Concrete Exposure Tests—Phase 1

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•FIFTEEN test slabs of portland cement concrete were subjected to outdoor exposure and a series of freeze-thaw cycles induced by high concentrations of sodium chloride and calcium chloride.

PURPOSE OF TESTS

The purposes of these tests are (a) to determine the comparative qualities of three wetting agents in producing high compressive strength, low water/cement ratio and workable plasticity; (b) to assay the value of surface sealants presently in use or contemplated for use by the Authority; (c) to obtain comparative data of wet curing vs air curing; and (d) to determine the spall resisting qualities of concrete made with expanded shale as a fine aggregate.

DESCRIPTION OF TEST SLABS

A total of 15 test slabs were cast of a 1:2:3½ concrete (Class A) mix with a water/cement ratio of 5 gal/bag. The slabs are 18 by 18 by 3 in. with a 2- by ¾-in. coping around the top surface to retain water. The slabs were cast in plyscore forms on a sand base. All concrete was mixed indoors at 65 F and cured at the same temperature for 28 days.

To provide uniformity, two master mixes were batched and mixed dry. Batch 1 was a mix using Lone Star Type 2 portland cement, a siliceous sand fine aggregate and limestone coarse aggregate. Batch 2 was a mix using Lone Star Type 2 portland cement, an expanded shale fine aggregate and a limestone coarse aggregate. The gradations of the aggregates are given in Table 1. The master batches were broken down into batches for the individual slabs and the water and admixtures were added. Slump in all cases was 2 in. Table 2 gives the admixtures, air content, slump, method of curing, compressive strength where applicable, and final rating.

TEST PROCEDURE

All blanket curing ceased 14 days after casting; 14 days later the test cylinders were broken by the New York State Department of Public Works Laboratory. The next day the slabs were placed outdoors, the surfaces were flooded with clear water, and the freeze-thaw cycles were begun. Every morning, if a freeze occurred, a mixture of 50 percent NaCl and 50 percent $CaCl_2$ was applied to induce thaw. This cycle was followed for 5 days, after which the slabs were flushed clean and refilled with clear water. The slabs were then left frozen for 48 hr, subject only to temperature-induced thaws. At the end of this period, the deicing salts were again applied for five cycles. During every 5-day period the slabs were either going through freeze-thaw cycles or lay covered with the brine solution. Within the limits of the field testing facilities, the salt solution was maintained at 5 percent.

During the 77 days of the exposure test, the slabs were subjected to 68 freeze-thaw cycles induced by 40 applications of deicing salts and by natural temperature variations. At the conclusion of Phase 1, the first winter's exposure, the slabs were flush-

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TABLE 1

AGGREGATE GRADATION

Aggregate	Passing Sieve (%)									
	1½ in.	1 in.	½ in.	¼ in.	No. 4	No. 8	No. 14	No. 28	No. 48	No. 100
Coarse:[a]										
No. 1	-	100	90-100	0-15	-	-	-	-	-	-
No. 2	100	90-100	0-15	-	-	-	-	-	-	-
Comb.[b]	100	93-100	27-58	0-8	-	-	-	-	-	-
Fine:										
Sand	-	-	-	-	100	80.2	45.4	24.6	13.6	8.4
Norlite	-	-	-	-	100	85.6	60.3	37.2	24.1	16.3

[a]Coarse aggregate: Type B limestone; specific gravity, 2.71; Deval abrasion test, 5.7% max. loss by wt; $MgSO_4$ soundness test, 10.0% max. loss by wt at 10 cycles; freeze-thaw test, 3.0% max. loss by wt at 25 cycles.
[b]Not > 50% or < 30% of No. 1 size.

TABLE 2

DESCRIPTION OF TEST SLABS[a]

Slab No.	Fine Aggregate	Cure	Comp. Strength (psi)	Air Content (%)	Rating	Admixture	Sealed
1	S	wet	4,630	7.0	3.50	AB	-
2	S	wet	6,350	7.0	8.50	AC	-
3	S	wet	6,700	4.0	2.50	D	-
4	S	wet	5,590	7.0	7.25	A	-
5	S	wet	6,720	2.0	5.15	-	-
6	S	air	-	8.0	9.45	A	-
7	S	air	-	8.0	9.35	A	O
8	S	wet	-	8.0	9.60	A	O
9	S	wet	-	8.0	8.20	A	H
10	S	air	-	8.0	7.70	A	H
11	S	air	-	2.0	9.80	-	-
12	S	air	-	8.0	5.75	A	P
13	ES	air	-	8.0	10.00	A	-
14	ES	air	-	8.0	10.00	A	P
15	ES	wet	5,150	6.0	9.80	A	-

