USE OF SILICONE ADMIXTURE IN BRIDGE DECK CONCRETE

H. L. Patterson, Michigan Department of State Highways

This report is the third in a series that resulted from a cooperative study, originally started in 1963 and sponsored jointly by the Dow Corning Corporation of Midland, Michigan, and the Michigan Department of State Highways, to determine the effects of using a silicone admixture in bridge deck construction. The previous reports dealt with the construction and initial inspection of the Scotten Avenue bridge over Michigan Avenue in Detroit and of the Coe Road bridge over US-27 in Isabella County.

•THE EFFECTS OF SILICONES on concrete have been investigated for several years by the Dow Corning Corporation, a major producer of silicones. Their initial efforts were directed toward hardened concrete sealants, but more recently the company has been interested in the use of silicones as an admixture in concrete. This led to the development of DC-777, an admixture that is a water-soluble, straw-colored, liquid-reactive polysiloxane containing 100 percent silicone and weighing approximately 8.45 lb/gal. Dow Corning engineers found that, when it is added to concrete in the amount of 0.3 percent by weight of the cement, it produced the following characteristics: substantially retarded the set of the concrete (Table 1); entrained a significant amount of air; increased the bond, compressive, and flexural strengths; reduced the net water-cement ratio; and increased the resistance to scaling on concrete of low or moderate air content when ice-removal salts were used.

TEST BRIDGES

Scotten Avenue Over US-12 (Michigan Avenue)

Dow Corning personnel presented a summary of laboratory studies to Michigan Department of State Highways (MDSH) representatives in Midland on April 25, 1963, and in Lansing on May 9, 1963. At this time it was decided to select a bridge whose deck would test the effectiveness of the admixture. The Scotten Avenue bridge over Michigan Avenue in Detroit, originally constructed in 1941, was scheduled to receive a deck replacement under a major maintenance contract. It was decided to use the admixture in conjunction with blast-furnace slag coarse aggregate on this deck.

The structure is a 2-span, through plate girder design, 141 ft long with a clear roadway of 42 ft. Curb, sidewalk, and girder encasement pours on both sides of the deck result in an overall width of 62 ft 8 in. The northeast and southwest deck pours were to contain the silicone admixture concrete, whereas the northwest and southeast pours were to be of conventional air-entrained concrete. Construction was completed in October 1963. This bridge receives heavy urban traffic and heavy winter salting for snow removal. Figure 1 shows profile and approach views of this bridge as it appeared in 1969.

Coe Road Over US-27

The second structure selected in the study is a 4-span, prestressed concrete I-beam bridge that carries Coe Road, a rural county road, over US-27, a limited-access,

Sponsored by Committee on Chemical Additions and Admixtures for Concrete.

divided highway, 6 miles north of Alma. The silicone admixture in conjunction with limestone coarse aggregate was used on this bridge. The bridge has a 24-ft roadway and a total length of 208 ft. All but 13 ft of the west half of the bridge deck was constructed with silicone admixture concrete, whereas the remainder was constructed with conventional air-entrained concrete containing a water-reducing and set-retarding admixture. Construction was completed in October 1964. This bridge receives light rural traffic and no salting in the winter. Figure 2 shows the profile and approach views of the bridge as it appeared in 1969.

TABLE 1

COMPARISON OF HOURS OF SETTING TIME

Temperature (F)	Normal Concrete[a]		Concrete With 0.3 Percent DC-777[a]	
	Initial	Final	Initial	Final
40	10½	15½	52	63
60	6	8	31½	37
80	4	5½	23	29
100	2	3	15	24

[a]Determined by ASTM Method C 403 (Test for Time of Setting of Concrete Mixtures by Penetration Resistance).

Figure 1a

Figure 1b

Figure 1. Scotten Avenue bridge over Michigan Avenue: (a) general view of bridge deck looking northwest and (b) profile view looking west along Michigan Avenue.

