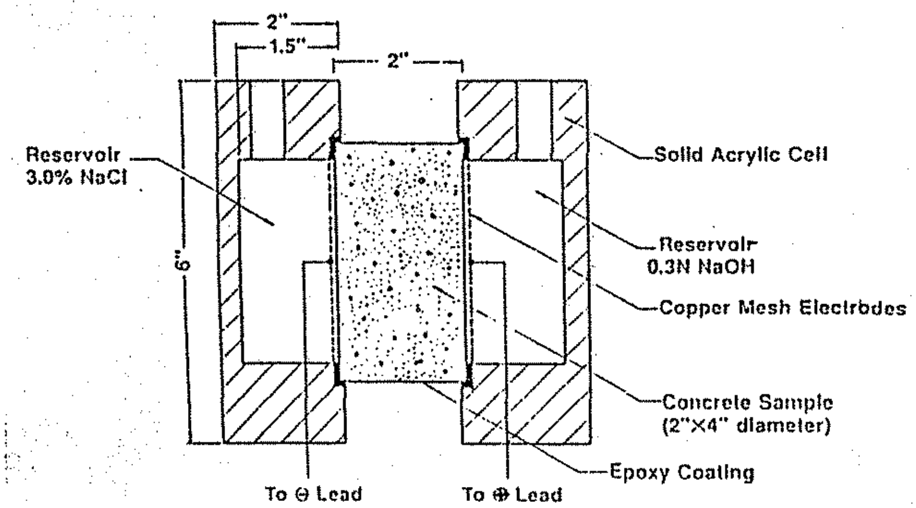


Figure 2

The triaxial compression chamber used as the vacuum desicator.

maintain vacuum for 3 hours. At 3 hours, (while the pump was still running) de-aerated water was added to completely cover the core. The vacuum was allowed to run another hour and then the pump was shut off. After 18 hours +/- 1 hour, the core was taken out of the desicator and attached on each side to an acrylic applied votage cell. In one cell, a 3% sodium chloride (NaCl) solution was added and in the other cell a 0.3 normal solution of sodium hydroxide (NaOH) (see figure 3). The cells were connected to the permeability machine. The NaCl lead was connected to the negative post on the machine and the NaOH lead was connected to the positive post on the machine (see figure 4). The machine was then turned on and set at 60 volts dc. The current in amperes was recorded every half-hour and the temperature of each cell was recorded every hour during the 6 hour test. The recorded values for amperes were plotted verses the total time in seconds. A smooth curve was drawn through the data, and the area underneath the curve was integrated to give the total number of coulombs (amps-sec.) for the core. The lower the coulombs the lower the chloride permeability of the p.c. concrete.

The salt ponding tests and chloride permeability tests were run at a temperature of 73 degrees +/- 3 degrees.



Cross-sectional view of applied voltage test cells and concrete sample.

Figure 3
Diagram of the applied voltage cell

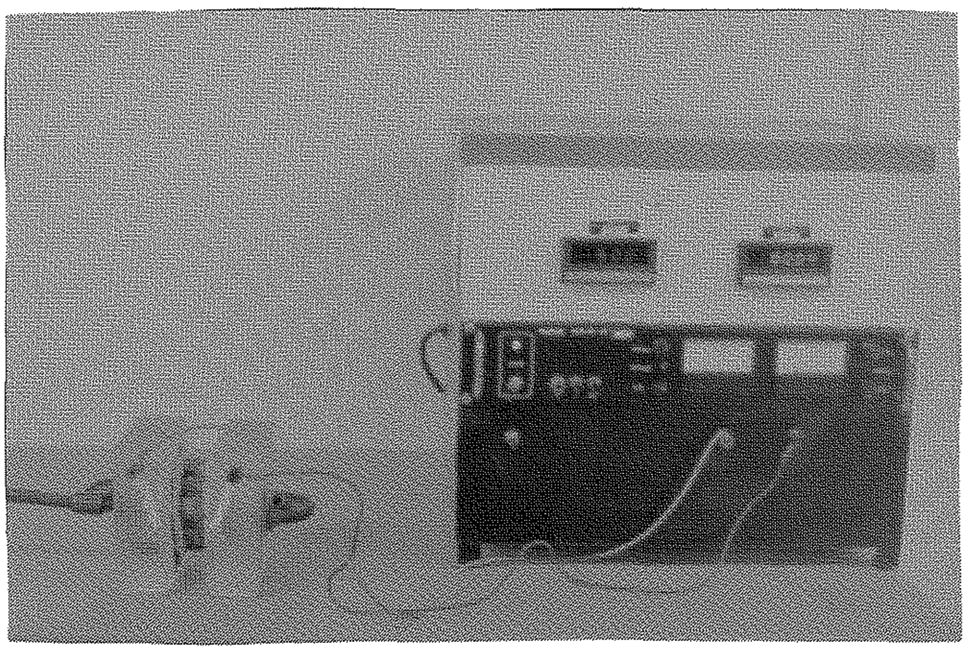


Figure 4
The applied voltage test cells with concrete sample
connected to the chloride permeability machine

E. Equipment

The Iowa D.O.T. lab built chloride permeability machine was made according to the specifications in the FHWA's report FHWA/RD-81/119, (see appendix D).

The applied voltage cells were milled from a 2" thick sheet of acrylic plastic (see appendix D).

A triaxial compression chamber was used as a desicator.

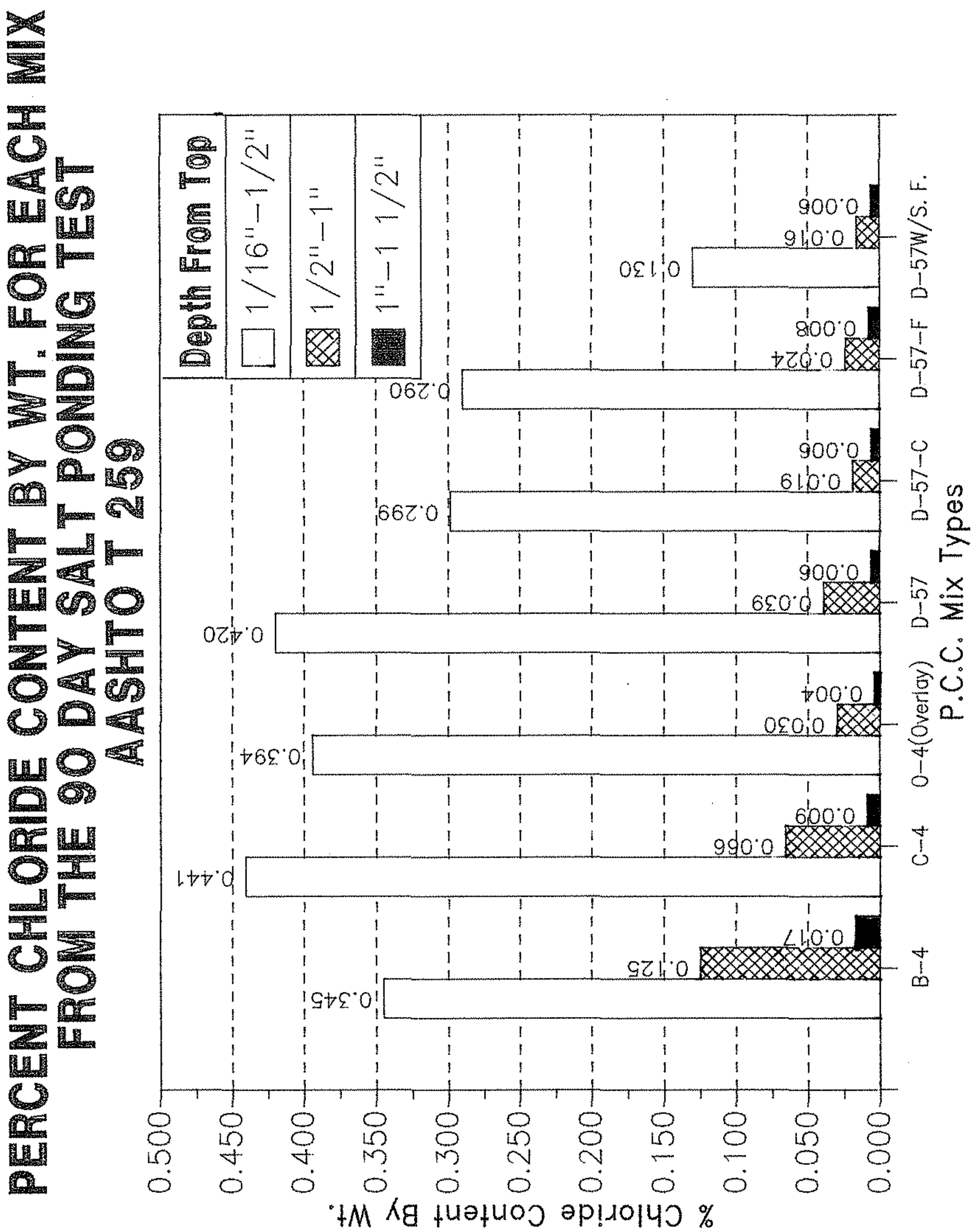
The pump used to supply the vacuum was Cenco Hyvac 2 powered by a General Electric 1/4 hp. motor.

TEST RESULTS AND INTERPETATION

A. 90-Day Salt Ponding Test

The results of the chloride ion content from the 90 day salt ponding tests are shown in figure 5. At depths between 1/16" and 1/2" the results were what was expected, except that the B-4 mix had a lower chloride content than the other mixes containing no pozzolans. The D-57 mixes containing pozzolans showed a lower chloride ion content than the D-57 mix without any pozzolans. The D-57 with silica fume had the lowest chloride ion content. The two mixes with fly ash, D-57-C and D-57-F, had relatively the same chloride ion content.

Figure 5


PERCENT CHLORIDE CONTENT BY WT. FOR EACH MIX
FROM THE 90 DAY SALT PONDING TEST
AASHTO T 259
Depth From Top
1/16"–1/2"
1/2"–1"
1"–1 1/2"
% Chloride Content By Wt.
0.500
0.450
0.400
0.350
0.300
0.250
0.200
0.150
0.100
0.050
0.000
P.C.C. Mix Types
B–4
C–4
O–4(Overlay)
D–57
D–57–C
D–57–F
D–57W/S. F.
0.345
0.125
0.017
0.441
0.066
0.009
0.394
0.030
0.004
0.420
0.039
0.006
0.299
0.019
0.006
0.290
0.024
0.008
0.130
0.016
0.006

At the depths between 1/2" and 1" the results were what was as expected. The cement factor and water/cement ratio had an effect on chloride content for the mixes containing no pozzolans. The B-4 and C-4 mixes had higher chloride ion contents than the 0-4 mix. Again, the D-57 mixes with pozzolans showed a lower chloride ion content than the D-57 mix without pozzolans.

