Development of a Concrete Admixture to Improve Freeze-Thaw Durability

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A study to determine the effect of various silicone admixtures on the resistance of concrete to freeze-thaw conditions has resulted in the development of a new silicone admixture (Dow Corning 777).

The most important improvement with the use of this admixture is the increase in resistance of concrete to the action of freezing and thawing in the presence of deicing chemicals. Using the Conrad rapid-cycle freeze-thaw test apparatus, specimens were continuously exposed in the presence of a 10 percent sodium chloride solution. The concrete specimens containing the admixture showed more than 50 percent improvement in durability compared with air-entrained control specimens. Scaling slab specimens continuously exposed to 2 percent sodium chloride and undergoing one freeze-thaw cycle per day also show good improvement in scaling resistance. Other improvements include increases in compressive strength, flexural strength, and bond to reinforcing steel. Although the admixture produces extended set times in concrete, field trials have indicated that successful placement is easily accomplished using standard techniques.

•SEVERAL YEARS ago it was discovered that the addition of certain silicon compounds to concrete would contribute to the freeze-thaw durability. This led to a study of the freeze-thaw properties of concrete and of methods of determining if any one of a wide variety of silicone chemicals could be used to improve concrete durability under very severe freeze-thaw conditions in the presence of ice-melting salts. Many silicones and silicon chemicals were tested as additives and one organo-siloxane material appeared most beneficial.

This new material is a unique compound from the family of chemical substances broadly identified as silicones. It bears no direct relationship, however, to the earlier types of silicones used as surface-applied water repellants or those materials initially tried as admixtures, many of which have been previously reported. For purposes of identification, this new admixture will be referred to here as "the silicone admixture." Besides improving freeze-thaw resistance, this new product provides substantial increases in compressive and flexural strengths and improves bond to reinforcing steel.

CONCRETE MATERIALS AND DESIGN

A considerable amount of study and care was devoted to selecting, preparing and proportioning all components used in the test program to eliminate as far as possible the usual variables due to non-uniformity of materials. Freeze-thaw durability, as well as other important physical properties, depends greatly on the care exercised in preparing the concrete.

Aggregates

Because of their high chemical purity traprock from New York State and Long Island silica sand were chosen as aggregates for this program. Both the coarse and fine aggre-

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TABLE 1

PROPORTIONS BY SIZE OF AGGREGATES USED

Aggregate	Proportion (% by wt)										
	1½-1 In.	1-¾ In.	¾-½ In.	½-⅜ In.	⅜ In.-No. 4	Nos. 4-8	Nos. 8-16	Nos. 16-30	Nos. 30-50	Nos. 50-100	Nos. 100-200
N. Y. traprock	5	20	30	15	25	5	—	—	—	—	—
L. I. sand	—	—	—	—	2	15	20	20	20	15	8

TABLE 2

CHEMICAL ANALYSIS OF AGGREGATES

Components	Percent	
	N. Y. Traprock	L. I. Sand
SiO_2	53.73	95.98
Al_2O_3	13.13	1.34
FeO	10.14	—
Fe_2O_3	2.65	0.55
CaO	9.09	0.19
MgO	4.78	0.28
Na_2O	3.25	0.20
K_2O	1.12	0.15
SO_3	0.01	—
CO_2	0.33	—
S	0.027	—
TiO_2	—	0.27
ZnO_2	—	0.34
Cr_2O_3	—	0.03
MnO_2	—	0.18
Organic C	0.01	—
Total C	0.10	—
Loss on ignition	0.53	0.24

TABLE 3

ANALYSIS OF BRAND E CEMENT[a]

Components	%
SiO_2	22.04
Fe_2O_3	2.36
Al_2O_3	4.62
CaO	62.94
MgO	2.72
SO_3	2.33
Ignition loss	1.80
Total	98.81
Free CaO	0.54
Alkalies as:	
Na_2O	0.30
K_2O	0.65
Total as Na_2O	0.73
Corrected calulated compound composition:	
C_3S	45.4
C_2S	29.0
C_3A	8.3
C_4AF	7.2
$CaSO_4$	4.0

[a]Blaine fineness, 3,290 sq cm/gm.

gates were dried, screened to size, and then remixed in predetermined proportions for each batch (Table 1). This procedure assured an accurate and uniform gradation between batches throughout the test program. Chemical analyses of the aggregates are given in Table 2.

Cement

Different brands of cement exhibit considerable variation in freeze-thaw durability and other physical properties. For this reason, the cement used in the program was purchased in quantities of 20 to 40 bbl to eliminate this variable throughout a given test series. The cement was stored in air-tight steel drums and used within a 6-mo period. Most of the results presented were obtained using cement Brand E. A chemical analysis of this cement is presented in Table 3.

Mix Design

Concrete designs were calculated using the recommended procedure outlined by the American Concrete Institute (ACI 613-54). A 6.32 sk/cu yd mix was used in most basic testing. Quantities used to produce 1 yd of concrete with this design are 593 lb cement,

1,880 lb coarse aggregate (traprock), 1,305 lb fine aggregate (silica sand), and 290 lb water (w/c = 0.49). The aggregate weights are on a dry basis.

PREPARATION OF TEST SPECIMENS

Mixing

Each batch of concrete was made by placing the stone, sand, and cement in a rotating inclined drum-type mixer with a rated capacity of 1¼ cu ft. The mortar content of the batch design was increased by 4 percent. This amount of mortar was found to adhere to the sides of the mixer after placing, allowing a more rapid preparation of concrete containing different admixtures because it was not necessary to "butter" the mixer before each pour. Sand, stone, and cement were dry blended for 2 min. Then admixture and water were added in amounts sufficient to give a 2- to 3-in. slump. A final wet mix of 5 min was given, with any required adjustment of water being made during the first 2 min. After mixing, the concrete was placed in a wheelbarrow and slowly agitated with a mortar hoe while slump and air (ASTM C-231) measurements were taken. Test specimens were then fabricated.

Freeze-Thaw Samples

Rapid-cycle freeze-thaw test specimens were prepared in 3- by 4- by 16-in. molds following procedures outlined in ASTM C-192. The test bars were cured in the mold for 3 days at 100 percent RH and 70 to 75 F. They were then removed from the molds and cured for an additional 11 days under the same conditions. Before freeze-thaw testing, the bars were removed from the humidity room and soaked for 16 hr in the solution in which they were to be tested.

Slow-cycle specimens were also formed according to ASTM C-192; however, the mold was somewhat smaller (7 by 4 by 2¼ in.). The slabs were cured for 7 days at 100 percent RH and then an additional 7 days at laboratory conditions. During the latter period, an aluminum weir was fastened around the perimeter of the specimen so that a ½-in. depth of solution could be retained on the screeded surface. The weir was fastened with room-temperature vulcanizing silicone rubber.

