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WATER VAPOR TRANSMISSION AND ELECTRICAL RESISTIVITY OF CONCRETE

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WATER VAPOR TRANSMISSION AND ELECTRICAL RESISTIVITY OF CONCRETE

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Type C Final Report

by

Robert L. Henry

ABSTRACT

This is the final report of a study of water vapor transmission (WVT) of plain concrete and of San Gabriel rock, corrosion of steel grids, and electrical resistivity of concrete.

The WVT studies involved San Gabriel rock and plain concrete with water-cement ratio, type of reinforcing steel grid, aggregate size, relative humidity, two admixtures (sodium chloride and oleic acid), and position of slice as variables in one or more of three phases of investigation. WVT rates decreased with an increase in age of concrete, in strength of concrete, in maximum aggregate size, and with the presence of 1.5 percent sodium chloride.

Two kinds of steel grids — mild reinforcing steel and high-strength prestressing wire — were embedded in the 2-inch-thick concrete disks of some of the WVT specimens. Upon completion of the test, a higher percent of corrosion of steel was found in the higher water-cement ratio concrete disks; nearly all of the grids in concrete containing sodium chloride showed some corrosion.

In order to determine the electrical resistivity of concrete, using the two-point method, sixteen concrete prisms were cast with carbon grids. Electrical resistivity increased with age and decreased with increased salinity of mixing water.

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The Laboratory invites comment on this report, particularly on the results obtained by those who have applied the information.

CONTENTS

INTRODUCTION

This is the third and final report of an investigation of water vapor transmission (WVT) which has been in progress at NCEL for approximately 4 years. The first report was "Water Vapor Transmission of Plain Concrete,"[1] and the second was "Water Vapor Transmission of Concrete and of Aggregate."[2] The material contained in Reference 1 also appeared in the December 1961 issue of the ACI Journal.[3]

A summary of the concrete mix design data appears in Appendix A. Plastic wet cup description and assembly appears in Appendixes B and C. A background for this entire investigation can be found in Reference 1.

WATER VAPOR TRANSMISSION

Phases I, II, and III

The mixing and casting procedures of Phases I, II, and III are described in detail in References 1 and 2. Tables I, II, and III together with the discussion below present the variables and the WVT rates for Phases I, II, and III.

Phase I involved four variables: strength of concrete, absence or presence of sodium chloride (NaCl), ambient relative humidity (RH), and location of slice cut from each cylinder in the as-cast position. A full-replicate experiment of 36 specimens was used (Table I).

Phase II involved six variables: the four variables of Phase I, plus maximum aggregate size, and absence or presence of oleic acid. A statistically designed quarter-replicate experiment of 16 specimens was used (Table II).

Phase III involved six variables: type of reinforcing steel plus all of the variables of Phase II except slice position (all Phase III specimens were cut from the center of the cylinder). A statistically designed half-replicate experiment of 48 specimens was used (Table III).

At the time of this report, the age of the test specimens for Phases I, II, and III was 1300, 1250, and 1050 days respectively. With these increased ages, there was no change in the WVT rates previously reported;[2] thus the findings remain the same:

1. WVT rates decreased when W/C was decreased (which increased strength).

2. WVT rates decreased when aggregate size (as used in this study) was increased.

3. WVT rates decreased when NaCl was present.

4. WVT rates decreased when concrete age increased.

5. WVT rates were independent of the type of reinforcing steel and of the absence or presence of oleic acid.

WVT rates appeared to decrease when RH was increased, but the data were inconclusive.

The formula used for calculating WVT, grains per square inch per day, is

$$WVT = \frac{W}{At} \qquad (1)$$

where: W = weight of water vapor transmitted, grains

A = area of cross section of flow path, square inches

t = time during which WVT occurred, days

San Gabriel Rock

WVT rates were determined by the wet-cup method with twenty specimens sawed from 4-inch-diameter cores taken from eight large rocks obtained from the Irwindale, California, pit. The results of megascopic examination, petrographic analysis, and classification for the rock specimens are presented in Appendix D.

The WVT rates (unchanged after approximately 1000 days age) are presented in Table IV and Figure 1.

COMPRESSIVE STRENGTH

The compressive strength aspect of the entire investigation is discussed in detail in References 1 and 2. Since no additional studies have been made, the findings presented therein remain unchanged: compressive strength is decreased (1) by an increase in W/C; (2) by the presence of 1.5 percent NaCl; and (3) by the presence of 0.25 percent oleic acid. Compressive strength appears to be independent of 3/8-inch and 3/4-inch maximum aggregate size.

CORROSION OF STEEL GRIDS OF PHASE III

In conjunction with the WVT study of Phase III, utilizing the wet-cup method, two types of steel grids (Figure 2) were investigated to determine the corrosion effect of the variables on the steel and the effect of the steel on the WVT. The grid on the left in Figure 2 (referred to as "B" steel) is 1/4-inch-diameter prestressing wire (high-strength, stress-relieved, uncoated) with an ultimate strength of 242,200 psi. The grid on the right (referred to as "A" steel) is No. 5, deformed, 5/8-inch-diameter, reinforcing bar of mild steel with an ultimate tensile strength of 81,000 psi. The maximum diameter of either grid was 5-1/2 inches. Table III presents the variables of Phase III, including kinds of steel.

When the wet-cup test was discontinued, each specimen containing a steel grid was broken open, and the grid was removed. The grids were cleaned in a sonic vibratory cleaner and then weighed. The percentage of corrosion was calculated by comparing this weight with the weight of the grid before casting. The corrosion percentages are presented in Table V.

Also presented in Table V for each specimen are various observations made just before destruction, such as NaCl whisker growth, cup-water discoloration, pH, total dissolved solids, and chlorides. Where there is no comment (1) there was no whisker growth, (2) the cup water appeared clear, (3) the weight loss of the grid due to corrosion was negligible, or (4) no sample of water was taken for pH, total dissolved solids, and chloride.

Distilled water was used in the wet cups, but when the tests were terminated, the pH had increased and the total dissolved solids and chlorides were quite high. Even though the flow of moisture was from the inside to the outside, a leaching action must have taken place between the concrete disk and the water. The discoloration of the cup water suggests that the corrosion products were carried down or migrated from the concrete into the cup. These observations indicate that there is movement in both directions through concrete, even though the water vapor gradient is in one direction.

Table V shows that as the compressive strength increased, the number of corroded grids and the percentage of corrosion decreased. (If the weight change caused by corrosion of a steel grid was less than 1 gram, it was considered negligible.) Eight out of twelve Type A steel grids and eight out of twelve Type B steel grids showed corrosion. For all specimens containing NaCl, the average percentage of corrosion of Type A steel grids was 1.37; that for Type B was 1.53. The difference is not significant. Therefore, since the same number of grids showed corrosion and the percentage of corrosion was nearly the same for Type A and Type B steel, it is concluded that there is no significant difference in the corrosion of these two types of steel.

ELECTRICAL RESISTIVITY OF CONCRETE

The objective of this study was to determine the electrical resistivity of plain concrete. The electrical resistivity (hereafter noted simply as resistivity) used in this experiment is the unit resistance, or volume resistivity, expressed in units of ohms per cubic inch of material. The ASTM standard for metallic conductors, as presented in ASTM Designation B193-49, is in ohms per mil-foot,[4] but no such standard is known for concrete. Therefore, the measured dc resistances, in ohms, were converted to dc resistivities, in ohm-inches. The formula used to convert resistance to resistivity is:

$$\rho = \text{Resistivity} = \frac{RA}{L} = \frac{R(16)}{8} = 2R \qquad (2)$$

where R = resistance

A = cross-sectional area of prism, square inches

L = distance between grids, inches

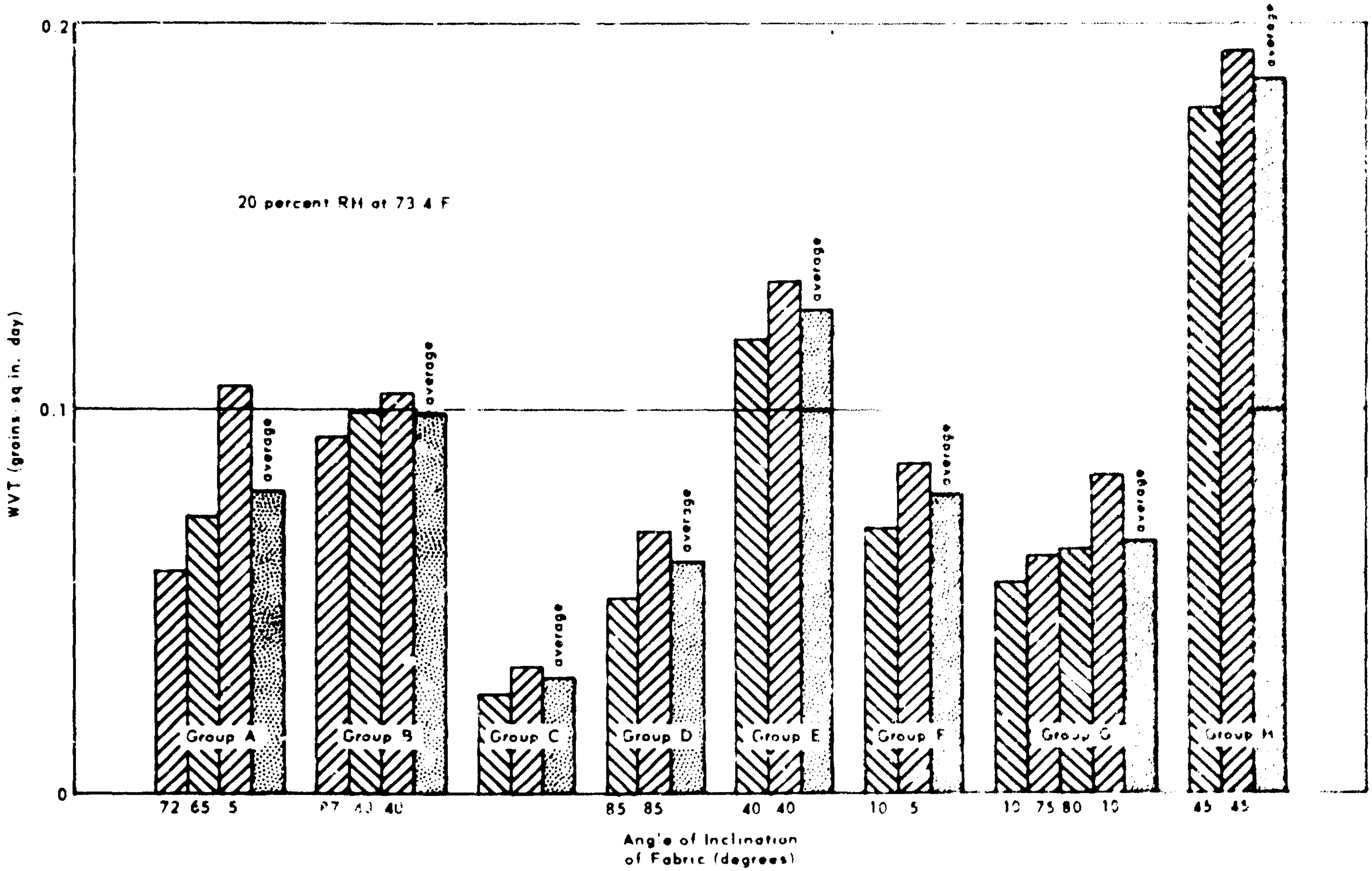

Figure 1. Bar graph of WVT for each SG group.
(Reprinted from TR-244)

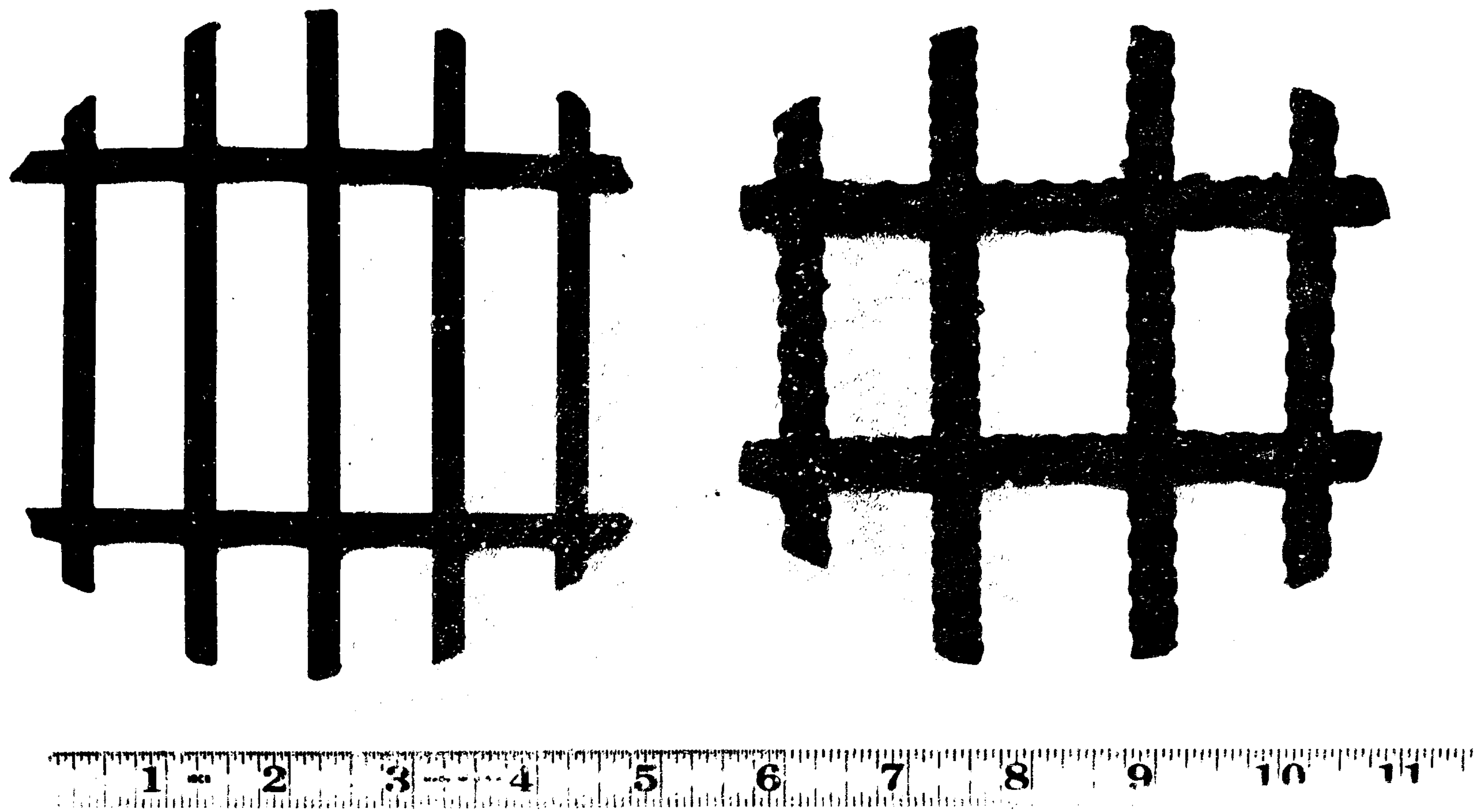

Figure 2. Two types of steel grids used in the corrosion study of Phase III.

The variables included in the resistivity study were:

1. Two concrete strengths:

   High Strength (W/C = 0.444)

   Low Strength (W/C = 0.702)

2. Four salinities of mixing water:

Salinity*	Description
0	Port Hueneme tap water
5.22	Brackish water (1 part sea water to 5 parts tap water)
23.0	NaCl (0.0236 lb NaCl per lb of tap water; NaCl content equal to that of sea water)
31.3	Sea water (from NCEL sea-water well)

*grams of salts per kilogram of mixing water solution

The summary of concrete mix design data (Appendix A) applies, with the following changes, to this study:

1. Colton Type II cement
2. Maximum size 3/4-inch San Gabriel aggregate only
3. Water in the same proportions but with variable salinities
4. NaCl as an additive only
5. No medium-strength mix (M)

The resistivity study employed a series of concrete prisms 4 inches square by 12 inches long. The prisms were cast and retained in acrylic boxes. The resistivity was measured by the two-point method between two 4-inch-square grids, each cast in the prism at 2 inches from each end of the prism to the center of the grid. There were 8 inches between grids, center to center. The grids consisted of 1/4-inch-thick pure plate carbon with a pattern of holes drilled to increase the bond and to simulate a grid (Figure 3). Also a cadmium-coated screw was positioned in the top edge for attachment of the lead wires. The assembled specimen with hardened concrete is shown in Figure 4.