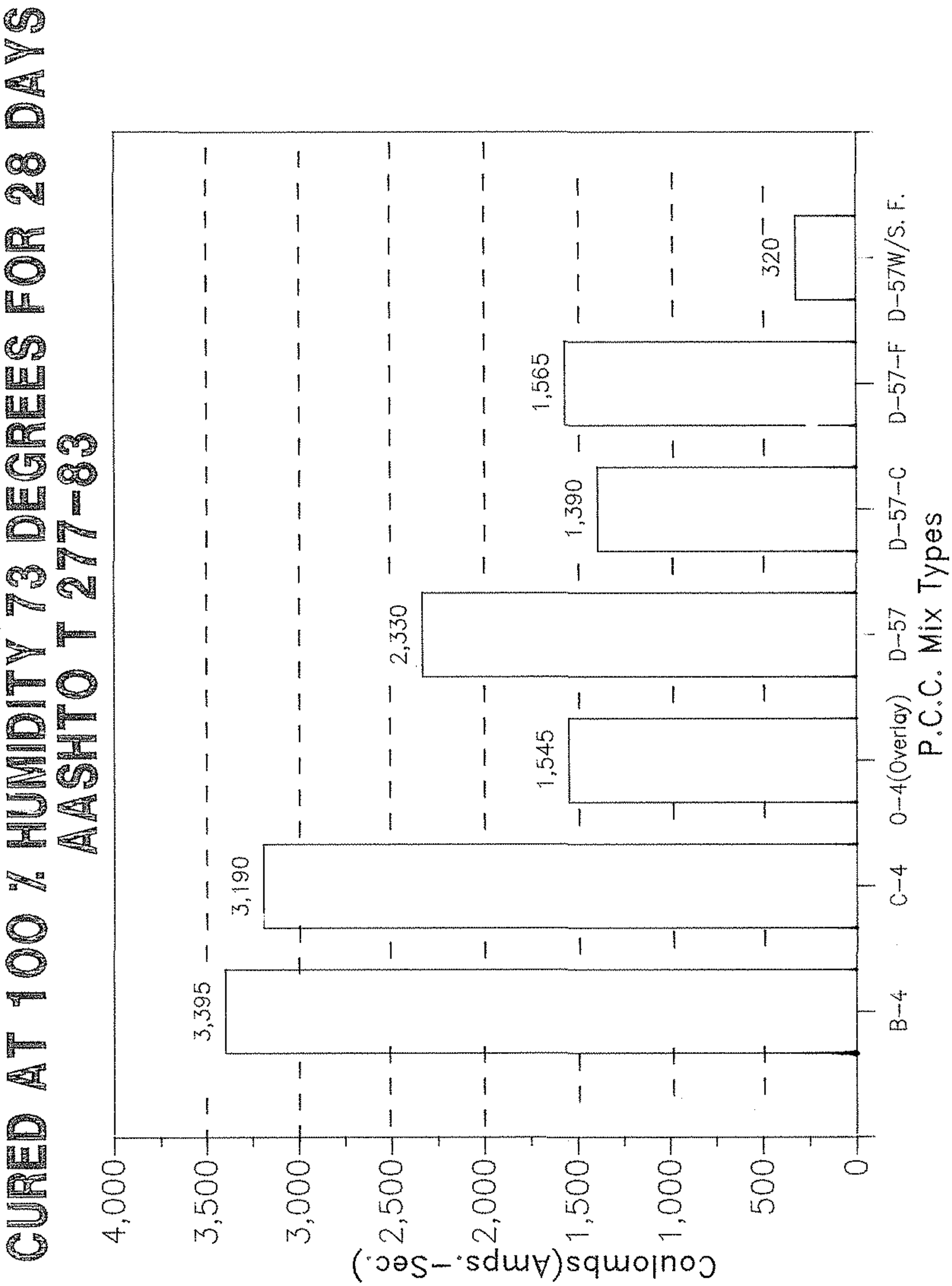
At depths between 1" and 1-1/2", only the B-4 mix showed any significant chloride ion content. In the rest of the mixes, the chloride ion content could be considered the baseline chloride ion content.

B. <u>28-Day Chloride Permeability Test on 28-Day Standard Cure Specimens</u>

The results from the 28-day cure chloride permeability test are on the bar graph in figure 6. For the mixes not containing any pozzolans, the cement factor and water/cement ratio affected the results. The B-4 mix had the highest number of coulombs followed closely by the C-4 mix. The addition of pozzolans in the D-57 mixes lowered the coulomb value as compared to the coulomb value of the D-57 mix without pozzolans. The D-57 mix with silica fume tested significantly lower than the other mixes. The 0-4 mix, D-57-C mix, and D-57-F had values close to each other.

Figure 7 shows the relationship between the 28-day chloride permeability and the water/cement ratio.

Figure 6


RAPID PERMEABILTY OF P.C.C.
CURED AT 100 % HUMIDITY 73 DEGREES FOR 28 DAYS
AASHTO T 277-83
Coulombs(Amps.-Sec.)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
3,395
3,190
1,545
2,330
1,390
1,565
320
B-4
C-4
O-4(Overlay)
D-57
D-57-C
D-57-F
D-57W/S. F.
P.C.C. Mix Types

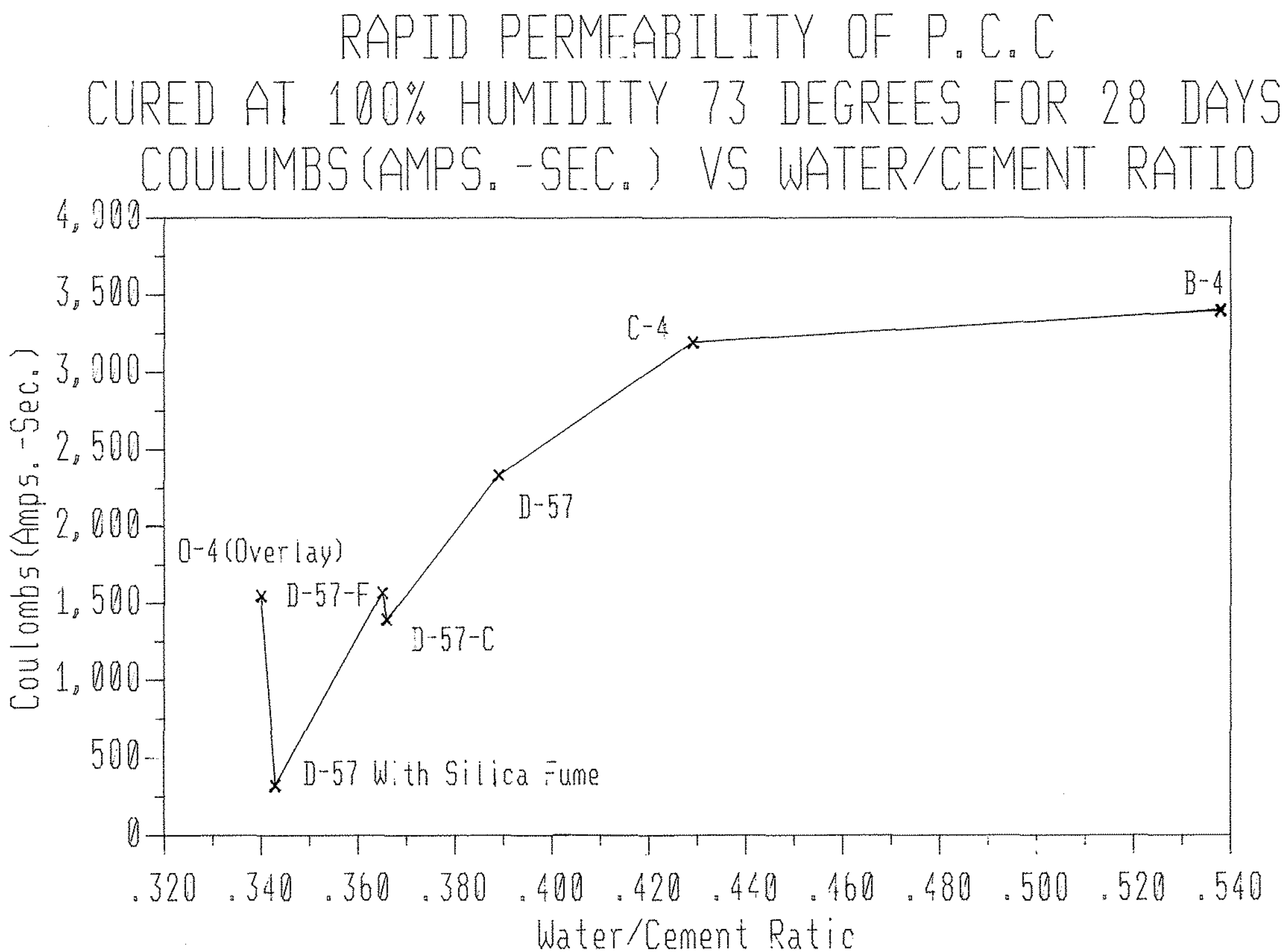

RAPID PERMEABILITY OF P.C.C
CURED AT 100% HUMIDITY 73 DEGREES FOR 28 DAYS
COULUMBS(AMPS.-SEC.) VS WATER/CEMENT RATIO
Coulombs(Amps.-Sec.)
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
.320 .340 .360 .380 .400 .420 .440 .460 .480 .500 .520 .540
Water/Cement Ratic
O-4(Overlay)
D-57-F
D-57-C
D-57 With Silica Fume
D-57
C-4
B-4

Figure 7

C. Chloride Content and Curing Effect on the Chloride Permeability Test

The cores taken from the salt ponding slabs and tested for chloride permeability showed very little effect from the chloride ion content in the concrete. In a research paper by David Whiting titled "In Situ Measurement of the Permeability of Concrete to Chloride Ions"(5), it was stated that the chloride ion content up to 3.5% by weight of the concrete had very little effect on the results on the chloride permeability test. It was determined that the chloride ion content (0.420% maximum) of our salt ponding specimens was not high enough to effect the rapid chloride permeability test.

It appears ponding of the slabs actually helped in the curing process. The coulomb value for each core was actually lower than the results of the 28-day cure chloride permeability test (shown in figure 8). Again the D-57 with silica fume had a low coulomb value. The coulomb value of the D-57-F specimen had a drop of more than 70 percent from the 28-day cure results.

The chloride permeability results for the 180-day cure specimens were very similar to the salt ponding cure results. Again the D-57-F showed a large drop in coulomb value from the 28-day cure results. The D-57 specimen was inadvertently destroyed before chloride 180-day permeability testing could be done.

