Performance of Concrete Slabs in Outdoor Exposure

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Performance data are presented for concrete slabs cast on grade and elevated above grade that are exposed to the weather in the Skokie outdoor exposure test plot. Variables discussed include curing, cements, pozzolans, aggregates, chemical admixtures, de-icers, and concrete surface treatments.

•THIS IS a report on the performance of various air-entrained concrete test slabs that have been exposed to normal weathering and chemical de-icing. A few non-air-entrained slabs are also included. These slabs are located in an exposure plot (Fig. 1) built on the grounds of the PCA Laboratories at Skokie, Illinois. Specimens were cast during the summer and fall of 1963 and 1964. As indicated in an earlier report (1), the exposure plot contains specimens that are subjected to the severe climate of northern Illinois, simulating exposure conditions to which certain types of full-scale structures in the Chicago area are subjected. For example, slabs placed on grade simulate pavements, while reinforced slabs elevated above ground on pipe columns simulate bridge decks. Whenever it is necessary to de-ice highway structures near the laboratory, the surfaces of slabs-on-grade and elevated slabs are treated with chemical de-icers.

Box-type specimens in the plot are used to evaluate the freezing and thawing durability of concretes similar to those used in the slabs, but not exposed to de-icers. These box-type specimens have depressions in their tops that are filled with sand. Since the sand is usually wet because of collected rain or snow, the exposure to which the boxes are subjected resembles that of retaining walls in northern Illinois. The boxes have not been exposed to chemical de-icers, as have the slabs, and no deterioration has developed in the boxes in this program. For this reason, this report is concerned only with the performance of the slabs.

SCOPE

This report describes the resistance to de-icer scaling of air-entrained concrete slabs in the exposure plot. A few non-air-entrained slabs are included. Variables considered are (a) curing procedures and curing times, at both normal and elevated temperatures, (b) concrete surface treatments obtained with proprietary chemicals or by special finishing techniques, (c) use of admixtures in concrete, (d) the use of various normal weight and lightweight concrete aggregates, (e) application of different types of chemical de-icers, (f) the effects of different depths of cover on corrosion of embedded steel, (g) the use of various cements, (h) the effect of water-cement ratio, and (i) different maximum sizes of coarse aggregates.

CONSTRUCTION DETAILS

Complete construction details of 21 elevated slabs and 99 slabs-on-grade were presented in an earlier report (1). For convenience, significant concrete mix information from that report is reproduced in the Appendix.

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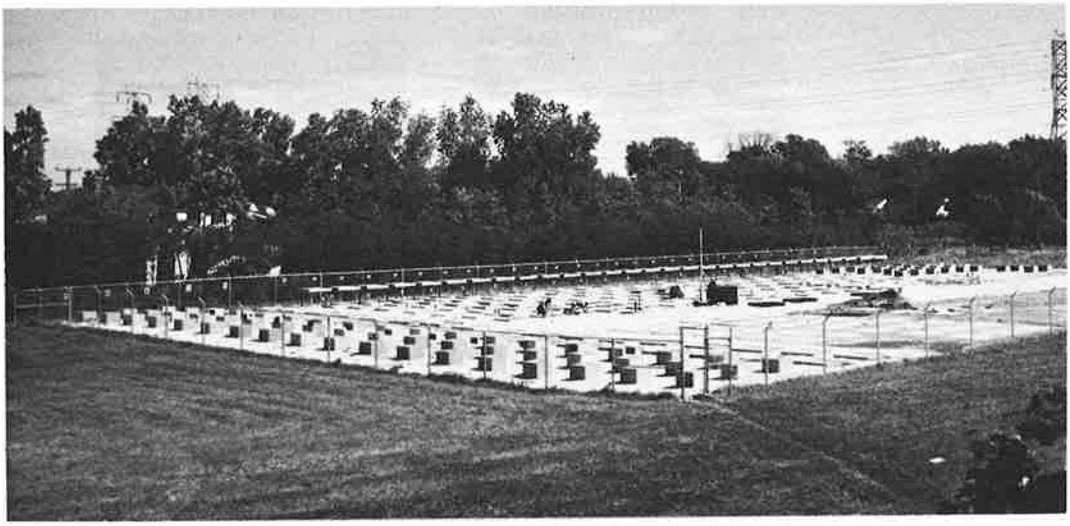


Figure 1. Skokie outdoor exposure plot.

Unless otherwise stated, slabs were cast on a moistened granular subbase and are 6 in. thick, 4 ft wide, and 5 ft long. These slabs-on-grade are not reinforced and were given a burlap drag finish. A dike of wood or air-entrained mortar is bonded to the top edges of the concrete slab to retain rain or snow and de-icer solutions at the top of the slab.

The elevated slabs were cast 3 ft above the ground on pipe supports. Elevated slabs were reinforced with a top and bottom mat of steel (1). Only in this respect and in their elevation are the elevated slabs different from the slabs cast on grade.

Unless otherwise stated in Table 1, the concrete slabs in the test plot were cast during the summer months of June, July, and August. The few specimens cast in late fall were generally made in late November.

Any exceptions to the standard slab curing of 7 days cover by polyethylene film are noted in Table 1.

DISCUSSION OF PERFORMANCE

The discussion of performance is based on a visual examination of test specimens made in the summer of 1968, supplemented by photographs taken at the same time. Thus, some of the specimens have been exposed to 5 winters and others to 4 winters. Casting dates are shown in Table 1. Items are discussed as they appear in the table.

Curing at Normal Ambient Temperatures

An extensive comparison was made between the resistance to de-icer scaling of air-entrained slabs-on-grade cast in the summer and in the late fall. A variety of concrete curing methods were investigated. Among these were (a) no curing, (b) curing with polyethylene film, (c) covering with curing paper, (d) ponding with water, and (e) use of membrane curing compounds. Figure 2 shows the various slabs in this study. Slabs cast in late fall showed more de-icer scaling than companion slabs cast in midsummer. The scaling of slabs cast in late fall occurred mainly during the first winter of exposure to de-icer solutions. Only slight additional scaling has occurred during the succeeding winters.

Curing method and duration appeared to affect significantly the degree of de-icer scaling that took place during the first winter on the surface of slabs cast in late fall. For example, the direct ponding of water on slab surfaces (Fig. 2D) led to more scaling of slabs cast in late fall than other types of curing that are less effective in retaining

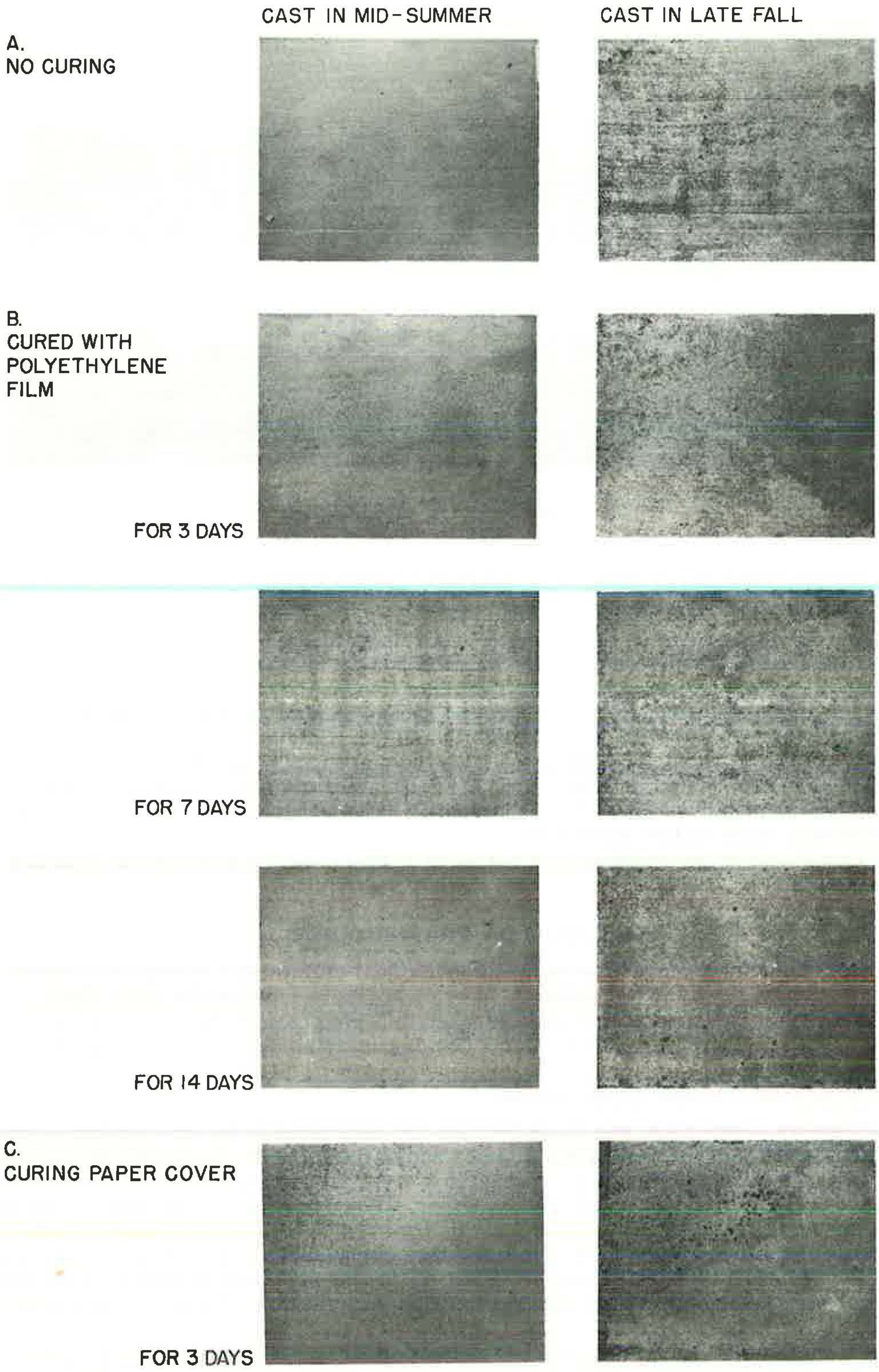


Figure 2. Effect of method of curing and time of casting.