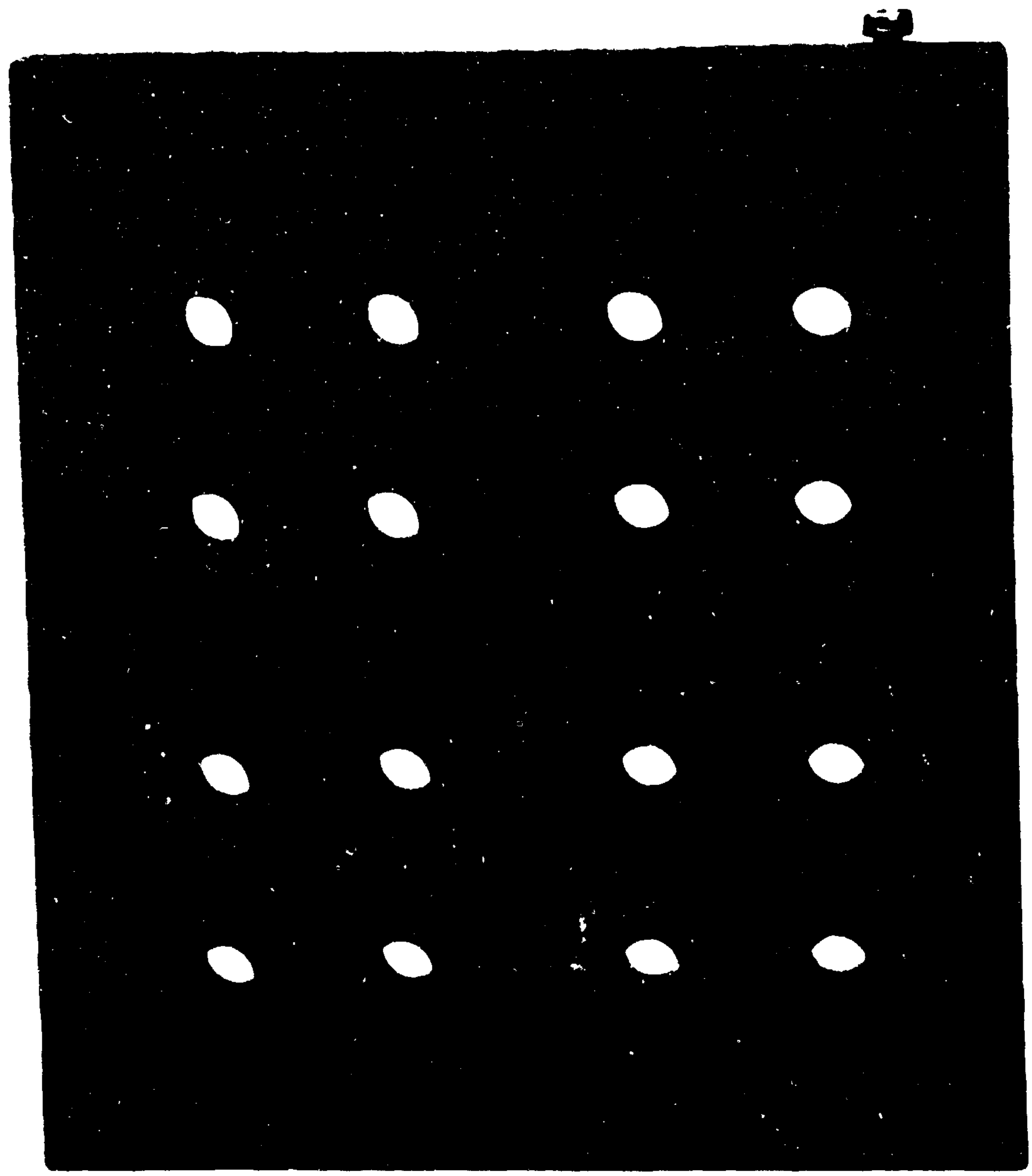

Figure 3. Carbon grid, 4" x 4" x 1/4", used in electrical resistivity study.

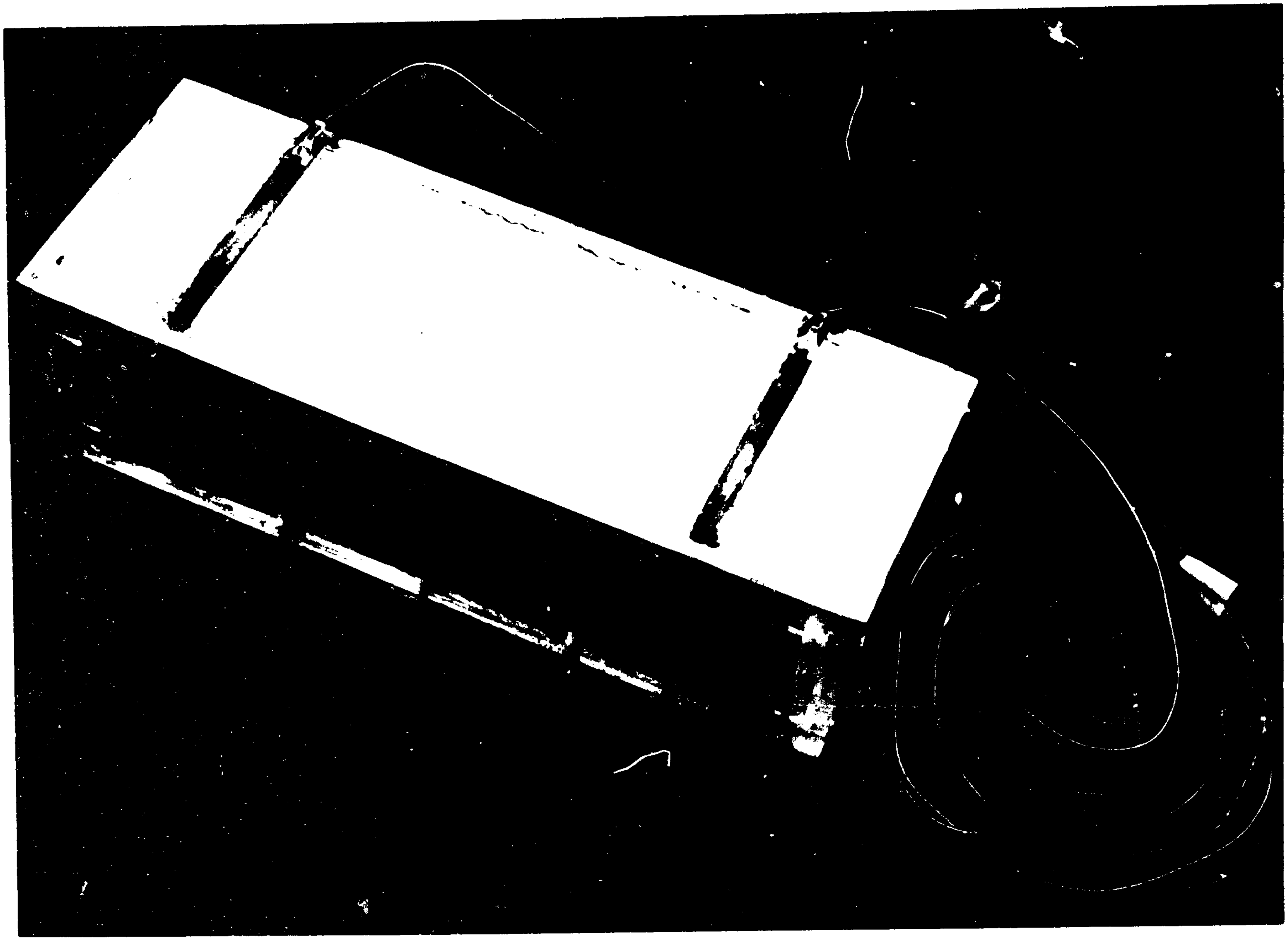

Figure 4. Concrete specimen and assembly for electrical resistivity study.

Immediately after mixing, the concrete was placed in the acrylic boxes (along with the grids) and stored in the 50 percent RH room at 73.4 F. The acrylic boxes were left open at the top and there was no attempt to cover the prisms or to keep the top surfaces moist. Obviously the ASTM standard curing method makes much more moisture available to the specimen than does the method used to cure the prisms of the resistivity study. Possibly there is a difference between the actual quality of the prisms and the expected quality, based on the ASTM curing method, but for this study the specimens cured at 50 percent RH were used.

The compressive strengths of the various batches, as determined from another series of identical batches, fog-cured to 28 days age at 73.4 F, are as follows:

	Batches			
Mixing water salinity, gm/kg	0	5.22	23.0	31.3
Low-strength concrete, psi	3,360	3,440	3,590	4,030
High-strength concrete, psi	6,650	6,310	6,220	6,390

This information is provided solely to give the reader an idea of the ranges of compressive strength. No cylinders were cast with the resistivity specimens.

Since resistivity is defined as unit resistance and since the prisms are larger than unit size, it was necessary to measure the total resistance of the prisms between the grids and convert this resistance to resistivity. Whether to use dc or ac to determine the resistivity was a problem that has only been partly solved. Natural phenomena, such as corrosion and current flows, generally involve dc. However, dc tends to polarize materials and electrodes, and thus to yield resistivity values which may or may not necessarily represent the true resistivity of the material. And, although ac does not polarize materials and thus yields their true resistivities, ac does not usually occur in nature.

To partially circumvent this difficulty, the noncorroding, highly conductive, carbon grid was used with 1.15 dc volts applied continuously to each prism. The current was measured with a highly sensitive current meter. From the dc voltage and current, the dc resistance of the prism was calculated. The dc resistance was later converted to resistivity by using Equation 2. Two identical specimens were cast from each batch, and the resulting resistivities were averaged to produce the figures of this study.

The resistivity study was carried on for 1000 hours for each specimen. By the end of 1000 hours, although equilibrium had not been reached, the rate of increase was quite slow and the study was discontinued. By this time, the differences among variables had been established.

After the resistivity values for each two identical specimens were averaged, curves were plotted on semilog graphs with resistivity, ρ, in ohm-inches versus time in hours, for each of eight averaged sets of data. For comparison, the four different salinity curves of one strength are plotted on one figure.

Figure 5 shows the four curves of low-strength (W/C = 0.702) concrete specimens. Each curve is identified by its salinity value. The three curves of salinities, 0, 5.22, and 31.3 gm/kg are of tap and/or sea water, whereas, the 23.0-gm/kg salinity curve is NaCl solution. This may account for the fact that the 23.0-gm/kg curve does not follow the pattern of the other three curves; i.e., as the salinity is increased, the resistivity is decreased. A very good spread is developed with the sea water curves up to about 300 hours age, after which more scattering is observed. The 0- and 23.0-gm/kg salinity curves develop a nice parallel pattern between themselves.

Figure 6 shows the four curves of high-strength (W/C = 0.444) concrete specimens. Each curve is identified by its salinity value. The three tap- and/or sea-water curves of the high-strength concrete (0, 5.22, and 31.3 gm/kg salinity) follow the same pattern — increased salinity with decreased resistivity — as those of the low-strength concrete (although with less spread between curves) until about 60 hours age. After this age, there is an intermingling of the two higher salinity curves (5.22 and 31.3 gm/kg). The NaCl curve (23.0 gm/kg salinity of the mixing water) is below all of the curves except at the extreme right side of Figure 6. This irregularity is probably accounted for by the fact that the 23.0-gm/kg curve is derived from concrete specimens containing NaCl salt, and the others are derived from concrete specimens containing sea-water salts. The 0- and 23.0-gm/kg salinity curves again develop a relationship between themselves similar to that developed in Figure 5 for low-strength concrete.