[a]Symbols used are defined as follows:
A = Darex,
B = Rockwood Wet,
C = Riverside Wetting Agent,
D = Deynor Multi-Wet,
ES = Norlite—expanded shale fine aggregate,
H = Hydrocide-SX-Hycon,
O = 50% boiled linseed oil and 50% mineral spirits,
P = Penetryn D-140 Primer, and
S = sand.

ed clean and left to weather in an exposed position. Phase 2, the second winter, was initiated on Nov. 15, 1963. The ultimate goal is to test the slabs to destruction or to the point where it may be assumed that the surface cannot be destroyed by deicing salts.

EVALUATION CRITERIA

The numerical rating system used for evaluating the tests established a perfect rating of 10 for a durable unblemished surface. A deteriorated test slab received a decreased rating. Five of the total of 10 points were assigned as a measure of the deteriorated area and the remaining 5 as a measure of the deteriorated depth. A 1-in. depth of deterioration by this method would result in no score with regard to the depth factor. Deterioration ½ in. deep would reduce the score of 5 to 2.5. A test specimen having 20 percent of its area affected to a depth of ½ in. would receive a final rating of 6.5 with 4 points for the unaffected area and 2.5 points for the unaffected depth.

The area of deterioration was attained by simple measurements. The depth of deterioration was taken as the average of a group of measurements representative of the points of deepest deterioration. Measurements were taken by bridging the spalled area with a steel straight edge and gaging the depth of penetration with a steel rod ground to a fine point. In the absence of precise measuring instruments, it was obvious that a human element would enter into any rating system devised. Therefore, to assure a correspondence in slab ratings, all rating was done by one individual.

EVALUATION OF TEST SITES

As used here, "spalling" refers to a measurable deterioration in depth; "scaling" refers to the shedding of a lamina of mortar approximately $\frac{1}{32}$ in. thick or less.

Slab 1

This slab shows surface defects on 90 percent of the area. The depth of deterioration extends for $\frac{3}{8}$ in. The addition of the wetting agent produced a loss in compressive strength of 960 psi when compared to the mix control slab. The surface survived 18 freeze-thaw cycles and ten applications of deicing salts before any scaling became apparent. Spalling developed gradually with 90 percent of the surface affected after 42 cycles and 29 applications of salts. During the remaining 26 cycles and 11 applications of chemicals, the depth of the surface pitting increased to $\frac{3}{8}$ in. and the slab showed a weight loss of $1\frac{1}{2}$ lb.

Slab 2

Surface defects appear on 10 percent of the area. The depth of the deterioration extends for $\frac{3}{16}$ in. The use of the wetting agent produced an increase of 760 psi over the compressive strength of the control slab. The surface survived 16 freeze-thaw cycles and nine applications of deicing salts before any surface defects became apparent. After the initial pitting, the slab went through 33 additional freeze-thaw cycles and 23 additional applications of deicing salts before any further deterioration was discernible. At this time the surface deterioration progressed to a light scaling and the remaining 19 freeze-thaw cycles and eight applications of chemicals did not produce a worsening of this condition. The slab showed a weight loss of $\frac{3}{4}$ lb.

Slab 3

This slab shows surface defects on 100 percent of the area. Deterioration extends to $\frac{1}{2}$ in. in depth. The use of the wetting agent produced an increase of 1,100 psi over the compressive strength of the control slab. The surface survived 14 freeze-thaw cycles and eight applications of deicing salts without any apparent damage. From this point the deterioration was exceedingly rapid and an additional 12 freeze-thaw cycles with eight applications of deicing chemical caused the 100 percent destruction of the surface. The slab showed a weight loss of $1\frac{1}{2}$ lb.

Slab 4

This was the control slab for evaluating the relative performance of the wetting agents. Surface defects appear on 30 percent of the area. The depth of the deterioration extends to $\frac{1}{4}$ in. The surface survived 18 freeze-thaw cycles and ten applications of deicing salts before scaling became apparent. The spalling developed gradually requiring an additional 27 cycles and 16 applications of deicing salts. The remaining 23 cycles and 14 applications of chemicals deepened the spalls. No weight loss was shown during exposure.