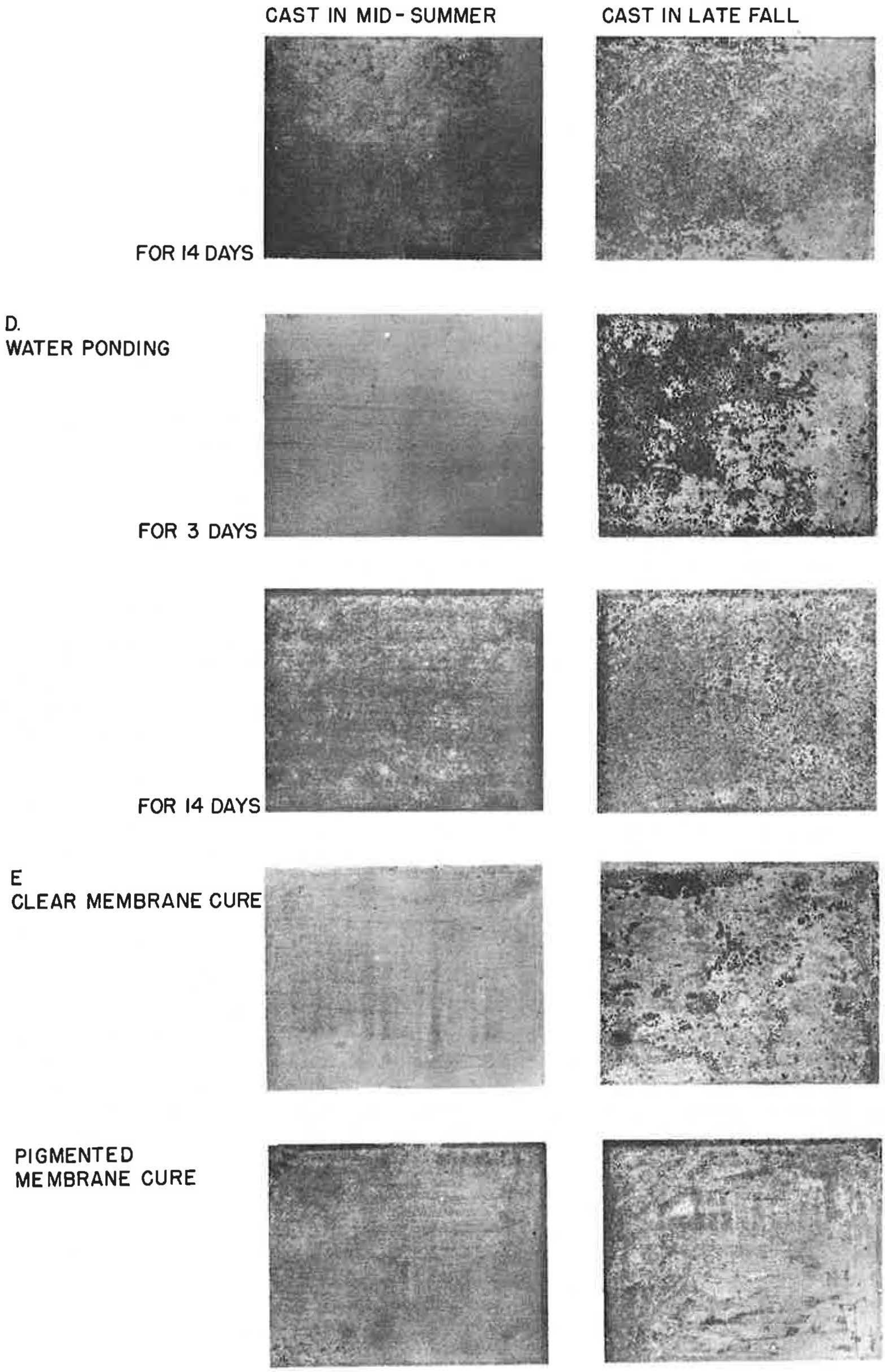


Figure 2. Continued.

water. Longer curing generally improves most properties of concrete. Yet the appearance of slabs given prolonged curing in late fall (Fig. 2B, 2C, 2D) suggests that longer curing of slabs cast late in the year will increase the tendency for de-icer scaling during the first winter season. It appears that the drying afforded by no curing or shorter curing periods is beneficial with respect to de-icer scaling.

It is obvious from Figure 2 that, if specimens are cast in the normal summer construction season and given an opportunity to dry before de-icers are applied, curing does not greatly affect the de-icer scaling resistance of the slab. All of the air-entrained slabs of this study that were cast in the summer are highly resistant to scaling. Hence, curing procedure and duration and their effect on de-icer scaling appear to be a matter of concern only for concretes cast quite late in the construction season.

Curing at Elevated Temperatures

Figure 3 shows companion pairs of small air-entrained and non-air-entrained slabs that were cured at various temperatures prior to exposure. The slab at the left in Figure 3A is non-air-entrained while that at the right is air-entrained. Both slabs were cast in the laboratory during the winter, cured in the laboratory under polyethylene at 73 F for 7 days, then stored outdoors. The slab without entrained air was only slightly scaled by de-icing chemicals after 5 years of exposure.

Figure 3B shows two small slabs that were high-temperature cured at 160 F and atmospheric pressure (24-hour cycle) and then placed outdoors. Although the air-entrained slab at the right is not scaled, the non-air-entrained slab shows significantly more scaling than the non-air-entrained slab cured at 73 F.

The slabs in Figure 3C and 3D were cured in an autoclave at 350 F (16-hour cycle). The concrete for the slabs in Figure 3D was made with a 40 percent by weight replacement of the cement with fine silica-flour. The air-entrained slab at the right in Figure 3C is acceptably resistant to de-icer scaling, but even adequate air entrainment did not impart suitable resistance to the air-entrained slab made with silica-flour cement replacement (Fig. 3D). Both non-air-entrained slabs cured in the autoclave were completely destroyed by de-icer action within 2 years after de-icer chemicals were first applied.

The test series illustrated in Figure 3 indicate that susceptibility of non-air-entrained concrete to de-icer scaling increases with increasing temperature of cure. With the exception of the autoclaved concrete with the silica-flour replacement, the air-entrained concretes showed no significant effect of curing temperature on de-icer scaling.

Concrete Surface Treatments

Surface Coating—The surfaces of some of the concrete slabs were treated with various coatings that have been used or recommended as a means of increasing resistance to de-icer scaling. Surface coatings used were silicones, linseed oil, and magnesium fluosilicate as shown in Table 1. It is believed that there has not been sufficient time to draw conclusions. Neither the non-air-entrained or air-entrained concretes coated with the silicones used nor linseed oil treatments scaled, nor did the air-entrained concrete coated with magnesium fluosilicate. In accelerated laboratory de-icer scaling tests (2) silicones were observed to be detrimental. This detrimental action has been confirmed by field experience on pavements. Note that the non-air-entrained concrete in Figure 3A, however, showed very little scaling for the same type and duration of exposure. Thus, specific conclusions as to the effectiveness or necessity of these treatments cannot be drawn at this time.

Finishing Procedure—Different finishing practices were used on three of the air-entrained concrete slabs in the exposure plot. One slab was floated for 15 minutes, one was sprinkled with water during finishing, and the wet surface of one slab was dusted with dry cement. After 4 winters (probably an insufficient time to warrant conclusions) none of the air-entrained concrete slabs in this study have scaled. However, based on actual and more extensive and prolonged field exposure, such practices are not recommended.