Comparing the curves of Figures 5 and 6, it is observed that the difference between varying salinity curves (spread of the curves) for high-strength concrete is smaller than between curves for low-strength concrete. This indicates that the resistivity of concrete is less affected by increasing salinities of mixing water at higher strengths. The curves also show that the resistivity values (curves) of

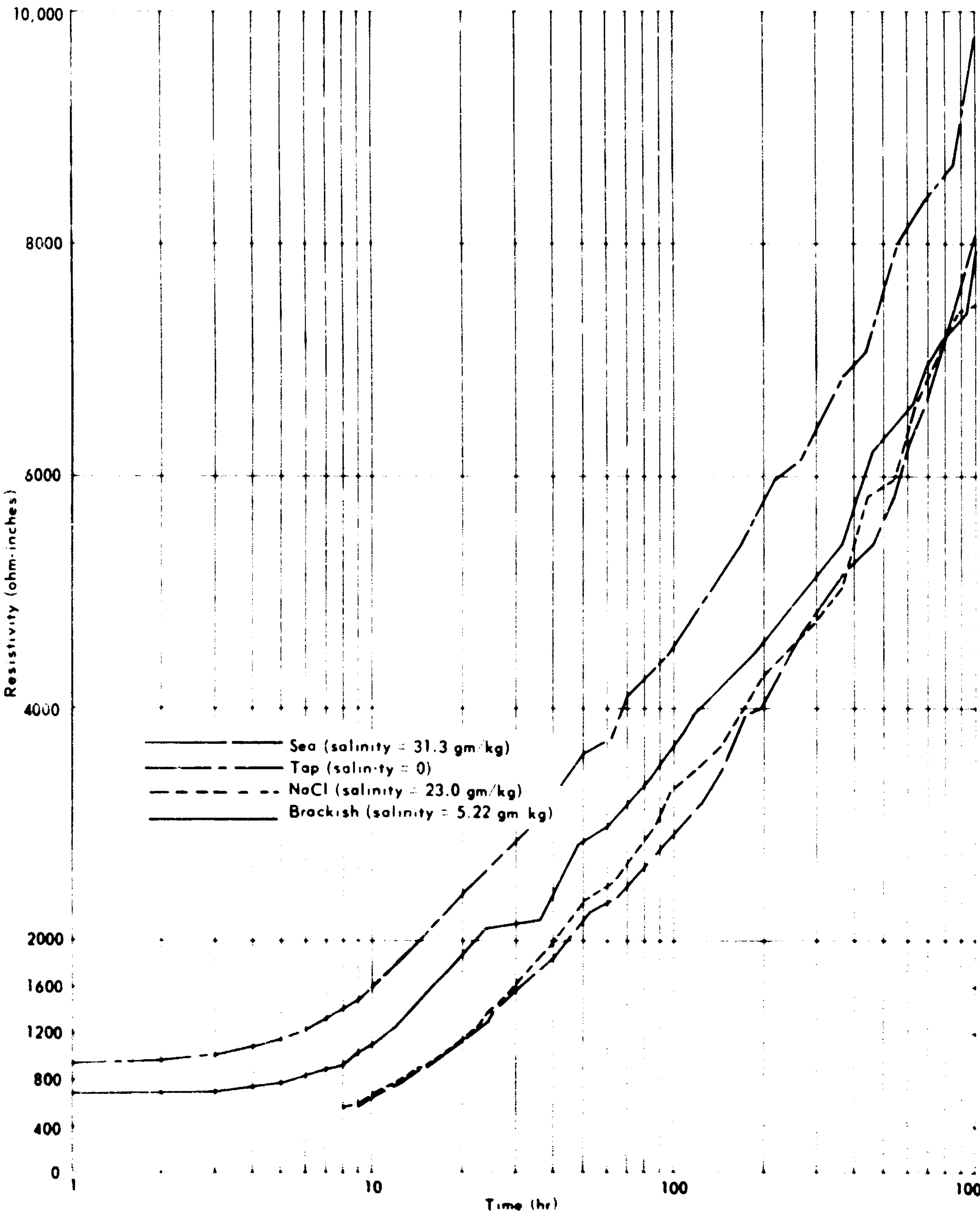

Figure 5. Electrical resistivity versus time for low-strength concrete (W/C = 0.702).

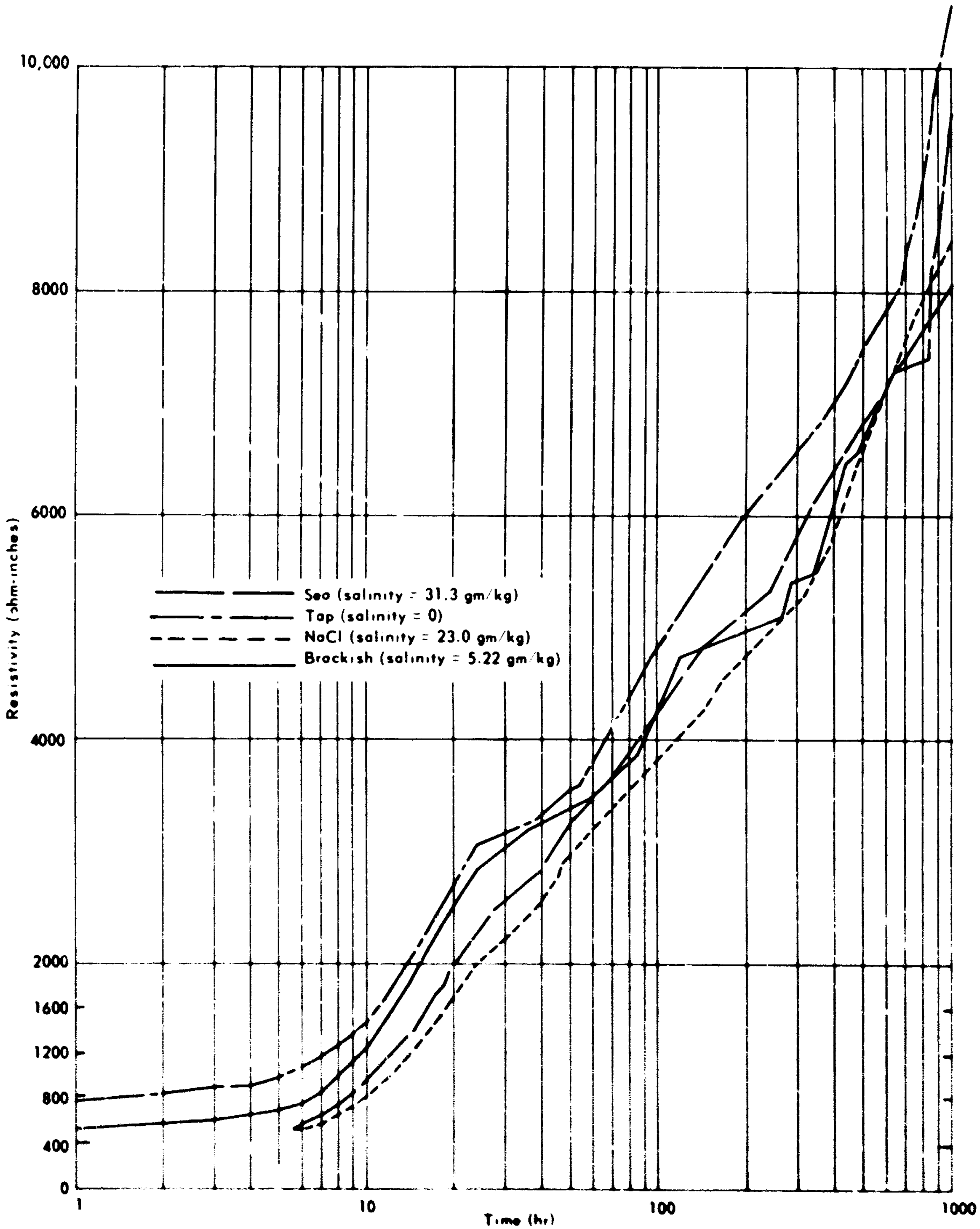

Figure 6. Electrical resistivity versus time for high-strength concrete (W/C = 0.444).

high-strength concrete are slightly lower than those of low-strength concrete up to about 10 hours; but, thereafter, the resistivity values of low-strength concrete are generally below those of high-strength concrete. This shows that the high-strength concrete offers greater resistivity than the low-strength concrete. This holds true for sea water or NaCl water. It appears that strength has little effect on resistivity when the mixing water has zero salinity.

This limited study shows that (1) the electrical resistivity of concrete varies inversely with the salinity of the mixing water, and (2) the electrical resistivity of concrete varies directly with the strength of the concrete when the salinity is something other than zero.

One final observation from Figures 5 and 6 is that the electrical resistivity increases with age of concrete, in a nonlinear nature, when plotted on a semilog graph.

FINDINGS AND CONCLUSIONS

The following findings and conclusions are for the entire investigation.

Water Vapor Transmission

1. An equation of the form WVT = W/At is most suitable to date for the observed phenomenon of this investigation.

2. WVT decreases with increase in age of concrete approaching an asymptotic value.

3. WVT decreases with an increase in strength of concrete.

4. WVT decreases with an increase in maximum aggregate size for aggregate used in this study.

5. WVT decreases with the presence of NaCl (1.5 percent by weight of fresh concrete).

6. WVT appears to decrease with an increase in RH (from 20 to 50 percent at 73.4 F), but the data were inconclusive.

7. WVT is independent of either of the two types of steel contained in the concrete.

8. WVT is independent of the presence of oleic acid.

Compressive Strength

1. The well-established fact that compressive strength is decreased by an increase in W/C ratio was verified.

2. Compressive strength is decreased by the presence of 1.5 percent NaCl in the concrete.

3. Compressive strength is decreased by the presence of 0.25 percent oleic acid in the concrete.

4. Within the scope of this investigation compressive strength appears to be independent of maximum aggregate size used in mix (for 3/8-inch maximum or 3/4-inch maximum aggregate sizes).