TESTING PROCEDURES

Rapid-Cycle Method

The most frequently used rapid-cycle freeze-thaw tests are freeze in air—thaw in water and freeze in water—thaw in water. Because deterioration of concrete is often associated with deicing salts, tests in salt solutions should also be considered. Samples of liquid, therefore, were taken from the wet surfaces of bridge decks and roadways to obtain some measure of the actual salt exposure. These samples were analyzed for NaCl content and the results are shown in Table 4. The continued evaporation of water from any given area can cause a variation in salt content from very dilute to very concentrated, depending on when the sample was taken. In view of the salt content revealed by these tests, it was decided to evaluate durability by the following rapid-cycle test methods:

1. Freeze in air and thaw in water (ASTM C-291),
2. Freeze and thaw in water (ASTM C-290),
3. Freeze and thaw in 2 percent NaCl solution, and
4. Freeze and thaw in 10 percent NaCl solution.

Freeze and thaw testing in water caused the containers used in the test machines to burst along the seams. Severe deformation of the cans occurred within the first 30 cycles. Because water expands approximately 10 percent during freezing, extreme pressures were being exerted on the test specimens as well as the containers. In all cases, pressure developed in the cans caused the specimens to fracture prematurely within a few cycles. Because all specimens failed before any surface deterioration took place, this test could not be used to measure freeze-thaw durability when run in rigid containers.

TABLE 4

SALT CONTENT OF LIQUID SAMPLES FROM BRIDGE AND ROADWAY SURFACES

Sample Source	NaCl[a]
Heavily traveled city bridge	9.1
	8.6
Expressway bridge	1.6
	0.9
	2.9
	2.4
Expressway catwalk	2.0
Expressway exit	1.5
Expressway roadway	2.7
Expressway entrance	3.2
	1.1
Expressway shoulder	2.5
Municipal street	1.6
Suburban intersection	0.1

[a] Analysis by chloride content; all trace chlorides are computed as NaCl. Analysis for calcium ion showed only trace amounts.

Experimentation with various containers revealed that the problem of testing in water could be solved by removing from the can a portion of one vertical corner and replacing it with a corner made of Silastic silicone rubber, which remains elastic at sub-zero temperatures. With this modification, compressive forces on the test specimen were eliminated and deterioration could be studied without premature cracking. Freeze-thaw testing in 10 percent salt solutions did not require the use of a diaphragm container.

Slow-Cycle Scaling Slab Test

This method was used to study scaling properties of the finished surface only. A 2 percent NaCl solution was placed on the surface and the slab was frozen overnight (16 hr) at -17 F in a vertical household freezer. During the day (8 hr) the freezer was turned off, the doors opened, and the specimens allowed to thaw at room temperature. The 2 percent salt solution was used in most scaling slab tests to secure a rapid rate of deterioration (1). The salt solution was left in continuous contact with the surface and replenished as needed. Once each week the specimens were rinsed with water, examined, and the degree of deterioration recorded against a 10 point reference scale (2). Fresh solution was placed on the surface after each reading (every 5 cycles).

Rapid-Cycle Scaling Slab Test

A rapid-cycle scaling slab test was developed because of the need for studying surface deterioration under something other than 2 percent salt solution. A portion of a Conrad rapid-cycle freeze-thaw machine was modified to accept scaling slab specimens. Test slabs were the same as those previously used in the slow-cycle test. They were sealed in polyethylene bags with water, 2 or 10 percent salt solutions on the surface and allowed to cycle between 0 and 40 F. Once each week (every 41 cycles) the slabs were examined, flushed with water, and rated for scaling condition.

Other Tests

Several other concrete properties were examined using ASTM recommended procedures as follows:

1. Procter set time (ASTM C-403),
2. Shrinkage on 1- by 1- by 10-in. mortar bars (ASTM C-226),
3. Compressive strength on 4- by 8-in. cylinders (ASTM C-39),
4. Flexural strength (ASTM C-293), and
5. Bond to reinforcing steel with failure taken at maximum load (ASTM C-234).

The rate of slump decrease was also measured. Slump measurements were taken in the laboratory at regular intervals until they reached zero. Before each slump test was made, the concrete was remixed for 15 sec to insure homogeneity.

DISCUSSION OF TEST RESULTS

Concrete with the silicone admixture was compared with air-entrained concrete by the four methods previously described under testing procedures.

The results in Table 5 show that the silicone-admixed concrete is superior to air-

TABLE 5

DURABILITY OF CONCRETE SUBJECTED TO RAPID FREEZE-THAW TESTS[a]

Type of Concrete	Air Content (%)	Number of Cycles Until Failure[b]			
		Method 1	Method 2	Method 3	Method 4
Non-air-entrained	1.5	50S	27S	16S	29S
Air-entrained	4.9	> 1,500	225W	150W	250W
	7.6	—	260W	140W	310W
0.3% silicone admixture	5.5	> 1,500	610W	230W	413W

[a]Based on average of three specimens; diaphragm containers used except in Method 1 which does not used containers.
[b]S = failure in sonic modulus (i.e., drop to 60% of the original value); W = denotes failure by 5 percent weight loss (5 percent adopted because surface deterioration was such as to be considered general surface failure).

entrained concrete when tested in water or salt solutions. It also is unaffected by the freeze in air—thaw in water test, further indicating excellent durability.

From this test work, freezing and thawing in 10 percent salt solution was selected as the basic test procedure because it embodied more clearly certain criteria believed necessary to indicate improved durability. This method differentiates between different air levels and produces the general type of surface failure seen in the field. It also incorporates the use of salt known to be present on highway concrete throughout the seasons when freezing and thawing occur.

Rapid Freeze-Thaw Tests With Traprock

During the development of the silicone admixture, several hundred specimens were tested by the rapid freeze-thaw method in 10 percent salt solutions and compared with air-entrained concrete. These tests have shown that both 5 percent air-entrained and admixed concretes fail by a progressive erosion of the exposed surface. Failure (5 percent weight loss) occurred much more slowly, however, when the silicone was used as an integral admixture. In freeze-thaw testing, exact duplication of results from batch to batch could not be obtained. Even with a careful reblending of seven sizes of silica sand and six sizes of traprock for each batch, there was still a considerable scattering of data. Due to this, it was felt that a probability curve would be the most realistic means of presenting a large number of freeze-thaw results.