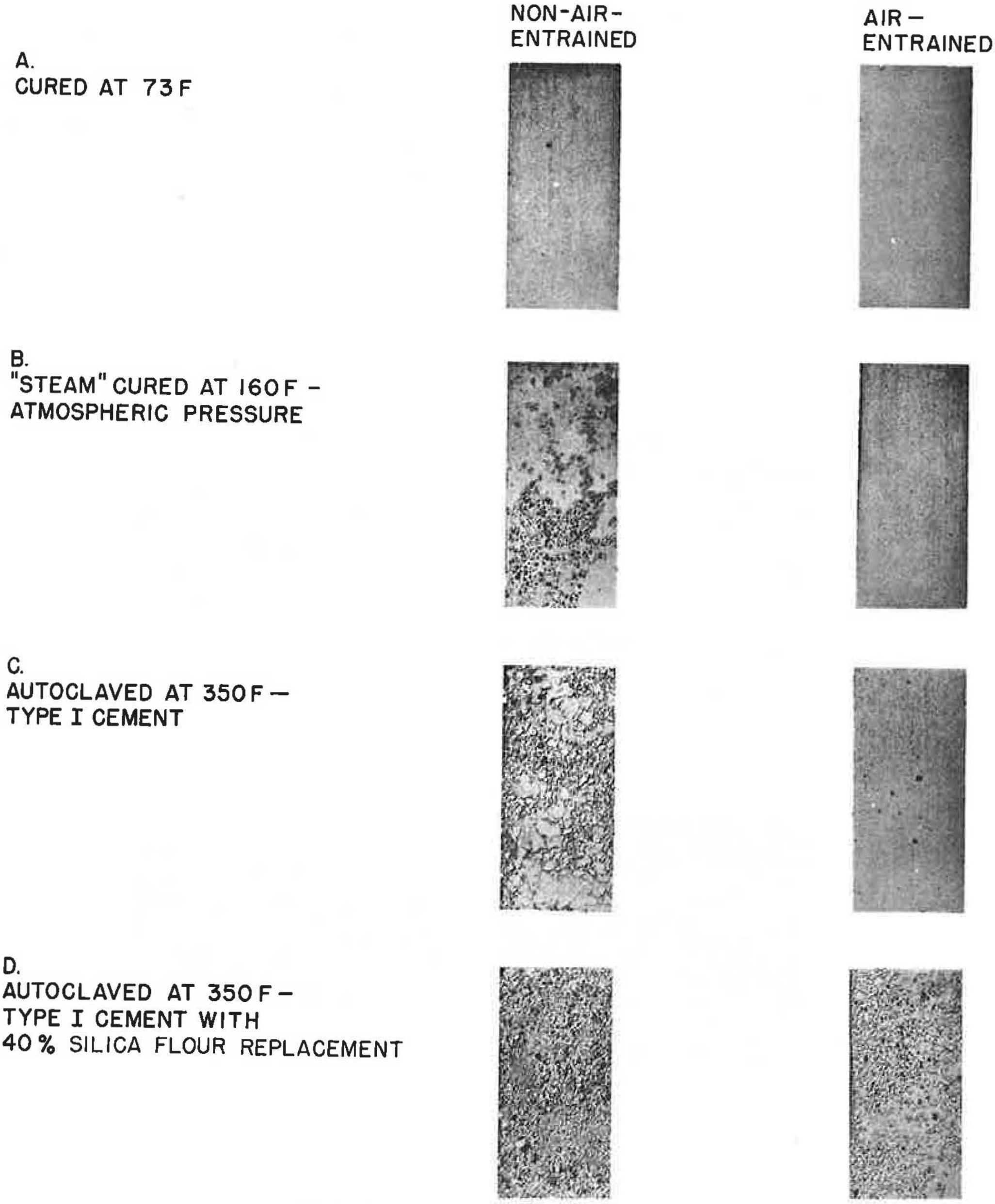


Figure 3. Effect of curing temperature.

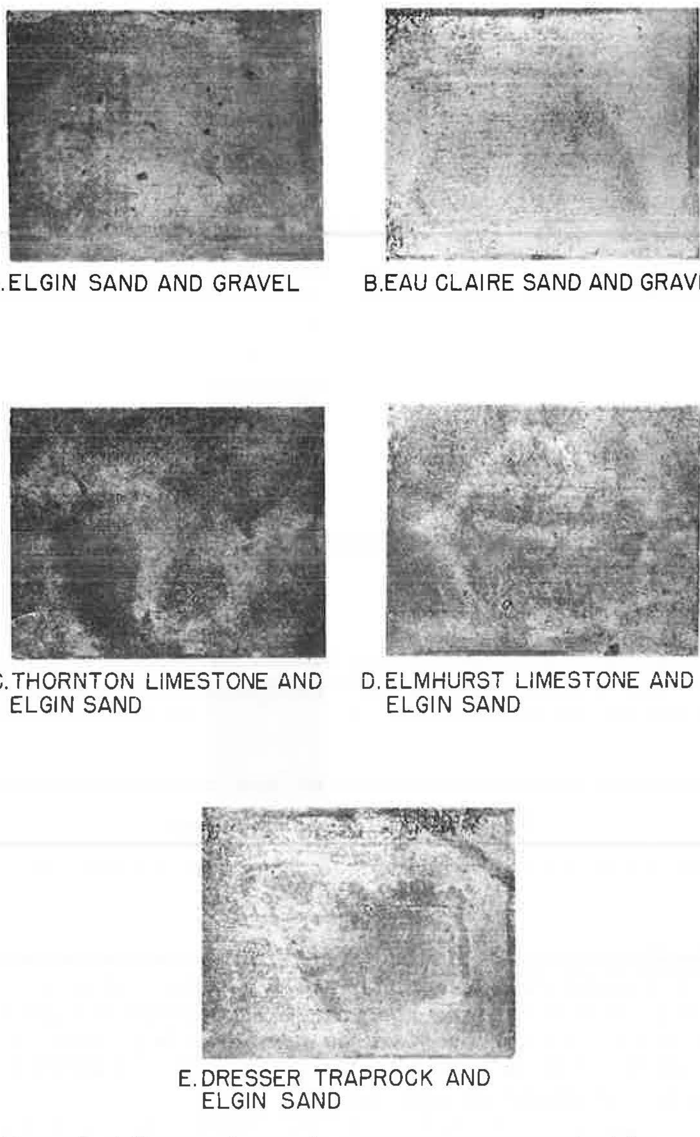
Admixtures

Various Air-Entraining Admixtures—Four different air-entraining admixtures were used in concretes cast during the summer and in late fall. After 5 winters of exposure, those cast during the summer show no scaling. For the late fall concretes, those containing two of the air-entraining admixtures show no scaling, while the slabs with the other two admixtures show only minor evidence of scaling. Additional exposure may be required to reveal significant differences.

Admixtures Other Than for Air Entrainment—As shown in Table 1, various air-entrained concrete slabs were made with chemical admixtures, such as integrally ad-

mixed silicones, water-reducers (ASTM C 494, Type A), water-reducer-retarders (ASTM C 494, Type D), water-reducer-accelerators (ASTM C 494, Type E), and an admixture of sugar plus calcium chloride. No significant differences in the surfaces of the slabs containing these admixtures have developed after 5 winters.

Fly Ash as an Admixture—Three air-entrained concrete slabs were made with three different fly ashes used as an admixture (a supplement to the cement rather than a replacement of cement) in the amount of 30 percent by weight of cement. The fly ash samples were reported to be "good," "fair," and "poor." At this time, there is little perceptible difference between the surfaces of the slabs with and without the fly ash admixtures at the same concrete air contents. The fly ash increased the amount of air-entraining admixture needed by about 1.7, 2.7, and 9.2 times for the "good," "fair," and "poor" fly ashes, respectively.



A. ELGIN SAND AND GRAVEL

B. EAU CLAIRE SAND AND GRAVEL

C. THORNTON LIMESTONE AND ELGIN SAND

D. ELMHURST LIMESTONE AND ELGIN SAND

E. DRESSER TRAPROCK AND ELGIN SAND

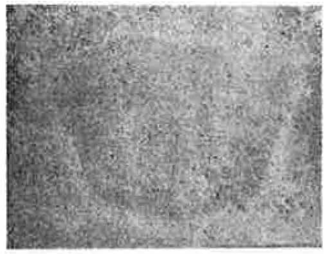
Figure 4. Influence of type of coarse aggregate on grade slabs.

Effect of Various Aggregates

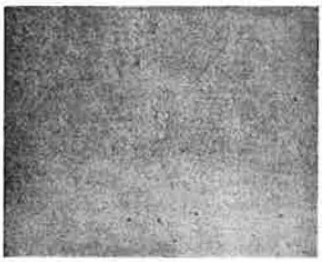
Normal Weight Aggregates—Figure 4 shows the surfaces of slabs, both on grade and elevated, made with different coarse aggregates. Of these aggregates, the Thornton limestone, the Dresser traprock, and the Eau Claire gravel are known to be more durable in freezing and thawing than the Elgin gravel or the Elmhurst limestone. It is apparent from these photographs that freezing and thawing and de-icing caused significantly greater surface distress on the slabs containing the less durable Elgin and Elmhurst coarse aggregates. The surface distress was in the form of popouts or popoffs of mortar over aggregate particles, rather than de-icer scaling.

Lightweight Aggregates—Air-entrained concrete slabs, both on grade and elevated, made with rotary kiln expanded shale, sintered expanded shale, and expanded slag were included in the exposure plot (Fig. 5). One variable of interest in this study was the possibility that slabs made with initially dry lightweight aggregate might be more dura-

F. ELGIN SAND AND GRAVEL

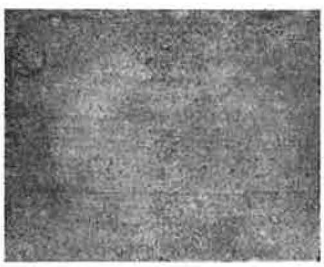


G. EAU CLAIRE SAND AND GRAVEL



H. THORNTON LIMESTONE AND ELGIN SAND

I. ELMHURST LIMESTONE AND ELGIN SAND



J. DRESSER TRAPROCK AND ELGIN SAND

Figure 4. Continued.