5. Compressive strength is affected by a W/C ratio — maximum aggregate size interaction. For example, at W/C = 0.444, the data suggest that compressive strength is decreased by an increase in maximum aggregate size; whereas, at W/C = 0.702, the data suggest that compressive strength is increased by an increase in maximum aggregate size.

Sodium Chloride Whisker Crystals

1. Whiskers grew only on the concrete specimens which contained NaCl.

2. The amounts of whiskers are greater on lower strengths of concrete.

Statistical Design and Analysis

Statistically designed and analyzed quarter- and half-replicate experiments were used successfully to determine WVT rates, thereby reducing the required number of specimens.

Corrosion of Steel Grids

1. Steel corrosion is negligible or nonexistent in concrete which does not contain NaCl.

2. Steel corrodes more readily in low-strength concrete than in high-strength concrete where 1.5 percent NaCl is present.

3. There is no difference in the percent corrosion of the two types of steel investigated.

Electrical Resistivity of Concrete

1. The carbon grid used in this investigation appears to be a satisfactory means of reducing the effect of electrolysis and polarization of the devices for measuring resistivity to a level at which resistivity can be measured more reliably.

2. The resistivity of concrete increases with age of concrete.

3. The resistivity of concrete decreases with an increase in salinity of mixing water.

4. The resistivity of concrete decreases with a decrease in strength of concrete when the salinity is something other than zero.

REFERENCES

1. U. S. Naval Civil Engineering Laboratory. Technical Report R-130, Water Vapor Transmission of Plain Concrete, by D. F. Griffin and R. L. Henry. Port Hueneme, California, 16 May 1961.

2. U. S. Naval Civil Engineering Laboratory. Technical Report R-244, Water Vapor Transmission of Concrete and of Aggregates, by R. L. Henry and G. K. Kurtz. Port Hueneme, California, 30 June 1963.

3. Griffin, D. F., and R. L. Henry. "Integral Sodium Chloride Effect on Strength, Water Vapor Transmission, and Efflorescence of Concrete," American Concrete Institute Proceedings, Vol. 58, No. 6, December 1961, pp 751-772.

4. American Society for Testing Materials, Committee B-1 on Wires for Electrical Conductors, "ASTM standards on metallic electrical conductors." American Society for Testing Materials, Philadelphia, 1952, pp 140-145.

Table I. WVT (Old and New) and Design Variables — Phase I (Reprinted from TR-244)

Batch No.	Cup No. a/	Strength b/	NaCl c/	RH d/	Old WVT e/	Old Conv. WVT f/	New W/t g/	New WVT h/
1L	N572T	L	A	H	—	—	0.162	—
1L	N572M	L	A	H	0.537	0.356	0.181	0.237
1L	N572B	L	A	H	—	—	0.170	—
1LS	N610T	L	P	H	—	—	0.114	—
1LS	N610M	L	P	H	0.298	0.197	0.120	0.167
1LS	N610B	L	P	H	—	—	0.127	—
1M	N671T	M	A	H	—	—	0.102	—
1M	N671M	M	A	H	0.356	0.237	0.125	0.161
1M	N671B	M	A	H	—	—	0.120	—
1MS	N683T	M	P	H	—	—	0.058	—
1MS	N683M	M	P	H	0.190	0.125	0.055	0.076
1MS	N683B	M	P	H	—	—	0.052	—
1H	N734T	H	A	H	—	—	0.051	—
1H	N734M	H	A	H	0.226	0.151	0.071	0.086
1H	N734B	H	A	H	—	—	0.065	—
1HS	N759T	H	P	H	—	—	0.034	—
1HS	N759M	H	P	H	0.121	0.081	—	0.050
1HS	N759B	H	P	H	—	—	0.037	—
1L	N579T	L	A	L	—	—	0.200	—
1L	N579M	L	A	L	0.617	0.401	0.180	0.276
1L	N579B	L	A	L	—	—	0.216	—
1LS	N599T	L	P	L	—	—	0.131	—
1LS	N599M	L	P	L	0.280	0.189	—	0.186
1LS	N599B	L	P	L	—	—	0.137	—
1M	N660T	M	A	L	—	—	0.135	—
1M	N660M	M	A	L	0.362	0.244	0.139	0.193
1M	N660B	M	A	L	—	—	0.143	—
1MS	N700T	M	P	L	—	—	0.063	—
1MS	N700M	M	P	L	0.172	0.115	0.070	0.091
1MS	N700B	M	P	L	—	—	0.054	—
1H	N719T	H	A	L	—	—	0.090	—
1H	N719M	H	A	L	0.259	0.173	0.099	0.139
1H	N719B	H	A	L	—	—	0.1[illegible]	—
1HS	N755T	H	P	L	—	—	0.051	—
1HS	N755M	H	P	L	0.133	0.088	0.053	0.077
1HS	N755B	H	P	L	—	—	0.063	—

a/ T, M, B: Top, middle, or bottom slice from cylinder as-cast.
b/ L, M, H: Low, medium, or high strength; e.g., W/C 0.702, 0.571, and 0.444 respectively.
c/ A, P: Absence or presence of NaCl (1.5 percent by weight of fresh concrete). For the values of W/C shown in Note b, the salt - cement ratios are 0.133, 0.108, and 0.084 respectively.
d/ L, H: 20 percent or 50 percent RH at 73.4 F.
e/ Average WVT from Reference 2 as calculated by Wl/At, inch-grains per square inch per day. For 100-day period (80-180 days age).
f/ Converted to $(W/t)C_A$, grains per square inch per day. For 100-day period.
g/ Slope of graph of weight loss versus time, grams per day. For 480-day period (400-880 days age).
h/ Grains per square inch per day. For 480-day period.

Note: All concrete had aggregate with maximum size of 3/4 inch.

Table II. WVT (Old and New) and Design Variables — Phase II (Reprinted from TR-244)

Batch No.	Cup No. a/	Strength b/	Aggregate c/	NaCl d/	Oleic Acid e/	Original RH f/	Present RH g/	Old WVT h/	Old Conv. WVT i/	New W/t j/	New WVT k/
S-1	N872B	L	S	A	A	L	H	0.714	0.477	0.166	0.231
S-2	P124T	H	L	A	P	L	H	0.292	0.194	0.073	0.101
S-3	N990T	H	S	P	A	H	L	0.274	0.183	0.094	0.131
S-4	P180B	L	L	P	P	H	L	0.329	0.215	0.107	0.149
S-5	P-66B	H	L	P	A	L	H	0.185	0.125	0.043	0.060
S-6	P248B	H	S	A	P	H	L	0.381	0.254	0.134	0.185
S-7	N852T	L	L	A	A	H	L	0.558	0.376	0.231	0.321
S-8	P385T	L	S	P	P	L	H	0.443	0.287	0.147	0.203
S-9	N947T	H	S	A	A	L	H	0.389	0.258	0.088	0.121
S-10	P214B	L	L	A	P	L	H	0.581	0.393	0.180	0.249
S-11	N919B	L	S	P	A	H	L	0.376	0.248	0.150	0.208
S-12	P147T	H	L	P	P	H	L	0.160	0.107	0.057	0.078
S-13	P-38B	H	L	A	A	H	L	0.281	0.186	0.102	0.142
S-14	P296B	H	S	P	P	L	H	0.228	0.150	0.052	0.073
S-15	P-17T	L	L	P	A	L	H	0.408	0.272	0.138	0.191
S-16	P344T	L	S	A	P	H	L	0.817	0.535	0.336	0.467

a/ T, B: Top or bottom slice. See Note a/ of Table I.
b/ L, H: Low or high strength. See Note b/ of Table I.
c/ S, L: Small (3/8-inch) or large (3/4-inch) maximum aggregate size.
d/ A, P: Absence or presence of NaCl. See Note c/ of Table I; for 3/8-inch maximum aggregate size the salt - cement ratios were 0.128 and 0.081 for W/C values of 0.702 and 0.444 respectively.
e/ A. P: Absence or presence of oleic acid.
f/ L, H: 20 percent or 50 percent RH at 73.4 F during 100-day period (80-180 days age).
g/ L, H: 20 percent or 50 percent RH at 73.4 F during 480-day period (400-880 days age). Specimens were moved from one RH to the other at 180 days age.
h/ WVT from Reference 2 as calculated by Wl/At, inch-grains per square inch per day. For 100-day period.
i/ Converted to $(W/t)C_A$, grains per square inch per day.
j/ Slope of graph of weight loss versus time, grams per day. For 480-day period.
k/ Grains per square inch per day. For 480-day period.