Figure 1 shows the probability curve developed for both air-entrained and admixed concretes. The mean values of the two curves (probability = 0.5) show air-entrained and admixed concretes have average durabilities of 250 and 560 cycles, respectively. This indicates that about a 120 percent increase in freeze-thaw durability can be expected when the silicone is used as an admixture. A regression analysis of the data used to obtain the probability curve showed that the resistance of the admixed concrete to freeze-thaw deterioration in 10 percent NaCl solution is primarily a function of silicone concentration and not air content.

Effect of Silicone Admixture on Freeze-Thaw Durability of Various Brands of Cement

Because the supply of cement purchased at one time lasted only 6 mo, it was necessary to change cements occasionally. In changing from lot to lot, it was noticed that all cements, even when of the same brand, did not have the same freeze-thaw durability. Figure 2 shows results obtained with several different brands of cement.

Although all cements did not have the same freeze-thaw durability, the improvement produced by the admixture was of the same order of magnitude in each case. These

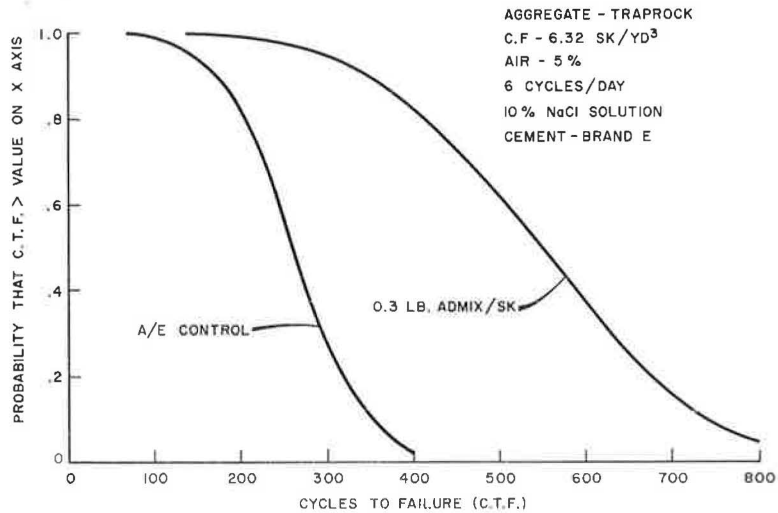

Figure 1. Probability vs cycles to failure.

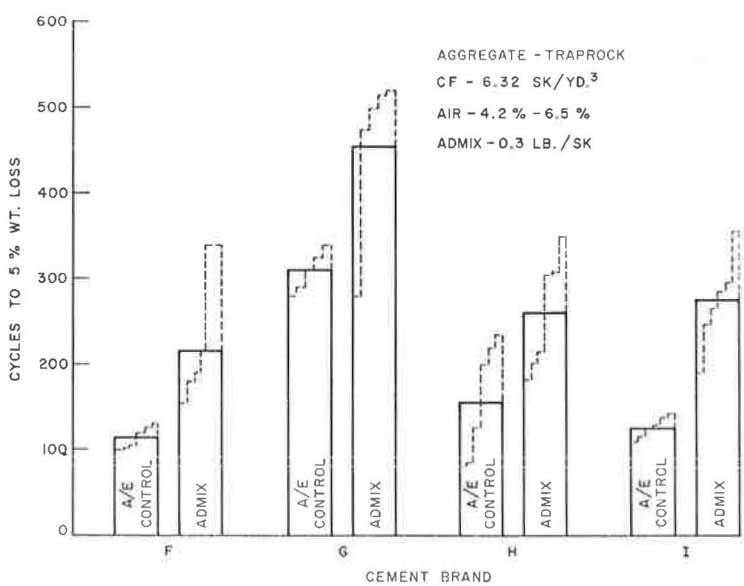

Figure 2. Cycles to 5 percent weight loss vs cement brand.

data indicate that the improved resistance to freeze-thaw in 10 percent salt solution is not peculiar to a given brand of cement.

Effect of Silicone Admixture on Durability of Concrete With Different Cement Factors

Using traprock and silica sand, concrete batches were designed with cement factors of 4, $5\frac{1}{2}$, and 7 sk/cu yd. Figure 3 shows the results obtained with concrete having these cement factors and freeze-thaw tested in 10 percent salt solution. It should be noted that in every case the freeze-thaw durability is increased when the silicone admixture is used.

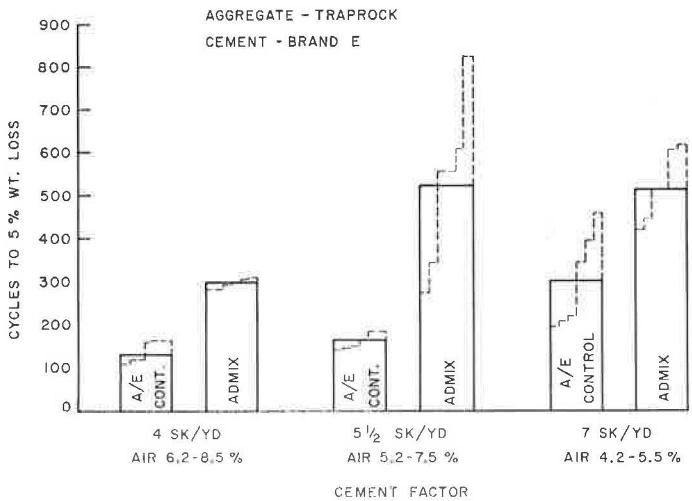

Figure 3. Cycles to 5 percent weight loss vs cement factor.

The addition of 0.3 percent of the silicone admixture improved the durability of a 4-sk design to the point where it is equal to that of a 7-sk air-entrained concrete. However, the reduction of cement content when the admixture is used is not recommended. A large reduction in cement factor would not permit the manufacture of higher quality concrete and this would defeat the purpose of using the silicone admixture. For instance, other properties of concrete, such as abrasion, are of significant importance, and these must also be considered in the selection of the cement factor. These data indicate the admixture can be used in concretes of both high and low cement factor to produce a building material that may be more durable and may require less maintenance than a conventional concrete.

Slow Freeze-Thaw Scaling Slab Tests

Surface scaling observations made on the rapid freeze-thaw test bars indicated that the silicone admixture greatly improved the scaling resistance of the screeded surface. To further evaluate this property, scaling slab tests were run with a 2 percent salt solution as corollaries to the rapid freeze-thaw test.

Figure 4 shows curves of surface scaling rating vs freeze-thaw cycles for air-entrained and admixed concrete. The most rapid rate of deterioration occurs during the first 20 cycles; after this the rate of deterioration is much slower. Concrete containing the admixture shows much improved resistance to scaling in the presence of de-icing salts. The admixed specimens at 85 cycles showed less scaling than the air-entrained specimens at 10 cycles. This indicates that about 700 to 800 percent increase in scaling resistance might be expected when the silicone admixture is used.