EFFECTS OF DIFFERENT POZZOLANS AND CURING METHODS ON CHLORIDE PERMEABILITY TEST RESULTS FOR A D-57 CONCRETE BY AASHTO T 277-83

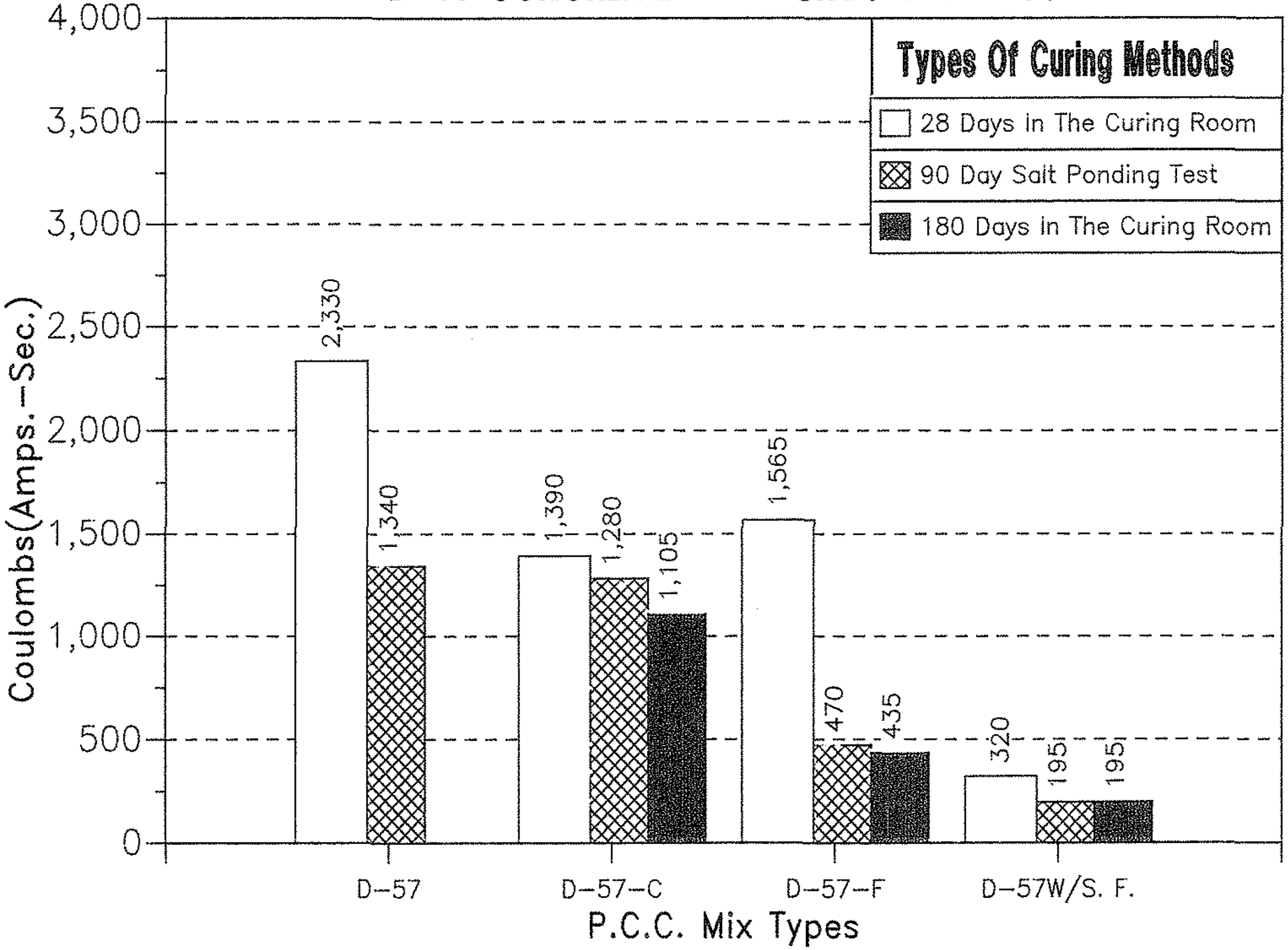


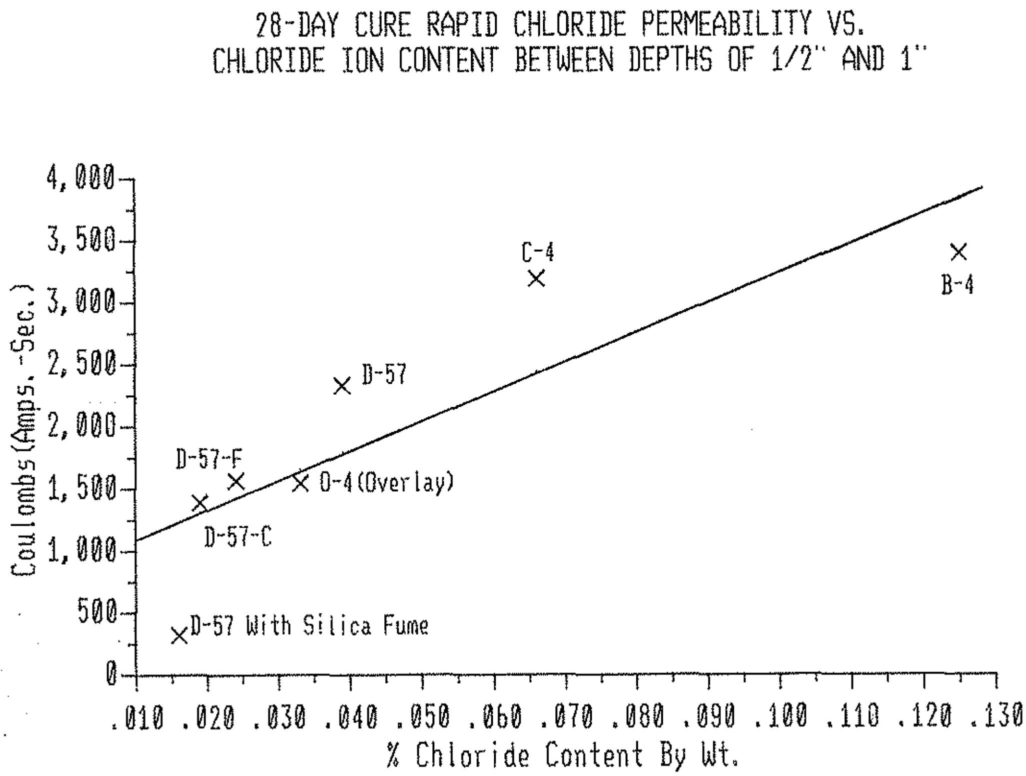
Figure 8

DISCUSSION OF RESULTS

A. Evaluation of the Chloride Permeability Machine

Except for the lower than expected chloride ion content of the B-4 mix at depths between 1/16" and 1/2", the results from the salt ponding tests and the 28-day cure chloride permeability tests generally had a good correlation. Figure 9 shows the correlation between the chloride ion contents at depths between 1/2" and 1" and the 28-day cure chloride permeability results.

Figure 9



The coulomb values for each mix by the 28-day cure rapid chloride permeability test fell into the ranges indicated on table 1 in AASHTO 277-83 used to evaluate the results (shown below).

NOTE 3: The terms in the middle column of Table 1 are not absolute. They are relative descriptions of the permeabilities of carefully prepared laboratory specimens.

Table 1. Chloride Permeability Based on Charge Passed (from Reference 2)

Charge Passed (coulombs)	Chloride Permeability	Typical of
>4,000	High	High water-cement ratio, conventional (≥0.6) PCC
2,000-4,000	Moderate	Moderate water-cement ratio, conventional (0.4-0.5) PCC
1,000-2,000	Low	Low water-cement ratio, conventional (<0.4) PCC
100-1,000	Very Low	Latex-modified concrete Internally sealed concrete
<100	Negligible	Polymer impregnated concrete Polymer concrete

[2]Whiting, D., "Rapid Determination of the Chloride Permeability of Concrete," Report No. FHWA/RD-81/119, August 1981, available from NTIS, PB No. 82140724.

B. Effects of Pozzolans

Both the salt ponding chloride ion content results and chloride permeability results indicate that the pozzolans lowered the permeability of the portland cement concrete. The D-57-C mix containing class C fly ash lowered the permeability compared to the D-57 control mix by 40 percent by the 28-day cure chloride permeability test and by 29 percent by the salt ponding test. The D-57-F mix containing class F fly ash lowered permeability compared to the D-57 control mix by 33 percent by the 28-day cure chloride permeability test and by 31 percent by the salt ponding test. The D-57 mix with silica fume lowered the permeability compared to the D-57 control mix by 86 percent by the 28-day cure chloride permeability test and by 69 percent by the salt ponding test.

The reason why pozzolans lower the permeability of portland cement concrete is stated by Robert F. M. Bakker in paper titled "Permeability of Blended Cement Concretes"(6). The pozzolanic activity of the fly ashes and the silica fume produces acids of $Al_2O_4^{-2}$ and SiO_3^{-2}. These acids react with surplus alkaline calcium hydroxide Ca(OH) (a soluble precipitate) formed from the hydration process of the portland cement between two Ca^{+2} clinker particles to form calcium aluminate hydrate Ca_4AlH_{13}, calcium silicate aluminate hydrate Ca_2AlSiH_8, and calcium silicate CaSiH. Ca_4AlH_{13}, Ca_2AlSiH_8, and CaSiH form impermeable precipitates between the portland cement particles and the pozzolan particles. These impermeable precipitates decrease the number of capillary pores in the concrete.

Since the condensed silica fume contains over 85 percent reactive silicon dioxide SiO_2 and is a highly reactive pozzolan, it is expected that it would significantly lower the permeability of concrete based on the explaination above.

At 28 days, the pozzolanic activity of both class F and class C fly ash used in this study is relatively the same. The permeability results from the 28-day cure chloride permeability test indicated this. The class F fly ash which contains more silicon dioxide SiO_2 and aluminum trioxide Al_2O_3 than the class C fly ash has probably a higher pozzonlanic activity potential. The reaction of the pozzonlanic activity of the class F fly ash is greater after 28 days than the class C fly ash. This might be an indication of why the permeability of the D-57-F concrete dropped significantly between the 28 days and 180 days as compared to the permeability difference in the D-57-C concrete.

CONCLUSIONS

Based on the data gathered in this study, the following conclusions are obtained:

1. The rapid determination of the chloride permeability of concrete by the Iowa D.O.T. laboratory built machine is a valid method to determine the chloride permeability of portland cement concrete in the laboratory.

2. The 28-day curing time for the concrete specimens tested in the chloride permeability machine appears to be an adequate time period to obtain satisfactory results for most concrete mixes. Concrete containing Class F fly ash caused

a significant drop in chloride permeability between 28 days and 180 days as measured by the permeability machine.

