NJDOT Report No. 79-007-7732
FINAL REPORT

EVALUATION OF ANTI-SCALING AGENTS FOR CONCRETE

by

Richard M. Weed

Bureau of Structures, Materials, and Applied Mechanics Research
Division of Research and Development
New Jersey Department of Transportation

HPR Study Number 7732

Prepared in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

March 1979

NOTICE

Disclaimer Statement

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
79-007-7732		

4. Title and Subtitle	5. Report Date
Evaluation of Anti-Scaling Agents for Concrete	March 1979
	6. Performing Organization Code
7. Author(s)	8. Performing Organization Report No.
Richard M. Weed	79-007-7732
9. Performing Organization Name and Address New Jersey Department of Transportation Division of Research and Development 1035 Parkway Avenue Trenton, New Jersey 08625	10. Work Unit No. 11. Contract or Grant No. N.J. HPR Study 7732
12. Sponsoring Agency Name and Address Same as 9.	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

This study was designed to (1) screen a large number of candidate anti-scaling agents, (2) field test those found most promising, and (3) investigate the scaling mechanism by means of laboratory freeze-thaw testing.

Accelerated outdoor exposure tests of a total of 41 treatments isolated four which were judged to be significantly beneficial on air-entrained concrete. Three of these were either difficult to apply or presented other problems which negated their usefulness. The fourth product, a water-reducing admixture, had no known drawbacks and was selected for further field testing on actual bridge decks.

Two products, a linseed oil formulation and a chlorinated rubber epoxy, were selected for field testing at the start of this project based on favorable reports by other researchers. Although the subsequent screening tests indicated beneficial tendencies, neither product performed well enough to be judged significantly beneficial. In the field tests, the chlorinated rubber epoxy material did somewhat better and, because of this, was used on additional test bridges. Tests of the top-rated material, the water-reducing admixture, are now in progress. All field tests will continue to be monitored for several years as part of another study.

(Continued)

17. Key Words	18. Distribution Statement
Concrete, Scaling, Air Entrainment, Admixture, Curing Compound, Penetrating Agent, Sealer	No Restrictions

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	70	

Form DOT F 1700.7 (8-69)

Abstract (Continued)

Although many laboratory freeze-thaw tests were performed, no significant results were obtained. After approximately one year, these tests were discontinued.

From the outdoor exposure tests, it was observed that adequate air entrainment appeared to be more beneficial than any of the treatments which were tested. As a result, an experiment was run to determine how much the specified air level could be increased without risking too great a loss of strength. This led to the recommendation that New Jersey's air-entrainment specification be increased from 4.5% to 6.0%. This was adopted in 1972.

Appendices are included which contain the concrete batch data, descriptions of the products tested, yearly durability ratings for individual products, air-entrainment vs. strength test data, data on Chace air meter tests, and the development of the statistical criteria for judging product effectiveness.

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EVALUATION OF ANTI-SCALING AGENTS FOR CONCRETE

1.0 SUMMARY AND CONCLUSIONS

Phase I, the outdoor exposure testing of a large number of anti-scaling agents, has isolated four apparently beneficial treatments. Since three of these were judged to present potential problems (difficult to apply and/or slippery when applied), they were not considered for further testing under Phase II (field testing). The remaining beneficial treatment, a water-reducing admixture (Treatment A-5), has no known drawbacks and has been scheduled for further field testing.

Phase II, field testing on actual bridges, was begun with the testing of a linseed oil product (C-1) and a chlorinated rubber epoxy material (C-2). Although these products fell short of being judged significantly beneficial in the outdoor exposure tests, the chlorinated rubber epoxy does appear to have performed well after seven years of exposure on the test bridges. Additional test bridges were installed using this material in 1974. All of these test decks will continue to be monitored for several years under another study.

The Phase I study demonstrated such a significant benefit of entrained air that a satellite study was conducted which led to the recommendation that New Jersey's air-entrainment specification be increased from 4.5 ± 1.5 percent to 6.0 ± 1.5 percent. This was implemented in 1972.

Phase III, laboratory freeze-thaw testing, was unproductive and was discontinued when it became apparent that it was not yielding meaningful results.

2.0 RECOMMENDATIONS

Test product C-2, the chlorinated rubber epoxy curing compound, just missed being judged significantly beneficial in the outdoor exposure tests and did appear to provide some scaling resistance on the field test bridges. Since this material drys quickly to provide a rain-resistant protective film, the contractor who applied this material later expressed a preference for it over the standard white-pigmented curing compound. Consequently, it is recommended as an alternative curing compound. Its trade name is Tri-Kote 26(g) by T-K Products, Inc. The material has the same appearance (white) and is sprayed on in the same manner as the standard curing compound.

Test product A-5, the water-reducing admixture, performed extremely well in the outdoor exposure tests but has not yet been tested in the field. The field testing of this product will be included in a future study. In the meantime, this product is given a tentative recommendation provided that the manufacturer's advice is solicited and followed. The product's trade name is Pozzolith 200-N, manufactured by Master Builders.

The Chace air meter is recommended as an auxilliary test device to determine the air-entrainment level in the surface mortar of fresh concrete. The speed and convenience of this method makes it possible to perform a more complete sampling of a concrete construction project. In particular, this device permits a determination of the percent air in the as-constructed (finished) concrete, providing a valuable complement to the as-delivered properties.

3.0 BACKGROUND

At the inception of this research, a study of New Jersey bridges[1] revealed that approximately one-third of the decks were experiencing some degree of scaling distress. This project was undertaken to explore various possible remedies. The work was divided into the following three phases:

Phase I

Test a relatively large number of anti-scaling agents by means of accelerated outdoor exposure tests in order to isolate those that hold promise for significantly increasing the scaling resistance of concrete.

Phase II

Field test on actual bridges the best performing materials found during Phase I. (Two additional products indicated to be effective by other researchers were also included.)

Phase III

Continue testing with the aid of a laboratory freeze-thaw chamber to attempt to develop a rapid test which can be used to quickly evaluate new products in the future.

4.0 ACCELERATED OUTDOOR EXPOSURE TESTING

This phase was begun in the summer of 1970 with the casting of over 200 test slabs and the application of 41 treatments of various types. The actual testing -- consisting of de-icer applications timed to take advantage of the natural freeze-thaw cycles -- took place during the next three winters.

4.1 TEST PROCEDURE

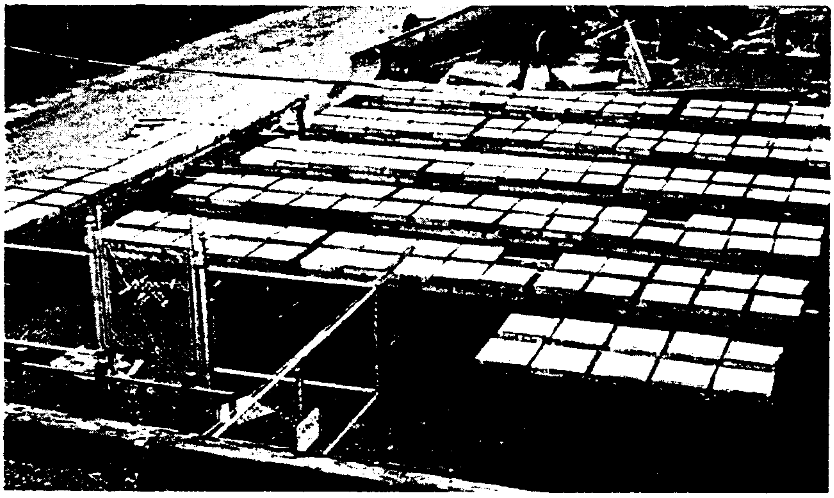
The test slabs were cast using carefully controlled mixes of New Jersey structural grade concrete. Approximately half of the slabs had the normal amount of entrained air (then 4.5 $\pm$ 1.5%) and half had no entrained air. Because of their recognized low freeze-thaw durability, the non-air-entrained slabs were included to ensure that there would be some noticeable deterioration by the end of the first winter.

A total of 188 slabs were placed on elevated stands to simulate bridge deck exposure conditions. Small dikes were constructed around the perimeters of the slabs so that water could be puddled on their surfaces. The weathering process was accelerated by applying water and deicing chemicals whenever the temperature fell below the freezing point. Figure I shows photographs taken at the test site.

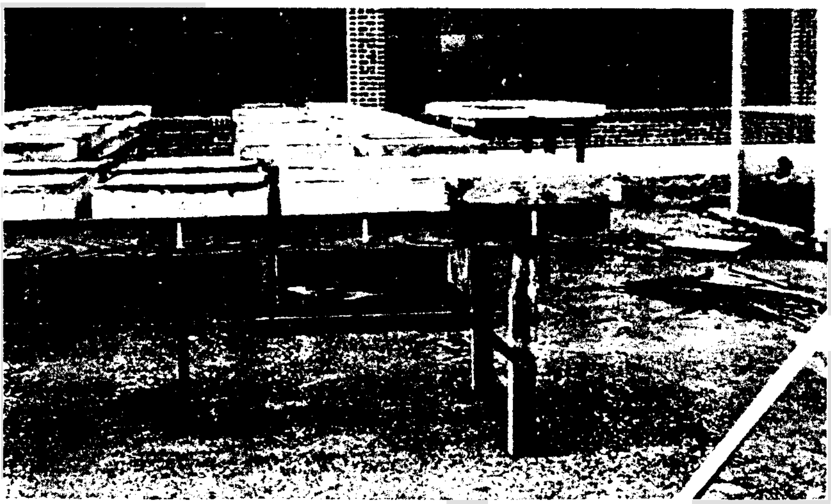
4.2 CONSTRUCTION OF TEST SLABS

The mix design for a typical New Jersey structural concrete was used except that some batches contained experimental admixtures and some were purposely non-air-entrained. The design characteristics were as follows:

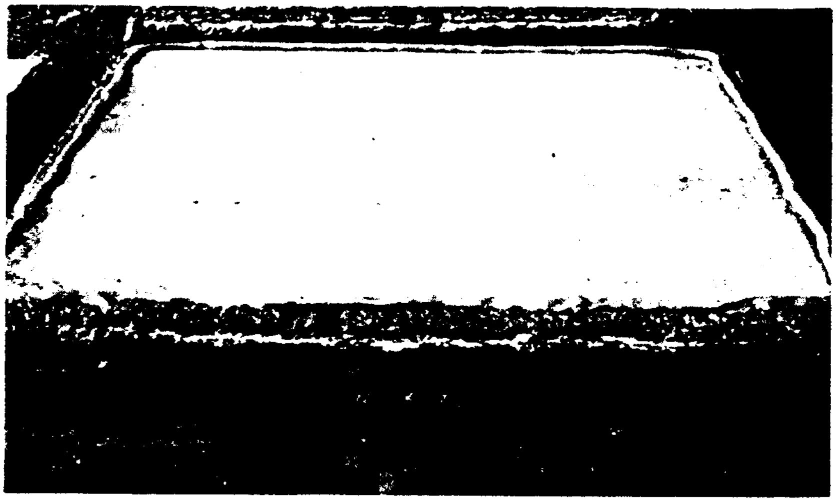
FIGURE I



Overall view of outdoor exposure test area showing the entire group of 188 test slabs.