Figure 2a

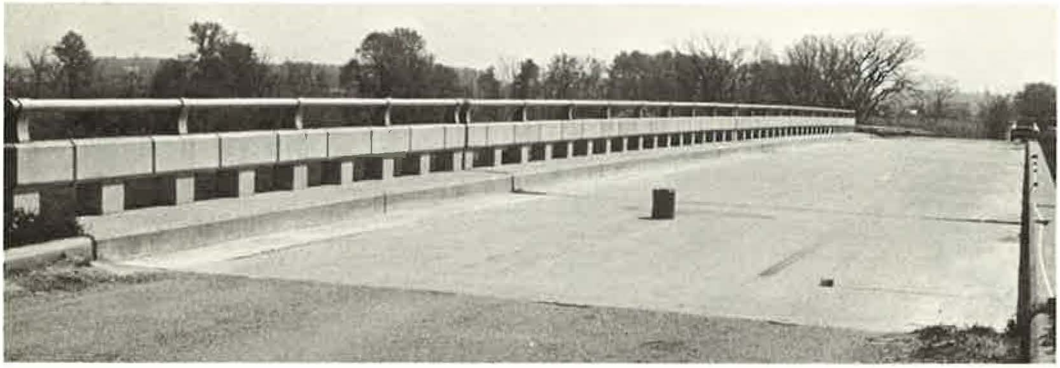

Figure 2b

Figure 2. Coe Road bridge over US-27 south of the village of Shepherd: (a) general view of bridge deck from the west approach and (b) k profile view looking northwest.

Eastbound M-78 Over the Grand Trunk and Western Railroad

The third structure selected in the study is a 3-span steel stringer bridge carrying eastbound M-78, a limited-access, divided highway, over the Grand Trunk and Western Railroad southwest of Flint. The bridge has a deck width of 38 ft 6 in., is 203 ft long, and has end spans that cantilever over their piers to support the suspended center span. The silicone admixture in conjunction with concrete containing gravel coarse aggregate was used on this bridge. The bridge deck and curb pours of the center span are cast with the silicone concrete, whereas the end spans have normal concrete that is air entrained and contains a water-reducing and set-retarding admixture. At the date of the construction of this bridge, Dow Corning engineers had modified their silicone admixture such that it could be used with regular air-entrained cement without entraining an excessive amount of air. The modified material was designated DC-777B. Construction was completed in September 1967, and the bridge currently receives heavy traffic and moderate salting for snow removal. Figure 3 shows profile and approach views of the bridge as it appeared in 1969.

EVALUATION

Slag Coarse Aggregate

The Scotten Avenue bridge deck in urban Detroit was covered with a concrete mix containing blast-furnace slag coarse aggregate and 6 sacks/cu yd of cement. The concrete was mixed in transit by ready-mix trucks, placed by a crane-lifted concrete

Figure 3a

Figure 3b

Figure 3. Eastbound M-78 bridge over the Grand Trunk and Western Railroad, southwest of the city of Flint: (a) general view of bridge deck looking west and (b) profile view looking northeast.

bucket, and hand screeded and finished. The deck concrete was cured with 4-mil white polyethylene and applied as soon as the surface moisture was gone.

Slag coarse aggregate has the advantage in bridge deck construction of reducing the bridge deck dead load by 10 percent, minimizing surface and internal disruptions caused by freeze-thaw vulnerable deleterious materials, and being cheap and readily available in this area. It has the disadvantages of being brittle, containing small amounts of iron, and having a high water-absorption capacity.

Because the original silicone admixture entrained air, Type I cement was used throughout the deck; an air-entraining admixture was added to supply the necessary air for the normal concrete.

Data given in Table 2 show that the water-cement ratio of the normal concrete was higher than that of the silicone concrete. This is because the deck was constructed before the Michigan Department of State Highways adopted water-reducing and set-retarding admixtures for use in bridge deck concrete to accommodate machine finishing. To achieve a 4-in. slump required that the water-cement ratio of the normal concrete be significantly higher than that for the silicone concrete because the silicone admixture acted as an internal lubricant in the mix. Thus, the silicone admixture effectively reduced the amount of water required to obtain a 4-in. slump.

TABLE 2

CHARACTERISTICS OF FRESH CONCRETE

Bridge	Coarse Aggre-gate	Concrete	Pour Date	Span	Cement		Net Water-Cement Ratio	Fine Aggregate/ Total Aggregate (percent)	Slump (in.)	Air (per-cent)	Admixture per Sack[a]
					Type	Sacks/ Cu Yd					
Scotten Avenue	Slag	Normal			I	6	0.49	50	4.1	6.6	2.5 oz AE
		Silicone			I	6	0.40	49	4.7	7.3	0.3 lb DC-777
Coe Road	Lime-stone	Normal			I	6	0.40	42	4.1	6.2	3.0 oz WR and SR, 1.5 oz AE
		Silicone			I	6	0.39	42	4.1	8.1	0.3 lb DC-777
M-78											
Deck	Gravel	Normal	8-14-67	1	IA	6	0.43	35	4.0	6.5	4.0 oz WR and SR, 0.5 oz AE
		Silicone	8-11-67	2	IA	6	0.43	35	4.0	7.5	0.25 lb DC-777B, 0.25 oz AE
		Normal	8-16-67	3	IA	6	0.42	35	4.5	7.1	4.0 oz WR and SR, 0.5 oz AE
Curb	Gravel	Normal	8-25-67	1	IA	6	0.44	33	3.0	8.5	3.0 oz WR and SR, 1.38 oz AE
		Silicone	8-30-67	2	IA	6	0.44	33	3.3	7.6	0.25 lb DC-777B, 0.25 oz AE
		Normal	8-29-67	3	IA	6	0.44	33	3.0	7.9	3.0 oz WR and SR, 1.25 oz AE

[a]AE = air-entrained agent; WR = water-reducing agent; and SR = set-retarding agent.