Scaling slabs were also fabricated from concrete containing different cements. Results of freeze-thaw testing of these slabs are shown in Figures 5 to 8. These curves on the four different cements show the same trend noticed in the Conrad rapid freeze-thaw equipment. Not all cements have the same degree of scale resistance when subjected to slow freeze-thaw under a 2 percent NaCl solution, but the use of the silicone admixture has produced relatively scale-free concrete with all brands of Type I cement used.

Rapid Freeze-Thaw Scaling Slab Test

By modifying a portion of one Conrad machine, rapid-cycle scaling slab tests were run with 2 and 10 percent salt solutions on the surfaces. Figures 9 and 10 depict the

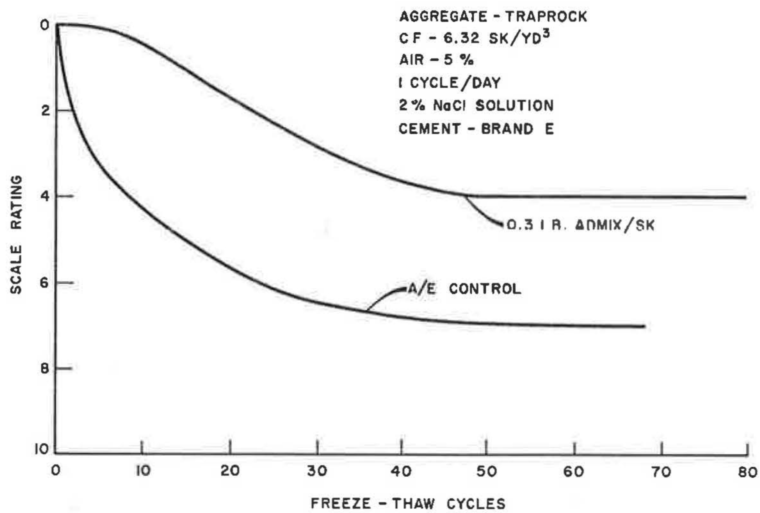

Figure 4. Scale rating vs freeze-thaw cycles.

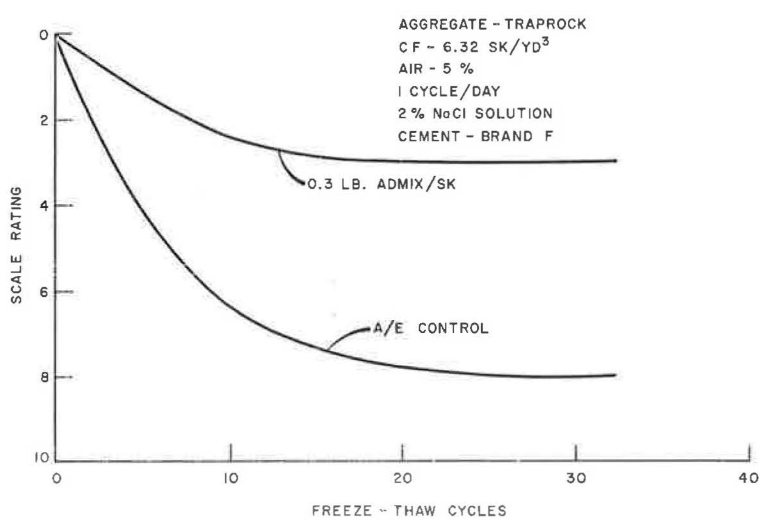

Figure 5. Scale rating vs freeze-thaw cycles.

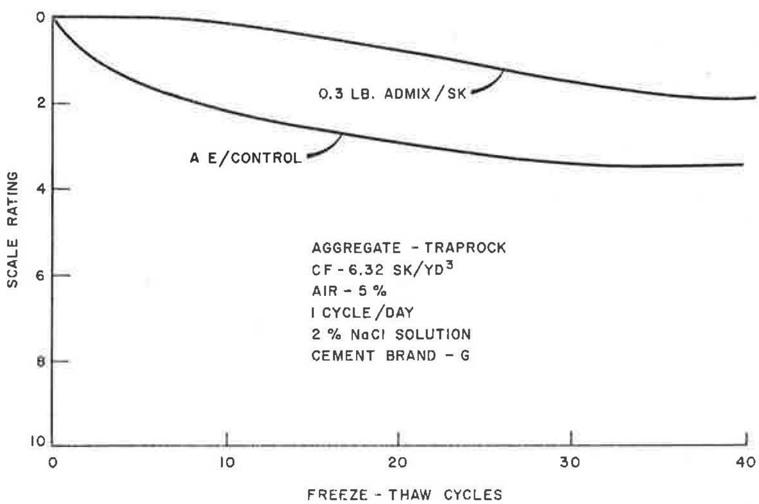

Figure 6. Scale rating vs freeze-thaw cycles.

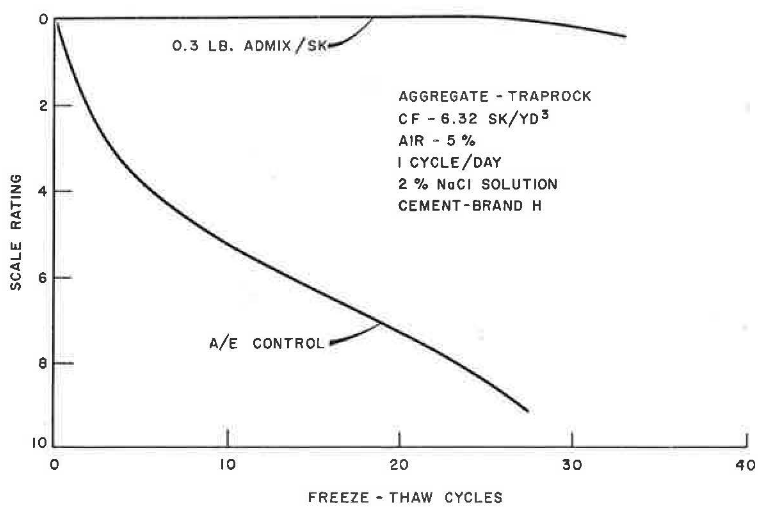

Figure 7. Scale rating vs freeze-thaw cycles.