Side view showing the open wooden stands which supported the test slabs at an elevation of approximately 3 feet above ground level.



Close-up view of a test slab showing the small dikes which trapped water on the surface.

Property	Value
Cement Factor	6-3/4 ± 1/4 $\frac{\text{sacks}}{\text{C.Y.}}$
Water Cement Ratio	5-1/2 ± 1/2 $\frac{\text{gals.}}{\text{sack}}$
Slump	2-1/2 ± 1/2 inches
Air Content	
Air-Entrained	3 - 6%
Non-Air-Entrained	0 - 3%
Expected 28 Day Compressive Strength	4500 psi (3-6% air)

The coarse aggregate used for all concrete batches was size 57 (1" nominal size) trap rock (diabase) conforming to the requirements of ASTM specification C33. The fine aggregate was a natural sand with a fineness modulus of 2.7. Type II portland cement was used. The concrete properties for each batch are listed in Appendix I.

The material was placed in a nominal one bag mixer and dry mixed until the mixture appeared uniform. The calculated amount of water was then added followed by alternate mixing, resting, and mixing times of 3 minutes, 3 minutes, and 2 minutes, respectively. A slump test was made during the 3 minute rest period and additional water was added at the start of the final mixing period, if necessary. If additional water was added, a second slump test was made before casting to check that the desired workability had been achieved.

The concrete was then placed in wooden molds measuring 2 ft. square by 4" thick and vibrated for a maximum of 30 seconds. All slabs except those receiving curing-sealing treatments had a single

#3 reinforcing bar placed at mid-depth to provide a potential site for spalling. After placement, the concrete specimens were struck-off and edged and later given a burlap-drag finish after bleeding was complete.

The various anti-scaling treatments were applied at the time and in the manner specified by the manufacturers. In some cases this was prior to curing and in others it was approximately one month later.

Immediately after casting, the concrete specimens were put into a moist room (90%-100% relative humidity, 68°-74°F) where they remained for three days. They were then taken to the test site and left on the ground for approximately one week, after which time the forms were stripped and the slabs were placed on the test stands.

4.3 PRODUCTS TESTED

The products to be tested were divided into four general classes:

(a) penetrating agents (PA)

(b) curing compounds (C)

(c) sealers (S)

(d) admixtures (A)

A slight problem was encountered in categorizing certain of the materials since the manufacturers sometimes referred to their product as "penetrating-sealers" or "curing-sealers" which would constitute a hybrid or cross between two of our classifications. The general approach was to call any treatment a curing compound if it was used as a curing compound (i.e., if used on wet concrete), a penetrating agent if it appeared to soak into the concrete, or a sealer if it appeared to remain on the surface of the concrete. The remaining category, admixtures, was an obvious classification. These products are described in Appendix II.

Although some difficulties were experienced in applying a few of the more exotic compounds, a total of 41 anti-scaling treatments were applied satisfactorily and were evaluated in this test. Approximately two-thirds of the total number of slabs received treatments while the other one-third were left untreated as controls.

4.4 TREATMENTS AND CONTROLS

In most cases, each penetrating agent and sealer was applied to a total of four slabs, two with air entrainment and two without. The two air-entrained slabs were randomly selected, one from the group above mid-range of air content and one from the group below. Controls for the penetrating agents and sealers were slabs from the same batch which were fog cured under the conditions described previously.

For the testing of the admixtures, two slabs (instead of the usual three) were cast from each batch. Controls for these were other fog cured control slabs which had very nearly the same cement factor, water/cement ratio, air content, and slump.

The curing-sealing materials were applied to both air-entrained and non-air-entrained slabs in a manner similar to the penetrating agents and sealers, with the controls being untreated slabs from the same batches. Because the fog room conditions would not only interfere with the proper application of the curing materials but would also obscure their effectiveness (or ineffectiveness) in achieving adequate curing, these slabs were stored indoors under ambient temperature and humidity conditions for a three day period. The controls for these slabs were stored in the same area and were cured with wet burlap. However, one control slab from one of the batches on each day was given the usual fog cure so that it would be possible to make some comparison between the curing-sealing materials and the other three classes of treatments.

4.5 EXPOSURE TESTING

Of the total of 188 slabs which were placed on outdoor elevated stands, all but two had watertight dikes approximately 3/8" high around their perimeters. The dikes were formed of an architectural sealing material and were later reinforced with roofing cement to guard against possible leaks.

Water was applied to these slabs to a depth of approximately 1/4" every weekday afternoon when there was a possibility that freezing temperatures would be reached overnight. Deicing chemicals were applied in the morning to all slabs if ice was present on any of them.

The deicing compound was a 4:1 mixture of rock salt and calcium chloride which was the mixture then in use on New Jersey highways. In order to accelerate the build-up of deicer concentrations in the concrete, the application rate was approximately three cubic inches per slab which represented approximately five times the normal amount of 500 pounds per lane mile put down on pavements.

4.6 EVALUATION

The degree of deterioration of each slab was determined periodically by averaging the individual ratings obtained from a panel of several engineers. The numerical rating for each slab reflected both the severity and extent of scaling and was based on the following chart:

Rating Scale

Condition	Surface Appearance (Severity)
0	No scaling
1	Very slight scaling, 1/16" deep or less, virtually no coarse aggregate visible, includes laitance scaling.
2	Slight to moderate scaling, between Condition 1 and Condition 3.
3	Moderate scaling, approximately 1/8" to 1/4" deep, some coarse aggregate visible.
4	Moderate to severe scaling, between Condition 3 and Condition 5.
5	Severe scaling, approximately 1/2" or deeper. Coarse aggregate completely exposed.

Sample Calculation

A slab which exhibits varying degress of scaling, say 30% Condition 3, 20% Condition 1, and 50% with no scaling, would be rated as follows:

Extent		Severity		
.30	x	3	=	.90
.20	x	1	=	.20
.50	x	0	=	0
		Total		1.10 Scaling Rating

The preceding example illustrates how a scaling rating was determined for each slab, including both treatment slabs and control slabs. Treatment effectiveness was judged from durability ratings which are defined to be the difference between the scaling ratings for a treatment and its control. As defined here, the durability rating is negative when an apparently effective treatment prevents a test slab from deteriorating as rapidly as its control.

To properly evaluate the durability ratings, it had to be determined at what level they may be interpreted to indicate a singificantly beneficial or detrimental effect. Theory tells us that every measurement has associated with it a certain amount of variability made up of components of variance from different sources. In this case, the primary components are the variability associated with the rating system and the variability inherent in the performance of the treatments themselves. The combination of these two will dictate what magnitude a durability rating must be in order for it to be attributed to something other than chance effect (i.e., the magnitude necessary to demonstrate a real beneficial or detrimental effect of the treatment).

The derivation of these critical levels is described in Appendix VII. It was found that a single test must achieve a durabilty rating of at least $\pm$ 1.16 to be judged significant, whereas a durability rating of only $\pm$ 0.82 was required when the average of two tests was available.

4.7 RESULTS OF OUTDOOR EXPOSURE TESTS

The yearly durability ratings for the three-year test period are listed in Appendix III. Examination of this data reveals several apparent trends. In many cases, the measured effect -- favorable or unfavorable -- is seen to increase as the number of freeze-thaw cycles increases. This is probably the normal case and is to be expected. In some cases, however, the trend seems to reverse itself while, in others, there is no obvious pattern. This could be the result of the variability of the rating system but may also indicate a change in the rate at which particular test slabs (or their controls) are weathering. It should also be realized that in a test of this type the trend for all durability ratings (test-control) is to tend toward zero as the freeze-thaw cycles increase indefinitely. This is so because both the test slab and its control eventually will be completely deteriorated, resulting in a difference of zero. For this reason, it was decided to terminate any individual test when either the test or the control reached the maximum scaling rating of 5.00. Figure II shows two non-air-entrained slabs which reached total failure after one winter's exposure.

The results obtained on air-entrained concrete and non-air- entrained concrete have been listed separately in Appendix III for two reasons. First, since exposed concrete is almost universally specified to be air-entrained, it was felt that the test results would be more useful if this factor were isolated. Second, there may be certain treatments which have different effects on the two types of concrete and their results might be obscured if they were averaged.

Table I lists the average durability ratings for the four general classes of materials tested. In this case, all general classes appear to be beneficial to some degree except for sealers and curing compounds on non-air-entrained concrete.

TABLE I

AVERAGE DURABILITY RATINGS FOR GENERAL CLASSES OF TREATMENTS

(Negative Values Indicate Beneficial Results)

Type	Air-Entrained Concrete		Non-Air-Entrained Concrete	
	Number of Products	Average Rating	Number of Products	Average Rating
Sealers (S)	7	-0.74[a]	5	POOR[b]
Penetrating Agents (PA)	17	-0.45[a]	16	-0.30[a]
Curing Compounds (C)	9	-0.34	8	+0.68[a]
Admixtures (A)	5	-0.24	-	NOT TESTED[c]

[a]Significant at 95% confidence level.

[b]Some test slabs reached total failure prior to the last rating and, therefore, were excluded. Had they been included, the would have contributed positive values which reflect poor performance.

[c]All admixtures tested caused the concrete to be air-entrained.

FIGURE II

Examples of two of the non-air-entrained slabs which reached total failure after one winter of outdoor exposure (approximately 47 freeze-thaw cycles).

An interesting thing to note in Table I is the performance of the sealers and the curing compounds, both of which provide a waterproof barrier at the surface of the concrete. The average effects for both these classes of treatments were very similar in that good results were obtained with air-entrained concrete and poor results were obtained with non-air-entrained concrete. It should be re-emphasized that these effects are comparisons (test-control) and exclude any effects attributable to air-entrainment itself. When viewed as a class, the sealers and curing compounds appear to improve the scaling resistance of air-entrained concrete but reduce the scaling resistance of non-air-entrained concrete.

A possible explanation can be offered for this. It has long been recognized that air-entrainment is advantageous because it provides room for expansion as the free water in the concrete freezes. It remains effective as long as the air voids are not filled with water. Both the curing compounds and the sealers were applied before the water and deicer applications were begun. Therefore, these treatments tended to keep the water out of the void systems and maintained their effectiveness. The relatively better performance of the sealers in comparison to the curing compounds may be the result of additional drying time before the sealers were applied, thereby reducing the free water content of these slabs still further.

In the case of the non-air-entrained slabs, there are insufficient air voids in the concrete to accommodate the increasing volume of water as it freezes. These slabs have very little frost resistance in any case but what resistance they have can be improved by a period of drying which would tend to empty whatever air voids are present. Since the slabs were cast during the summer, those that did not receive curing or sealing compounds did experience a substantial period of drying. Those that received curing and sealing compounds would have remained fairly saturated which may account for their poorer performance.