In the laboratory, the performance of the silicone concrete field specimens was superior to that of the normal concrete in both strength and shrinkage measurements (Table 3). This could have been the combined effect of 2 factors: first, the beneficial effect of the silicone admixture; and, second, the lower water-cement ratio of the silicone concrete. The measurements are the average of several specimens that were sampled at various times during the pour. The compressive strength, flexure strength, and shrinkage measurements were measured respectively from the 4- by 8-in. cylinders, 3- by 4- by 16-in. beams, and 3- by 3- by 15-in. prisms cast with stainless steel end studs. The complete test data for the bridge are contained in the original report (1).

A field inspection was conducted 6 years after the deck was poured and showed the entire deck to be functioning well. Figure 4 shows a diagram of all the deterioration features that were visible at the time of inspection. The plastic shrinkage cracks and

TABLE 3

LABORATORY TEST RESULTS OF FIELD SPECIMENS

Bridge	Coarse Aggre-gate	Concrete	Span	Average Compressive Strength (psi)		Average Flexural Strength (psi)		Shrinkage (percent)		
				7-Day	28-Day	7-Day	28-Day	7-Day	28-Day	3-Month
Scotten Avenue	Slag	Normal			4,610		660		0.017	0.044
		Silicone			6,080		860		0.009	0.036
Coe Road	Lime-stone	Normal			5,800		–		0.008	0.030
		Silicone			5,420		–		0.010	0.033
M-78										
Deck	Gravel	Silicone	2	3,670	4,200	710	880	0.035	0.051	
		Normal	3	3,450	4,200	610	720	0.036	0.049	
Curb	Gravel	Normal	1	3,240	3,350	640	800	0.024	0.050	
		Silicone	2	3,450	3,860	710	830	0.042	0.059	

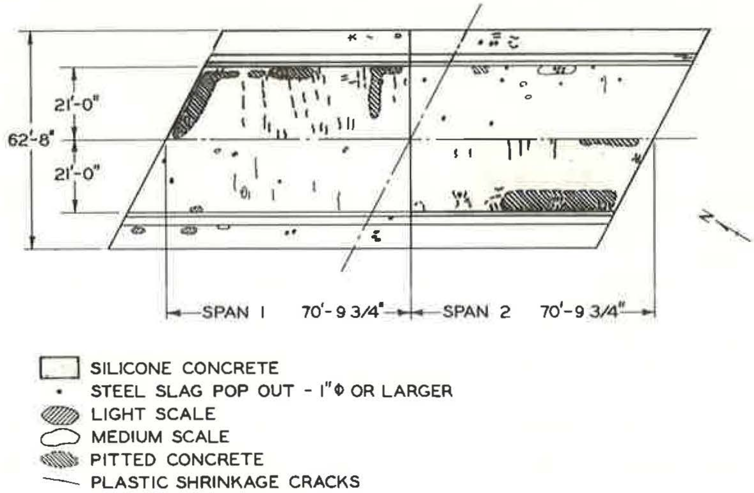

Figure 4. Surface deterioration observed on Scotten Avenue bridge deck containing slag coarse aggregate.

large pitted areas were generally confined to the silicone concrete, whereas the scaled areas and rusted iron pop-outs were generally confined to the normal concrete.

The plastic shrinkage cracks in the silicone developed within 36 hours after finishing and were prominently visible at that time. Three known conditions could have contributed to their formation: (a) the silicone concrete took 36 hours to set; (b) the slag aggregate, with its great absorption potential, had adequate time to absorb a significant amount of mix water; and (c) the polyethylene sheeting, with which the deck was cured, could have allowed air movement underneath if it was not properly sealed around its perimeter. The first 2 factors are considered to be the most critical on this project.