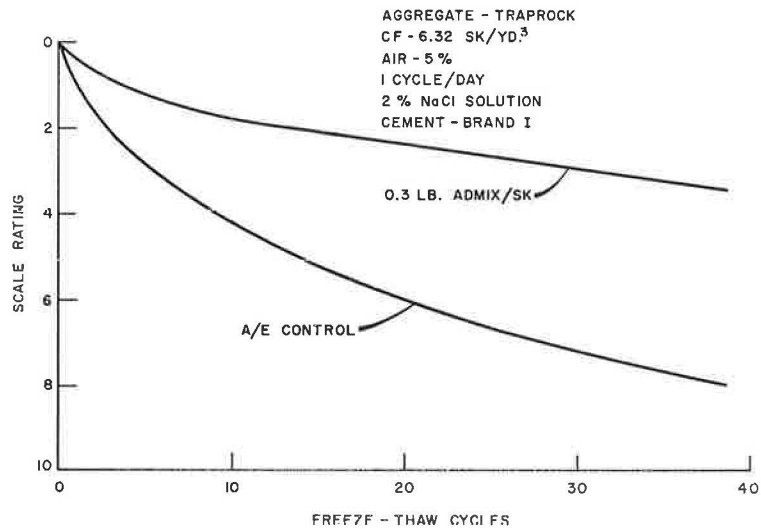

Figure 8. Scale rating vs freeze-thaw cycles.

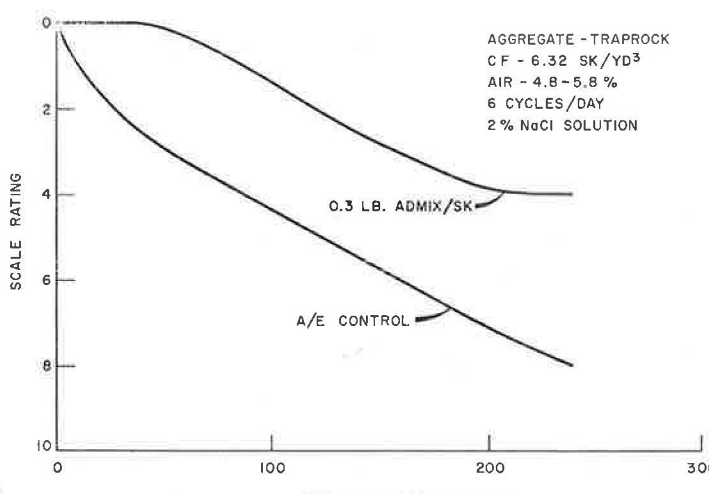

Figure 9. Scale rating vs freeze-thaw cycles.

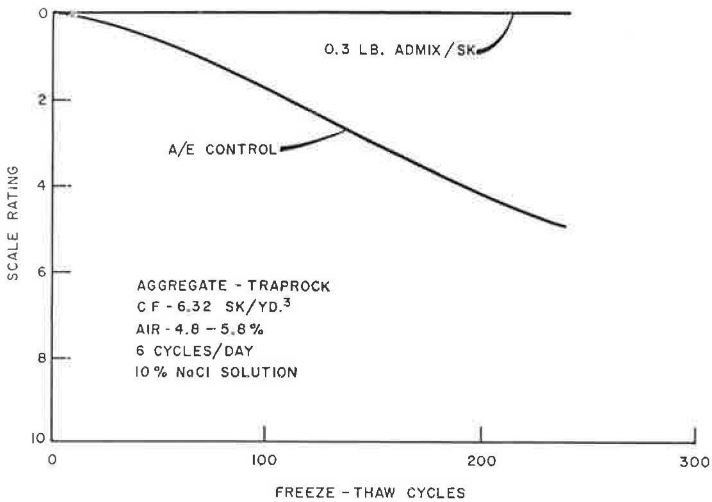

Figure 10. Scale rating vs freeze-thaw cycles.

results of these tests. The relative rates of deterioration are quite slow when the slabs are run with 10 percent salt solution on the surface, whereas deterioration under a 2 percent salt concentration is relatively rapid. The rate of concrete deterioration is much slower than with the slow-cycle test, indicating that a faster rate of freezing over a small temperature range (0 to 40 F) is less severe than a slower rate of freezing over a large temperature range (- 17 to + 70 F). In each of the freeze-thaw test methods evaluated in this report, the use of the silicone admixture has definitely improved the resistance of concrete to surface scaling over standard air-entrained concrete.

Effect of Admixture on Other Properties

Set Time—Proctor Penetrometer. —Incorporation of the silicone admixture extends the set time of concrete. A series of set times (Proctor set time, ASTM C-403) were run at 40, 60, and 100 F to compare the set times of air-entrained concrete with concrete containing the admixture (Figs. 11, 12, 13). Initial set times are delayed by several hours, depending on the ambient temperatures. Amines, hydroxides, carbonates, calcium chloride and other set accelerators have been evaluated in an effort to reduce the set time of the admixed concrete. At the present time there is no known accelerator that will shorten set time without a reduction of durability of the admixed concrete.

Slump Characteristics. —Another important property of concrete is the manner in which the consistency (as measured by the slump test) varies as a function of time. This was determined in the laboratory for both silicone admixed and air-entrained control concretes. The results show there is little difference between the admixed and air-entrained control concretes in the manner in which slump decreases over a period of time (Fig. 14). The Proctor set time test shows approximately a three- to five-fold increase in set time. The slump characteristics appear to be very similar to air-entrained concrete.

Compressive Strength. —When the silicone is admixed with concrete, the compressive strength is increased. Compressive strength tests were conducted on 4- by 8-in. cylinders in accordance with ASTM Method C-39. A normal distribution of data was observed. A typical S-shaped probability curve was generated when frequency vs 28-day compressive strength was plotted (Fig. 15). There is a 25 percent increase in mean compressive strength value with the silicone admixture. This compressive strength increase is not a result of a significant decrease in water to cement ratio.

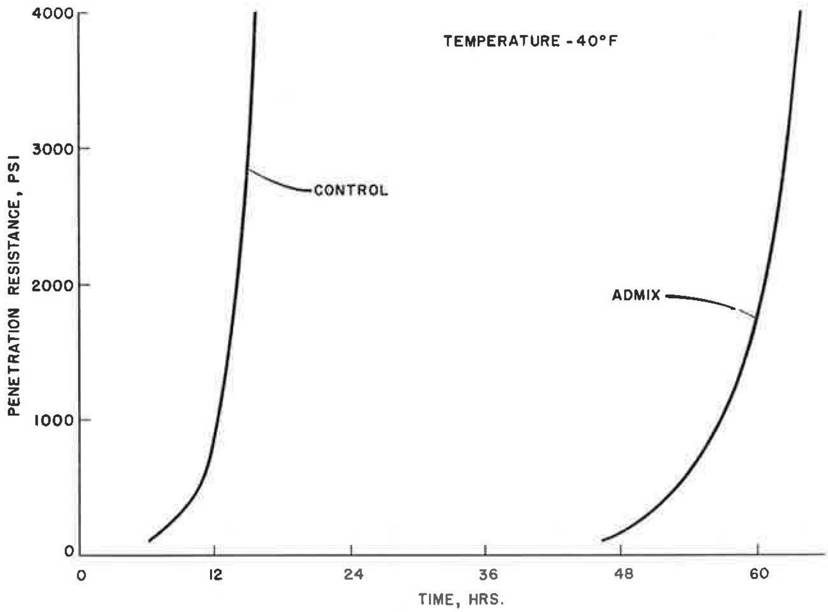

Figure 11. Penetration resistance vs time, hr.