In Table II, the treatments are ranked by durability rating. In Section A of this table, several interesting observations may be made of the effects of these treatments on air-entrained concrete. Treatments C-1 and C-2, which were field tested as a result of favorable reports by other researchers, are seen to rank 16th and 12th, respectively, out of a total of 41 treatments. Although their average durability ratings of -0.46 and -0.74 are favorable (negative), neither achieved the level of -0.82 considered necessary to be confident that they are beneficial.

Another interesting observation in Table II-A is that all four general types of treatments have individual ratings near the top of the list, although none of the penetrating agents quite achieved the level judged to indicate significance. The tests for two of the penetrating agents (PA-12, soybean oil, and PA-13 castor oil, were split to include both cut (combined with an equal amount of mineral spirits) and uncut (pure) versions of these treatments. For this reason, no replicate tests were available from which to judge within-treatment variability. However, it is interesting to note that the

TABLE II-A

TREATMENTS RANKED BY DURABILITY RATING

AIR-ENTRAINED CONCRETE

Rank	Test Designation	Durability Rating	Significant at 95% Level	Rank	Test Designation	Durability Rating	Significan at 95% Leve
1	A-5	-1.51	YES*	21	PA-4	-0.32	NO*
2	S-6	-1.34	YES	22	C-0	-0.29	NO
3	S-4	-1.30	YES	23	A-4b	-0.20	NO*
4	PA-12a	-1.13	NO	24	C-4	-0.20	NO*
5	S-5	-1.11	NO	25	PA-3	-0.16	NO*
6	PA-13a	-1.06	NO	26	PA-12b	-0.14	NO
7	PA-8	-0.99	NO	27	C-8	-0.13	NO*
8	PA-14	-0.89	NO	28	PA-17	-0.12	NO
9	C-5	-0.86	YES*	29	PA-18	-0.09	NO
10	S-1	-0.85	NO	30	PA-5 on C-0	-0.09	NO
11	PA-15	-0.80	NO*	31	C-6	-0.08	NO*
12	C-2	-0.74	NO*	32	PA-10	-0.06	NO*
13	PA-7	-0.60	NO*	33	A-4a	-0.06	NO*
14	PA-5	-0.56	NO*	34	C-7	+0.10	NO*
15	PA-1	-0.50	NO*	35	PA-2	+0.10	NO*
16	C-1	-0.46	NO*	36	PA-13b	+0.15	NO
17	PA-6	-0.42	NO*	37	S-2	+0.20	NO*
18	S-8	-0.40	NO	38	A-3	+0.22	NO*
19	C-3	-0.38	NO*	39	A-1	+0.35	NO*
20	S-3	-0.38	NO	40	PA-4 on C-0	+1.06	NO
				41	LO-MS on C-0	+2.03	YES

*Represents average of two tests, in which case a durability rating of ±0.82 or more is considered significant at the 95 percent level of confidence. Others are single tests for which a durability rating of ± 1.16 or more demonstrates significance.

TABLE II-B

TREATMENTS RANKED BY DURABILITY RATING

AIR-ENTRAINED CONCRETE

Rank	Test Designation	Durability Rating	Significant at 95% Level	Rank	Test Designation	Durability Rating	Significant at 95% Level
1	S-1	-2.03	YES	16	S-2	0	NO*
2	PA-13a	-1.23	YES	17	PA-12b	+0.03	NO
3	PA-12a	-0.99	NO	18	C-1	+0.13	NO
4	PA-6	-0.96	YES*	19	S-8	+0.14	NO*
5	C-5	-0.70	NO*	20	PA-7	+0.62	NO*
6	C-3	-0.64	NO	21	PA-14	+0.67	NO
7	PA-10	-0.62	NO*	22	C-7	+0.76	NO*
8	PA-18	-0.57	NO	23	PA-1	+0.80	NO
9	PA-8	-0.52	NO	24	C-8	+0.88	YES*
10	PA-15	-0.50	NO*	25	C-6	+1.10	YES*
11	PA-2	-0.37	NO*	26	C-2	+1.27	YES*
12	PA-13b	-0.34	NO	27	C-4	+2.65	YES
13	PA-4	-0.33	NO*	28	S-3	POOR	YES**
14	PA-5	-0.30	NO*	29	S-4	POOR	YES**
15	PA-3	-0.25	NO*				

*Represents average of two tests, in which case a durability rating of ±0.82 or more is considered significant at the 95 percent level of confidence. Others are single tests for which a durability rating of ± 1.16 or more demonstrates significance.

**Some test slabs reached total failure prior to the last rating and, therefore, were excluded. Had they been included, they would have received high positive ratings.

cut versions appear near the top of the list for both air-entrained and non-air-entrained concrete while the uncut versions appear substantially farther down in both cases. It seems unlikely that this is due only to chance factors, and it is assumed to indicate that the effectiveness of these treatments is improved by the addition of mineral spirits. A possible rationale for this difference in performance is that the thinner (cut) material penetrates deeper and remains for a longer time in the surface layer of the concrete.

Of the four treatments that rank as significantly beneficial on air-entrained concrete in Table II-A, the one that tops the list (treatment A-5, a water-reducing admixture) has several very desirable features. First, since it is an admixture, it is simpler to use than the other three types of treatment, requiring only that the correct amount be added to the mix during batching. Second, since it is not a surface coating, there is no surface slipperiness problem that is a concern with some of the other treatments. Third, although two test slabs is a relatively small sample, the durability ratings for this treatment are remarkably consistent (-1.46 and -1.56). Fourth, auxilliary benefits claimed for this treatment are an increase in strength and a decrease in permeability due to a lower water-cement ratio. Because this treatment thus appears to be beneficial in every respect with apparently no undesirable characteristics, it will receive the major emphasis for future field testing.

The next two ranking beneficial treatments in Table II-A (S-6, an epoxy resin, and S-4, a urethane) demonstrated certain undesirable features and will not be investigated further. Both are difficult chemicals to work with and both require a sand topping to prevent a slipperiness problem. Although the skid resistance of the sand topping appeared adequate by our test method (British Portable Tester[2]), it is not known how it would perform under traffic.

The remaining treatment which passed the test of being significantly beneficial on air-entrained concrete is treatment C-5, a two-component epoxy curing compound which is also comparatively difficult to use. A sand topping was not used and an undesirably low skid value was obtained. A further drawback was its failure to pass the moisture retention test for curing compounds. For these reasons, this treatment was not considered for field testing.

4.8 CORROSION OF REINFORCING STEEL

Once the accelerated outdoor exposure tests were completed, several test slabs were broken open to inspect the reinforcing steel which had been placed at a depth of 2" to simulate the top mat of steel in bridge decks. In all cases, the steel was in remarkably good condition (no noticeable rust), despite the fact that laboratory analyses indicates that in about 50% of the cases the chloride levels around the bars exceeded the critical limit of 2 lbs./c.y. suggested by the FHWA[3]. It is theorized that the chlorides may have reached this level at a time near the termination of the testing and that there consequently might not have been sufficient time for corrosion to occur.

5.0 AIR-ENTRAINMENT STUDY

Although it was not specifically planned to confirm the beneficial effect of air-entrainment, this was easily accomplished by comparing the air-entrained and non-air-entrained control slabs used in the Phase I investigation. In making this analysis, the scaling ratings were used since durability ratings (test-control) could not be calculated for control slabs alone. Since there were 26 control slabs each of air-entrained and non-air-entrained concrete, a reasonably good comparison of their scaling resistance could be made. The individual scaling ratings for the control slabs are listed in Appendix IV. Histograms plotted from these data showed both distributions to be nearly normal with standard deviations of 0.45 and 0.91 for AE and NAE concrete, respectively. Since the standard deviations are quite different, the "t" test for unknown and unequal standard deviations was used to compare these two groups. For the observed mean scaling ratings of 1.18 and 2.40 for AE and NAE concrete, respectively, the "t" statistic is calculated to be 6.13. This far exceeds the critical value and indicates a highly significant benefit derived from an average air-entrainment level of 4.5 percent when compared against no air entrainment.

Because of this very beneficial effect of air-entrainment, plus the fact that most states specified levels of air-entrainment higher than New Jersey's it was decided to investigate the feasibility of increasing the current specification of 4.5 $\pm$ 1.5 percent to some higher level. Since it was recognized that additional air entrainment would be accompanied by an attendant loss of strength, the basic question to be resolved was to what extent the air level could be increased without seriously jeopardizing the structural strength of the concrete.

In order to determine the expected loss of strength resulting from increased air content, a series of test cylinders with varying levels of air entrainment was cast. Several laboratory batches of structural grade concrete were prepared with a cement factor of 6.7 sacks/c.y. and the water-cement ratio controlled as closely as possible at 5.25 gallons/sack. The air content of the fresh concrete was measured by the pressure method and was varied from 3 percent to 12 percent. This resulted in a total of 67 cylinders to be used for the analysis. The compressive strengths and air levels of these cylinders are listed in Appendix IV.

Because these batches were carefully controlled and the cylinders were cured in an optimum manner, the resulting strengths represent the potential of field concrete under the best conditions. Strengths achieved in the field would be expected to be lower. However, the rate of decline of compressive strength with increasing air entrainment can reasonably be assumed to be approximately the same for both laboratory and field concrete, thus permitting estimates of actual (field) strength results to be made from idealized (laboratory) data.

The solid line in Figure III shows the linear regression line obtained from the laboratory cylinder strengths. In order to approximate the line for field concrete, the dashed line in Figure III is drawn through the known mean strength for field concrete (4750 psi at an average air level of 4.5 percent) parallel to the laboratory line. Using the approximate relationship for field concrete, it is seen that the specified air content can be raised as high as 6% while still maintaining the compressive strength at more than two standard errors of the estimate above the design strength of 3000 psi. Based on this, it was judged that an increase in New Jersey's entrained-air specification to 6.0 ± 1.5% would produce very little concrete below design strength. This was adopted in 1972 and it is believed that a substantial improvement in concrete durability has been realized as a result.

6.0 FIELD DURABILITY TESTS

The objective of this phase was to field test on actual bridges those treatments found to be most promising during the accelerated outdoor exposure tests. This work was begun ahead of schedule in 1970 with the testing of two products considered promising by other researchers. Ultimately, four test products and accompanying control materials were placed on a total of eight decks. However, two decks were subsequently excluded from the study due to a later-discovered materials problem (clay lumps in the concrete produced extensive surface distress obscuring any differences between the tests and controls).