Table III. WVT and Design Variables — Phase III
(Reprinted from TR-244)

Batch No.[a]	Cup No.	Kind of Steel [b]	Aggregate [c]	NaCl [d]	Oleic Acid [e]	RH [f]	W/t [g]	WVT [h]
SSL-1	S212	B	S	A	A	L	0.678	0.401
SSL-2	S256	B	S	A	P	H	0.560	0.332
SSL-3	S272	B	S	P	P	L	0.386	0.229
SSL-4	S296	B	S	P	A	H	0.319	0.189
SSL-5	S240	B	L	A	A	H	0.558	0.330
SSL-6	S312	B	L	A	P	L	0.544	0.322
SSL-7	S328	B	L	P	P	H	0.253	0.150
SSL-8	S344	B	L	P	A	L	0.299	0.177
SSL-9	S360	A	S	A	A	H	0.615	0.364
SSL-10	S129	A	S	A	P	L	0.663	0.392
SSL-11	S416	A	S	P	P	H	0.326	0.193
SSL-12	S376	A	S	P	A	L	0.383	0.227
SSL-13	S148	A	L	A	A	L	0.551	0.326
SSL-14	S164	A	L	A	P	H	0.512	0.303
SSL-15	S180	A	L	P	P	L	0.282	0.167
SSL-16	S196	A	L	P	A	H	0.206	0.122
SSM-1	T774	B	S	A	A	L	0.590	0.350
SSM-2	T290	B	S	A	P	H	0.487	0.288
SSM-3	T306	B	S	P	P	L	0.207	0.123
SSM-4	T322	B	S	P	A	H	0.172	0.102
SSM-5	T362	B	L	A	A	H	0.318	0.188
SSM-6	T411	B	L	A	P	L	[illegible]47	0.265
SSM-7	T427	B	L	P	P	H	0.200	0.118
SSM-8	T443	B	L	P	A	L	0.135	0.080
SSM-9	T564	A	S	A	A	H	0.438	0.259
SSM-10	T614	A	S	A	P	L	0.570	0.337
SSM-11	T630	A	S	P	P	H	0.209	0.124
SSM-12	T663	A	S	P	A	L	0.317	0.188
SSM-13	T679	A	L	A	A	L	0.395	0.234
SSM-14	T743	A	L	A	P	H	0.305	0.181
SSM-15	T795	A	L	P	P	L	0.166	0.098
SSM-16	T847	A	L	P	A	H	0.113	0.067
SSH-1	T941	B	S	A	A	L	0.352	0.208
SSH-2	T993	B	S	A	P	H	0.274	0.162
SSH-3	U34	B	S	P	P	L	0.126	0.075
SSH-4	U86	B	S	P	A	H	0.101	0.060
SSH-5	U176	B	L	A	A	H	0.226	0.134
SSH-6	U142	B	L	A	P	L	0.285	0.169
SSH-7	U182	B	L	P	P	H	0.082	0.049
SSH-8	U198	B	L	P	A	L	0.110	0.065
SSH-9	U214	A	S	A	A	H	0.283	0.168
SSH-10	U230	A	S	A	P	L	0.345	0.204
SSH-11	U246	A	S	P	P	H	0.106	0.063
SSH-12	U262	A	S	P	A	L	0.129	0.076
SSH-13	U290	A	L	A	A	L	0.273	0.162
SSH-14	U234	A	L	A	P	H	0.203	0.120
SSH-15	U340	A	L	P	P	L	0.118	0.070
SSH-16	U356	A	L	P	A	H	0.076	0.045

a/ SSL, SSM, SSH: Low, medium, or high strength; SS = statistical study. (W/C = 0.702, 0.571, 0.444 respectively)

b/ A, B: No. 5 deformed bar grid or 1/4-inch high-strength prestressing wire grid.

c/ S, L: Small (3/8-inch) or large (3/4-inch) maximum aggregate size.

d/ A, P: Absence or presence of NaCl (1.5 percent by weight of fresh concrete).

e/ A, P: Absence or presence of oleic acid (0.25 percent by weight of cement).

f/ L, H: 20 percent or 50 percent RH at 73.4 F.

g/ Slope of the graph of weight loss versus time, grams per day.

h/ WVT = $(W/t)C_A$ (for 6-inch-dia. disk, C_A = 0.592), grains per square inch per day. For a 300-day period [illegible]

Table IV. WVT of San Gabriel
(Reprinted from TR-244)

Group Symbol	Cup No.	l a/	Inclination of Fabric Plane b/	W/t c/	WVT d/	Average WVT e/
A	U737	3.04	5	0.0738	0.102	–
A	U738	1.55	72	0.0402	0.056	–
A	U739	3.03	65	0.0517	0.072	0.077
B	U602	3.03	40	0.0716	0.099	–
B	U603	1.54	40	0.0708	0.098	–
B	U604	1.43	87	0.0633	0.087	0.095
C	U857	3.02	–	0.0195	0.027	–
C	U858	1.52	–	0.0258	0.036	0.032
D	U859	3.08	85	0.0375	0.052	–
D	U860	1.52	85	0.0487	0.068	0.060
E	U861	3.05	40	0.0972	0.135	–
E	U862	1.54	40	0.0831	0.115	0.125
F	U863	1.60	10	0.0490	0.068	–
F	U864	3.04	5	0.0582	0.081	0.075
G	U865	1.52	10	0.0574	0.080	–
G	U866	2.99	10	0.0390	0.054	–
G	U867	1.53	80	0.0465	0.065	–
G	U868	3.00	75	0.0444	0.062	0.065
H	U869	1.52	45	0.127	0.176	–
H	U870	2.98	45	0.131	0.181	0.179

a/ Length of flow path (thickness of disk), inches.

b/ Angle of inclination of fabric, measured from vertical (axis of disk), degrees.

c/ Slope of graph of weight loss versus time, grams per day.

d/ WVT = $(W/t)C_A$ (for 4-inch-dia. disk, C_A = 1.388), grains per square inch per day. For a 400-day period (100-500 days age).

e/ Average for each group.

Note: 20 percent RH at 73.4 F.

Table V. Phase III V

Cup No.	Batch No. a/	Kind of Steel b/	Agg. Size c/	NaCl d/	RH e/	Grid Wt When Cast (gm)	Grid Wt After Cleaning (gm) f/	Corrosion (%)	Water Discolo
S212	SSL-1	B	S	A	20	235.0	n	0	
S256	SSL-2	B	S	A	50	233.5	232.0	0.64 g/	
S272	SSL-3	B	S	P	20	231.0	227.5	1.52	
S296	SSL-4	B	S	P	50	228.0	220.0	3.51	very slight
S240	SSL-5	B	L	A	50	240.0	n	0	
S312	SSL-6	B	L	A	20	233.5	n	0	
S328	SSL-7	B	L	P	50	224.0	–	–	very slight
S344	SSL-8	B	L	P	20	226.0	218.5	3.32	
S360	SSL-9	A	S	A	50	431.0	n	0	
S129	SSL-10	A	S	A	20	405.0	n	0	
S416	SSL-11	A	S	P	50	418.5	413.0	2.43	very rusty reddish
S376	SSL-12	A	S	P	20	398.0	393.0	1.26	
S148	SSL-13	A	L	A	20	393.0	n	0	
S164	SSL-14	A	L	A	50	417.5	n	0	
S180	SSL-15	A	L	P	20	419.5	414.0	1.31	slight, one rust dro on under surface
S196	SSL-16	A	L	P	50	409.0	401.0	1.96	dark brownish rust sediment
T274	SSM-1	B	S	A	20	224.5	n	0	
T290	SSM-2	B	S	A	50	224.5	n	0	
T306	SSM-3	B	S	P	20	232.0	229.0	1.29	slight
T322	SSM-4	B	S	P	50	236.0	234.5	0.64	very slight

Table V. Phase III Variables and Observations

Grid Wt When Cast (gm)	Grid Wt After Cleaning (gm)[f]	Corrosion (%)	Water Discoloration	Whisker Growth	pH
235.0	n	0			
233.5	232.0	0.64[g]			
231.0	227.5	1.52		thick, white; long single curls; matty	10.8
228.0	220.0	3.51	very slight	white, heavy, short, fuzzy	
240.0	n	0			
233.5	n	0			
224.0	—	—	very slight	white, short and fuzzy	11.8
226.0	218.5	3.32		white, stubby, topped with fuzz	
431.0	n	0			
405.0	n	0			8.8
418.5	413.0	2.43	very rusty reddish	grey, very short and fuzzy	
398.0	393.0	1.26			
393.0	n	0			
417.5	n	0			
419.5	414.0	1.31	slight, one rust droplet formed on under surface	grey, hard and stubby	
409.0	401.0	1.96	dark brownish rust color with sediment	grey, very short, hard fuzzy	9.3
224.5	n	0			8.6
224.5	n	0			
232.0	229.0	1.29	slight	hard and short; mostly around perimeter	
236.0	234.5	0.64	very slight	white, fuzzy in spots; color of concrete between rocks darkened	

l Variables and Observations

loration	Whisker Growth	pH	Total Dissolved Solids (ppm)	Chloride (ppm)	Remarks
	thick, white; long single curls; matty	10.8	5,650	2,910	
	white, heavy, short, fuzzy				two rust spots size of 25-cent piece on top surface of disk
	white, short and fuzzy	11.8	15,890	6,220	
	white, stubby, topped with fuzz				
		8.8	110	0	
h	grey, very short and fuzzy				
lroplet formed	grey, hard and stubby				rust colored deposit on top of disk, above droplet
st color with	grey, very short, hard fuzzy	9.3	11,750	6.600	two rust spots on top, one rust droplet
		8.6	113	0	
	hard and short; mostly around perimeter				rust deposit on top of disk
	white, fuzzy in spots; color of concrete between rocks darkened				

Table V. Phase III Variables

Cup No.	Batch No. a/	Kind of Steel b/	Agg. Size c/	NaCl d/	RH e/	Grid Wt When Cast (gm)	Grid Wt After Cleaning (gm) f/	Corrosion (%)	Water Discol
T36?	SSM-5	B	L	A	50	237.0	n	0	
T411	SSM-6	B	L	A	20	225.5	n	0	
T427	SSM-7	B	L	P	50	224.0	222.5	0.67	very slight
T443	SSM-8	B	L	P	20	231.5	n	0	
T564	SSM-9	A	S	A	50	421.0	n	0	
T614	SSM-10	A	S	A	20	401.0	n	0	
T630	SSM-11	A	S	P	50	402.0	395.5	1.62	very rusty - dark b sediment
T663	SSM-12	A	S	P	20	396.5	392.0	1.13	slight, heavy rust- sediment
T679	SSM-13	A	L	A	20	420.0	n	0	
T743	SSM-14	A	L	A	50	394.0	n	0	
T795	SSM-15	A	L	P	20	392.5	390.5	0.51	slight
T847	SSM-16	A	L	P	50	395.0	n	0	very slight
T941	SSH-1	B	S	A	20	225.5	n	0	
T993	SSH-2	B	S	A	50	222.0	n	0	
U34	SSH-3	B	S	P	20	219.0	n	0	
U86	SSH-4	B	S	P	50	225.5	223.5	0.89	light amber
U126	SSH-5	B	L	A	50	223.5	n	0	
U142	SSH-6	B	L	A	20	225.0	n	0	