Slab 5

This slab shows surface defects on 60 percent of the area. The depth of deterioration extends to $\frac{3}{8}$ in.

The composition and casting of this slab vary from control slab 4 only in the absence of an air-entraining agent. The 2 percent air entrainment was induced solely by the cement. The surface survived 14 freeze-thaw cycles and eight applications of deicing salts without any apparent damage. A further 27 cycles and 16 applications of deicing salts produced only light scaling. From this point, deterioration accelerated and an additional five cycles and four applications of chemicals produced heavy spalling over 60 percent of the area. The remaining 22 cycles and 12 applications of chemicals added to the depth of deterioration. There was a weight loss of $\frac{3}{4}$ lb during exposure.

Slab 6

This slab shows surface defects on 5 percent of the area. The depth of the defects is $\frac{1}{16}$ in. This slab varies from control slab 4 in that it contains 1 percent more air and was air cured rather than wet cured. The surface survived 18 freeze-thaw cycles and ten applications of deicing salts without any apparent defects. An additional 26 cycles and 16 applications of chemicals produced only minor scaling on 10 percent of the surface. The remaining 24 cycles and 14 applications of salts produced no worsening of the open area. This slab showed an increase in weight of $1\frac{1}{2}$ lb after exposure.

Slab 7

This slab shows minor surface defects on 10 percent of the area. The depth of the scaling is approximately $\frac{1}{32}$ in. This slab is identical with slab 6, except for the addition of a seal coat of boiled linseed oil and mineral spirit. The sealant was applied 24 hr after casting. The minor marring or stipling of the surface was probably due to this early application of a sealer. The surface survived 44 freeze-thaw cycles and 28 applications of deicing salts before the minor scaling appeared. The remaining 22 cycles and 12 applications of chemicals produced no further deterioration. There was an increase in weight of $\frac{3}{4}$ lb after exposure.

Slab 8

This slab shows minor surface defects on 5 percent of the area. The depth of these defects is approximately $\frac{1}{32}$ in. The sealant was applied after fourteen 14 days of curing. The resistance of the surface to spalling closely paralleled that of slab 7. It required the same number of freeze-thaw cycles and the identical amount of deicing salts to produce minor scaling on both slabs. On this slab, however, the area affected was one-half of that affected on slab 7. The additional cycles and chemicals produced no further deterioration. Weight increased 1 lb after exposure.

Slab 9

Two coats of the sealer were applied after 14 days. This slab shows surface defects on 30 percent of the area. The spalls extend to a depth of $\frac{1}{16}$ in. The surface survived 18 freeze-thaw cycles and ten applications of deicing salts without any apparent defects. The next 26 cycles and 16 applications of chemical produced superficial scaling. With the remaining 24 cycles and 14 applications of salts, the superficial scaling spread to 30 percent of the surface. The slab showed a weight loss of $\frac{1}{2}$ lb during exposure.

Slab 10

Two coats of the sealer were applied after 48 hr. This slab shows minor scaling on 40 percent of the area. The spalls extend to a depth of $\frac{1}{16}$ in. The surface survived 49 freeze-thaw cycles and 31 applications of deicing salts before any surface defects appeared. The remaining 19 cycles and nine applications of chemical spread this superficial scaling, but with no appreciable penetration. The slab showed an increase in weight of $1\frac{1}{4}$ lb after exposure.

Slab 11

The slab was cast from the basic mix without any admixtures or sealants. It shows minor pitting. The combined areas are equal to about 1 percent of the surface. The depth of the pit marks range from $\frac{1}{16}$ to $\frac{1}{4}$ in. The pitting occurred after 18 freeze-thaw cycles and ten applications of deicing salts. An additional 50 cycles and 30 applications of chemicals failed to produce any additional deterioration. The slab showed an increase in weight of $1\frac{1}{2}$ lb after exposure.

Slab 12

Two coats of sealer were applied after 48 hr. This slab shows heavy scaling of 60 percent of the area. The depth of deterioration extends to $\frac{1}{4}$ in. The surface survived

49 freeze-thaw cycles and 31 applications of deicing salts before any defects became apparent. Once spalling started the deterioration was exceedingly rapid, the remaining 19 cycles and nine applications of chemicals doing the final damage. The slab showed a weight loss of $\frac{1}{2}$ lb.