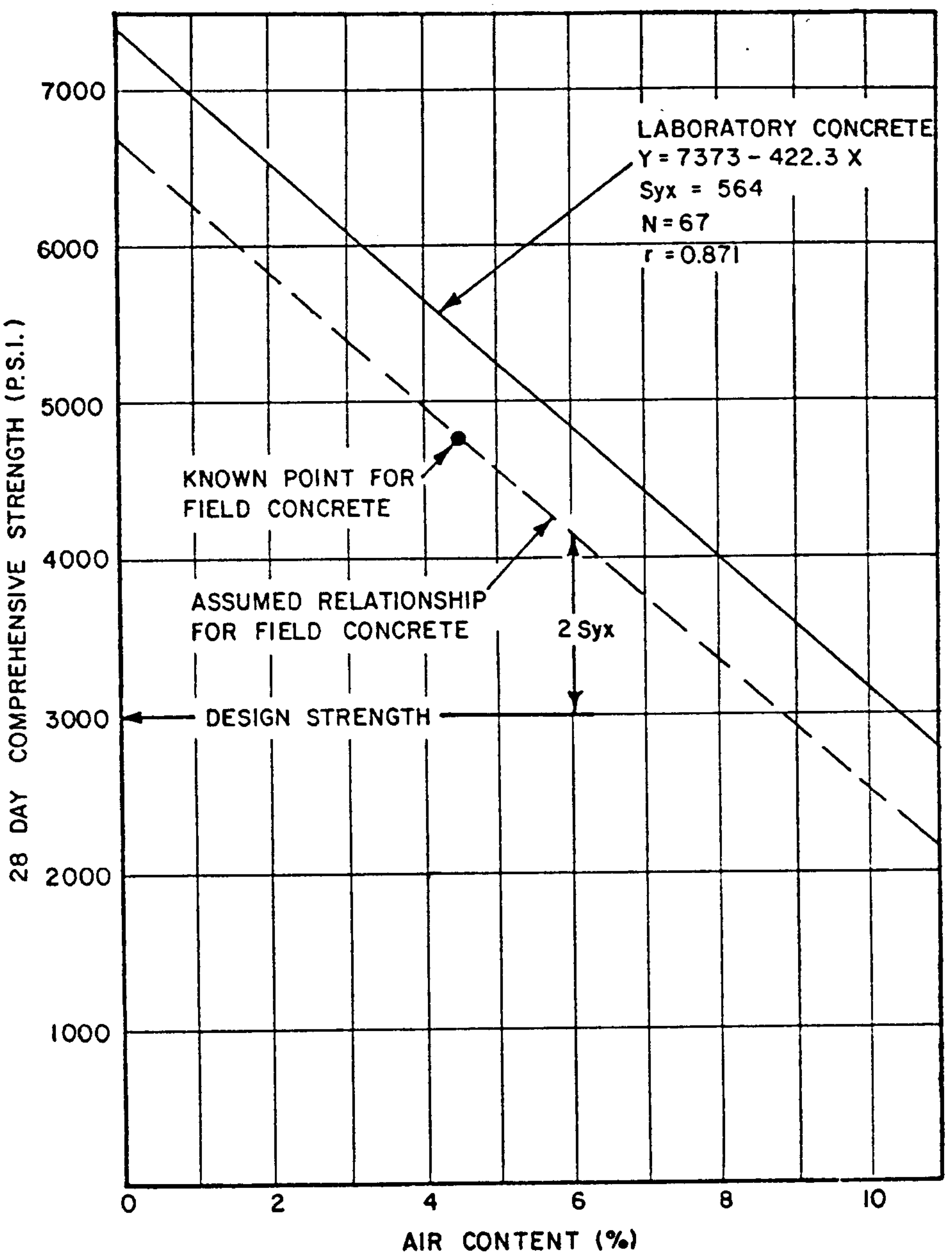


FIGURE III. Relationship of Compressive Strength and Air Content.

6.1 EARLY TESTS

Based on favorable comments by others, the first two products to be tested were a linseed oil emulsion and a chlorinated rubber epoxy. North Dakota has reported favorably on this particular linseed oil formulation and both California and the Bureau of Public Roads had obtained good results with the chlorinated rubber epoxy.

Both of these products are curing compounds and were designated C-1 and C-2 in the outdoor exposure testing phase of this study. Controls for the test decks were adjacent decks (or portions of the same deck) cured with the standard white pigmented curing compound (test designation C-0). The characteristics of these products are described further in Appendix II.

Based on New Jersey laboratory tests, both experimental products provide adequate cure and skid resistance and thus were judged suitable to test for the additional benefit of scaling resistance.

MATERIAL	ASTM TEST C156-65 MOISTURE LOSS GMS./SQ.CM. (MUST BE 0.055 OR LESS)	BRITISH PORTABLE TESTER AVERAGE SKID VALUES (55 OR ABOVE IS SATISFACTORY)	
		PRELIMINARY TESTS	ACTUAL BRIDGES
C-1 (LINSEED OIL EMULSION)	0.018	70	61
C-2 (CHLORINATED RUBBER EPOXY)	0.041	58	53[a]

[a]It is believed that the recommended application rate may have been exceeded in some areas.

For all of these test decks, the construction procedure from beginning to end was observed by research personnel and a bridge construction engineer. Each truckload of concrete was checked for air content (pressure method) and slump. Chace air tests were made on the finished concrete. The location and time of placement of each truckload of concrete was plotted on pour diagrams and any discrepancies or unusual occurrences were noted to aid in evaluating the results when the decks are periodically checked in the future.

The first formal rating of these decks was made in December, 1977, after 7 years of field exposure. All were scaled to some (relatively slight) degree, much of it occurring in narrow transverse strips. Attempts to correlate these strips with the properties of particular material deliveries shown on the pour diagrams revealed no obvious relationships. However, since the transverse-roller finishing technique used on this project yields "strip" finishing, the observed pattern of scaling may be related to this construction procedure. Scaling ratings for these decks were calculated by the author in the same manner used for the outdoor exposure tests. The results are listed in Table III.

Omitting the scaling rating of the rain-damaged deck, the following product averages are obtained.

Product	Average Scaling Rating[a]
Linseed Oil (C-1)	1.6
Chlorinated Rubber Epoxy (C-2)	0.3
Control (C-0)	0.6

[a]Larger values indicate a greater degree of scaling.

Unlike the outdoor exposure tests, we don't have the necessary information to determine how large a difference is required to be judged significant. However, it appears that the studied linseed oil formulation provides less scaling resistance than the standard curing compound and that the chlorinated rubber epoxy is about equal to the standard material or slightly better.

This information suggests that the chlorinated rubber epoxy (C-2) may deserve further consideration. First, it barely missed being judged significantly beneficial in the outdoor exposure tests. Second, it appears to have performed better than our standard curing compound in both the outdoor exposure-testing phase and the field-testing phase of the study. Third, because of its fast-drying properties, it can provide quicker protection for fresh concrete. Since some type of curing compound is always required, it was felt appropriate to encourage further installations of this product. The contractor who had applied this material on the earlier installation (and who had experienced rain-damage using an alternate curing method) was very eager to cooperate in this effort. Consequently, this product was used on several additional bridges built in 1974. (Details of this work are given in Appendix V.) These bridges were also observed in 1977 and found to be in excellent condition.

6.2 FIELD TESTING OF PRODUCT A-5

Some difficulty was experienced in finding a suitable structure which could be used to test product A-5, the water-reducing admixture which performed best in the outdoor exposure tests. A firm committment has now been received and it is planned that this product will be used in a bridge deck to be built in the near future.

6.3 LONG-TERM MONITORING

The long term monitoring of all field test decks will be continued under another study.

7.0 CHACE AIR METER TESTS

In preparing the pour diagrams for the field test decks, a Chace air meter was used to obtain additional air-entrainment measurements at various locations in the finished surface of the concrete. The primary purpose was to check the air level at the point most critical for scaling resistance: the exposed surface of the concrete. A previous study[4] has shown that uncorrected Chace readings can be expected to be slightly higher than corresponding readings by the pressure method below an air-entrainment level of 4% and slightly lower than pressure method values above this level. Since most of the Chace readings obtained on the decks studied in this research were above the 4% level, this indicated that a reasonably satisfactory amount of air-entrainment was achieved in the surface of the field test decks. This data is reported in Appendix VI.

Based on the experience obtained with the Chace air meter in this study, it was recommended as a useful auxilliary test device for engineers in the field. Several units have been purchased and provided to the construction offices throughout the State.

8.0 LABORATORY FREEZE-THAW TESTS

The purpose of this phase of the study was to investigate the fundamental nature of the scaling mechanism in an attempt to develop a rapid test capable of evaluating the effectivenss of additional anti-scaling treatments in the future.

This work was begun in late 1970 with the installation of a laboratory freeze-thaw chamber. The device consisted of an enclosed bath filled with water-saturated kerosene into which the test specimens were placed. Automatic controls were capable of continuously cycling the temperature from 50°F to 0°F and back at a preset rate. The tests were monitored by (a) several thermocouples placed at varying depths below the surface of each specimen, (b) strain gauges contacting special metal plugs mounted in the specimens to measure dilation, and (c) a thermocouple placed in the kerosene bath to measure its temperature. The outputs of all these devices were recorded by multipoint recorders.

The approach to the analysis of this temperaure and strain data was patterned after a similar study conducted by Havens[5] at the University of Kentucky. It was theorized that isotherms (periods of constant temperature) at various depths in the specimens could be related to hydraulic pressure within the concrete which, in turn, is related to scaling resistance. At atmospheric pressure, water freezes at 32°F and remains at that temperature until all the available water is frozen. If an isotherm occurred at a temperature below 32°F, a phase diagram of water could be utilized to estimate the hydraulic pressure existing within the concrete. The strain gauges would monitor length changes and would indicate when the concrete no longer returned to its original length. Any "permanent set" could be interpreted to indicate some degree of physical damage.

In order to provide the greatest opportunity for scaling to occur, the test specimens were placed in the freeze-thaw chamber in a saturated state. To accomplish this, they were stored either in a fog room or a salt water bath from the time of casting until they were tested.

The freeze-thaw chamber was put into operation in the fall of 1971 and, although it performed according to specification, it soon became a source of continual maintenance problems which interrupted the continuity of the testing. However, even during the periods of normal operation, the expected results were not achieved. For example, no isotherms were detected even after 200 freeze-thaw cycles.

Although the large volume of kerosene in the freeze-thaw chamber provided considerable thermal inertia which was expected to damp out the cycling of both the refrigeration and heating units, the thermocouple in the bath showed that a slight step function existed. In order to determine if these steps were obscuring the isotherms, the unit was put into a constant cooling mode so that the temperature of the kerosene (and, therefore, the test specimens) would follow a smooth descending curve. This, too, was unsuccessful as no isotherms could be observed.

An additional attempt to detect isotherms was made with smaller specimens, some of which were sealed with paraffin. The idea was to test whether the size of the specimen or the possible intrusion of kerosene could somehow affect the detection of the isotherms. However, as in all the other cases, no isotherms were observed.

Because of the lack of success of the freeze-thaw testing, it was necessary to re-evaluate this phase of the project. Since the freeze-thaw chamber was not producing meaningful results and was becoming increasingly more difficult to maintain, plus the fact that the other phases of the project had already yielded implementable results (increased air-entrainment specification), it was decided to terminate the laboratory freeze-thaw testing part of the research.