Table V. Phase III Variables and Observations (Cont'd)

Grid Wt When Cast (gm)	Grid Wt After Cleaning (gm)[f]	Corrosion (%)	Water Discoloration	Whisker Growth	pH
237.0	n	0			
225.5	n	0			
224.0	222.5	0.67	very slight	fuzzy over surface; color of concrete between rocks darkened	
231.5	n	0			
421.0	n	0			
401.0	n	0			
402.0	395.5	1.62	very rusty - dark brown, with sediment	slightly stubby growth; color of concrete between rocks darkened	11.2
396.5	392.0	1.13	slight, heavy rust-colored sediment	rough surface; smoother in center; crystal outgrowth at one spot	10.5
420.0	n	0			8.6
394.0	n	0			
392.5	390.5	0.51	slight	rough surface; smoother in center	
395.0	n	0	very slight	slightly stubby with single whiskers; color of concrete between rocks darkened	
225.5	n	0			7.4
222.0	n	0			
219.0	n	0		slight roughness except in center	
225.5	223.5	0.89	light amber	no whiskers, slight roughness; concrete between rocks darkened considerably	
223.5	n	0			
225.0	n	0			

—

ɪs and Observations (Cont'd)

ɔloration	Whisker Growth	pH	Total Dissolved Solids (ppm)	Chloride (ppm)	Remarks
	fuzzy over surface; color of concrete between rocks darkened				
: brown, with	slightly stubby growth; color of concrete between rocks darkened	11.2	13,740	4,290	two good size rust droplets and spots on bottom of disk
t-colored	rough surface; smoother in center; crystal outgrowth at one spot	10.5	9,460	4,400	five rust droplets, dark blue-green spots below droplets, in sediment
		8.6	310	0	
	rough surface; smoother in center				
	slightly stubby with single whiskers; color of concrete between rocks darkened				
		7.4	280	0	
	slight roughness except in center				
	no whiskers, slight roughness; concrete between rocks darkened considerably				

Table V. Phase III Variables and Ob

Cup No.	Batch No. a/	Kind of Steel b/	Agg. Size c/	NaCl d/	RH e/	Grid Wt When Cast (gm)	Grid Wt After Cleaning (gm) f/	Corrosion (%)	Water Discolora
U182	SSH-7	B	L	P	50	226.0	225.0	0.44	amber
U198	SSH-8	B	L	P	20	226.5	n	0	amber, slight sedime
U214	SSH-9	A	S	A	50	394.5	391.5	0.76	
U230	SSH-10	A	S	A	20	408.5	n	0	
U246	SSH-11	A	S	P	50	422.5	n	0	reddish rust color, w sediment
U262	SSH-12	A	S	P	20	416.5	n	0	slight
U290	SSH-13	A	L	A	20	427.5	n	0	
U234	SSH-14	A	L	A	50	424.5	n	0	
U340	SSH-15	[illegible]	L	P	20	388.0	n	0	amber
U356	SSH-16	A	L	P	50	398.5	n	0	amber

a/ SSL, SSM, SSH: Low, medium, or high strength; e.g., W/C = 0.702, 0.571, and 0.444, respectively.
b/ A, B: No. 5 deformed bar grid or 1/4-inch high-strength prestressing wire grid.
c/ S, L: Small (3/8-inch) or large (3/4-inch) maximum aggregate size.
d A, P: Absence or presence of NaCl (1.5 percent by weight of fresh concrete).
e/ L, H: 20 percent or 50 percent RH at 73.4 F.
f/ n = negligible weight change, less than 1 gram.
g/ Unexplainable.

Table V. Phase III Variables and Observations (Cont'd)

:H e/	Grid Wt When Cast (gm)	Grid Wt After Cleaning (gm)f/	Corrosion (%)	Water Discoloration	Whisker Growth
50	226.0	225.0	0.44	amber	no whiskers, slight roughness; concrete between rocks darkened considerably
20	226.5	n	0	amber, slight sediment	very slight roughness; smooth in center
50	394.5	391.5	0.76		
20	408.5	n	0		
50	422.5	n	0	reddish rust color, with sediment	no whiskers, slight roughness; concrete between rocks darkened considerably
20	416.5	n	0	slight	very slight roughness; smooth in center
20	427.5	n	0		
50	424.5	n	0		
20	388.0	n	0	amber	very slight roughness; smooth in center; one small outcrop crack
50	398.5	n	0	amber	no whiskers, slight roughness; concrete between rocks darkened considerably

; e.g., W/C - 0.702, 0.571, and 0.444, respectively.
h-strength prestressing wire grid.
kimum aggregate size.
nt by weight of fresh concrete).

n.

Observations (Cont'd)

oration	Whisker Growth	pH	Total Dissolved Solids (ppm)	Chloride (ppm)	Remarks
	no whiskers, slight roughness; concrete between rocks darkened considerably				
ment	very slight roughness; smooth in center	12.0	15,330	4,940	
with	no whiskers, slight roughness; concrete between rocks darkened considerably				two rust droplets; steel grid sawed and exposed in bottom of disk
	very slight roughness; smooth in center				
	very slight roughness; smooth in center; one small outcrop crack	12.1	13,260	5,000	
	no whiskers, slight roughness; concrete between rocks darkened considerably				

Appendix A

SUMMARY OF CONCRETE MIX DESIGN DATA
(Reprinted from TR-244)

A. Characteristics of Materials

Cement: Victor, Type III
Aggregate: San Gabriel rock (SG)

Coarse: sp gr = 2.66; 24-hr abs = 1.6 percent
Fine: sp gr = 2.63; 24-hr abs = 1.8 percent
Grading:

Pounds Retained on Each Sieve for 2.25-Cu-Ft Batch

Sieve	3/4-Inch Max.			3/8-Inch Max.		
	H	M	L	H	M	L
3/4	7.[illegible]	7.8	6.2	0	0	0
3/8	74.[illegible]	75.5	73.7	0	0	0
No. 4	46.9	44.2	45.4	103.9	106.0	106.2
No. 8	27.2	28.6	32.2	38.3	39.4	39.8
No. 16	24.[illegible]	31.2	31.1	27.0	29.4	31.8
No. 30	7.2	28.6	31.3	23.6	24.1	23.7
No. 50	[illegible]2.2	23.4	28.6	18.7	20.9	24.0
No. 100	12.4	13.0	14.6	18.4	19.8	21.0
Pan	5.0	7.8	7.0	17.2	18.4	19.2
Total	247.1	260.1	270.1	247.1	258.0	265.7

Note: H, M, L = high, medium, and low relative strengths.

Water: Port Hueneme tap water at 73.4 F

Chemical analysis (ppm): hydroxide (0.0); carbonate (0.0); bicarbonate (137.0); chlorides (62.0); calcium (38.0); magnesium (14.6); sulphate (465.0); sodium and potassium (219.0)

Slump: 3 inches (without additives)
Additives: Sodium chloride, U.S.P. granular; F.W. = 58.45 (1.5 percent by weight of plastic concrete unless otherwise noted); oleic acid, U.S.P. (0.25 percent by weight of cement)

B. Mix Designs (each batch 2.25 cu ft)

Aggregate: 3/4-inch maximum particle size
Sand: FM = 3.16

Mix	Cement (lb)	Water [a] (lb)	Cement Factor (sacks per cu yd)	W/C
H	59.50	26.4	7.62	0.444
M	46.25	26.4	5.92	0.571
L	37.60	26.4	4.81	0.702

Aggregate: 3/8-inch maximum particle size
Sand: FM = 2.95

Mix	Cement (lb)	Water [a] (lb)	Cement Factor (sacks per cu yd)	W/C
H	61.9	27.5	7.92	0.444
M	48.1	27.5	6.16	0.571
L	39.2	27.5	5.02	0.702

a/ The quantity of water added at the mixer was corrected for moisture present in the aggregate and moisture required for absorption.

Appendix B

PLASTIC WET CUP DESCRIPTION

(Reprinted from TR-130)

The following is a detailed description of the plastic wet cup and component parts.

The main body of the cup, which is cut from Cadco polished colorless and transparent cast-acrylic-resin tubing, is 5-1/2 inches long, with a 5-inch outside diameter and a 4-1/2-inch inside diameter. The tubing is machined smooth on both ends, cut with three circumferential gaging grooves on the inside near the top within the dimension of the thickness of the specimen, and drilled for the access tubes. The purpose of the grooves is to offer the maximum seal with the epoxy.

The top ring is cut and machined to size from 1/4-inch Plexiglas "G" sheets. The outside diameter is 5 inches and the inside diameter is 3-3/4 inches ± 1/64 inch.

The annular ring with the counterbore is cut and machined from 3/8-inch Plexiglas to fit tightly inside the main tubing body. The outside diameter is approximately 4-1/2 inches and the inside diameter is 3-3/4 inches ± 1/64 inch; the counterbore is 4 inches + 1/16 inch in diameter and 3/16 inch deep. It is important that this ring fits tightly in order to have a perfect seal.

The bottom plate is cut and machined to size from 3/8-inch Plexiglas, with a diameter of 5 inches ± 1/32 inch. A shoulder 1/8 inch deep and approximately 1/4 inch wide is machined to fit the bottom of each section of the main tubing.