Slab 13

This slab shows no defects after the entire test of 68 freeze-thaw cycles and 40 applications of deicing salts. There was no weight change during exposure.

Slab 14

Two coats of sealer were applied after 48 hr. This slab shows no defects. The only apparent effect of the freeze-thaw cycles and the deicing salts was the peeling of the top coat of the sealer after 56 days of exposure. There was no weight change during exposure.

Slab 15

This slab shows minor pitting. The combined areas of the pits are equal to approximately 1 percent of the surface. The depth of the pits range from $\frac{1}{16}$ to $\frac{1}{4}$ in. The pitting appeared after 63 freeze-thaw cycles and 36 applications of deicing salts. The extent to which the pitting would have progressed is uncertain because there remained only five more cycles and four additional applications of chemicals to complete the first phase of the test.

TRENDS AND IMPRESSIONS

At the conclusion of Phase 1 of the test, two trends of particular interest were noticeable:

1. Where the slabs were permitted to cure in the open air but shielded from direct sunlight and wind-drying, the average rating after exposure was 8.88. This average is based on ratings of seven of the 15 slabs. Of the eight slabs that were cured with wet burlap, the average rating was 6.81. Five of the seven air-cured slabs had ratings greater than 9.00, whereas only two of the eight wet-cured slabs survived the tests with a rating of 9.00 or better.
2. Slabs made of concrete in which the fine aggregate was expanded shale showed greater resistance to deicing salts and freeze-thaw cycles than slabs in which conventional sand was used. Three slabs were cast of concrete containing expanded shale fine aggregate. Of the three, two were air-cured and one had a wet cure of 14 days. One of the air-cured slabs was sealed with two coats of Penetryn D-140 Primer; the other air-cured slab was untreated. The untreated slab gave a performance equal to the sealed specimen. The wet-cured slab that had not been sealed showed minor pitting and finished with a rating slightly below the two air-cured specimens.

The following impressions, rather than conclusions, have been gathered from Phase 1:

1. The choice of a wetting agent should be carefully weighed and considered. Of the three used in the test, one seemed to serve no useful purpose. In fact, its action was detrimental in that it lowered the compressive strength of the mix 17.1 percent below that of the control slab. The other two, Riverside Co. Wetting Agent and Deynor Multi-Wet, increased the compressive strength by 13.6 percent and 19.6 percent, respectively. However, the specimen with the highest compressive strength proved to be the most susceptible to the ravages of deicing salts. There was no appreciable difference in the workability of the test mixes containing wetting agents when compared to the test mix of the control slab without a wetting agent. No conclusion should be reached from this fact, however, because experience in the field with larger batches has consistently shown that the addition of 4 oz of Deynor Multi-Wet per cubic yard of concrete will allow a 15 percent reduction in water without any reduction in the slump.
2. Of the sealants used on the slabs made with conventional mixes, the mixture of 50 percent boiled linseed oil and 50 percent mineral spirits was the most effective.

The material appears to be slightly more effective when applied 14 days after casting than when it was applied 1 day after casting. This is borne out by a rating of 9.60 on the 14-day old slab, as against a 9.35 rating on the 1-day old slab. The silicone-type sealer was considerably more effective when applied to a 14-day old slab vs 2-day old specimen. The ratings were 8.20 and 7.70, respectively.

3. Of interest is a comparison between slabs 4, 5 and 11. These slabs are basically the same mix with slab 4 having 7 percent air entrainment and 14-day wet cure, slab 5 having 2 percent air entrainment and a 14-day wet cure, and slab 11 having 2 percent air entrainment and air curing. The ratings of these slabs are 7.25, 5.15, and 9.80, respectively. The first two follow the classic pattern that a reduction in air content increases the susceptibility to spalling. Slab 11 with its low air content and anti-spalling character indicates that further testing of curing methods is warranted.

SUMMATION

Phase 1 of the Thruway's concrete exposure tests has been concluded. Phase 2 will be a continuation of the tests on the original 15 slabs and additional slabs necessary to test the trends established in Phase 1. Phase 2 will cover the evaluation of the four bridge sites where concrete repairs were made in the summer of 1963 using expanded shale as a fine aggregate. Results obtained with this material in the exposure test warranted their use in a field installation.

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