REFERENCES

1. PCA, "Durability of Concrete Bridge Decks", 1968.

2. Road Research Laboratory, "Road Note No. 27", 1960.

3. Clear, K.C., "Evaluation of Portland Cement Concrete for Permanent Bridge Deck Repair", FHWA, 1974.

4. Newlon, H.H., "A Field Investigation of the AE-55 Air Indicator", HRB Bulletin 305, 1961.

5. Havens, J.H., "Thermal Analysis of the Freeze-Thaw Mechanisms in Concrete", University of Kentucky Engineering Research, 1961.

APPENDIX I

CONCRETE BATCH DATA

BATCH	SLAB NUMBERS	AIR CONTENT (%)	WATER/CEMENT RATIO (GAL./SACK)	SLUMP (INCHES)	AVERAGE 28-DAY COMPRESSIVE STRENGTH (PSI)
1	28,29,30	0.6	5.4	2-1/2	6890
2	22,23,24	0.6	5.4	2-3/4	6170
3*	34,35,36	4.8	5-1/2±1/2	2-3/4	3715
4*	7,8,9	3.9	5-1/2±1/2	2-1/4	5845
5*	1,2,3	5.4	5-1/2±1/2	2-1/2	3715
6*	67,68,69	4.9	5-1/2±1/2	2-1/2	4045
7*	13,14,15	4.8	5-1/2±1/2	3	4015
8			NOT USED		
9*	40,41,42	4.1	5-1/2±1/2	3	5080
10			NOT USED		
11	100,101,102	4.6	5.0	2-1/2	4685
12	73,74,75	4.6	5.0	3	5450
13	31,32,33	4.0	5.0	2-1/2	5840
14	61,62,63	3.8	4.8	2-1/2	5200
15	10,11,12	4.6	5.1	2-1/2	4760
16	97,98,99	5.2	5.1	1-1/2	4880
17	43,44,45	4.8	5.0	2-1/4	5590
18	37,38,39	4.8	4.9	2-1/4	5455

*The records of the fine aggregate moisture content, determined in the field at the mix site, were lost for these particular batches. Since both the slumps and the compressive strengths for these batches are normal, it is assumed that the water contents are within the desired range.

BATCH	SLAB NUMBERS	AIR CONTENT (%)	WATER/CEMENT RATIO (GAL./SACK)	SLUMP (INCHES)	AVERAGE 28-DAY COMPRESSIVE STRENGTH (PSI)
19	64,65,66	5.2	5.0	3	4680
20	70,71,72	4.8	5.0	3	4630
21	103,104,105	4.8	5.0	2-3/4	4120
22	4,5,6	4.2	5.2	2	4865
23	25,26,27	2.2	5.0	2-3/4	7360
24	19,20,21	1.3	5.0	2-1/2	6510
25*	82,83,84	1.6	5-1/2±1/2	1-3/4	6945
26	49,50,51	1.8	5.2	2-1/4	4795
27	16,17,18	1.3	5.1	2-1/4	6015
28	46,47,48	1.4	5.4	2	6245
29	55,56,57	1.2	5.5	2-1/4	6615
30	52,53,54	1.0	5.5	2	6000
31	109,110,111	1.1	5.8	2-1/4	7230
32	88,89,90	0.8	5.7	3	6155
33	106,107,108	1.5	5.4	2	7780
34		NOT USED			
35	58,59,60	2.3	5.5	2	6420
36	85,86,87	2.3	5.4	2-1/2	4945
37	79,80,81	1.6	5.0	2-1/2	6110
38	76,77,78	1.8	5.7	2	6205
39	112,113,114	1.5	5.4	2-1/2	6775
40		NOT USED			
41		NOT USED			
42	190	3.0	5.4	2	5175

BATCH	SLAB NUMBERS	AIR CONTENT (%)	WATER/CEMENT RATIO (GAL./SACK)	SLUMP (INCHES)	AVERAGE 28-DAY COMPRESSIVE STRENGTH (PSI)
43	95,96	4.8	5.4	2-1/2	4650
44	181,182	6.4	5.4	2-1/2	3800
45	115,116	5.0	5.4	3	4500
46		NOT USED			
47		NOT USED			
48		NOT USED			
49		NOT USED			
50	91,92	5.4	4.9	2-1/2	6880
51	119,120	5.2	5.3	2-1/2	4775
52	186,187	4.6	5.2	2	5430
53	117,118	3.0	5.4	1-3/4	5570
54	93	3.0	5.4	2	5855
55	127,128,144	1.0	6.0	3	5835
56	129,142,143	1.4	5.6	2-3/4	6185
57	125,145	0.8	5.6	3	5375
58	124,146,147	1.0	5.6	2-1/4	5975
59	133,134,135	0.7	5.7	3	5715
60	136,137,138	1.1	5.4	2	7480
61	131,132,139	1.1	5.0	2	6225
62	130,140,141	1.0	5.2	2	7075
63	123,148,149	1.0	5.0	3	5415
64	121,122,150	0.6	5.9	2-1/2	5615
65	163,164,165	4.9	5.2	2-1/4	5270

BATCH	SLAB NUMBERS	AIR CONTENT (%)	WATER/CEMENT RATIO (GAL./SACK)	SLUMP (INCHES)	AVERAGE 28-DAY COMPRESSIVE STRENGTH (PSI)
66	166,167,168	4.8	5.2	2	5175
67	152,153,154	4.8	4.9	2-1/2	4460
68	176,177,178	4.5	5.2	1-1/2	5775
69	155,156,157	5.7	5.2	3	5270
70	173,174,175	4.8	5.3	2-1/2	5065
71	158,159,160	5.4	5.8	3	4820
72	188,189	6.6	5.6	4	4220
73	161,162,169	6.0	4.9	3	4033
74	170,171,172	4.6	5.9	3	5463
75	151,179,180	3.8	6.1	3	4880
76	183,184,185	5.2	5.2	2-1/2	5170

APPENDIX II

ANTI-SCALING AGENTS

Note:
Skid values were obtained with the British Portable Tester as described in ASTM Designation E303-66T. The interpretations listed here were obtained from the Road Research Laboratory "Road Note No.27", 1960.

SKID VALUE	INTERPRETATION
65 or above	Good
55 to 65	Generally satisfactory
45 to 55	Conditionally satisfactory (gentle curves & grades, etc.)
45 or below	Potentially slippery

TEST DESIGNATION	DESCRIPTION OF MATERIAL	TIME	APPLICATION RATE	METHOD	AVG. SKID VALUE	SLAB IDENTIFICATION NUMBERS: AIR-ENTRAINED TEST SLABS	SLAB IDENTIFICATION NUMBERS: AIR-ENTRAINED CON-TROL SLABS	SLAB IDENTIFICATION NUMBERS: NON AIR ENTRAINED TEST SLABS	SLAB IDENTIFICATION NUMBERS: NON AIR ENTRAINED CON-TROL SLABS	MOISTURE LOSS ASTM C-156-65 GMS/CM (REQ.0.055 OR LESS)
PA-1	Linseed Oil (50% Mineral Spirits)	28 days after placement	1st Coat: .025 gal/ S.Y. 2nd Coat .015 gal/ S.Y.	Spray	68	2 4	3 6	25	27	
PA-2	Fish Oil (50% Mineral Spirits)	28 days after placement	1st Coat: .025 gal/ S.Y. 2nd Coat: .015 gal/ S.Y.	Spray	67	7 10	9 12	20 24	21 23	

TEST DESIGNATION	DESCRIPTION OF MATERIAL	TIME	APPLICATION RATE	METHOD	AVG. SKID VALUE	SLAB IDENTIFICATION NUMBERS: AIR-ENTRAINED TEST SLABS	AIR-ENTRAINED CON-TROL SLABS	NON AIR-ENTRAINED TEST SLABS	NON AIR-ENTRAINED CON-TROL SLABS	MOISTURE LOSS ASTM C-156-65 GMS/CM (REQ.0.055 OR LESS)
PA-3	Linseed and Fish Oils (50% Mineral Spirits)	28 days after placement	1st Coat: .025 gal/ S.Y. 2nd Coat: .015 gal/ S.Y.	Spray	70	8 11	9 12	19 22	21 23	
PA-4	Tall Oil (50% Mineral Spirits)	28 days after placement	1 Coat: .045 gal/ S.Y.	Spray	74	13 44	14 45	18 47	17 48	
PA-5	Tung Oil (50% Mineral Spirits)	28 days after placement	1st Coat: .018 gal/ S.Y. 2nd Coat: .015 gal/ S.Y.	Spray	55	15 43	14 45	16 46	17 48	
PA-6	Emulsifiable Linseed Oil	28 days after placement	1st Coat: .025 gal/ S.Y. 2nd Coat: .015 gal/ S.Y.	Spray	68	33 66	32 65	51 58	50 60	

TEST DESIGNATION	DESCRIPTION OF MATERIAL	TIME	APPLICATION RATE	METHOD	AVG. SKID VALUE	SLAB IDENTIFICATION NUMBERS: AIR-ENTRAINED TEST SLABS	SLAB IDENTIFICATION NUMBERS: AIR-ENTRAINED CON-TROL SLABS	SLAB IDENTIFICATION NUMBERS: NON AIR-ENTRAINED TEST SLABS	SLAB IDENTIFICATION NUMBERS: NON AIR-ENTRAINED CON-TROL SLABS	MOISTURE LOSS ASTM C-156-65 GMS/CM (REQ.0.055 OR LESS)
PA-7	Linseed Oil "Special Solvent"	28 days after placement	1st Coat: .025 gal/ S.Y. 2nd Coat .015 gal/ S.Y.	Spray	72	1 5	3 6	26 28	27 30	
PA-8	Polysulfide Epoxy	28 days after placement	.06 gal/ S.Y.	Acid etch then brush	67	72	70	83	82	
PA-10	Polymerized solution of metal organic compounds	28 days after placement	.05 gal/ S.Y.	Spray	71	34 37	36 38	53 55	54 57	
PA-12	Soybean Oil (50% Mineral Spirits)	28 days after placement	2 Coats .02 gal/ S.Y.each	Brush	64	99	97	110	111	
PA-12	Soybean Oil (Uncut)	28 days after placement	1 Coat .02 gal/ S.Y.	Brush	59	102	101	113	112	

TEST DESIGNATION	DESCRIPTION OF MATERIAL	TIME	APPLICATION RATE	METHOD	AVG. SKID VALUE	SLAB IDENTIFICATION NUMBERS: AIR-ENTRAINED		SLAB IDENTIFICATION NUMBERS: NON AIR-ENTRAINED		MOISTURE LOSS ASTM C-156-65 GMS/CM (REQ.0.055 OR LESS)
						TEST SLABS	CON-TROL SLABS	TEST SLABS	CON-TROL SLABS	
PA-13	Castor Oil (50% Mineral Spirits)	28 days after placement	2 Coat .02 gal/ S.Y.each	Brush	71	98	97	108	107	
PA-13	Castor Oil (Uncut)	28 days after placement	1 Coat .02 gal/ S.Y	Brush	70	100	101	114	112	
PA-14	Linseed Oil (Uncut)	28 days after placement	1 Coat .02 gal/ S.Y.	Brush	63	104	103	109	111	
PA-15	Chlorinated Rubber Epoxy	28 days after placement	.035 gal/ S.Y. on AE Slabs .057 gal/ S.Y. on NAE Slabs	Spray	54	35 39	36 38	52 56	54 57	
PA-17	Commercial Waterproofing Compound	28 days after placement	.065 gal/ S.Y.	Spray	65	68 73	69 74	79 85	80 87	