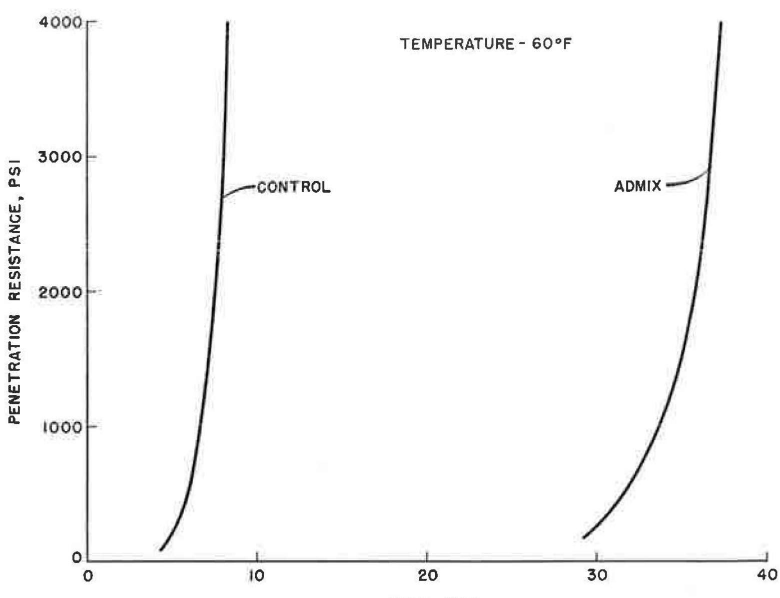

Figure 12. Penetration resistance vs time, hr.

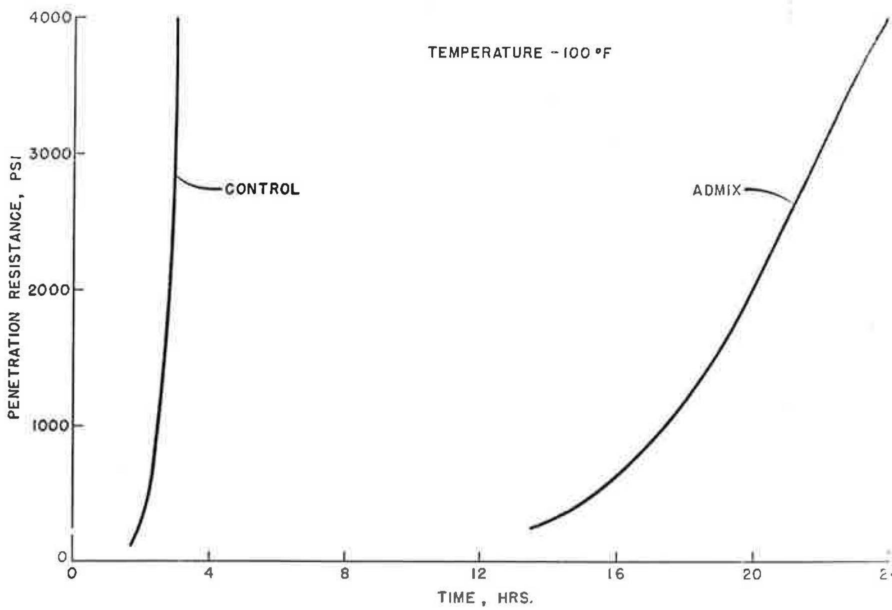

Figure 13. Penetration resistance vs time, hr.

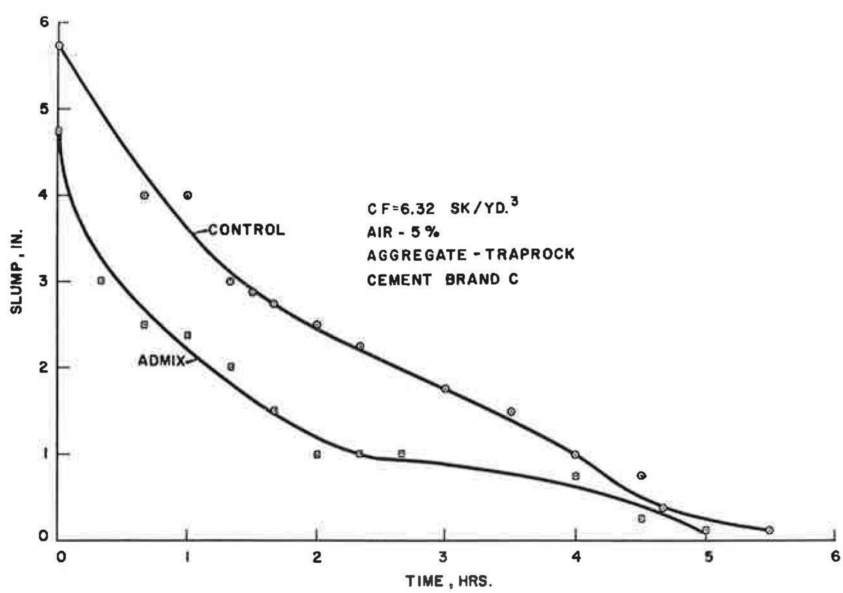

Figure 14. Slump vs time.

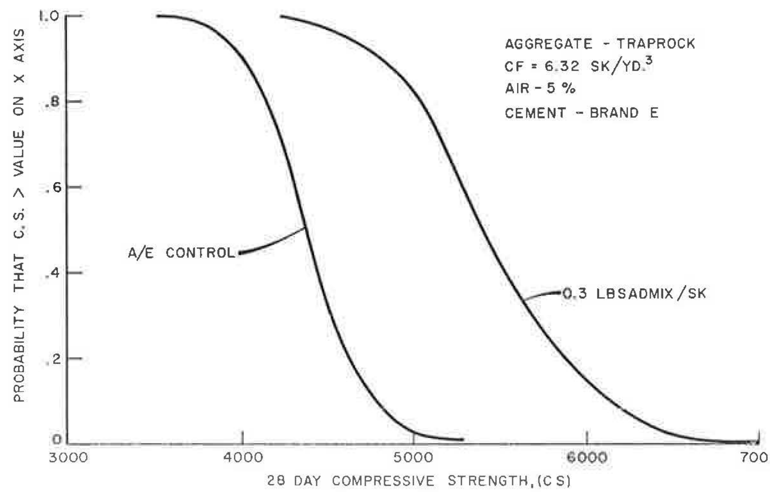

Figure 15. Probability vs 28-day compressive strength.