3. The addition of class C fly ash, class F fly ash, and silica fume to a concrete mix lowers the chloride permeability of concrete as measured by the permeability machine.

RECOMMENDATIONS

1. Consideration should be given to and including the chloride permeability test as an Iowa D.O.T. test method based on the testing procedures listed in this study and in AASHTO T 277-83.

2. The machine should be modified to test two or more specimens at the same time. This would be more efficient and allow for averages to be made between specimens to increase accuracy.

3. More study is needed to determine the concrete chloride ion content that would affect the chloride permeability test results.

4. An evaluation of chloride permeability of bridge decks and bridge deck overlays containing different types of pozzolans should be done.

5. Section 3.3 of AASHTO T277-83 states that care should be taken when interpreting the chloride permeability results of surface-treated concrete. Limited testing should be done to examine the effects of bridge deck sealers on the chloride permeability test.

REFERENCES

1. Whiting, D., Rapid Determination of Chloride Permeability of Concrete, Federal Highway Administration, Report No. FHWA/RD-81/119, August 1981.

2. AASHTO T 277-83. Standard Specifications for Transportation Materials and Methods of Sampling and Testing, The American Association of State Highway and Transportation Officials, Fourteenth Addition, Part II, August 1986, pp. 1229-1234.

3. AASHTO T 259-80. Standard Specifications for Transportation Materials and Methods of Sampling and Testing. The American Association of State Highway and Transportation Officials, Fourteenth Addition, Part II, August 1986, pp. 1108-1109.

4. AASHTO T 260-84. Standard Specifications for Transportation Materials and Methods of Sampling and Testing, The American Association of State Highway and Transportation Officials, Fourteenth Addition, Part II, August 1986, pp. 1110-1121.

5. Whiting, D., In Situ Measurement of the Permeability of Concrete Ions, In Situ//Non Destructive Testing of Concrete, American Concrete Institute, SP 82-25, pp. 501-524.

6. Bakker, R. F. M., Permeability of Blended Cement Concretes, Fly Ash, Silica Fume, Slag & Other Mineral By-Products in Concrete, America Concrete Institute, Vol. I, Sp-79, pp. 589-596.

7. Improved Method for Measuring the Chloride Permeability of Concrete, Transportation Research News, May-June 1987, pp. 18-19.

8. Bergeson, K., Schlorholtz, S., Demerial, T., Development of a Rational Characteration Method for Fly Ash, Iowa State University Engineering Research Institute, Iowa D.O.T. Project HR-286, ERI Project 1847, Annual Progress Report 1, Nov. 30, 1986.

9. Specification SS-1035, Iowa DOT Supplemental Specification for PCC Concrete Proportions, March 31, 1987.

APPENDICES

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Appendix A

Table 1: Concrete Properties and Proportions of Mixes Used

Table 1

Concrete Properties And Proportions Of The P.C.C. Mixes Used For MLR-86-11 'Rapid Determination Of The Permeabilty OF Portland Cement Concrete By AASHTO T 277-83'

Mix No.	Type of Mix	Date Mixed	Cement Lb/Yd3	Fly Ash Lb/Yd3	F. Agg. Lb/Yd3	C. Agg. Lb/Yd3	W/C Ratio	Slump In.	Air %	Density lb/ft3
1A	B-4	1-7-87	492	---	1552.0	1552.0	0.538	2.5	5.5	144.8
2A	C-4	1-14-87	624	---	1489.0	1493.5	0.429	2.5	6.2	144.0
3A	O-4 Overlay	1-21-87	825	---	1399.0	1403.5	0.340	1.0	5.5	144.8
1B	D-57	1-28-87	709	---	1426.0	1421.5	0.389	2.0	6.2	143.6
2B	D-57-C	2-4-87	603	104	1417.0	1417.0	0.366	2.5	5.6	145.6
3B	D-57-F	2-11-87	603	133	1376.5	1376.5	0.365	2.0	6.1	143.6
4B	D-57/W Silica	3-11-87	709	39	1397.0	1397.0	0.343	2.5	5.5	146.4

Notes:

1: 1A thru 4B are PCC with the following materials in common:
  A: Cement - Std. Lab Blend(10 producers) Type I; Sp. Gr. - 3.14
  B: Water - Ames, Ia tap water
  C: Fine Agg. - Mississippi River Sand, Cordova, IL(AAS6-201); Sp. Gr. - 2.67
  D: Coarse Agg. - Martin Marrietta, Ft. Dodge, IA(AAC6-647); Sp Gr. - 2.67
  E: Air-Entraining Agent - Ad-Aire Single Strength vinsol resin(ACA6-110)

2: Mix no. 3A uses WRDA-82 water reducer(ACI6-36); Dos. - 3oz./100lb. of cement.

3: Mix no. 2B uses class C Ottumwa fly ash(ACF6-88); Sp. Gr. - 2.69

4: Mix no. 3B uses class F Clinton fly ash(ACF7-1); Sp. Gr. - 2.40

5: Mix no. 4B uses Force 10000 condense silica fume; Dos 1gal./100 lb. of cement and Daracem 100 super water reducer; Dos. 14oz./100lb. of Cement.

6: Mixes 2B and 3B the fly ash is included in the water/cement ratio.

7: Mixes 1A and 2A were controlled to slump of 2" +/- 1/2" and an air content 6.0% +/- 0.5%.

8: Mix no. 3A was controlled to a maximum slump of 1" and an air content of 6.5% +/- 1%.

9: Mixes 1B, 2B, 3B, and 4B were controlled to a slump of 2" +/- 1/2" and an air content of 6.5% +/- 1%.

Appendix B

Table 2: Coarse Agg. Gradations for the B-4, C-4, D-57, D-57-C, D-57-F, and D-57 with Silica Fume Mixes

Table 3: The Coarse Aggregate Gradation for the O-4 Mix

Table 2

The Coarse Aggregate Gradation for the B-4, C-4, D-57, D57-C, D-57-F, and D-57 With Silica Fume

Sieve No.	% Psg.
1"	100
3/4"	77
1/2"	40
3/8"	12.0
No. 4	0.5
No. 8	0.3

Table 3

The coarse Aggregate Gradation for the O-4 Mix

Sieve No.	% Psg.
1"	100
3/4"	100
1/2"	100
3/8"	83
No. 4	10.0
No. 8	0.5

Appendix C

Table 4: Chloride Ion Content Results

Table 5: 28 Day Cure Rapid Chloride Permeability Results

Table 6: The Effects of Pozzolans and Curing

Table 4

Percent Chloride Content By Weight Of Each P.C.C. Mix
From The 90 Day Salt Ponding Test AASHTO T 259

Mix No.	Type of Mix	W/C Ratio	Slump In.	Air %	Density Lb./ft3	% Chloride Content By Wt. At Each Depth from Top Of Slab 1/16"-1/2"	1/2"-1"	1"-1 1/2"
1A	B-4	0.538	2.5	5.5	144.8	0.345	0.125	0.017
2A	C-4	0.429	2.5	6.2	144.0	0.441	0.066	0.009
3A	O-4 Overlay	0.340	1.0	5.5	144.8	0.394	0.030	0.004
1B	D-57	0.389	2.0	6.2	143.6	0.420	0.039	0.006
2B	D-57-C	0.366	2.5	5.6	145.6	0.299	0.019	0.006
3B	D-57-F	0.365	2.0	6.1	143.6	0.290	0.024	0.008
4B	D-57/W Silica	0.343	2.5	5.5	146.4	0.130	0.016	0.006

Table 5

Chloride Permeability Determination of PCC By AASHTO T 277-83
From Cores That Were Cured At 100% Humidity
And 73 Degrees +/- 3 Degrees For 28 Days

Mix No.	Type of Mix	W/C Ratio	Slump In.	Air %	Density lb/ft3	Coulombs Amp-Sec	Chloride Perm. Standard By ASSHTO T 277-83
1A	B-4	0.538	2.5	5.5	144.8	3395	Moderate Mid-Range
2A	C-4	0.429	2.5	6.2	144.0	3190	Moderate Mid-Range
3A	O-4 Overlay	0.340	1.0	5.5	144.8	1545	Low Mid-Range
1B	D-57	0.389	2.0	6.2	143.6	2330	Moderate Low-Range
2B	D-57-C	0.366	2.5	5.6	145.6	1390	Low Mid-Range
3B	D-57-F	0.365	2.0	6.1	143.6	1565	Low Mid-Range
4B	D-57/W Silica	0.343	2.5	5.5	146.4	320	Very Low Mid-Range

Table 6

Effects Of Pozzolans And Curing On The Chloride Permeability Test ASSHTO T 277-83 For D-57 Mixes

Mix No.	Type of Mix	W/C Ratio	Slump In.	Air %	Density Lb/Ft3	Coulombs(Amp-Sec) For Each Type Of Cure: 28 Day Cure	Salt Pond Cure	180 Day Cure
1B	D-57	0.389	2.0	6.2	143.6	2330	1340	---
2B	D-57-C	0.366	2.5	5.6	145.6	1390	1280	1105
3B	D-57-F	0.365	2.0	6.1	143.6	1565	470	435
4B	D-57/W Silica	0.343	2.5	5.5	146.4	320	195	195

Notes:

1: The 28 day cure and 180 day cure core specimans were cured in a moisture room at a 100% humidity and at 73 deg. +/- 3 deg.

2: The salt ponding cure specimans were cored from the slabs used for the 90 day salt ponding test AASHTO T 259.

3: The speciman for the 180 day cure of mix no. 1B was in-advently destroyed before chloride permeabilty testing could be done.

Appendix D

Procedures and Equipment Needed to Determine the Rapid Chloride Permeability

Procedure

1. Vigorously boil tapwater in a large (2 L) florence flask. Cap tightly a short while after removing from hotplate and allow to cool overnight.
2. Allow specimen to surface dry in air for 1 hour. Thoroughly mix 5 grams of epoxy resin with 5 grams of hardener and brush onto sides of specimen (placing specimen on a small stud while applying coating will help). Allow coating to cure 3 hours at lab temperature.
3. Check coating for tack-free surface. Place specimen in 500 ml s.s. beaker, and place beaker into vacuum desiccator. Seal desiccator and turn on vacuum pump. Vacuum should reduce to less than 1 mm Hg (1330 kPa) within a few minutes. Run pump for 3 hours.
4. Fill 500 ml separatory funnel with de-aerated water. With pump still running open stop-cock and drain sufficient water into stainless steel beaker to cover specimen (do not allow air to enter desiccator through stopcock).
5. Close stopcock and allow pump to run for an additional hour.
6. Close desiccator sleeve, turn off pump, allow air to re-enter desiccator.
7. Drain oil from vacuum pump and replace with fresh oil.
8. Allow specimen to soak under water for 17-19 hours (overnight).