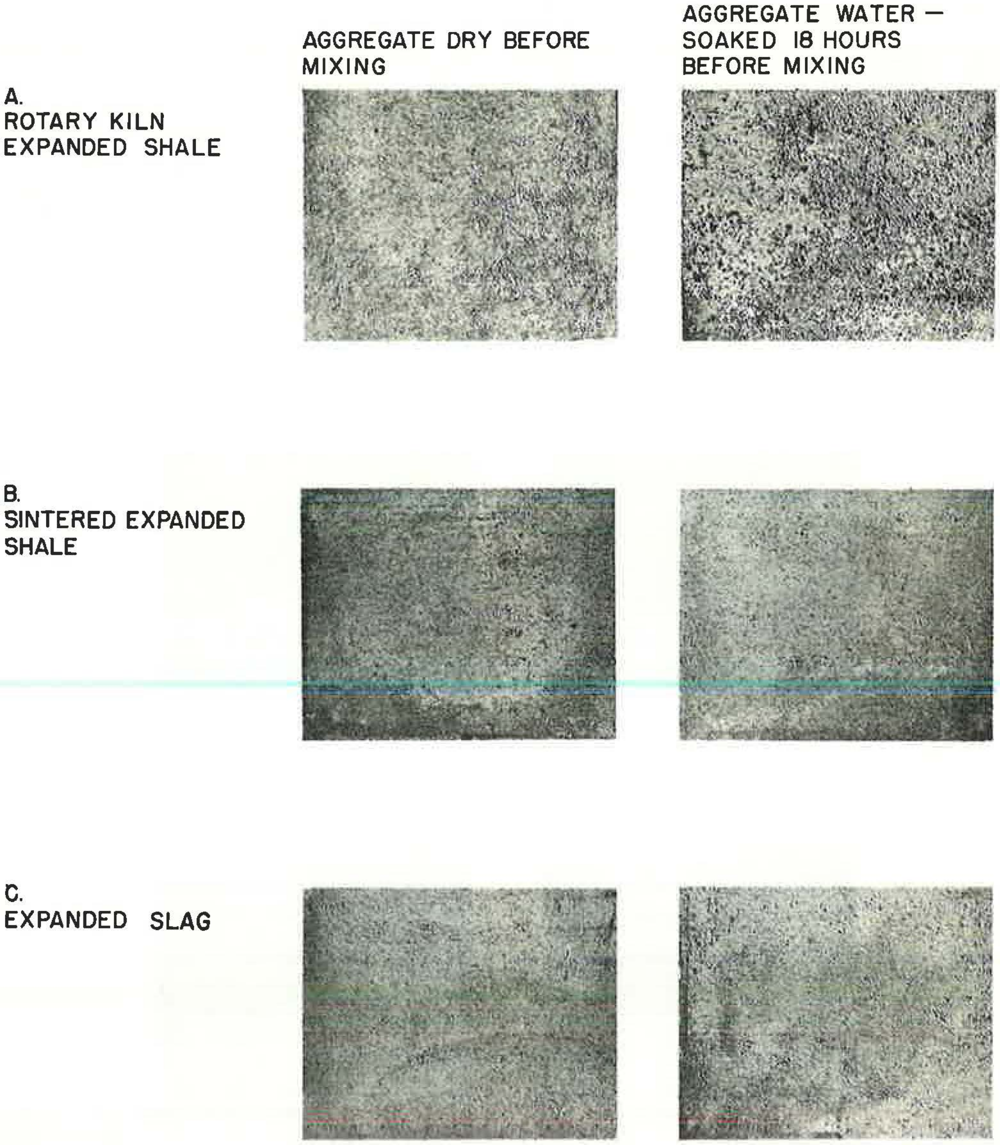
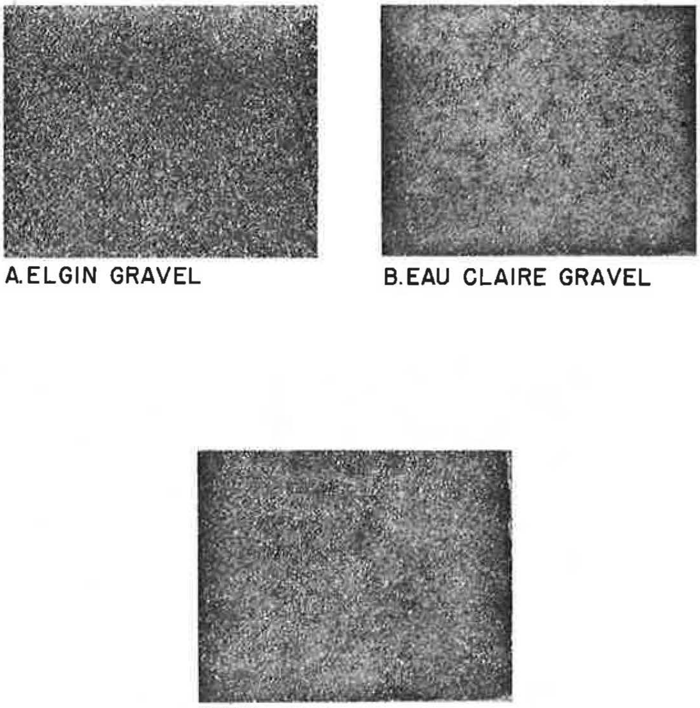


Figure 5. Effect of moisture content of lightweight aggregate (elevated slabs).

ble than slabs made with similar aggregate that had been pre-wet by soaking in water (3). Use is sometimes made of pre-wet lightweight aggregate in order to avoid control problems associated with absorption of water from the mix by dry lightweight aggregate.

For the elevated slabs (Fig. 5) there was a significantly greater amount of shallow de-icer scaling from the slabs cast with the pre-wet aggregate. For the companion slabs on grade, the initial moisture condition of the aggregate was relatively unimportant.

Exposed Aggregate Surfaces—Three air-entrained concrete slabs were given an exposed aggregate surface by applying quantities of $\frac{3}{8}$- to $\frac{1}{4}$-in. size gravel to the screeded top slab surfaces, compacting the material into the upper slab surface, applying a retarder, and scrubbing the surfaces of the slabs to expose aggregates at the surface when the slabs were 1 day old. The use of such surfaces in walkways, driveways, patios and other flat slab areas is becoming quite popular. Figure 6 shows the



A. ELGIN GRAVEL

B. EAU CLAIRE GRAVEL

C. MERAMEC CHERT

Figure 6. Exposed aggregate surfaces.

slabs after 4 winters of de-icer application. The slab with the less durable exposed aggregate, Elgin gravel, has lost only a few particles. However, this has not harmed the appearance of the slabs. Slabs with the exposed durable Eau Claire gravel and the moderately durable Meramec chert have hardly been affected by de-icer application. The performance of these slabs shows that adequately air-entrained slabs with exposed aggregate surfaces should not be unduly affected by de-icer chemicals.

Influence of Various De-icers

Flake calcium chloride was the chemical de-icer generally used in the outdoor exposure plot to de-ice the slabs after snow or ice storms. Certain slabs in the test plot were de-iced by materials other than calcium chloride in an effort to substantiate information on such de-icers obtained in laboratory tests (4). In all cases, the amount of de-icer used was equivalent to about a 3 percent concentration, assuming ½ in. of ice on the surface.

Figure 7 shows the surfaces of slabs in the exposure plot that were treated by various de-icers. The effect of de-icing with rock salt or with a combination of rock salt and calcium chloride was not significantly different from that for applications of flake calcium chloride alone. Note again, as in Figure 2, that the slabs cast in late fall are less resistant than those cast during the summer.

Figure 7 shows that the application of ammonium sulfate or nitrate as "de-icers" is extremely detrimental and to be avoided. The surfaces of the air-entrained concrete slabs cast in summer and in late fall and de-iced by these chemicals are badly scaled. The late fall slabs in particular resemble exposed aggregate concrete. These two de-icers, and other chemically similar in nature, are chemically aggressive and should not be used on concrete.