The access tubes are cut 1-1/2 inches long from extruded acrylic tubing with a 3/8-inch outer diameter and a 1/4-inch inner diameter. The tubes and holes in the main body are tapered slightly to provide a tight fit.

Appendix C

WET CUP ASSEMBLY

(Reprinted from TR-130)

The following is a detailed description of the step-by-step procedure for assembling the wet cup.

1. Measure the thickness of the concrete disk in four different places with a micrometer and record the average thickness.

2. Clean all plastic parts of cup with ethyl alcohol and allow to dry.

3. Fit counterbore of annular ring onto bottom of concrete disk.

4. Mix the desired quantity of epoxy in the proportion of four parts Shell Epon Resin 815 with one part Shell Curing Agent T-1 by weight and thicken to consistency of paste with a thickening agent, "Cab-O-Sil," and seal the ring to the disk by constructing a fillet of paste on the top surface of the ring adjacent to the concrete.

5. Place the main body of the cup (4-1/2-inch-ID tubing) over the inverted disk-ring component and press it down so that the concrete disk is flush with the top of the plastic main body in the inverted position.

6. Seal the disk-ring component in the main body with Cadco-94 General Purpose Acrylic Cement (consistency of water). At the same time, seal the access tubes in place. Allow to dry 15 minutes.

7. Mix the desired quantity of epoxy in the same proportions as in step 4 without thickener. Set the cup upright on a level surface and fill the annular space.

8. Allow the epoxy to set until hardened. This may take as much as 5 hours.

9. Seal the top ring onto the cup with a thin layer of epoxy. Place a pressure plate and weight (12-15 pounds) on top of the ring to hold it in position. Allow to set.

10. Seal the bottom plate to the cup with a thick acrylic cement. Place a pressure plate and weight (12-15 pounds) on top of the cup to hold it in place. Allow 30 to 45 minutes to set.

11. Attach a 2-inch length of Tygon flexible plastic tubing (Formulation R-3603; 3/8-inch ID, 1/2-inch OD) securely to the bottom access tube.

The cup assembly is now completed and the cup is ready to be filled with water, washed with gas, and to have the manometer attached to the upper access tube, if one is desired. If a manometer is not required the upper access tube is not needed.

Appendix D

ANALYSIS AND CLASSIFICATION — SAN GABRIEL ROCK
(Reprinted from TR-244)

A. MEGASCOPIC EXAMINATION OF SG (WVT SPECIMENS)

Group Symbol	Cup No.	Inclination (degrees) of Fabric Plane from Vertical Axis of Cylinder*	Remarks
A	U737	5	Fractured
A	U738	72	Weakly banded
A	U739	65	Weakly banded and fractured
B	U602	40	—
B	U603	40	—
B	U604	87	—
C	U857	—	Fabric not sufficiently
C	U858	—	developed to measure
D	U859	85	Fabric weakly developed
D	U860	85	Healed fracture
E	U861	40	—
E	U862	40	Fractured
F	U863	10	—
F	U864	5	—
G	U865	10	Banded gneiss
G	U866	10	Banded gneiss
G	U867	80	Healed fracture
G	U868	75	Banded gneiss
H	U869	45	Fabric weakly developed
H	U870	45	—

*Fabric is the orientation in space of the crystals of which a rock is composed.

B. PETROGRAPHIC DESCRIPTION AND CLASSIFICATION OF SG (WVT SPECIMENS)

1. Leucocratic Quartzo-Feldspathic Cataclastic Gneiss

Group A shows considerable granulation with abundant large relic grains of feldspar and quartz (up to 1 cm). Cataclastic textures have been partly obliterated by recrystallization of groundmass quartz and alkali feldspar. Feldspars and quartz exhibit pronounced undulatory extinction and sutured grain contacts. Plagioclase is badly saussuritized. Fine-grained quartz and muscovite are oriented along shear planes which give the rock a distinct foliation.

This material is moderately fresh and due to the paucity of mafic minerals it should be relatively resistant to both chemical and mechanical attack.

Mode	Percent
alkali feldspar (including microcline)	40
plagioclase (oligoclase)	15
quartz	30
muscovite	10
garnet	Tr*
clinopyroxene	3
green biotite	2
hematite	Tr

*Trace (less than 1 percent)

2. Hornblende-Clinopyroxene Quartzo-Feldspathic Gneiss

Group B is a coarse-grained (2-4 mm) equigranular rock with granoblastic texture and sutured grain boundaries. Lineation results from preferred orientation of hornblende; weak foliation is due to compositional banding (quartz + feldspar layers alternate with quartz + feldspar + mafic mineral bands). Quartz and feldspars show strain shadows and some myrmekitic intergrowths, but all phases are fresh.

The abundant mafic clots of hornblende + clinopyroxene indicate that, although the rock is as yet unaltered, it is susceptible to chemical attack.

Mode	Percent
alkali feldspar (including microcline)	25
plagioclase (andesine-oligoclase)	30
quartz	25
green-brown hornblende	12
clinopyroxene	4
apatite	Tr
magnetite	2
biotite	2

3. Monzonite Porphyry

Group C is a hiatal porphyry. Large (3 mm) euthedra of strongly zoned (oscillatory) plagioclase are set in a fine-grained, intensely altered mesostasis of alkali feldspar + quartz + mafic minerals. Weak (magmatic) flow banding results from orientation of plagioclase tablets and chlorite + biotite flakes. Primary clinopyroxene has been almost completely eliminated by alteration processes which have sericitized much of the groundmass feldspar. The phenocrysts of intermediate plagioclase are relatively fresh but are susceptible to chemical attack.

Mode	Percent
phenocrysts	
oligoclase-andesine (strongly zoned, fragmented)	25
saussuritized plagioclase (sericite + epidote + calcite)	2
groundmass	
quartz	10
alkali feldspar (including plagioclase)	40
biotite	6
chlorite	14

Continued

Mode	Percent
carbonate	2
clinopyroxene	Tr
magnetite	1
hematite	Tr
sphene	Tr

4. Hornblende Quartz Plagioclase Schist

Group D has a medium-grained (2 mm) granular texture with foliation produced by planar orientation of chlorite + biotite and by lineation of hornblende. Long axes of plagioclase + quartz grains are also aligned with this lineation. There are spotty patches of intensely sericitized plagioclase.

Equigranularity of this rock tends to increase its mechanical strength, but chemical weathering of the abundant mafic minerals would decrease its stability.

Mode	Percent
plagioclase (andesine), including saussuritized plagioclase	50
quartz	20
hornblende	13
biotite	4
chlorite	7
clinopyroxene	5
magnetite	1
zoisite	Tr
apatite	Tr
carbonate (calcite)	Tr

5. Coarsely Porphyroblastic Hornblende Quartzo-Feldspathic Gneiss

Group E contains about 20 percent very large (up to 3 x 2 cm) porphyroblasts of microcline set in a medium-grained (2-3 mm) groundmass. Some quartz is slightly strained and shows sutured grain boundaries. The plagioclase, alkali feldspar, and quartz are intergrown in a typical granular (granoblastic) texture; rare quartz-alkali feldspar myrmekite is also evident. The original mafic mineral was probably clinopyroxene but has been largely converted to hornblende, biotite, chlorite, sphene, and magnetite through hydration, oxidation, and recrystallization.

Partial decomposition of mafics and the coarsely porphyroblastic texture probably mean this rock is relatively vulnerable to mechanical and chemical breakdown.

Mode	Percent
alkali feldspar (microcline)	
porphyroblasts	20
groundmass	15
plagioclase (calcic oligoclase)	30
quartz	15
chlorite	3
biotite	7
clinopyroxene	2
magnetite	3
sphene	2
blue-green hornblende	3

6. Fine-Grained Porphyroblastic Biotite Gneiss

Group F is a medium-grained (2-3 mm) granoblastic gneiss with minor porphyroblasts (5-8 mm) of perthitic alkali feldspar and plagioclase. The porphyroblasts have been somewhat milled and give the appearance of small augen in hand specimen. Quartz exhibits strain shadows. Foliation is due to preferred orientation of biotite flakes. Minor myrmekitic intergrowths of quartz and alkali feldspar are present.

This rock in general and the feldspars in particular look very fresh.

Mode	Percent
plagioclase (oligoclase)	20
alakali feldspar (microcline)	30
quartz	35
biotite	13
chlorite	Tr
magnetite	1
hematite	Tr
tourmaline	Tr
apatite	Tr
sphene	1

7. Hornblende-Quartzo-Feldspathic Gneiss

Group G is a foliated granoblastic equigranular gneiss. Quartz shows undulatory extinction and is more or less restricted to specific laminae. Hornblende is sub-oriented in the plane of foliation; mafics in general are "strung out" in this plane. Felsic and mafic minerals are all very fresh.

Abundant hornblende clots probably will cause this rock to alter along shear planes during oxidation.

Mode	Percent
alkali feldspar (microcline)	Tr
quartz	25
plagioclase (calcic oligoclase)	50
blue-green hornblende	20
magnetite	1
sphene	2
clinopyroxene	1
chlorite	1
apatite	Tr

8. Equigranular Biotite Granite Gneiss

Group H is a medium-grained (approximately 3 mm) equigranular gneiss with granoblastic texture. Sutured contacts are common, quartz shows strongly undulatory extinction, and feldspars exhibit weak twinning. Plagioclase is faintly zoned. Rare wormy intergrowths between quartz and microcline were observed. Feldspars are moderately sericitized and biotite is partly replaced by chlorite.

Mode	Percent
alkali feldspar (microcline)	35
quartz	20
plagioclase (albite-oligoclase)	30
brown biotite	12
muscovite	1
chlorite	1
magnetite	1

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