Step 4 - Testing of Specimen

Materials

1. Silastic Rubber (Dow Corning 3112 RTV +0.5% catalyst F).
2. 3.0% by weight sodium chloride (Reagent grade) solution.
3. 0.3N sodium hydroxide (pellets - Reagent grade) solution.
4. Paper discs - 3-in. diameter.

Equipment

1. Applied Voltage Cell (Figures 67 and 68).
2. 4-1/2 digit DVM - 200.00 mv full scale (Fluke Model 8600A or equivalent).
3. 3-1/2 digit DVM - 99.9 v full scale (Fluke Model 8020A or equivalent).
4. 100 mv shunt resistor - 10 amp rating (GE 50-140-034-MTAA).
5. D.C. constant voltage power supply. 0-80 Vdc 0-6 A (Sorenson Model 80-6 or equivalent).
6. No. 14 (1.6 mm) two conductor insulated 600 V cable.
7. Miscellaneous electrical components, hookup wire, banana jacks.
8. Long stem plastic funnel.
9. Thermocouple wire and readout device (Optional).

Note: An electrical block diagram of the equipment is shown in Figure 69. All wires carrying the current which passes through the cell should be No. 14 (1.6 mm) high voltage cable. Wires leading to the meters can be standard electrical hookup wire.

Procedure

1. Remove specimen from water, blot off excess water, transfer to sealed can.
2. Mix 20 grams of RTV rubber with 0.1 gram of Catalyst F.
3. Place paper disc over one cell screen; trowel RTV rubber over screen borders adjacent to

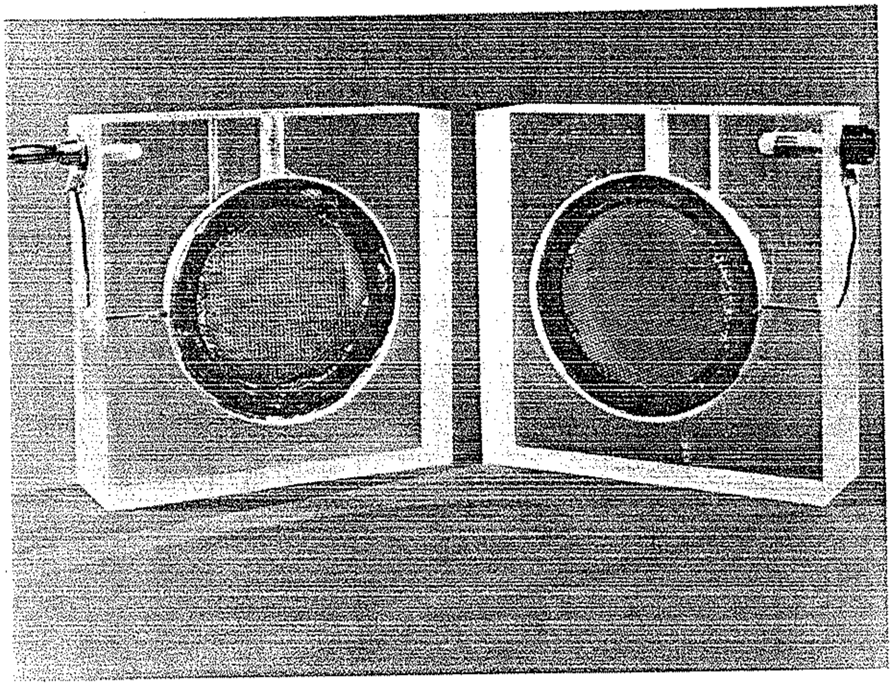


FIGURE 67. APPLIED VOLTAGE CELL–FACE VIEW.

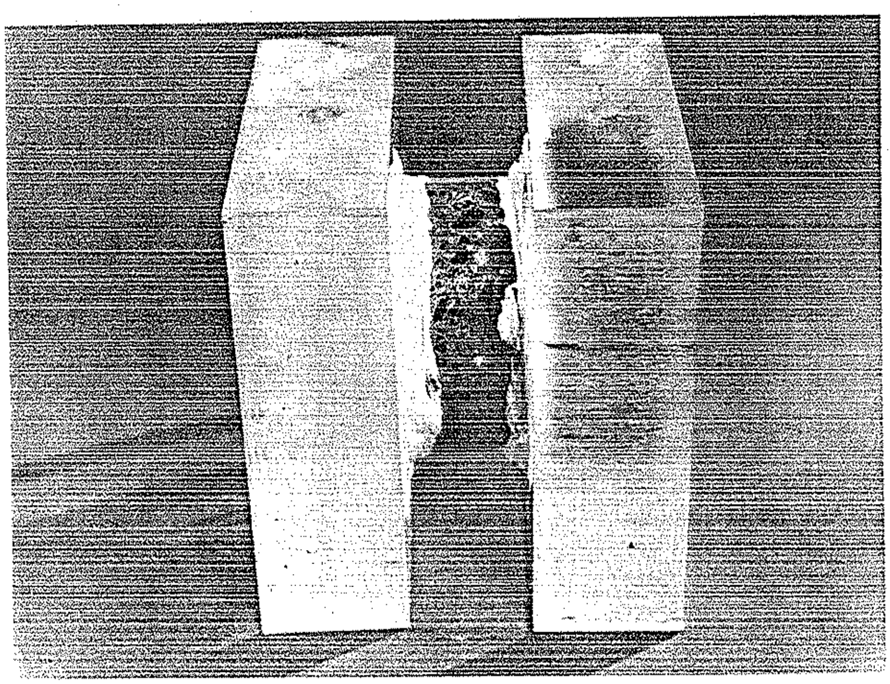


FIGURE 68. SPECIMEN READY FOR TEST.

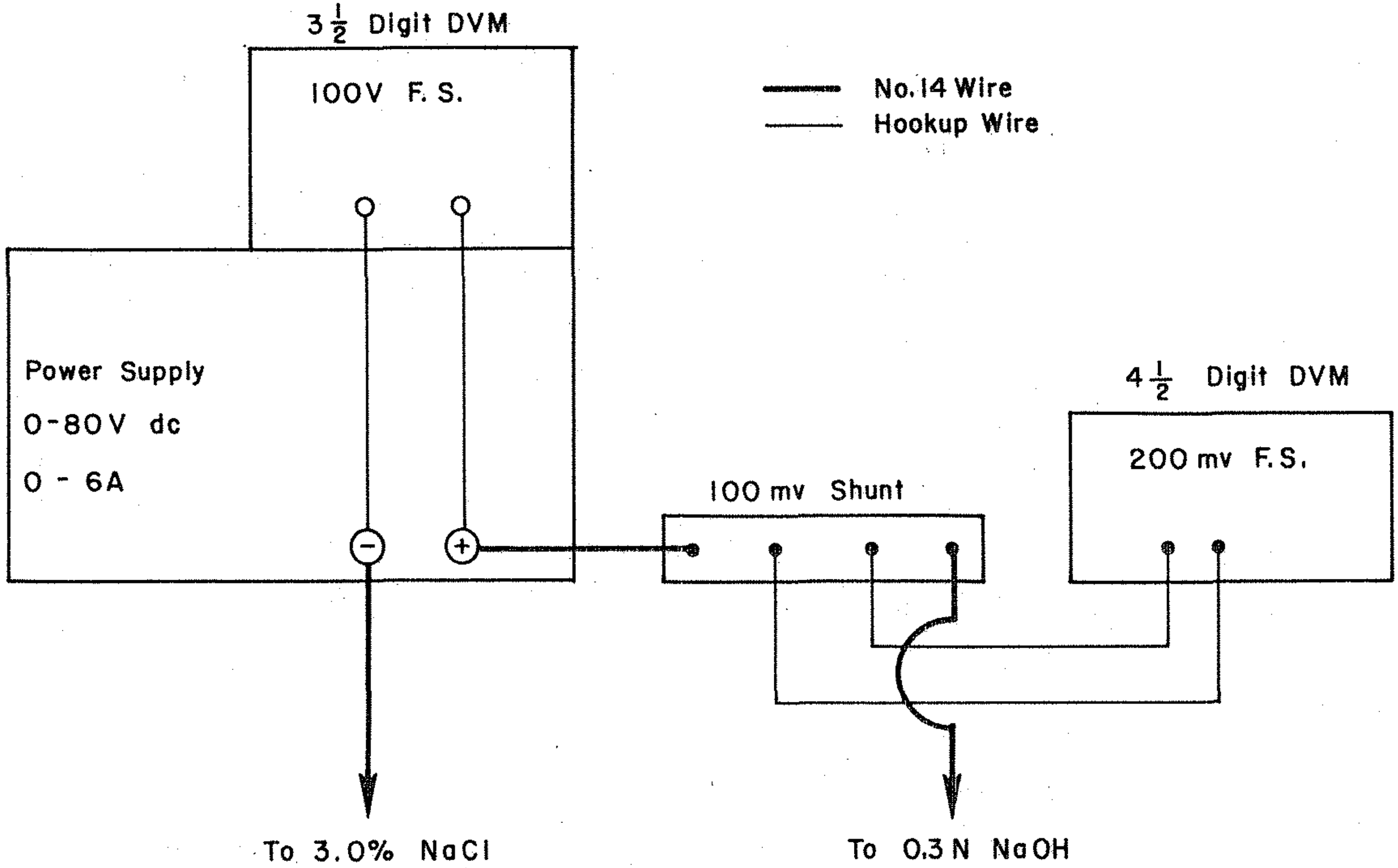


FIGURE 69. ELECTRICAL BLOCK DIAGRAM.

plastic cell. Carefully remove paper disc.

4. Press specimen onto screen; remove excess RTV rubber which flows out of specimen/cell boundary. Cover exposed face of specimen with an impermeable material such as solid rubber sheeting. Place a rubber stopper into cell vent-hole to restrict moisture movement. Allow 10 minutes for rubber to cure.
5. Repeat Steps 3-4 on second half of cell. Allow rubber to cure 10 minutes.
6. Fill left hand (-) side of cell with 3.0% NaCl using a long-stem funnel. Fill right hand (+) side of cell with 0.3N NaOH.
7. Attach lead wires to cell banana posts. Turn on power supply, set to 60.0 V, and record initial current reading.

Note: If a 4-1/2 digit DVM is used in conjunction with the 100 mv shunt, the display can be read directly in milliamps, disregarding the decimal point (i.e., 0.01 mv equals 1 milliamp).

8. Read current every 30 minutes. Monitor temperature inside of cell if desired (thermocouple can be run through 1/8-in. (3 mm) venthole in top of cell).

Note: If temperature exceeds 190°F (88°C), discontinue test in order to avoid damage to cell.