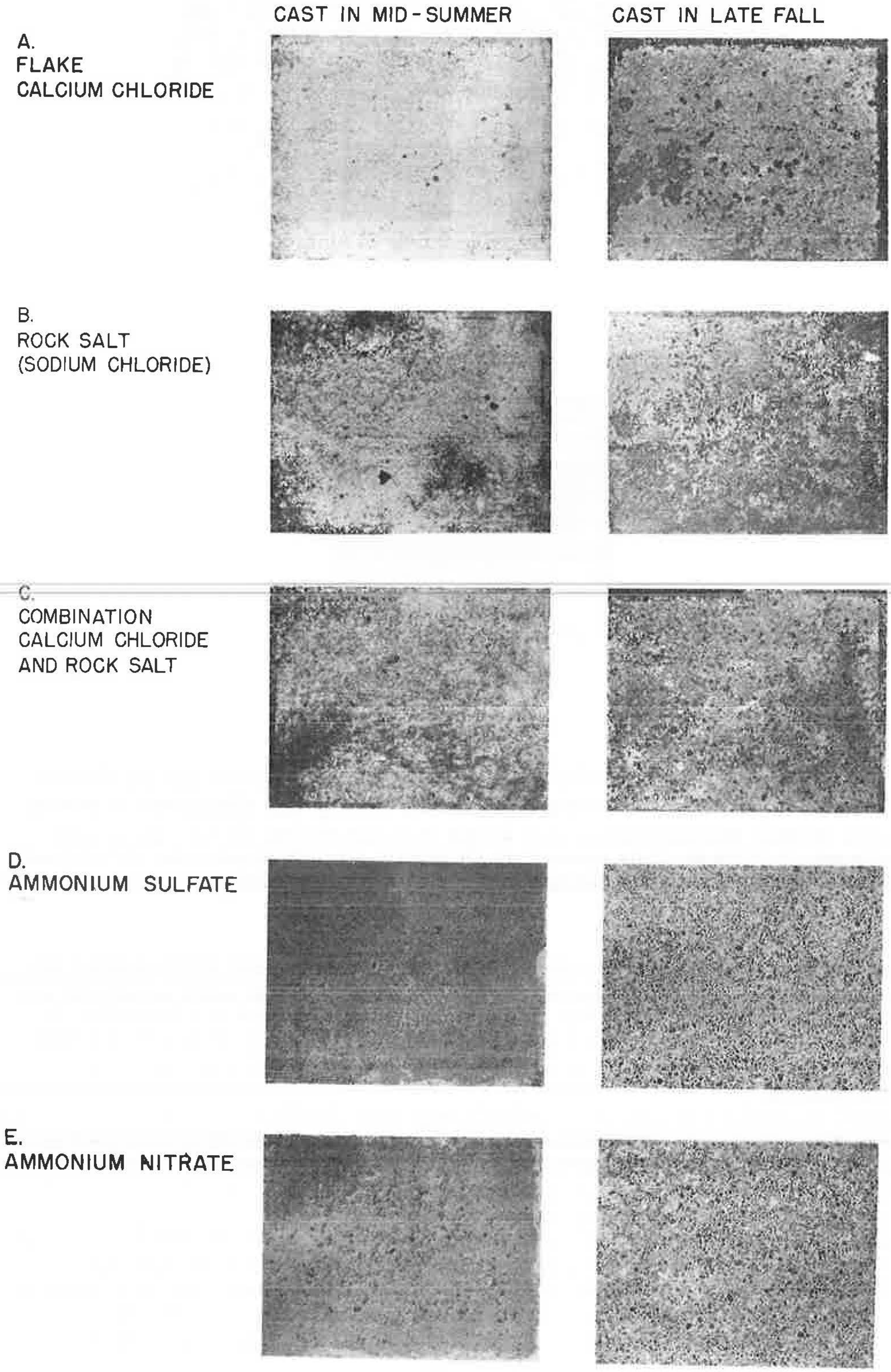


Figure 7. Effect of different de-icers.

Depth of Cover Over Reinforcing Steel

Figure 8 shows elevated air-entrained concrete slabs having different water-cement ratios and depths of cover over the top layer of reinforcing steel. No surface evidence of any rusting of the steel is apparent on slabs made with 1½-in. depth of cover. All of the slabs made with the ½-in. depth of cover have rust stains on their surfaces indicating some steel corrosion. The slabs having ½-in. cover and 0.38 and 0.44 water-cement ratios, made with good quality air-entrained concrete, show only a few signs of distress, but these are manifested by very pronounced spalls. A great many rust spots are evident on the surfaces of the 0.51 and 0.58 water-cement ratio concrete slabs, but

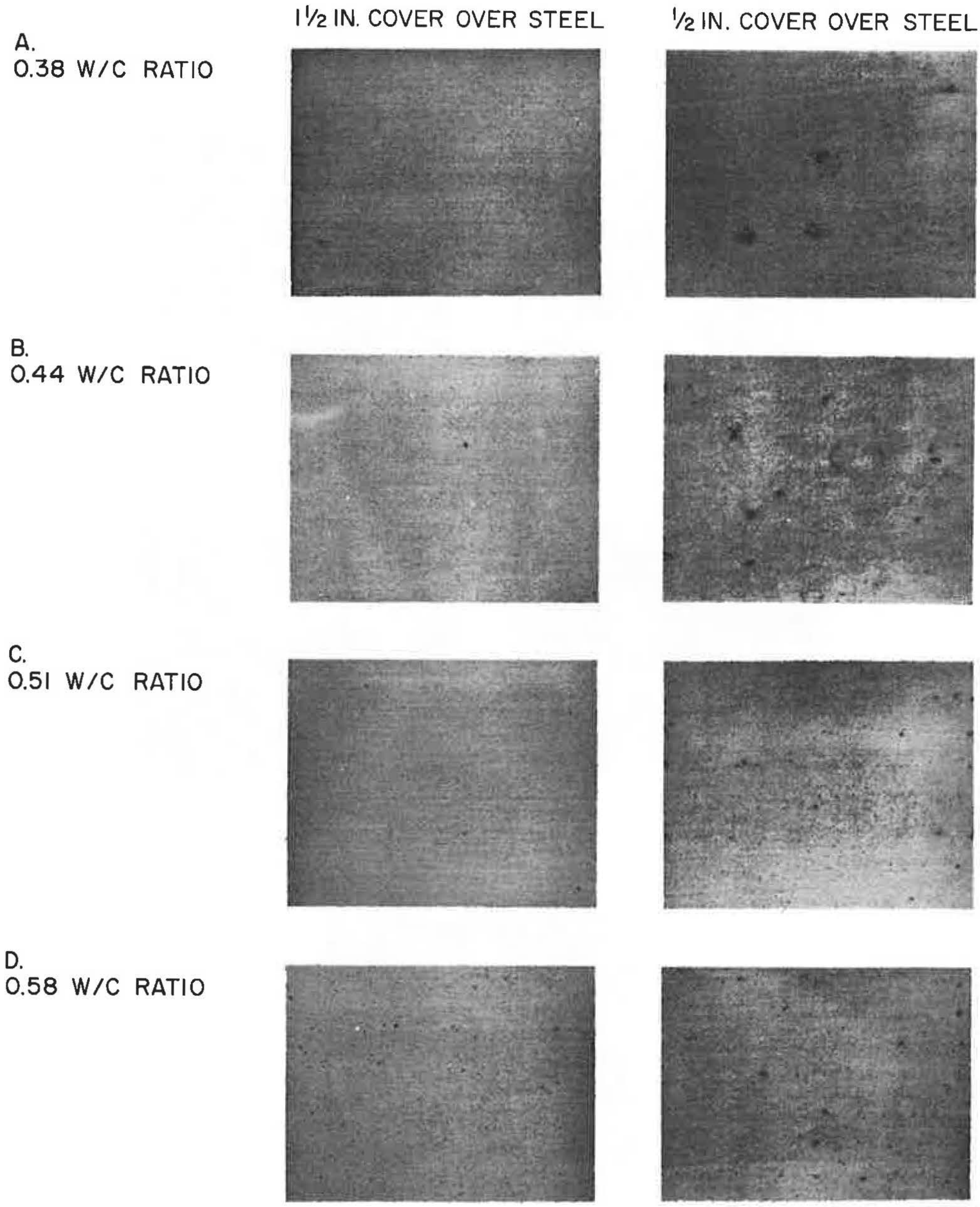


Figure 8. Influence of concrete cover on steel corrosion.

no pronounced spalls have developed. It is apparent from these tests that the amount of cover over the steel is important with respect to protection against corrosion.

Miscellaneous Factors

Concrete Water-Cement Ratio—Figure 8 shows that air-entrained concrete with a water-cement ratio of 0.58 by weight ($6\frac{1}{2}$ gal/bag) is somewhat less resistant to de-icer scaling than the concretes with lower water-cement ratios. Figure 9, slabs-on-grade, shows the 0.58 w/c ratio concrete to be resistant to de-icer scaling in this exposure. Some scaling is evident on the 0.64 w/c ratio ($7\frac{1}{4}$ gal/bag) concrete on grade. This indicates that a lower w/c ratio concrete may be required for bridge deck exposures than is required for pavement slabs. However, at this time, the differences do not appear significant from a practical standpoint.

Various Cements—Air-entrained concrete slabs, using white portland cement, were cast in the summer and in late fall. The performance of these white cement, air-

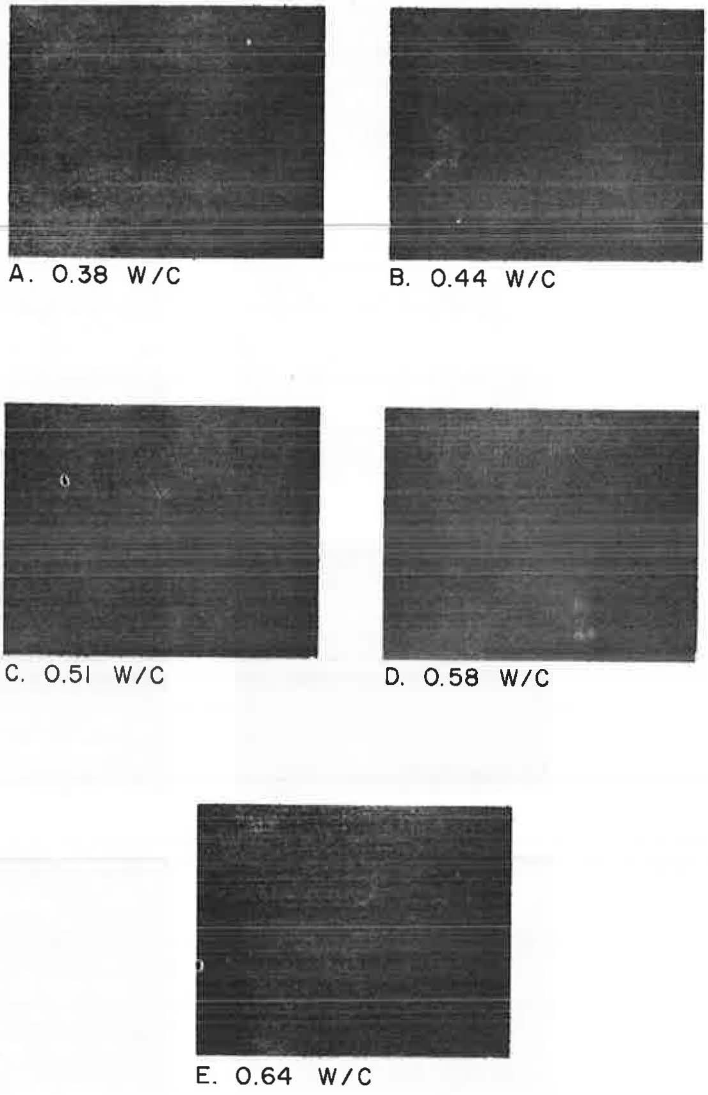


Figure 9. Effect of water-cement ratio on scaling of air-entrained grade slabs.

entrained, concrete slabs was indistinguishable from that of gray Type I cement air-entrained concrete slabs.