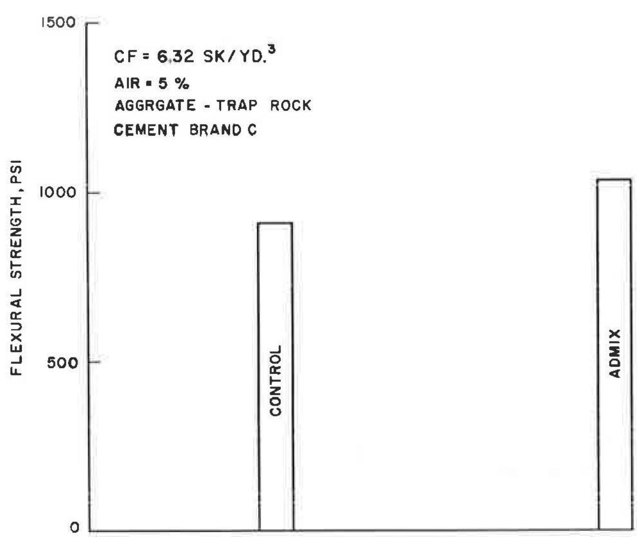

Figure 16. Flexural strength, control vs admix.

Flexural Strength. —Flexural strength is improved approximately 10 percent by the silicone admixture (Fig. 16).

Bond to Reinforcing Steel. —Bond to reinforcing steel was run according to ASTM C-234. Failure was taken at the maximum load the bond could support; slippage measurements were not made. Results of bond strength tests with admixed concrete are shown in Figure 17. The average increase in ultimate bond strength for admixed concrete is about 65 percent over an air-entrained control using a traprock aggregate system.

Shrinkage. —Shrinkage studies showed little difference between admixed and control samples (Table 6). The mortar bars were made in conformity with ASTM C-226. The shrinkage measurements were run for the first 28 days at 100 percent RH and for an additional 28 days at 50 percent RH.

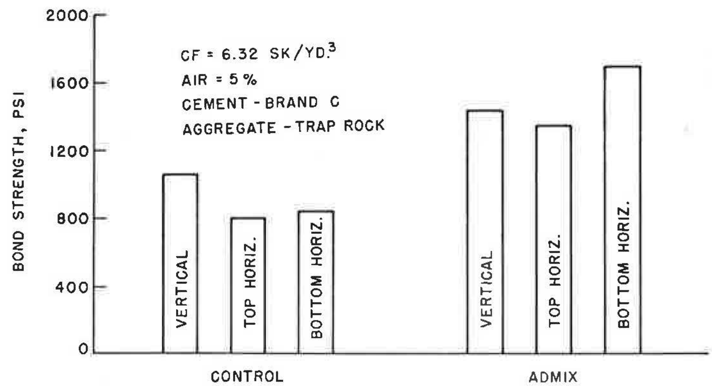

Figure 17. Bond strength, control vs admix.

Field Tests

During the summer of 1963 full-scale field trials were conducted. The first use of the silicone admixture in a significantly large test was at the Dow Corning plant at Elizabethtown, Ky. Over 100 yd of admixed concrete have been placed in areas such as shipping and receiving docks, tank farms, cooling water spray ponds, footings, and retaining walls. Air-entrained control areas have been placed in all cases in close proximity to the experiment.

Several field trials have been made on bridge decks, highway curbing and concrete guardrails. These tests were made in cooperation with various State highway departments. Each field trial has been thoroughly documented with air, slump, and strength measurements for each load of concrete used. In addition, freeze-thaw specimens have been made from each load of concrete and will be freeze-thaw tested in the laboratory.

Early strength figures look excellent on these field pours. Of course, durability of the concrete can only be conclusively determined after some appreciable service life. A complete report is not possible at this time.

TABLE 6

SHRINKAGE OF ADMIXED VS CONTROL CONCRETE

Aging Time (days)	Shrinkage (%) Control	Shrinkage (%) 3% Admixture
(a) Cured at 100% RH		
2	+ 0.007	+ 0.009
7	+ 0.011	+ 0.022
14	+ 0.010	+ 0.024
28	+ 0.013	+ 0.030
(b) Cured at 50% RH[a]		
7	- 0.037	- 0.033
14	- 0.053	- 0.051
28	- 0.070	- 0.063

[a]After 28 days at 100% RH.

CONCLUSIONS

Concrete prepared under procedures outlined in this report and freeze-thaw tested with the described rapid-cycle and slow-cycle methods leads to the following conclusions:

1. The silicone, when admixed with concrete at the rate of 0.3 lb/sk, will cause average freeze-thaw durability increases of 120 percent in mixes carefully formulated with traprock aggregate and Long Island silica sand.
2. The primary freeze-thaw test used was a rapid-cycle procedure in 10 percent NaCl solution. This durability increase is of the same general order of magnitude when run in water or 2 percent NaCl solution.
3. The admixture increases the freeze-thaw durability of concrete made with different brands of cement, indicating that its function is not peculiar to any cement brand.
4. Tests of concrete at cement factors of 4, 5.5, 6.3, and 7 sk/yd indicate that the admixture improves freeze-thaw durability of concrete made with low, intermediate and high cement factors.
5. The type of deterioration produced by rapid-cycle tests in water and salt solutions

was a progressive erosion of the concrete surfaces determined by both a visual rating and a weight loss measurement. Structural failure did not occur when the admixture was used and appeared only on control concrete of air content less than 4 percent.

6. Slow-cycle scaling slab test results with 2 percent salt solution on the surface were in close agreement with rapid-cycle tests. The rate of deterioration was much more rapid due to the difference in testing procedure, but the type of deterioration was the same. Scaling slab tests show the silicone admixture increases freeze-thaw resistance when used with the different cement brands and at various cement factors.