9. Terminate test after 6 hours has elapsed.
10. Remove specimen. Rinse cell thoroughly in running water; strip out and discard residual RTV rubber seal.

<u>Step 5 - Interpretation of Results</u>

1. Construct a plot of current (in amperes) vs. time (in seconds). Draw a smooth curve through the data, and integrate the area underneath the curve in order to obtain the ampere-seconds, or coulombs, of charge passed during the 6-hour test period.

Note: While conventional integration techniques such as planimetry or paper weighing can be used, programmable hand-held calculators are now available which can be used to numerically integrate the plots.

2. Refer to Table 35 for evaluating the test results. These parameters were developed from data on 3.75-in. (95 mm) diameter x 2-in. (51 mm) long core slices taken from laboratory slabs prepared from various types of concretes. They have shown good correlations with 90-day chloride ponding results on companion slabs cast from the same concrete mixes.

Note: The effects of such variables as aggregate type and size, cement content and composition, density, and other factors have not been evaluated. We recommend that persons using this procedure prepare a set of concretes from local materials and use these to establish their own correlation between charge passed and known chloride permeability for their own particular materials. The values given in Table I may be used as estimates until more data has been

TABLE 35

APPLIED VOLTAGE TEST

Interpretation of Results

Chloride Permeability	Charge Passed (coulombs)	Type of Concrete
High	4,000	High water-cement ratios ($\geq$0.6)
Moderate	2,000-4,000	Moderate water-cement ratio (0.4-0.5)
Low	1,000-2,000	Low water-cement ratios "Iowa" dense concrete
Very Low	100-1,000	Latex modified concrete Internally sealed concrete
Negligible	100	Polymer impregnated concrete Polymer concrete

developed by a number of agencies on a wider range of concretes.

Notes on Cell Construction - Figure 70

1. Attachment of Lead Wire to Screen

Solder one end of the nylclad lead wire to the outer edge of the brass shim which holds the screen. The nylclad insulation should be removed prior to soldering by burning off with a propane torch and then removing the charred residue with wire wool.

2. Attachment of Screen to Cell

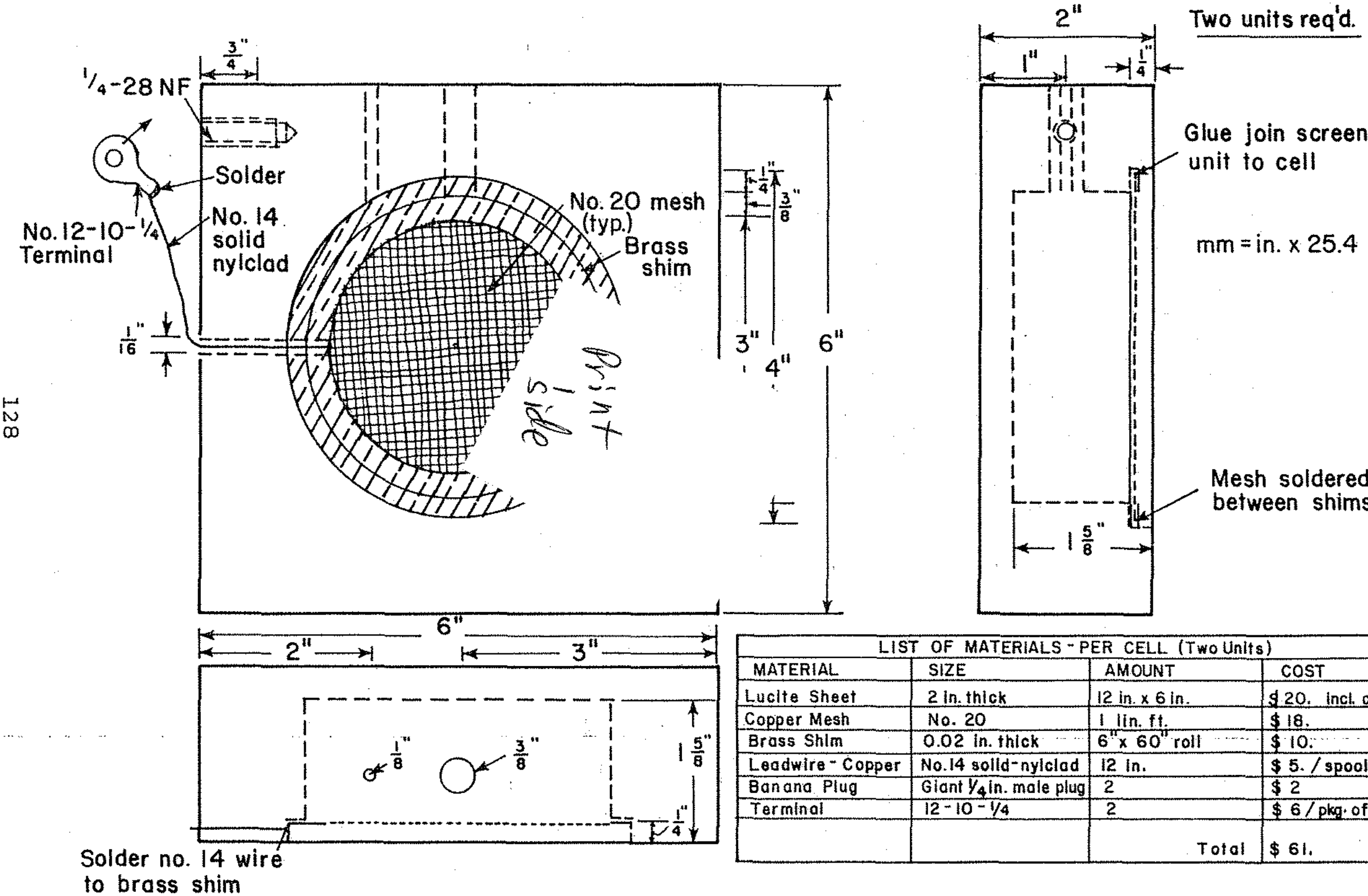
The screen is bonded to the cell by using a high quality waterproof adhesive (Scotch "super-strength adhesive" or equivalent). Scour both the screen shim and the cell lip with medium sandpaper prior to applying adhesive in order to obtain good metal to plastic bond. Apply a coating of adhesive to both cell and screen, run lead wire through 1/16-in. (1.5 mm) hole inside of cell, then gently push screen into place on cell lip. Wipe excess adhesive off face side of screen shim and place a weight on screen until adhesive has fully cured (24 hours).

3. Attachment of Lead Wire to Banana Plug

Solder a 12-10-1/4 ring terminal onto the bare end of the lead wire, keeping excess wire length to a minimum. Run the threaded end of the banana plug through the eyelet of the ring terminal, then thread banana plug into the 1/4-28 threaded hole in the side of the cell, tighten securely. Then fill the 1/6-in. (1.5 mm) hole with clear silicone rubber caulk (Dow Corning No. 732 or equivalent).

4. Materials Quantities and Cost

Some materials may not be available in the small quantities necessary to construct a single cell. In these cases package quantities have been quoted. Lucite sheet stock will probably need to be pre-cut by the suppliers, and the buyer will need to pay cutting charges unless he has another use for the full stock width.



LIST OF MATERIALS - PER CELL (Two Units)			
MATERIAL	SIZE	AMOUNT	COST
Lucite Sheet	2 in. thick	12 in. x 6 in.	$ 20. incl. cut
Copper Mesh	No. 20	1 lin. ft.	$ 18.
Brass Shim	0.02 in. thick	6" x 60" roll	$ 10.
Leadwire - Copper	No. 14 solid-nylclad	12 in.	$ 5. / spool
Banana Plug	Giant 1/4 in. male plug	2	$ 2
Terminal	12 - 10 - 1/4	2	$ 6 / pkg. of 50
		Total	$ 61.

FIGURE 70. APPLIED VOLTAGE CELL (CONSTRUCTION DRAWING).

Appendix E

AASHTO 277-83

Rapid Determination of the Chloride Permeability of Concrete

Standard Method of Test for

Rapid Determination of the Chloride Permeability of Concrete

AASHTO DESIGNATION: T 277-83

1. SCOPE

1.1 This method covers the determination of the permeability of conventional portland cement and specialized, e.g., latex-modified and polymer, concretes to chloride ions. It consists of monitoring the amount of electrical current passed through 95 mm (3.75 in.) diameter by 51 mm (2 in.) long cores when one end of the core is immersed in a sodium chloride solution and a potential difference of 60 V dc is maintained across the specimen for 6 hours. The total charge passed, in coulombs, is related to chloride permeability.

2. APPLICABLE DOCUMENTS

2.1 *AASHTO Standards:*
T 24 Obtaining and Testing Drilled Cores and Sawed Beams of Concrete
T 259 Resistance of Concrete to Chloride Ion Penetration

3. SIGNIFICANCE AND USE

3.1 This method covers the laboratory evaluation of the relative permeability of concrete samples to chloride ions. The test results have shown good correlation with the results of 90-day chloride ponding tests (AASHTO T 259) on companion slabs cast from the same concrete mixes.

3.2 The method is suitable for specification acceptance, design purposes, service evaluation, and research and development.

3.3 Care should be taken in interpreting results of this test when it is used on surface-treated concretes. The results from this test on some such concretes show high chloride permeabilities, while 90-day chloride ponding tests on companion slabs show low permeabilities.

3.4 The method may be used on cores of diameters other than 95 mm (3.75 in.) and thicknesses other than 51 mm (2 in.). The values in Table 1 are not valid for any other size specimens, however, and no relationships have been established to adjust the values in that table for other specimen sizes. Data for specimens of other sizes may be used for relative comparisons of chloride permeabilities among specimens of the same size.

4. APPARATUS, REAGENTS, AND MATERIALS

4.1 Vacuum Saturation Apparatus (see Figure 1).

4.1.1 Separatory funnel – 500 ml capacity.

4.1.2 Beaker – 1,000 ml

4.1.3 Vacuum desiccator[1]—250 mm I.D.

4.1.4 Vacuum pump—capable of maintaining a pressure of less than 1 mm Hg (133 Pa) in dessicator.

4.1.5 Vacuum gage or manometer—accurate to ± 0.5 mm Hg (±66 Pa) over range 0 – 10 mm Hg (0-13,30 Pa) pressure.

4.2 Epoxy Coating Apparatus and Materials

4.2.1 Epoxy resin—rapid setting, capable of sealing side surface of concrete cores.

4.2.2 Balance or scale, paper cups, wooden spatulas, and disposable brushes—for mixing and applying epoxy.

4.3 Specimen Sizing Equipment

4.3.1 Movable bed diamond saw.

4.4 Voltage Application Apparatus, Reagents, and Materials

4.4.1 Specimen-cell sealant—RTV silicone rubber or silicone rubber caulking.

4.4.2 Sodium chloride solution—3.0 percent by weight (reagent grade) in demineralized water.

4.4.3 Sodium hydroxide solution—0.3N, reagent grade.

4.4.4 Filter papers—No. 2, 90 mm diameter.

[1]Desiccator must allow two hose connections, through rubber stopper and sleeve or through rubber stopper only. Each connection must be equipped with a stopcock.