Air-entrained concrete slabs, both on grade and elevated, were made with two different shrinkage-compensating cements. Those on grade contained the same steel reinforcement as the elevated slabs. The performance of the two reinforced slabs-on-grade and their companion reinforced elevated slabs was satisfactory except for some loss of mortar (popoff) over coarse aggregate particles close to the slab surfaces.

Aggregate Gradation—Two slabs had maximum sizes of coarse aggregate smaller than the 1½-in. size in the rest of the slabs in the outdoor test plot. The air-entrained slab with a ¾-in. Eau Claire maximum size aggregate and the air-entrained slab made only with Elgin sand (No. 4 sieve maximum size) were not affected by de-icers. Good performance would be expected for the durable Eau Claire coarse aggregate and for the Elgin sand alone. The use of Elgin coarse aggregate (Fig. 4) resulted in a significant number of popouts.

Subbase—Two slabs were cast on different subbase treatments from the other slabs in the plot, which were cast on a pre-moistened granular subbase. One of these slabs, cast on a dry sand subbase, is still in excellent condition. The other slab, cast on a polyethylene film-covered subbase, is gradually exhibiting more and more small popoffs over aggregate particles. One possible explanation for the continued scaling of the slab on the impervious base is that the concrete, and hence the slab surface, could not initially lose moisture to the subgrade, resulting in a higher water-cement ratio in the upper surface of the slab than for the slab cast on the dry sand subbase. As indicated elsewhere, slabs made with concrete of high water-cement ratio are more susceptible to de-icer scaling. Similar indications have been reported in tests conducted by the Bureau of Public Roads (5).

SUMMARY

Based on the performance of slabs during 4 to 5 years in the outdoor exposure plot, the following conclusions appear to be justifiable:

1. Concrete cast late in the fall is more susceptible to de-icer scaling than similar concrete cast in the summer. The duration and method of curing concrete cast late in the fall are important factors affecting the ability of concrete to withstand early de-icing. Curing methods that retain or add water for relatively long periods of time leave late fall concrete more saturated and thus more vulnerable to early freezing. Since drying is relatively slow at temperatures below 50 F, shorter protection periods may provide a proper balance between reduced strength development and improved durability due to lower degree of saturation.
2. Non-air-entrained concretes, steam-cured or autoclaved, were less durable than similar concrete cured at normal temperatures. Air-entrained concretes, steam-cured or autoclaved, performed well, except for autoclaved concrete in which a silica-flour cement replacement was used.
3. Little difference was noted between the degree of de-icer scaling caused by flake calcium chloride, rock salt, or a combination of rock salt and calcium chloride. The use of ammonium sulfate and ammonium nitrate as de-icers resulted in severe chemical attack and their use as de-icers should be prohibited.
4. There is a tendency toward decreased resistance to de-icer scaling of these air-entrained concretes with increase in water-cement ratio above about 0.58 by weight (6½ gal/bag).
5. Adequate cover over the top reinforcing steel in a concrete bridge deck slab appears essential on structures treated with de-icers if rusting of the steel is to be avoided.
6. Different coarse aggregates influenced the number of popouts and popoffs, but had no influence on de-icer scaling, per se.
7. The use of chemical admixtures has not affected the de-icer scale resistance of these air-entrained concrete slabs.

Although more time is needed to develop more clearly possible additional differences in performance, the following comments rather than conclusions may be of interest:

1. Only a slight amount of scaling developed on the surfaces of non-air-entrained concrete coated with silicones or linseed oil. However, uncoated non-air-entrained concrete also has shown little, if any, scaling to date.
2. Slabs made with shrinkage-compensating cements tended to have a number of shallow mortar popoffs above coarse aggregate particles close to the surface.
3. Fly ash as an admixture has had little effect to date on the resistance of these air-entrained concretes to de-icer scaling. The increase in air-entraining admixture requirements ranged from 1.7 to 9.2 times that of concrete without fly ash.
4. For air-entrained concretes cast late in the fall, those containing two of the air-entraining admixtures showed no scaling, while the slabs with the other two admixtures showed only minor evidence of scaling.
5. Air-entrained concrete cast on a dry sand subbase was somewhat more resistant to de-icer scaling than a similar slab cast on a polyethylene film-covered subbase.
6. There are indications that the surfaces of lightweight aggregate concrete made with pre-wet aggregate are somewhat more susceptible to de-icer scaling than the surfaces of similar concrete made with initially dry aggregate. The effect was more pronounced for the elevated slabs than for the slabs cast on grade.
7. Exposed aggregate air-entrained concrete slabs resisted de-icing action adequately.
8. Variations in finishing procedures for these air-entrained concretes had little influence on resistance to de-icer scaling to date.

REFERENCES

1. Tatman, Phil J., and Landgren, Robert. Outdoor Concrete Exposure Test Plot at Skokie. Jour. PCA Research and Development Laboratories, Vol. 8, No. 2, p. 30-41, May 1966; PCA Research Dept. Bull. 202.
2. Klieger, Paul, and Perenchio, William. Silicone Influence on Concrete Resistance to Freeze Thaw and De Icer Damage. Highway Research Record 18, p. 33-47, 1963; PCA Research Dept. Bull. 169.
3. Klieger, Paul, and Hanson, J. A. Freezing and Thawing Tests of Lightweight Concrete. Jour. American Concrete Inst., Jan. 1961; Proc., Vol. 57, p. 779-796, 1961; PCA Resarch Dept. Bull. 121.
4. Verbeck, George, and Klieger, Paul. Studies of "Salt" Scaling of Concrete. HRB Bull. 150, p. 1-13, 1957; PCA Research Dept. Bull. 83.
5. Grieb, W. E., Werner, G., and Woolf, D. O. Resistance of Concrete Surfaces to Scaling by De-Icing Agents. Public Roads, Vol. 32, No. 3, p. 64-73, Aug. 1962; HRB Bull. 323, p. 43-62, 1962.

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Appendix

APPENDIX 1—DATA ON TEST SPECIMENS

The Data are Mean Values for Two Similar Batches, Except Curing Series 2 (Small Specimens)