TEST DESIGNATION	DESCRIPTION OF MATERIAL	TIME	APPLICATION RATE	METHOD	AVG. SKID VALUE	SLAB IDENTIFICATION NUMBERS: AIR-ENTRAINED TEST SLABS	AIR-ENTRAINED CON-TROL SLABS	NON AIR-ENTRAINED TEST SLABS	NON AIR-ENTRAINED CON-TROL SLABS	MOISTURE LOSS ASTM C-156-65 GMS/CM (REQ.0.055 OR LESS)
PA-18	Penetrating Epoxy	28 days after placement	Primer .055 gal/ S.Y. Seal Coat .14 gal/ S.Y.	Brush	74	75	74	84	82	
S-1	Tar-Based Sealer	28 days after placement	.05 gal/ S.Y.	Spray at 140-180°F	78	105	103	106	107	
S-2	Resin-Based Sealer	28 days after placement	Trial .05 gal/ S.Y.	Spray No Heat	75	67 71	69 70	81 86	80 87	
S-3	Styrene Butadiene	28 days after placement	.05 gal/ S.Y.	Brush plus sand	67	63	61	88	90	
S-4	Urethane	28 days after placement	.05 gal/ S.Y.	Brush plus sand	61	62	61	89	90	

TEST DESIGNATION	DESCRIPTION OF MATERIAL	TIME	APPLICATION RATE	METHOD	AVG. SKID VALUE	SLAB IDENTIFICATION NUMBERS: AIR-ENTRAINED: TEST SLABS	SLAB IDENTIFICATION NUMBERS: AIR-ENTRAINED: CONTROL SLABS	SLAB IDENTIFICATION NUMBERS: NON AIR-ENTRAINED: TEST SLABS	SLAB IDENTIFICATION NUMBERS: NON AIR-ENTRAINED: CONTROL SLABS	MOISTURE LOSS ASTM C-156-65 GMS/CM (REQ. 0.055 OR LESS)
S-5	Furan Resin	28 days after placement	.05 gal/ S.Y.	Acid wash then brush plus sand	58	41	42			
S-6	Epoxy Resin	28 days after placement	.09 gal/ S.Y.	Acid wash then brush plus sand	66	40	42			
S-8	Butyrate Polymer	28 days after placement	.03 gal/ S.Y.	Brush	33	31	32	49 59	50 60	
A-1	Reactive Silane	Add at mixer	1.5 lbs/ C.Y.	Add at same time as mix water	84	91	119			
A-3	Polymerized solution of metal organic compounds	Add at mixer	Replaces 0.5 gal/ C.Y. of water	Add after mix water	70	93	117			

TEST DESIGNATION	DESCRIPTION OF MATERIAL	TIME	APPLICATION RATE	METHOD	AVG. SKID VALUE	SLAB IDENTIFICATION NUMBERS AIR-ENTRAINED TEST SLABS	SLAB IDENTIFICATION NUMBERS AIR-ENTRAINED CON-TROL SLABS	NON AIR-ENTRAINED TEST SLABS	NON AIR-ENTRAINED CON-TROL SLABS	MOISTURE LOSS ASTM C-156-65 GMS/CM (REQ.0.055 OR LESS)
A-4	Calcium chloride based waterproofing agent	Add at mixer	Replaces 1.5 gal/ C.Y. of water	Add at same time as mix water	71	115 181 116 182	95 189 (Fog Cure) 96 189 (Dry Cure)*			
A-5	Multi-component, chloride free, water reducing admixture	Add at mixer		4 oz. per 100 lbs cement	81	186 187	176			
C-1	Linseed Oil Emulsion (Diluted with 1/3 water)	May be placed on wet conc.	.045 gal/ S.Y.	Spray	70	154 177	152 176	135 136	134 137	.018

*Manufacturer claims no cure necessary.

TEST DESIGNATION	DESCRIPTION OF MATERIAL	TIME	APPLICATION RATE	METHOD	AVG. SKID VALUE	SLAB IDENTIFICATION NUMBERS: AIR-ENTRAINED TEST SLABS	SLAB IDENTIFICATION NUMBERS: AIR-ENTRAINED CON-TROL SLABS	SLAB IDENTIFICATION NUMBERS: NON AIR-ENTRAINED TEST SLABS	SLAB IDENTIFICATION NUMBERS: NON AIR-ENTRAINED CON-TROL SLABS	MOISTURE LOSS ASTM C-156-65 GMS/CM (REQ.0.055 OR LESS)
C-2	Chlorinated rubber epoxy	Just after surface water dis-appears	.045 gal/ S.Y.	Spray	58	153 178	152 176	128 129	127 142	.041
C-3	Reactive Silane	Just after finish-ing	.045 gal/ S.Y.	Spray	60	156 175	157 174	144 145	127	.013
C-4	Commercial Curing Compound	When concrete is hard enough to pre-vent marring	.045 gal/ S.Y.	Brush	77	158 173	159 174	146 125	147	.08 (Other agencies report less)
C-5	Two component epoxy	Just after surface water disappears	.045 gal/ S.Y.	Brush	38	165 166	164 167	122 149	121 148	.100

TEST DESIGNATION	DESCRIPTION OF MATERIAL	TIME	APPLICATION RATE	METHOD	AVG. SKID VALUE	SLAB IDENTIFICATION NUMBERS: AIR-ENTRAINED TEST SLABS	AIR-ENTRAINED CON-TROL SLABS	NON AIR-ENTRAINED TEST SLABS	NON AIR-ENTRAINED CON-TROL SLABS	MOISTURE LOSS ASTM C-156-65 GMS/CM (REQ. 0.055 OR LESS)
C-6	Epoxy Modified Acrylic Polymer	Just after surface water disappears	.045 gal/ S.Y.	Spray	65	162 163	169 164	123 124	148 147	.191
C-7	Chlorinated Rubber Curing Compound (Higher Solids Content)	1 to 2 hours after finishing	.045 gal/ S.Y.	Brush	59	140 131	130 132	160 171	159 172	.038
C-8	Chlorinated Rubber Curing Compound (Lower Solids Content)	1 to 2 hours after finishing	.045 gal/ S.Y.	Spray	56	161 170	169 172	139 138	132 137	.193

TEST DESIGNATION	DESCRIPTION OF MATERIAL	TIME	APPLICATION RATE	METHOD	AVG. SKID VALUE	SLAB IDENTIFICATION NUMBERS AIR-ENTRAINED TEST SLABS	AIR-ENTRAINED CON-TROL SLABS	NON AIR-ENTRAINED TEST SLABS	NON AIR-ENTRAINED CON-TROL SLABS	MOISTURE LOSS ASTM C-156-65 GMS/CM (REQ.0.055 OR LESS)
C-0	New Jersey Specification quality white pigmented curing compound	Membrane curing compound applied soon after finishing. Oils applied approx. 28 days later	Both curing compound and oils applied at .045 gal/sy	Spray for both curing compound and oils	74	185	183 184			Less than .055
PA-4 on C-0	Tall oil and mineral spirits on Orion Membrane curing compound				65	179	185			
PA-5 on C-0	Tung oil and mineral spirits on Orion Membrane curing compound				42	151	185			
LO-MS on C-0	Linseed oil and mineral spirits on Orion Membrane curing compound				39	180	185			

APPENDIX III

DURABILITY RATINGS

Notes:

1. Values in parentheses are average of ratings of two test slabs.
2. Negative values indicate beneficial results.
3. Critical levels for significance are ± 1.16 for single tests, ± 0.82 for average of two tests.

Test Designation	Description of Material	Air-Entrained Concrete Freeze-Thaw Cycles 46	102	147	Significant at 95%	Non-Air-Entrained Concrete Freeze-Thaw Cycles 46	102	147	Significant at 95%
PA-1	Linseed Oil (50% Mineral Spirits)	-.28 +.26 (-.01)	-.63 -.22 (-.42)	-.71 -.28 (-.50)	NO	+.06	+.75	+.80	NO
PA-2	Fish Oil (50% Mineral Spirits)	+.07 +.08 (+.08)	-.12 +.67 (+.28)	-.43 +.63 (+.10)	NO	-1.23 +.04 (-.60)	-.90 -.17 (-.53)	-.93 +.19 (-.37)	NO
PA-3	Linseed and Fish Oils (50% Mineral Spirits	-.20 +.01 (-.10)	+.41 -.11 (+.15)	+.18 -.50 (-.16)	NO	-1.01 -.18 (-.60)	-.65 -.32 (-.48)	-.52 +.02 (-.25)	NO
PA-4	Tall Oil (50% Mineral Spirits)	-.78 0 (-.39)	-.92 +.42 (-.25)	-1.03 +.38 (-.32)	NO	-.74 +.29 (-.22)	-.86 +.01 (-.42)	-.87 +.21 (-.33)	NO

Test Designation	Description of Material	Air-Entrained Concrete Freeze-Thaw Cycles				Non-Air-Entrained Concrete Freeze-Thaw Cycles			
		46	102	147	Significant at 95%	46	102	147	Significant at 95%
PA-5	Tung Oil (50% Mineral Spirits)	-.49 -.17 (-.33)	-1.03 -.13 (-.58)	-1.02 -.09 (-.56)	NO	-.88 +.19 (-.34)	-.38 +.01 (-.18)	-.40 -.21 (-.30)	NO
PA-6	Emulsifiable Linseed Oil	-.37 -.06 (-.22)	-.79 -.08 (-.44)	-.70 -.14 (-.42)	NO	-.44 -.58 (-.51)	-.68 -.83 (-.76)	-.44 -1.47 (-.96)	YES
PA-7	Linseed Oil "Special Solvent"	-.37 -.38 (-.38)	-.66 -.22 (-.44)	-.99 -.21 (-.60)	NO	+.35 +.25 (+.30)	+.57 +.32 (+.44)	+.99 +.25 (+.62)	NO
PA-8	Polysulfide Epoxy	-.10	-.60	-.99	NO	-.39	-.57	-.52	NO
PA-10	Polymerized Solution of Metal Organic Compounds	+.10 -.13 (-.02)	-.26 +.08 (-.09)	-.37 +.26 (-.06)	NO	-.52 -.12 (-.32)	-.85 -.50 (-.68)	-.88 -.36 (-.62)	NO
PA-12a	Soybean Oil (50% Mineral Spirits)	-.25	-.82	-1.13	NO	-.51	-.94	-.99	NO
PA-12b	Soybean Oil (Uncut)	-.09	-.10	-.14	NO	+.09	-.38	+.03	NO