4.4.5 Digital voltmeter (DVM)—4½-digit, 200 mV full scale.
4.4.6 Digital voltmeter—3½ digit, 99.9 V full scale.
4.4.7 Shunt resistor—100 mV, 10 A rating.
4.4.8 Constant voltage power supply—0 − 80 V dc, 0 − 6 A, capable of holding voltage constant at 60 ± 0.1 V over entire range of currents.
4.4.9 Cable—two conductor, No. 14 (1.6mm), insulated, 600 V.
4.4.10 Funnel—plastic, long stem.
4.4.11 Applied voltage cell (see Figures 2 and 3, Appendix).
4.4.12 Thermocouple wire and readout device (optional)—0-120 C (30-250 F) range.

5. TEST SPECIMENS

5.1 Obtain samples from the structure to be evaluated using a core drilling rig equipped with a nominal 4-in (102 mm) diameter (3.75-in (95mm) actual I.D.) diamond-dressed core bit. Select and core samples following procedures in AASHTO Method T 24. Place the cores in a plastic bag for transport to the laboratory.
5.2 Using the diamond saw, cut a 2-inch (51 mm) slice from the top of the core, with the cut parallel to the top of the core. This slice will be the test specimen. Use a belt sander to remove any burrs on the end of the specimen.

6. CONDITIONING

6.1 Vigorously boil tapwater in a large (2L) florence flask. Remove flask from heat, cap tightly, and allow water to cool to ambient temperature.
6.2 Allow specimen prepared in Section 5 to surface dry in air for 1 hour. Prepare approximately 10 g of rapid setting epoxy and brush onto sides of specimen. Place sample on sample-support stud while coating to ensure compete coating of sides. Allow coating to cure per manufacturer's instructions.
6.3 Check coating for tack-free surface. Place specimen in 1,000 ml beaker, then place beaker in vacuum desiccator. Seal desiccator and start vacuum pump. Pressure should decrease to less than 1 mm Hg (1,330 kPa) within a few minutes. Maintain vacuum for 3 hours.
6.4 Fill 500 ml separatory funnel with de-aerated water. With vacuum pump still running, open water stopcock and drain sufficient water into beaker to cover specimen (do not allow air to enter desiccator through this stopcock).
6.5 Close water stopcock and allow vacuum pump to run for 1 additional hour.
6.6 Close vacuum line stopcock, then turn off pump. Turn vacuum line stopcock to allow air to reenter desiccator.
6.7 Soak specimen under water in the beaker for 18 ± 1 hours.

7. PROCEDURE

7.1 Remove specimen from water, blot off excess water, and transfer specimen to can and seal temporarily.
7.2 If using two-part specimen-cell sealant, prepare approximately 20 g.
7.3 Place filter paper over one screen of the applied voltage cell; trowel sealant over brass shims adjacent to cast acrylic cell body. Carefully remove filter paper.
7.4 Press specimen onto screen; remove excess sealant which has flowed out of specimen/cell boundary. Cover exposed face of specimen with an impermeable material such as solid rubber sheeting. Place rubber stopper in cell vent-hole to restrict moisture movement. Allow sealant to cure per manufacturer's instructions.
7.5 Repeat steps 7.3 and 7.4 on second half of cell. (Specimen in applied voltage cell now appears as shown in Figure 4.)
7.6 Using the long stem funnel, fill left hand (−) side of cell, i.e., the side containing the top surface of the specimen, with 3.0 percent NaCl solution. Fill right hand (+) side of cell with 0.3N NaOH solution.
7.7 Attach lead wires to cell banana posts. Make electrical connections as shown in Figure 5. Turn power supply on, set to 60.0 ± 0.1 V, and record initial current reading (When the 4½-digit DVM specified in Section 4.4.5 is used with the 100 mV shunt, the DVM display can be read directly in milliamps disregarding the decimal point, i.e., 0.01 mV equals 1 milliamp.).

7.8 Read and record current every 30 minutes. Monitor temperature inside of cell if desired (thermocouple can be installed through ⅛ in. (3 mm) venthole in top of cell).

NOTE 1: If temperature exceeds 190 F (88 C), discontinue test in order to avoid damage to cell. Such temperatures generally occur only for high permeability concretes and for specimens thinner than 51 mm (2 in.).

7.9 Terminate test after 6 hours.

7.10 Remove specimen. Rinse cell thoroughly in tapwater; strip out and discard residual sealant.

8. CALCULATION AND INTERPRETATION OF RESULTS

8.1 Plot current (in amperes) vs. time (in seconds). Draw a smooth curve through the data, and integrate the area underneath the curve in order to obtain the ampere-seconds, or coulombs, of charge passed during the 6-hour test period.

NOTE 2: While conventional integration techniques such as planimetry or paper weighing can be used, programmable hand-held calculators which are now available can be used to numerically integrate the plots.

8.2 Use Table 1 to evaluate the test results. These values were developed from data on 3.75-in. (95 mm) diameter × 2-in. (51 mm) long core slices taken from laboratory slabs prepared from various types of concretes.

NOTE 3: The terms in the middle column of Table 1 are not absolute. They are relative descriptions of the permeabilities of carefully prepared laboratory specimens.

Table 1. Chloride Permeability Based on Charge Passed (from Reference 2)

Charge Passed (coulombs)	Chloride Permeability	Typical of
>4,000	High	High water-cement ratio, conventional (≥0.6) PCC
2,000-4,000	Moderate	Moderate water-cement ratio, conventional (0.4-0.5) PCC
1,000-2,000	Low	Low water-cement ratio, conventional (<0.4) PCC
100-1,000	Very Low	Latex-modified concrete Internally sealed concrete
<100	Negligible	Polymer impregnated concrete Polymer concrete

[2]Whiting, D., "Rapid Determination of the Chloride Permeability of Concrete," Report No. FHWA/RD-81/119, August 1981, available from NTIS, PB No. 82140724.

9. REPORT

9.1 The report shall include the following:

9.1.1 Source of core, in terms of the structure and the particular location in the structure from which the core was obtained.

9.1.2 Identification number of core and specimen.

9.1.3 Location of specimen within core.

9.1.4 Type of concrete, including binder type, water-cement ratio, and other relevant data supplied with cores.

9.1.5 Description of specimen, including presence and location of reinforcing steel, presence and thickness of overlay, and presence and thickness of surface treatment.

9.1.6 Unusual specimen preparation, e.g., removal of surface treatment.

9.1.7 Test results, reported as the total charge passed over the test period and the maximum current recorded during the test period.

9.1.8 The chloride permeability equivalent to the calculated charge passed (from Table 1).

10. PRECISION

The following criterion should be used for judging the acceptability of results (95 percent probability).

10.1 Test results by the same operator on duplicate specimens from the same concrete should not be considered suspect unless they differ by more than 19.5 percent.

APPENDIX—NOTES ON APPLIED VOLTAGE CELL CONSTRUCTION (REFER TO FIGURE 3).

1. ATTACHMENT OF LEAD WIRE TO SCREEN

Solder one end of the nylclad lead wire to the outer edge of the brass shim which holds the screen. The nylclad insulation should be removed prior to soldering by burning off with a propane torch and then removing the charred residue with wire wool.

2. ATTACHMENT OF SCREEN TO CELL

The screen is bonded to the cell by using a high quality waterproof adhesive. Scour both the screen shim and the cell lip with medium sandpaper prior to applying adhesive in order to obtain good metal to plastic bond. Apply a coating of adhesive to both cell and screen, run lead wire through 1/16 in. (1.5 mm) hole inside of cell, then gently push screen into place on cell lip. Wipe excess adhesive off faceside of screen shim and place a weight on screen until adhesive has fully cured (24 hours).

3. ATTACHMENT OF LEAD WIRE TO BANANA PLUG

Solder a 12-10¼ ring terminal onto the bare end of the lead wire, keeping excess wire length to a minimum. Run the threaded end of the banana plug through the eyelet of the ring terminal, then thread banana plug into the ¼-28 threaded hole in the side of the cell, tighten securely. Then fill the 1/16 in. (1.5 mm) hole with clear silicone rubber caulk.

4. MATERIALS QUANTITIES AND COST

Some materials may not be available in the small quantities necessary to construct a single cell. In these cases package quantities have been quoted. Cast acrylic sheet stock will probably need to be precut by the suppliers, and the buyer will need to pay cutting charges unless he has another use for the full stock width.

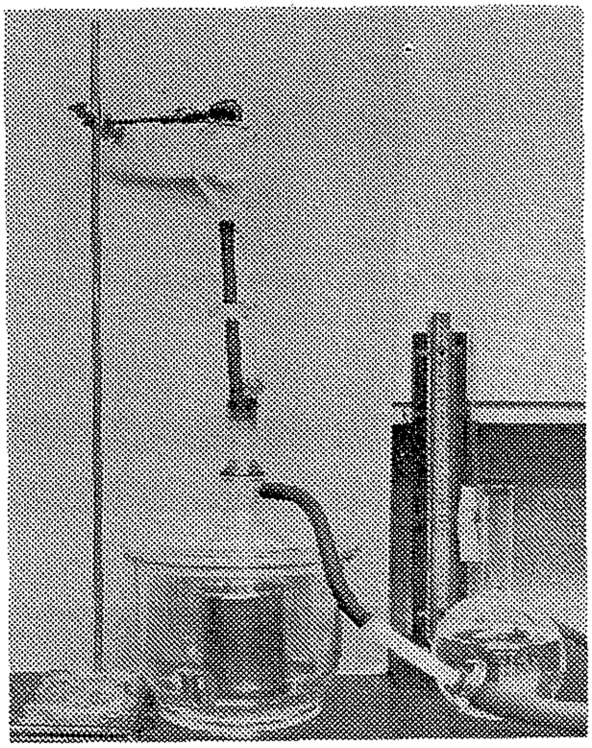


FIGURE 1 VACUUM SATURATION APPARATUS.