Specimen	Specimen Type: Box	Specimen Type: Slab on Grade	Specimen Type: Elevated Slab	Cement*	Cement Factor, bags per cu yd	Net W/C, gal per bag	Slump, in.	Air Content, %	Unit Wt, lb per cu ft	Year Cast	Special Details
Curing Series: (1) Normal Temperatures											
A1a	—	x	—	I-1	5.93	4.97	3	5.7	146.8	'63	No cure—cast in summer
A1b	—	x	—	I-1	5.93	4.93	3¼	5.8	146.1	'63	White pigmented polyethylene film cover—cast in summer—cover 3 days
A1c	—	x	—	I-1	5.97	4.93	2¾	5.2	148.0	'63	White pigmented polyethylene film cover—cast in summer—cover 7 days
A1d	—	x	—	I-1	5.93	4.85	3	5.7	146.7	'63	White pigmented polyethylene film cover—cast in summer—cover 14 days
A1e	—	x	—	I-1	5.97	4.53	2¼	5.0	148.0	'63	No cure—cast in late fall
A1f	—	x	—	I-1	5.87	4.53	2½	6.0	145.4	'63	White pigmented polyethylene film cover—cast in late fall—cover 3 days
A1g	—	x	—	I-1	5.91	4.53	2¾	5.9	146.5	'63	White pigmented polyethylene film cover—cast in late fall—cover 7 days
A1h	—	x	—	I-1	5.93	4.53	2¾	5.2	147.1	'63	White pigmented polyethylene film cover—cast in late fall—cover 14 days
A2a	—	x	—	I-1	5.91	4.73	2¾	5.9	146.2	'64	Curing paper cover—cast in summer—cure 3 days
A2b	—	x	—	I-1	6.00	4.81	2	4.9	148.2	'64	Curing paper cover—cast in summer—cure 14 days
A2c	—	x	—	I-3	5.98	4.13	2	5.5	146.9	'64	Curing paper cover—cast in late fall—cure 3 days
A2d	—	x	—	I-3	5.97	4.17	2½	5.7	146.7	'64	Curing paper cover—cast in late fall—cure 14 days
A2e	—	x	—	I-1	5.93	4.69	3	5.3	146.6	'64	Water ponded—cast in summer—cure 3 days
A2f	—	x	—	I-1	6.00	4.57	3¼	5.3	148.6	'64	Water ponded—cast in summer—cure 14 days
A2g	—	x	—	I-3	5.95	4.17	2¾	5.7	146.3	'64	Water ponded—cast in late fall—cure 3 days
A2h	—	x	—	I-3	5.95	4.17	2½	5.8	146.2	'64	Water ponded—cast in late fall—cure 14 days
A2i	—	x	—	I-1	5.95	4.73	3	5.3	147.2	'64	Clear membrane spray—cast in summer
A2k	—	x	—	I-3	6.01	4.33	2¼	4.9	142.0	'64	Clear membrane spray—cast in late fall
A2m	—	x	—	I-1	5.94	4.61	2¾	5.3	146.8	'64	Pigmented membrane spray—cast in summer
A2n	—	x	—	I-3	5.98	4.41	2½	5.5	147.5	'64	Pigmented membrane spray—cast in late fall
Curing Series: (2) Elevated Temperatures (Small Specimens)											
A3c	x	x	—	I-1	5.94	4.61	2¾	5.3	146.7	63/64	73°F cure—A/E—Control
A3f	x	x	—	I-1	6.14	4.92	2½	1.6	152.8	63/64	73°F cure—non-A/E—Control
A3a	x	x	—	I-1	5.93	4.61	2¾	5.5	146.6	63/64	160°F cure—atmospheric pressure—A/E
A3d	x	x	—	I-1	6.16	4.75	2¾	1.2	153.1	63/64	160°F cure—atmospheric pressure—non-A/E
A3b	x	x	—	I-1	5.93	4.61	2¾	5.7	146.6	63/64	350°F (125 psi)—autoclave cure—no silica flour—A/E
A3e	x	x	—	I-1	6.12	4.75	2¼	1.2	152.1	63/64	350°F (125 psi)—autoclave cure—no silica flour—non-A/E
A3g	x	x	—	I-1	5.78	4.93	2¾	6.4	143.4	63/64	350°F (125 psi)—autoclave cure—40% silica flour (replacement)—A/E
A3h	x	x	—	I-1	6.10	5.08	2½	0.9	152.2	63/64	350°F (125 psi)—autoclave cure—40% silica flour (replacement)—non-A/E
Surface Treatment Series: (1) Finishing Procedure											
B1a	—	x	—	I-1	6.02	4.77	2	4.8	149.0	'64	"Overfinished" surface
B1b	—	x	—	I-1	5.96	4.57	2½	5.7	147.2	'64	Surface sprinkled with water during finishing
B1c	—	x	—	I-1	5.94	4.61	2¼	5.8	146.8	'64	Surface dusted with cement during finishing
Surface Treatment Series: (2) Surface Coatings											
B2b	—	x	—	I-1	6.01	4.85	2½	5.3	148.6	'63	3% silicone (in water)
B2c	—	x	—	I-1	5.97	4.82	2¾	5.5	147.7	'63	5% silicone (in water)
B2g	—	x	—	I-1	6.17	5.08	2¼	0.8	153.9	'63	3% silicone (in water)—non-A/E slab
B2h	—	x	—	I-1	6.17	5.08	2½	0.8	154.0	'63	5% silicone (in water)—non-A/E slab
B2d	—	x	—	I-1	5.93	4.85	3	6.2	146.6	'63	3% silicone (in mineral spirits)
B2e	—	x	—	I-1	5.94	4.79	2½	5.0	146.9	'63	5% silicone (in mineral spirits)
B2j	—	x	—	I-1	6.17	5.04	2½	0.8	153.8	'63	3% silicone (in mineral spirits)—non-A/E slab
B2k	—	x	—	I-1	6.16	4.88	2¾	0.8	153.4	'63	5% silicone (in mineral spirits)—non-A/E slab (silicones applied in 2 coats totaling 1 gal/100 sq. ft. of concrete)
B3a	—	x	—	I-3	5.94	4.73	2½	5.6	146.7	'64	Magnesium fluosilicate (in water)—2 coats totaling 3.8 lbs. solid/100 sq. ft. concrete
B4a	—	x	—	I-3	5.92	4.93	2½	5.1	147.0	'63	Linseed oil—after 7 d. cure, 21 d. dry
B4c	—	x	—	I-1	6.13	5.08	2	0.7	152.9	'63	Linseed oil—after 7 d. cure, 21 d. dry—non-A/E slab
B4b	—	x	—	I-1	5.84	4.85	5¾	5.6	144.8	'63	Linseed oil—after 2 d. cure, 5 d. dry
B4d	—	x	—	I-1	6.05	5.08	4	0.8	152.1	'63	Linseed oil—after 2 d. cure, 5 d. dry—non-A/E slab (linseed oil applied in 2 coats totaling 1 gal/400 sq. ft. of concrete)

* I-1—Type I cement blend.
I-2—Type I cement blend.
I-3—Type I cement blend.
I-A—Type I A cement.
WPC—White portland cement.

(Cont'd)

APPENDIX 1—DATA ON TEST SPECIMENS (CONT'D)

Spec-imen	Specimen Type: Box	Specimen Type: Slab on Grade	Specimen Type: Ele-vated Slab	Cement	Cement Factor, bags per cu yd	Net W/C, gal per bag	Slump, in.	Air Con-tent, %	Unit Wt, lb per cu ft	Year Cast	Special Details
Admixture Series: (1) Air-entraining Admixtures											
C2a	—	x	—	I-1	5.99	4.69	2½	5.0	148.1	'63	Neutralized Vinsol resin—cast in summer
C2a	x	—	—	I-1	5.97	4.77	2¼	5.3	147.8	'63	Neutralized Vinsol resin—cast in summer
C2d	—	x	—	I-1	5.89	4.85	5	5.4	146.1	'63	Neutralized Vinsol resin—cast in fall
C2d	x	—	—	I-1	5.87	4.85	5¼	5.4	145.5	'63	Neutralized Vinsol resin—cast in fall
C2b	—	x	—	I-1	5.90	4.85	1¾	5.6	146.3	'63	Airalon AEA—cast in summer
C2e	—	x	—	I-1	5.84	5.00	6¼	5.5	145.0	'63	Airalon AEA—cast in fall
C2c	—	x	—	I-1	5.90	4.97	2½	5.2	146.4	'63	Solar AEA—cast in summer
C2f	—	x	—	I-1	5.85	4.85	5½	5.7	145.0	'63	Solar AEA—cast in fall
Admixture Series: (2) Other Chemical Admixtures											
B2a	—	x	—	I-1	6.04	4.67	2½	2.2	151.2	'63	Silicone admixture—0.3% of cement weight (dosage recommended by manufacturer)
B2a	x	—	—	I-1	6.01	4.72	3¼	3.1	150.4	'63	Silicone admixture—0.3% of cement weight
B2f	x	—	—	I-1	5.34	4.36	4½	10.6	133.0	'63	Silicone admixture—0.6% of cement weight (double dosage)
B2f	—	x	—	I-1	5.83	4.52	2¾	6.5	145.6	'63	Silicone admixture—0.6% of cement weight
C1a	—	x	—	I-1	6.01	4.37	2¼	5.3	148.2	'63	Water reducer
C1a	x	—	—	I-1	5.95	4.52	2½	5.3	146.8	'63	Water reducer
C1b	—	x	—	I-1	5.92	5.08	2¼	5.2	147.0	'63	Retarder
C1b	x	—	—	I-1	5.92	4.77	3¼	5.5	146.5	'63	Retarder
C1d	—	x	—	I-1	5.92	4.93	3	4.9	146.8	'63	Water reducer—accelerator
C1d	x	—	—	I-1	5.89	4.77	2½	5.6	145.8	'63	Water reducer—accelerator
C1c	—	x	—	I-1	5.92	4.45	3¾	6.0	146.0	'63	Water reducer—retarder
C1c	x	—	—	I-1	5.97	4.45	2½	5.1	147.3	'63	Water reducer—retarder
C1f	—	x	—	I-1	6.03	4.45	3	5.1	148.6	'63	Water reducer—retarder
C1f	x	—	—	I-1	6.02	4.45	2¾	5.3	148.6	'63	Water reducer—retarder
C1e	—	x	—	I-1	6.01	4.49	2	4.9	148.3	'63	Sugar—calcium chloride
C1e	x	—	—	I-1	5.93	4.45	2½	5.8	146.2	'63	Sugar—calcium chloride
Admixture Series: (3) Pozzolans											
C3a	—	x	—	I-1	5.03	5.50	2¾	5.4	146.0	'63	Control (No fly ash)—5 bag per cu yd
C3a	x	—	—	I-1	5.05	5.55	2	5.2	146.6	'63	Control (No fly ash)—5 bag per cu yd
C3b	—	x	—	I-1	5.79*	5.41	2¼	5.4	144.5	'63	Poor fly ash (141 lbs/cu yd)
C3b	x	—	—	I-1	5.81*	5.33	2½	5.5	145.0	'63	Poor fly ash (141 lbs/cu yd)
C3c	—	x	—	I-1	5.90*	4.89	2¼	5.6	146.3	'63	Fair fly ash (141 lbs/cu yd)
C3c	x	—	—	I-1	5.93*	4.89	2½	5.4	147.2	'63	Fair fly ash (141 lbs/cu yd)
C3d	—	x	—	I-1	5.97*	4.61	2½	5.2	147.6	'63	Good fly ash (141 lbs/cu yd)
C3d	x	—	—	I-1	5.96*	4.61	2	5.2	147.2	'63	Good fly ash (141 lbs/cu yd)
Aggregate Series: (1) Normal Weight Aggregates											
F1a	—	x	—	I-2	6.01	4.65	2½	5.6	147.2	'64	1½" Elgin sand and gravel
F1a	x	—	—	I-2	6.05	4.73	1¾	4.9	148.4	'64	1½" Elgin sand and gravel
F1f	—	—	x	I-2	5.94	4.81	2½	5.9	145.8	'64	1½" Elgin sand and gravel
F1b	—	x	—	I-2	6.01	4.57	2	6.0	145.8	'64	1½" Eau Claire sand and gravel
F1b	x	—	—	I-2	6.06	4.38	2¾	5.7	146.3	'64	1½" Eau Claire sand and gravel
F1g	—	—	x	I-2	6.06	4.44	2¾	5.5	146.9	'64	1½" Eau Claire sand and gravel
F1c	—	x	—	I-2	5.90	5.06	2¼	6.2	144.7	'64	1½" Crushed Thornton, Ill. limestone and Elgin sand
F1c	x	—	—	I-2	5.98	5.19	2	5.4	146.9	'64	1½" Crushed Thornton, Ill. limestone and Elgin sand
F1h	—	—	x	I-2	6.03	5.25	1¾	4.9	148.3	'64	1½" Crushed Thornton, Ill. limestone and Elgin sand
F1d	—	x	—	I-2	5.98	5.27	2½	5.1	146.9	'64	1½" Crushed Elmhurst, Ill. limestone and Elgin sand
F1d	x	—	—	I-2	5.94	5.27	2	5.5	146.1	'64	1½" Crushed Elmhurst, Ill. limestone and Elgin sand
F1k	—	—	x	I-2	5.92	5.23	2	5.5	145.4	'64	1½" Crushed Elmhurst, Ill. limestone and Elgin sand
F1e	—	x	—	I-3	6.04	5.19	1¾	5.1	154.9	'64	1½" Crushed Dresser, Wisc. trap rock and Elgin sand
F1e	x	—	—	I-3	6.02	5.27	1¾	5.6	154.5	'64	1½" Crushed Dresser, Wisc. trap rock and Elgin sand
F1m	—	—	x	I-3	5.96	5.27	2½	5.8	153.0	'64	1½" Crushed Dresser, Wisc. trap rock and Elgin sand
Aggregate Series: (2) Smaller Maximum Size Aggregate											
D2b	—	x	—	I-2	6.05	4.84	2¼	6.7	144.1	'64	¾" Eau Claire gravel and Elgin sand
D2a	—	x	—	I-2	5.98	7.10	2½	10.6	130.3	'64	No. 4 Elgin sand