Test Designation	Description of Material	Air-Entrained Concrete Freeze-Thaw Cycles				Non-Air-Entrained Concrete Freeze-Thaw Cycles			
		46	102	147	Significant at 95%	46	102	147	Significant at 95%
PA-13a	Castor Oil (50% Mineral Spirits)	-.37	-.62	-1.06	NO	-1.22	-1.16	-1.23	YES
PA-13b	Castor Oil (Uncut)	-.16	+.12	+.15	NO	-.06	-.40	-.34	NO
PA-14	Linseed Oil (Uncut)	-.22	-.67	-.89	NO	+.07	+.35	+.67	NO
PA-15	Chlorinated Rubber Epoxy	-.02 +.35 (+.16)	-.28 -.74 (-.51)	-.49 -1.12 (-.80)	NO	+.09 -.50 (-.20)	-.29 -.45 (-.37)	-.32 -.69 (-.50)	NO
PA-17	Water-proofing Compound	-.02 +.03 (0)	-.06 +.01 (-.02)	-.13 -.10 (-.12)	NO	+.33 -.18 (+.08)	+.31 -.29 (+.01)	+.22 -.09 (+.06)	NO
PA-18	Penetrating Epoxy	+.08	+.02	-.09	NO	-.37	-.68	-.57	NO
S-1	Tar-Based Sealer	-.17	-.58	-.85	NO	1-.43	-1.60	-2.03	YES

Test Designation	Description of Material	Air-Entrained Concrete Freeze-Thaw Cycles				Non-Air-Entrained Concrete Freeze-Thaw Cycles			
		46	102	147	Significant at 95%	46	102	147	Significant at 95%
S-2	Resin-Based Sealer	-.14 +.17 (+.02)	-.08 +.25 (+.08)	+.09 +.31 (+.20)	NO	-.34 -.25 (-.30)	-.33 -.32 (-.32)	+.05 -.06 (0)	NO
S-3	Styrene Butadiene	-.17	-.42	-.38	NO	+2.37	+2.86	--	YES
S-4	Urethane	-.21	-.89	-1.30	YES	+1.74	+2.86	--	YES
S-5	Furan Resin	+.01	-.76	-1.11	NO	--	--	--	--
S-6	Epoxy Resin	-.29	-.82	-1.34	YES	--	--	--	--
S-8	Butyrate Polymer	-.20	-.42	-.40	NO	-.41 +.14 (-.14)	-.18 -.14 (-.16)	+.12 +.16 (+.14)	NO
A-1	Reactive Silane	-.27	+.05	+.35	NO	--	--	--	--
A-3	Polymerized Solution of Metal Organic Compounds	-.05	+.07	+.22	NO	--	--	--	--

Designation	Description of Material	Air-Entrained Concrete Freeze-Thaw Cycles				Non-Air-Entrained Concrete Freeze-Thaw Cycles			
		46	102	147	Significant at 95%	46	102	147	Significant at 95%
A-4a	Calcium Chloride Based Water-proofing Agent	-.39 +.28 (-.06)	-.55 +.27 (-.14)	-.76 +.65 (-.06)	NO	--	--	--	--
A-4b*	Calcium Chloride Based Water-proofing Agent	-.15 -.08 (-.12)	-1.10 +.10 (-.50)	-1.23 +.82 (-.20)	NO	--	--	--	--
A-5	Multi-component, Chloride Free, Water Reducing Admixture	-.15 -.08 (-.12)	-1.21 -1.33 (-1.27)	-1.46 -1.56 (-1.51)	YES	--	--	--	--
C-1	Linseed Oil Emulsion (Diluted with 1/3 Water)	+.10 +.58 (+.34)	-.44 -.68 (-.56)	-.40 -.51 (-.46)	NO	-.12 -.26 (-.19)	+.03 +.93 (+.48)	+.14 +.12 (+.13)	NO

*These slabs were dry cured because the manufacturer claims no special curing procedure is necessary.

Designation	Description of Material	Air-Entrained Concrete Freeze-Thaw Cycles				Non-Air-Entrained Concrete Freeze-Thaw Cycles			
		46	102	147	Significant at 95%	46	102	147	Significant at 95%
C-2	Chlorinated Rubber Epoxy	-.07 -.21 (-.14)	-.55 -.88 (-.72)	-.86 -.61 (-.74)	NO	+.70 +.48 (+.59)	+2.06 +.17 (+1.16)	+1.99 +.55 (+1.27)	YES
C-3	Reactive Silane	+.10 -.04 (+.03)	+.01 -.73 (-.36)	+.11 -.87 (-.38)	NO	-.35	-.50	-.64	NO
C-4	Commercial Curing Compound	-.06 -.08 (-.07)	+.08 -.60 (-.26)	0 -.41 (-.20)	NO	+3.27	+3.58	+2.65	YES
C-5	Two Component Epoxy	-.21 -.31 (-.26)	-.60 -.61 (-.60)	-.87 -.85 (-.86)	YES	-.69 -1.17 (-.93)	-.25 -1.43 (-1.34)	+.11 -1.52 (-.70)	NO
C-6	Epoxy Modified Acrylic Polymer	-.10 +.46 (+.18)	-.16 +.10 (-.03)	-.33 +.16 (-.08)	NO	-.37 +1.10 (+.36)	+.83 +1.93 (+1.38)	+.43 +1.77 (+1.10)	YES
C-7	Chlorinated Rubber Curing Compound (Higher Solids Content)	+.10 -.07 (+.02)	+.26 -.28 (-.01)	+1.12 +.40 (+.76)	NO NO	-1.05 +.02 (-.52)	+1.21 +.77 (+.99)	+.29 -.10 (+.10)	NO NO

Designation	Description of Material	Air-Entrained Concrete Freeze-Thaw Cycles				Non-Air-Entrained Concrete Freeze-Thaw Cycles			
		46	102	147	Significant at 95%	46	102	147	Significant at 95%
C-8	Chlorinated Rubber Curing Compound (Lower Solids Content)	-.17 +.09 (-.04)	-.16 -.28 (-.22)	-.33 +.07 (-.13)	NO	0 +.56 (+.28)	+.81 +2.42 (+1.62)	+.39 +1.37 (+.88)	YES
C-0	N.J.Specification Quality White Pigmented Curing Compund	-.07	+.02	-.29	NO	--	--	--	
PA-4 on C-0	Tall Oil & Mineral Spirits Applied Over Curing Compound	+1.46	+1.72	+1.06	NO	--	--	--	--

Designation	Description of Material	Air-Entrained Concrete Freeze-Thaw Cycles				Non-Air-Entrained Concrete Freeze-Thaw Cycles			
		46	102	147	Significant at 95%	46	102	147	Significant at 95%
PA-5 on C-O	Tung Oil & Mineral Spirits Applied Over Curing Compound	-.04	-.14	-.09	NO	--	--	--	--
LO-MS on C-O	Linseed Oil & Mineral Spirits Applied Over Curing Compound	-.04	-.06	+2.03	YES	--	--	--	--

APPENDIX IV

DATA FOR AIR ENTRAINMENT STUDY

AIR-ENTRAINED CONCRETE

Slab Number	Air Level	Scaling Rating
3	5.4	1.25
6	4.2	0.35
9	3.9	1.42
12	4.6	1.03
14	4.8	1.64
32	4.0	1.35
36	4.8	1.60
38	4.8	1.52
45	4.8	0.82
61	3.8	1.82
65	5.2	0.71
69	4.9	0.81
70	4.8	1.29
74	4.6	1.64
97	5.2	2.03
101	4.6	0.75
103	4.8	1.32
152	4.8	1.20
157	5.7	0.81
159	5.4	0.44
164	4.9	0.98
167	4.8	1.12
169	6.0	0.76
172	4.6	0.75
174	4.8	1.32
176	4.5	1.98

NON-AIR-ENTRAINED CONCRETE

Slab Number	Air Level	Scaling Rating
17	1.3	2.08
21	1.3	1.98
23	0.6	1.62
27	2.2	1.38
30	0.6	0.69
48	1.4	1.92
50	1.8	2.29
54	1.0	2.30
57	1.2	2.28
60	2.3	1.94
80	1.6	1.95
82	1.6	2.04
87	2.3	1.61
90	0.8	2.57
107	1.5	3.24
111	1.1	2.45
112	1.5	2.14
121	0.6	1.75
127	1.0	1.82
130	1.0	3.02
132	1.1	3.65
134	0.7	4.86
137	1.1	3.51
142	1.4	2.80
147	1.0	2.35
148	1.0	4.28

CYLINDER STRENGTH (PSI.) VS. AIR LEVEL (%)

WATER/CEMENT RATIO = 5.25 GALS/SACK

CEMENT FACTOR = 6.7 SACKS/C.Y.

CYLINDER STRENGTH	AIR LEVEL	CYLINDER STRENGTH	AIR LEVEL	CYLINDER STRENGTH	AIR LEVEL
4140	3.3	5130	6.0	3570	7.5
5550	3.3	5060	6.0	3400	7.8
5590	3.3	5060	6.0	3080	7.8
5660	3.3	4880	6.0	3430	7.8
6510	3.6	4740	6.4	3310	7.8
6620	3.6	4690	6.4	4100	8.0
6620	3.6	4900	6.4	4210	8.0
6640	3.6	4710	6.4	4480	8.0
5840	3.8	3960	7.0	4170	8.0
5730	3.8	3910	7.0	4120	9.1
5910	3.8	3960	7.0	4490	9.1
5940	3.8	3640	7.0	3930	9.1
5910	5.0	5020	7.2	4170	9.1
5340	5.0	4670	7.2	3030	10.5
5380	5.0	4560	7.2	3040	10.5
6010	5.0	4810	7.2	3040	10.5
4100	5.0	4880	7.5	3010	10.5
5220	5.0	5160	7.5	1980	12.0
5180	5.0	4690	7.5	1930	12.0
4740	5.0	4990	7.5	2040	12.0
5110	5.0	3840	7.5	1880	12.0
5130	5.0	3130	7.5		
4620	5.0	4070	7.5		

APPENDIX V

DATA ON ADDITIONAL FIELD TESTS

Location: Route I-295, Section 7D & 8A

Date: 1974

Placement Method: Conveyor

Finishing Method: Machine Roller Finish (Gomaco)

Test Products:

1. Chlorinated Rubber Epoxy (C-2)
2. Clear epoxy curing compound (Kure-Rite) which was included on one deck at the request of the Central Laboratory because of an impending shortage of the white pigmenting material used in most curing compounds. The average moisture loss (ASTM C-156-65) for two tests was 0.044 grams/sq.cm.

Control Product: One of New Jersey's standard curing compounds, Sealtight WP-60, manufactured by W. R. Meadows, Chicago, Illinois.