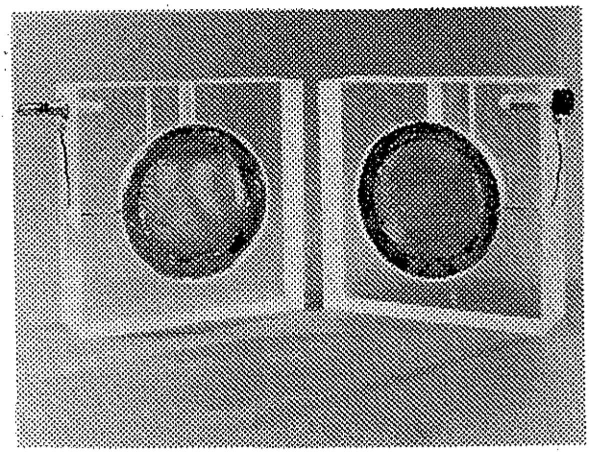
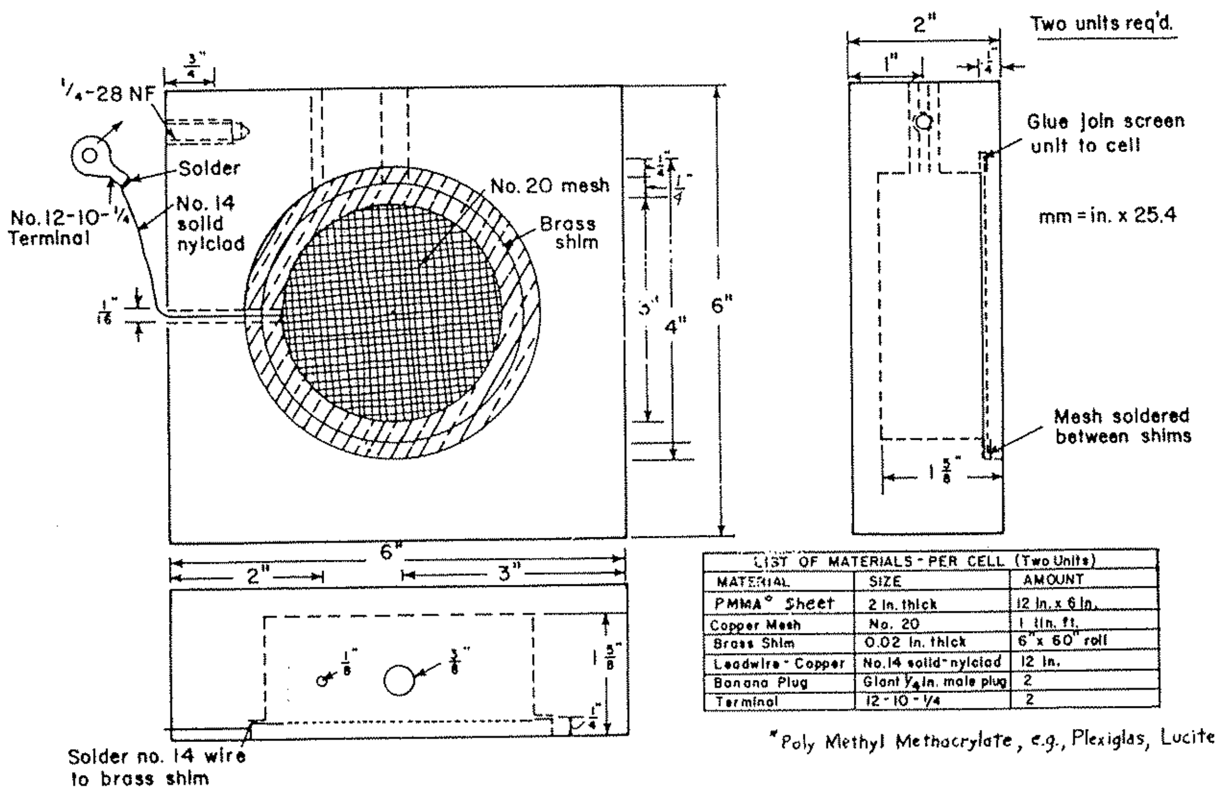


FIGURE 2 APPLIED VOLTAGE CELL—FACE VIEW.



LIST OF MATERIALS - PER CELL (Two Units)		
MATERIAL	SIZE	AMOUNT
PMMA* Sheet	2 in. thick	12 in. x 6 in.
Copper Mesh	No. 20	1 lin. ft.
Brass Shim	0.02 in. thick	6" x 60" roll
Leadwire - Copper	No. 14 solid-nylclad	12 in.
Banana Plug	Giant ¼ in. male plug	2
Terminal	12 - 10 - ¼	2

*Poly Methyl Methacrylate, e.g., Plexiglas, Lucite

FIGURE 3 APPLIED VOLTAGE CELL (CONSTRUCTION DRAWING).

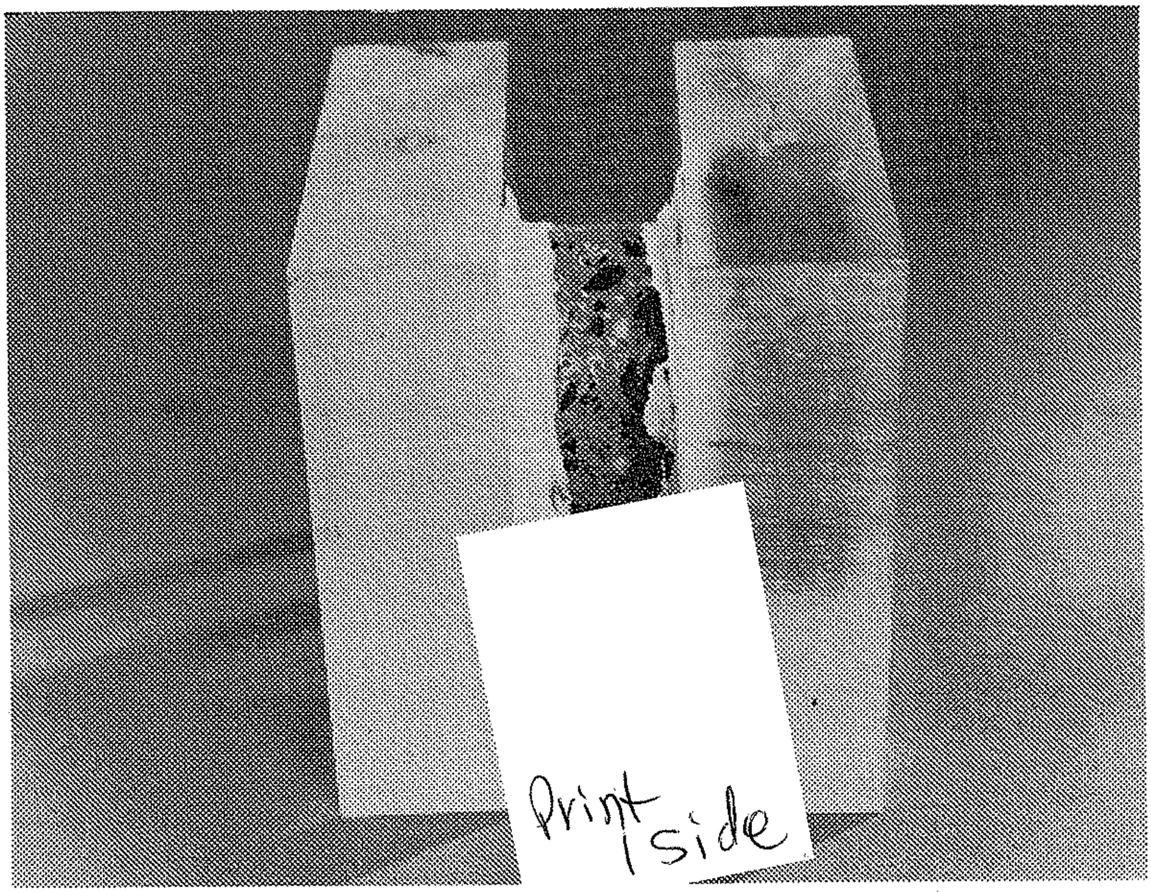


FIGURE 4 SPECIMEN READY FOR TEST.

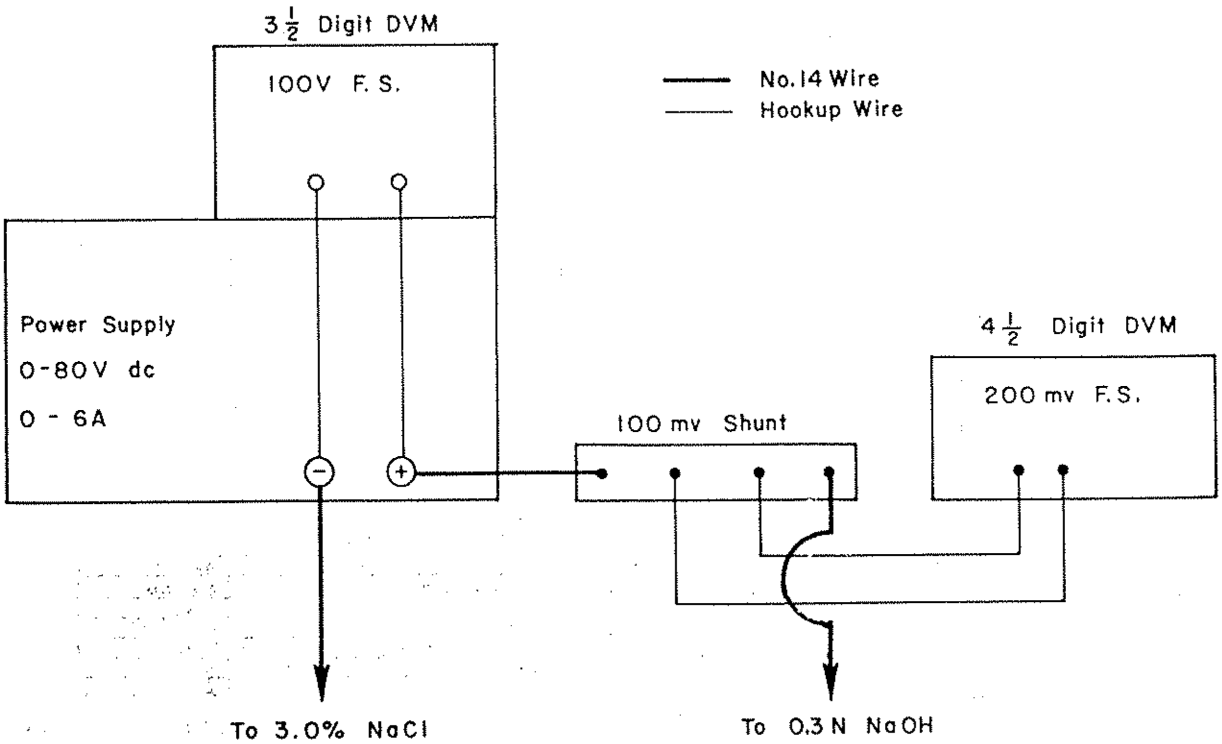


FIGURE 5 ELECTRICAL BLOCK DIAGRAM.