*Cement factor calculated on basis of weight of cement plus fly ash, considering 94 lbs. as one bag.

APPENDIX 1—DATA ON TEST SPECIMENS (CONCLUDED)

Specimen	Specimen Type: Box	Specimen Type: Slab on Grade	Specimen Type: Elevated Slab	Cement	Cement Factor, bags per cu yd	Net W/C, gal per bag	Slump, in.	Air Content, %	Unit Wt, lb per cu ft	Year Cast	Special Details
Aggregate Series: (3) Lightweight Aggregates											
G1a	—	x	—	I-2	5.54	—	2¼	8.6	99.2	'64	Rotary kiln expanded shale—dry aggregate
G1a	x	—	—	I-2	5.57	—	2	8.1	99.6	'64	Rotary kiln expanded shale—dry aggregate
G1g	—	—	x	I-2	5.60	—	2	8.1	100.0	'64	Rotary kiln expanded shale—dry aggregate
G1b	—	x	—	I-2	5.60	—	2	8.4	103.0	'64	Rotary kiln expanded shale—aggregate wetted for 18 hrs
G1b	x	—	—	I-2	5.49	—	2	8.6	101.2	'64	Rotary kiln expanded shale—aggregate wetted for 18 hrs
G1h	—	—	x	I-2	5.53	—	3	8.6	101.9	'64	Rotary kiln expanded shale—aggregate wetted for 18 hrs
G1c	—	x	—	I-2	7.94	—	2¾	7.5	96.1	'64	Sintered expanded shale—dry aggregate
G1c	x	—	—	I-2	8.08	—	2¼	6.6	97.6	'64	Sintered expanded shale—dry aggregate
G1j	—	—	x	I-2	8.10	—	2¼	6.3	97.8	'64	Sintered expanded shale—dry aggregate
G1d	—	x	—	I-2	8.12	—	2¼	6.0	100.3	'64	Sintered expanded shale—aggregate wetted for 18 hrs
G1d	x	—	—	I-2	8.19	—	2¾	7.1	101.3	'64	Sintered expanded shale—aggregate wetted for 18 hrs
G1k	—	—	x	I-2	8.03	—	2½	6.3	99.2	'64	Sintered expanded shale—aggregate wetted for 18 hrs
G1e	—	x	—	I-2	8.61	—	2¼	7.5	107.5	'64	Expanded slag—dry aggregate
G1e	x	—	—	I-2	8.84	—	1¾	6.2	110.8	'64	Expanded slag—dry aggregate
G1m	—	—	x	I-2	8.84	—	1¾	6.2	110.7	'64	Expanded slag—dry aggregate
G1f	—	x	—	I-2	8.77	—	2	6.2	111.1	'64	Expanded slag—aggregate wetted for 18 hrs
G1f	x	—	—	I-3	8.74	—	2¼	6.6	114.5	'64	Expanded slag—aggregate wetted for 18 hrs
G1n	—	—	x	I-2	8.79	—	2½	6.0	111.4	'64	Expanded slag—aggregate wetted for 18 hrs
Aggregate Series: (4) Surface Retarded—Exposed Aggregate Finishes											
L1a	—	x	—	I-3	5.93	5.02	5	5.9	145.7	'64	⅜" Elgin gravel surface
L1b	—	x	—	I-3	5.99	4.94	5	5.2	146.9	'64	⅜" Eau Claire gravel surface
L1c	—	x	—	I-3	5.90	4.90	5	5.9	144.8	'64	⅜" Dense chert (Meramec) gravel surface
Cement Series: (1) White Portland Cement Concrete											
E1a	—	x	—	WPC	5.93	5.13	2½	5.0	147.6	'63	Cast in summer
E1a	x	—	—	WPC	5.93	5.13	2½	5.3	147.4	'63	Cast in summer
E1b	—	x	—	WPC	5.78	5.17	5½	6.1	143.9	'63	Cast in fall
E1b	x	—	—	WPC	5.86	5.17	4½	5.2	145.9	'63	Cast in fall
Cement Series: (2) Shrinkage-Compensating Concretes											
E2a	—	x	—	—	7.56	4.14	5¾	5.7	146.1	'64	Klein type shrinkage-compensating cement
E2b	—	—	x	—	7.52	4.11	5¾	5.9	145.1	'64	Klein type shrinkage-compensating cement
E2c	—	x	—	—	7.35	4.79	5½	5.9	142.5	'64	Portland cement—calcium aluminate cement—gypsum, experimental mixture
E2d	—	—	x	—	7.38	4.79	5½	5.3	143.2	'64	Portland cement—calcium aluminate cement—gypsum, experimental mixture
Miscellaneous: (1) Variable Water-Cement Ratios—Variable Reinforcing Steel Cover											
D1a	—	x	—	I-1	7.82	4.25	2¼	5.1	146.3	'63	4¼ gal/bag, no reinforcing
D1e	—	—	x	I-1	7.75	4.25	3	5.9	145.0	'63	4¼ gal/bag, 1½ in. cover over steel
D1k	—	—	x	I-1	7.83	4.19	2¾	5.6	146.4	'63	4¼ gal/bag, ½ in. cover over steel
D1b	—	x	—	I-1	5.81	5.04	2¼	5.5	146.1	'63	5 gal/bag, no reinforcing
D1f	—	—	x	I-1	5.82	5.00	3	5.7	146.2	'63	5 gal/bag, 1½ in. cover over steel
D1m	—	—	x	I-1	5.84	5.08	2¾	5.8	146.8	'63	5 gal/bag, ½ in. cover over steel
D1c	—	x	—	I-1	4.97	5.69	2¾	5.2	146.7	'63	5¾ gal/bag, no reinforcing
D1g	—	—	x	I-1	5.03	5.35	2¼	5.5	147.8	'63	5¾ gal/bag, 1½ in. cover over steel
D1n	—	—	x	I-1	5.02	5.45	3	5.3	147.7	'63	5¾ gal/bag, ½ in. cover over steel
D1d	—	x	—	I-1	4.19	6.53	2½	5.7	145.9	'63	6½ gal/bag, no reinforcing
D1h	—	—	x	I-1	4.22	6.41	2	6.2	146.7	'63	6½ gal/bag, 1½ in. cover over steel
D1p	—	—	x	I-1	4.23	6.23	3¼	5.7	146.9	'63	6½ gal/bag, ½ in. cover over steel
D1x	—	x	—	I-1	3.65	7.29	2¾	6.1	146.3	'63	7¼ gal/bag, no reinforcing
Miscellaneous: (2) Type of Subbase											
H1a	—	x	—	I-2	5.88	4.85	2	5.9	145.7	'64	Polyethylene film over the subbase
H1b	—	x	—	I-2	5.87	4.89	2½	5.9	145.6	'64	Dry sand subbase
Miscellaneous: (3) Various Deicing Salts											
K1a	—	x	—	I-A	6.02	4.49	2½	4.7	148.6	'64	Flake calcium chloride—cast in summer
K1f	—	x	—	I-A	5.95	4.57	3¼	5.1	147.1	'64	Flake calcium chloride—cast in fall
K1b	—	x	—	I-A	6.00	4.53	2¼	4.8	148.2	'64	Rock salt (sodium chloride)—cast in summer
K1g	—	x	—	I-A	6.02	4.57	2¾	4.4	148.6	'64	Rock salt (sodium chloride)—cast in fall
K1c	—	x	—	I-A	6.01	4.53	2½	4.8	148.5	'64	Calcium chloride plus rock salt—cast in summer
K1h	—	x	—	I-A	5.95	4.53	3	5.1	146.8	'64	Calcium chloride plus rock salt—cast in fall
K1d	—	x	—	I-A	6.03	4.61	2¼	4.6	149.0	'64	Ammonium sulfate—cast in summer
K1i	—	x	—	I-A	5.97	4.50	2¾	4.9	147.4	'64	Ammonium sulfate—cast in fall
K1e	—	x	—	I-A	6.01	4.61	2½	4.9	148.6	'64	Ammonium nitrate—cast in summer
K1j	—	x	—	I-A	6.03	4.29	2	4.5	148.5	'64	Ammonium nitrate—cast in fall