Structure	Span	Air Content(%)	Slump(in.)	Curing Material
#2 Bear Swamp Rd.	N.E.	6.2,7.5,6.0,7.3	2,3	Clear Epoxy
	N.W.	5.7	2,2.75	C-2
	S.E.	7.5,7.3	2.75,3,3.5	Control
	S.W.	7.5,7.5	3,3.5	Control
#5 East State St.	N.B.	5.8,5.8,6.2,4.9,7.8	3,3.25,3.5	Control
	S.B.	6.1,5.5,4.5	2.5,2.75,3,3.25	Control
#6 Nottingham Way	N.B. (C-D)	4.9,5.7,6.1,6.0,6.7	3,3.25,3.5	C-2
	N.B.	6.5,5.5,5.2,6.1	2,2.25,3	Control
	S.B.	6.5,5.6,6.3	15,3.25,3.25	Control
	S.B. (Ramp C)	6.2,6.4	2,2.75,3	C-2
#7 Hamilton Ave.	N.B.	7.2,8.1,9.6,9.6,6.6	3.5,2.5	C-2
	N.B. (C-D)	6.6,8.6	2.75,3.25,2.5	Control
	S.B.	6.2,7.2,8.1,6.8,6.7,7.3	3(avg.)	Control
	S.B. (Ramp B)	6.4,6.9	3,2.75	C-2
#9 Klockner Rd.	W.B.	6.5,6.4,6.3,7.0	3.5,3,2.75,3.5	C-2
	E.B.	7.5,6.1,6.3,5.8	2.5,2.75,3,3.75	Control
#10 Cypress Lane	W.B.	5.9,6.0	2,2.5	C-2
	E.B.	6.0,6.1,6.3	2.75,3.25,3.5	Control

APPENDIX VI

AIR METER DATA

Bridge	Air Meter Readings (%) Chace	Pressure	Difference
Beverly-Mt.Holly Road over I295	4.0	5.0	-1.0
	5.4	5.2	0.2
	4.5	4.6	-0.1
	6.3	5.4	0.9
	5.4	5.1	0.3
	4.8	4.8	0.0
I295 over Burlington-Mt.Holly Road	5.5	3.5	2.0
	5.4	5.6	-0.2
	4.1	5.0	-0.9
	5.9	6.0	-0.1
I80 over Waterloo Road	2.7	3.7	-1.0
	4.0	4.2	-0.2
	6.3	5.3	1.0
	4.5	3.4	1.1
	3.2	3.3	-0.1
	2.8	2.7	0.1
	3.6	3.0	0.6

$\overline{X} = 0.153$
$S = 0.792$

$$t = \frac{0.153}{0.792/\sqrt{17}} = 0.797$$

Based on this limited amount of data, there appears to be no statistically significant difference between the readings obtained by the two devices within the range of air-entrainment encompassed by this data.

APPENDIX VII

DEVELOPMENT OF STATISTICAL SIGNIFICANCE CRITERIA

The variability associated with the rating system was relatively easy to determine by having the group make replicate ratings. This was done within a short enough period of time so that no real changes in the slabs occurred, and in a manner which made it extremely unlikely that any rater would be biased by remembering previous ratings. Since the durability rating (test minus control, hereinafter designated T-C) is the parameter of interest, the corresponding durability ratings were calculated for the replicate evaluation. In order to apply the techniques of statistical analysis, a variable of the form $X_i = [(T\text{-}C)_1 - (T\text{-}C_2]_i$ was used in which the subscripts 1 and 2 represent the replicate evaluations and the subscript "i" represents particular treatments. It was theorized and later confirmed by chi-square and "t" tests, that this variable is approximately normally distributed with a mean of zero. Since the durability ratings are averages which are reported to the second decimal place, the distribution will be considered continuous.

The analysis of this particular variable furnished two very important bits of information. First, the mean of zero confirmed the intuitive belief that, even though the rating group might be generally more severe on one day than on some other, there will (on the average) be no effect on the durability ratings which are the differences between two scaling ratings (T-C). That is, if both the T and C values are rated higher (or lower) by about the same amount, the difference (durability rating) will remain about the same. Thus, it is assumed that any possible rating group bias can be ignored. Second, the principle of additive variances enables us to calculate the standard deviation attributable to the rating system (σ_{RS}). The distribution of the difference between two normally distributed variables is also normal with a variance equal to the sum of the variances of the two original variables. This can be expressed mathematically as follows:

$$\sigma_X^2 = \sigma^2_{(T-C)_1} + \sigma^2_{(T-C)_2}$$

Since $(T\text{-}C)_1$ and $(T\text{-}C)_2$ designate the same pair of slabs for the replicate rating tests,

$$\sigma_X^2 = 2\sigma^2_{(T-C)} = 2\sigma^2_{RS} \quad \text{so}$$

$$\sigma_{RS} = \sigma_X / \sqrt{2}$$

σ_X was found to be 0.194 and, from this, σ_{RS} = 0.14 rating units. This implies, for example, that if there is truly no difference between a test slab and its control, the rating group will indicate differences as great as $\pm$ 1.96 σ_{RS} = $\pm$ 0.27 rating units 95 percent of the time. Therefore, a difference of at least $\pm$ 0.27 must be obtained for any particular test before it could be attributed to anything other than the variability of the rating system (at the 95 percent confidence level).

By itself, this is not sufficient information to establish at what level a durability rating is to be judged significant. An additional component of variability which must be accounted for is the variability of the effectiveness of the treatments. The large quantity of treatments being evaluated made it impractical to include enough replicate rest slabs to calculate this parameter accurately for each individual treatment. Instead, it was necessary to use all treatment pairs to estimate an average (pooled) standard deviation for treatment effectiveness (σ_{TE}) which will be assumed to apply to all treatments for the Phase I screening test.

The variable to be used to establish the statistical significance criteria is $X_i = [(T-C)_1 = (T-C)_2]_i$ in which the subscripts 1 and 2 represent the two test slabs upon which treatment "i" was applied. This variable automatically includes the component of variability due to the rating system (σ_{RS}).

Using the data from Appendix III, standard deviations were calculated for each pair of durability ratings. These were then pooled to obtain average values of 0.58 and 0.60 for air-entrained and non-air-entrained concrete, respectively. These were so nearly the same that it was decided to use an average value of 0.59 to establish the critical levels at which durability ratings are judged to be significant.

If there is no real difference between a test and its control, the rating group can be expected to indicate a difference as large as $\pm$ 1.96 x 0.59 = $\pm$ 1.16 rating units 95% of the time. Therefore, at the 95% level of confidence, a single test must achieve a durability rating of at least $\pm$ 1.16 to be considered significant. In most cases, the durability ratings are the average of two tests for which a level of $\pm 1.16/\sqrt{2} = \pm 0.82$ is required to establish significance.

APPENDIX VIII

PROJECT 7732

ANTI-SCALING AGENTS FOR CONCRETE

IDENTIFICATION OF PRODUCTS

TEST DESIGNATION	DESCRIPTION OF MATERIAL	MANUFACTURER AND TRADE NAME
PA-1	Linseed Oil (50% Mineral Spirits)	Archer-Daniels-Midland, "Anti-Spall(SCB)"
PA-2	Fish Oil (50% Mineral Spirits)	Archer-Daniels-Midland, "Anti-Spall(LCP)"
PA-3	Linseed and Fish Oils (50% Mineral Spirits)	Archer-Daniels-Midland "Anti-Spall (SCB-LCP)"
PA-4	Tall Oil (50% Mineral Spirits)	Glidden-Durkee, "Sylvatal 40"
PA-5	Tung Oil (50% Mineral Spirits)	Pan American Tung Oil Development League
PA-6	Emulsifiable Linseed Oil	Sherwin Williams Company
PA-7	Linseed Oil "Special Solvent"	PPG Industries, "Deepgard"

TEST DESIGNATION	DESCRIPTION OF MATERIAL	MANUFACTURER AND TRADE NAME
PA-8	Polysulfide Epoxy	Steelcote Mfg.Co. "PE-50 Penetrating Sealer"
PA-10	Polymerized Solution of Metal Organic Compounds	E.A.Thompson Co., "Waterseal No.101"
PA-12	Soybean Oil (50% Mineral Spirits)	Drew Chemical Co.
PA-12	Soybean Oil (Uncut)	Drew Chemical Co.
PA-13	Castor Oil (50% Mineral Spirits)	Baker Castor Oil Company
PA-13	Castor Oil (Uncut)	Baker Castor Oil Company
PA-14	Linseed Oil (Uncut)	
PA-15	Chlorinated Rubber Epoxy	T-K Products, "Tri-Kote 18"
PA-17	Chemstop Waterproofing Compound	Chemstop Mfg.Co., Waterproofing
PA-18	Penetrating Epoxy	Steelcote Mfg.Co., "161-C-101 Penetrating Sealer"
S-1	Tar-Based Sealer	Koppers Co.,Inc.
S-2	Resin-Based Sealer	Koppers Co.,Inc.
S-3	Styrene Butadiene	Atlas Minerals & Chemicals Div., "Zerok 110"

TEST DESIGNATION	DESCRIPTION OF MATERIAL	MANUFACTURER AND TRADE NAME
S-4	Urethane	Atlas Minerals & Chemicals Div., "Sealer 233-75B"
S-5	Furan Resin	Atlas Minerals & Chemicals Div., "Sealer 233-75C"
S-6	Epoxy Resin	Atlas Minerals & Chemicals Div., "Sealer 233-75D"
S-8	Butyrate Polymer	Atlantic Barrier Corp. Barrier Type B"
A-1	Reactive Silane	Dow Corning, "777B Concrete Admixture"
A-3	Polymerized Solution of Metal Organic Compounds	E.A.Thompson Co., "Water Seal"
A-4	Calcium Chloride Based Waterproofing Agent	Anti-Hydro Waterproofing Co., "Anti-Hydro"
A-5	Multi-Component, Chloride Free, Water Reducing Admixture	Master Builders Co., "Pozzolith 200-N"
C-1	Linseed Oil Emulsion(Diluted with 1/3 Water)	National Flaxseed Producers Assn.
C-2	Chlorinated Rubber Epoxy	T-K Products Tri-Kote 26(g)
C-3	Reactive Silane	Dow Corning "XR-6-5046 Resin"
C-4	Masters Builders Curing Compound	Master Builders Co., Masterseal

TEST DESIGNATION	DESCRIPTION OF MATERIAL	MANUFACTURER AND TRADE NAME
C-5	Two Component Epoxy	Sika Chemical Co., "Colma Membrane"
C-6	Epoxy Modified Acrylic Polymer	Cement Materials Corp. "Seal-Cure"
C-7	Chlorinated Rubber Curing Compound(Higher Solids Content)	W.R. Grace, "Horn Clearseal"
C-8	Chlorinated Rubber Curing Compound(Lower Solids Content)	W.R. Grace, "Horn Clearseal 150"
C-0	N.J. Specification quality white pigmented curing compound	Orion Membrane Curing Compound
PA-4 on C-0	Tall oil and mineral spirits on Orion Membrane curing compound	
PA-5 on C-0	Tung oil and mineral spirits on Orion Membrane curing compound	
LO-MS on C-0	Linseed oil and mineral spirits on Orion Membrane curing compound	