Other properties of concrete affected by the silicone admixture are summarized as follows:

1. The set time, as measured by the Proctor penetrometer, is three to five times longer than a conventional concrete. Measurement of slump change with time and field experience indicates that admixed concrete has good handling properties.
2. Compressive strength advantages are not the same for all cement brands and factors tested, but in all cases a compressive strength increase can be expected from the admixed concrete.
3. The admixture increases bond to reinforcing steel approximately 65 percent and flexural strength by 10 percent.

Shrinkage does not appear to be greatly affected when the admixture is used.

REFERENCES

1. Verbeck, G. J., and Klieger, P., "Studies of 'Salt' Scaling of Concrete." HRB Bull. 150, pp. 1-13 (1957).
2. Public Roads, 28(7).

Discussion

P. SMITH and J. RYELL, respectively, Senior Materials Engineer (Concrete) and Concrete Testing Engineer, Materials and Research Division, Ontario Department of Highways. —Field trials are, of course, essential to any new concrete material or process. It may be worth mentioning a limited field trial undertaken in the fall of 1963, in co-operation with the authors, on a section of concrete curb and gutter at the junction of Highway 403 and the Queen Elizabeth Way some 30 west of Toronto, Ontario.

Approximately 1,000 lin ft of curb and gutter were split into random sections, alternating between the silicone admixture and the control air-entrained concrete in 5 cu yd loads of ready-mixed concrete. The concrete had a cement factor of 525 lb/cu yd, a slump of 2½ in. and used gravel aggregate of ¾-in. nominal maximum size and a well-graded natural sand.

The following was observed in this field trial, which might not be obvious from a laboratory evaluation:

1. The air content of the concrete after 15 min of mixing was approximately 5 percent; at the time of discharge this had dropped to less than 3 percent. Microscopic examination of the hardened concrete with 3 percent air content indicated that the spacing factor was slightly greater than 0.01. Thus, silicone concrete under field conditions might have a much less favorable air-void system than laboratory mixed concrete.
2. The mix containing the silicone admixture proved very difficult to finish in the curb and gutter section. This was no doubt partly due to the low air content, but the mix itself lacked the cohesiveness necessary for float finishing. The initial sand content was 40 percent; increasing this to 44 percent near the end of the trial section did not overcome this problem.

3. This particular silicone is a retarder. The initial set of the concrete (500 psi Proctor) occurred at 33½ hr, compared with 7 hr for the control mix. Considerations of extended curing, formwork pressures removal, opening to traffic, and possible damage by rain or freezing limit this type of concrete for some field uses.

4. The water reduction properties of the silicone admixture are approximately equal to that of a good lignosulfonate admixture with an air-entraining agent.

5. Four sets of standard test cylinders were made from both the silicone concrete and the control concrete. The control mix contained a lignosulfonate admixture; cement content of both mixes was 525 lb/cu yd concrete. The mean 28-day strength of the cylinders from the silicone mix was 7,070 psi; the mean 28-day strength of the control mix was 4,630 psi.

It may, therefore, be proper to ask if the promised advantages in strength gain and durability outweigh the problems encountered. Of the problems, those of retardation and difficulty of finishing might appear critical in acceptance of this class of admixture. Of the advantages, those of increased strength and durability might be considerable if, taking these into account, the concrete is no more expensive or any premium is worth the gains. Here the critical question must be—is normal air entraining, properly executed, inadequate to provide durability? In the discussors' experience it is adequate, but they wonder if the authors' experience is to the contrary. Problems with air entraining usually turn out to be traceable to acts of omission, such as not adding the agent or not checking the air content of the concrete at the time of placing. There seems to be no reason why a silicone admixture should not be just as vulnerable to a failing of man or dispenser.

B. C. CARLSON, R. C. HEDLUND, and D. F. CURTIS, Closure. —In the field trial in Ontario to which the discussors refer, there was, in some instances, a loss of entrained air from the time the concrete was mixed at the batch plant until it was received at the job site. Seven batches of admixed concrete were mixed and in four of these an air reduction of 2 percent or more was observed. However, a similar phenomenon was observed in one of the five air-entrained control batches in which a reduction of about 2 percent entrained air between first mixing and placing was observed. On three other field trials, no such occurrence was observed. These trials comprised a total of 43 batches of concrete whose total volume was 275 cu yd. In no case did the entrained air level fall below 4 percent.

Opinions on the difficulty of finishing the silicone admixed concrete have varied widely. On field trials, some finishers have reported that the admixed concrete was considerably stickier. The reverse observation was made on the part of other finishers who reported an improvement over the handling characteristics of ordinary air-entrained concrete. It is the opinion of the authors that a slight increase in stickiness does exist when the silicone admixture is added to the concrete.

Mr. Smith's Proctor penetrometer measurements concur exactly with those found by the authors. Laboratory and field trials have indicated, however, that extended curing is not required and that curing may be conducted with wet burlap, polyethylene film, or membrance curing compounds. The time of application of either burlap or polyethylene film is only slightly delayed and has been applied on bridge structures 4½ to 5 hr after placement of the concrete. On bridge superstructures, where the admixture is initially being tried, there has been no delay of formwork removal or opening to traffic. Forms are ordinarily not removed for at least 10 days and opening to traffic occurs normally at 28 days. Even at 4 days, the admixed concrete will equal or exceed the strength of normally air-entrained concrete; therefore, no delay because of strength considerations is encountered. If the admixed concrete is covered with burlap or polyethylene film, it will be no more subject to damage from rainfall than is ordinary air-entrained concrete because the covering of the admixed concrete can take place at about the same time as normal placements. Longer protection from freezing, particularly through the first and possibly the second night, may be required in the case of admixed concrete. This factor is presently under consideration and test by the authors.

The authors' observations are that the water reduction is approximately 4 percent when the silicone admixture is used. The increase in compressive strength observed on the Ontario test project was 52 percent when the admixture was employed in the concrete. Other documented field trials have shown increases in compressive strength of 38, 26 and 32 percent. The Ontario pour demonstrates that the admix does indeed produce a stronger concrete. In fact, the field trials have exceeded the predictions of the laboratory investigations wherein the mean improvement in compressive strength was computed to be 25 percent.

The authors do have personal knowledge of one case where concrete containing a sufficient amount of entrained air, measured before placing, and placed with the best possible workmanship has spalled. It is admitted that the failure may actually be due to lack of air in the surface of the hardened concrete. Assuming this to be the case, the premature failure of this concrete appears due to unknown phenomena and has little relationship to the amount of air-entraining agent present in the design. It is the authors' contention that the silicone admixture promotes durability in concrete by mechanisms apart from simple air entrainment. Whereas it is true that it will be no easier to control the amount of silicone in the concrete than it is the amount of air-entraining agent, it is believed that premature failures will be materially reduced because the concrete will be less subject to failures caused by mishandling of the material during placement.