The pitted areas seem to have been produced by traffic abrasion, to which slag aggregate appears to be vulnerable. On successive annual inspections, it was noted that surface features photographed the first year could not be identified the second year. Although this abrasion was by no means confined to the silicone concrete, it was more distinct there because of the unfavorable location it occupied on the bridge deck with respect to traffic. That is, the bridge was on a vertical curve and the nature of the traffic pattern was such that vehicles would be braking as they left either end of the bridge deck where the silicone concrete was located.

The few small scaled areas and scattered iron pop-outs on the bridge appeared to be confined to the normal concrete pours. This would indicate that the silicone was effective in preventing these types of deterioration. Figure 5 shows some of the most prominent deterioration features found on the deck.

Limestone Coarse Aggregate

In the bridge deck of rural county Coe Road, the concrete mix contained limestone coarse aggregate and 6 sacks/cu yd of cement. Limestone coarse aggregate (6AA) has the advantage in bridge deck construction of providing a uniform, dense material that has a high compressive load capacity and low absorption. Because of these properties, it is very resistant to freeze-thaw deterioration.

Limestone coarse aggregate has the disadvantage of producing a harsh mix, being relatively soft, and being relatively expensive. The harshness is caused by the irregular angular shape of the crushed limestone and can only be rectified by increasing the percentage of the aggregate in the mix. This increases the volume of the mortar,

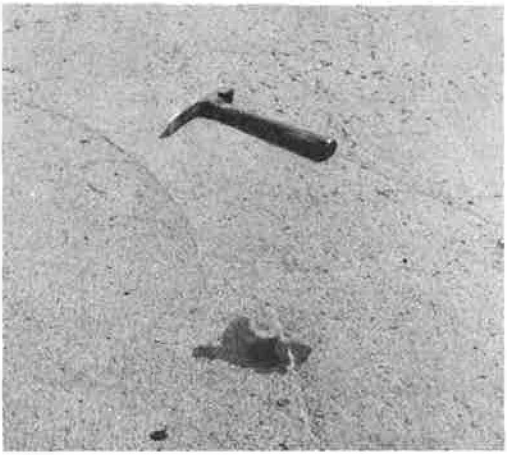

Figure 5a

Figure 5b

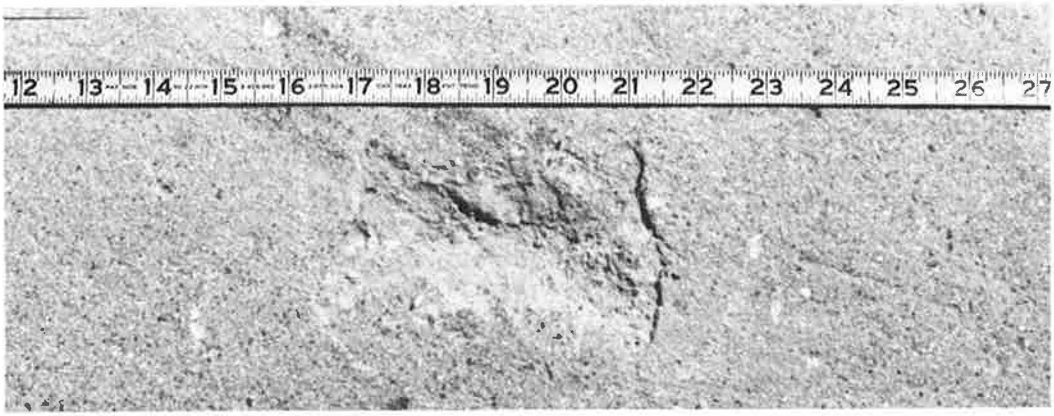

Figure 5c

Figure 5. Deterioration on the Scotten Avenue bridge: (a) typical plastic shrinkage cracks found in silicone concrete, (b) light pitting to which slag aggregate appears vulnerable, and (c) 3- by 5-in. scale spot caused by volume expansion of rusting iron.

dilutes its cement content, and increases the water-cement ratio. The softness of the limestone makes it vulnerable to traffic abrasion.

As with the Detroit bridge, Type I cement was used throughout the deck because the silicone admixture entrained the air. A water-reducing set-retarding admixture and an air-entraining admixture were added to the control or normal concrete. The concrete was mixed in transit by ready-mix trucks, placed by a crane-lifted bucket, and finished by a transverse screeding machine. The concrete was sprayed with a white curing membrane applied at 200 sq ft/gal soon after finishing.

Table 2 gives the water-cement ratio, the rest of the mix proportioning, and the slump; these were nearly the same for both the silicone and normal concretes. They differed only in that the silicone concrete contained about 2 percent more entrained air.

Table 3 gives the results of the tests of the field specimens that were cured and tested in the laboratory. The normal concrete, aided by its water-reducing and

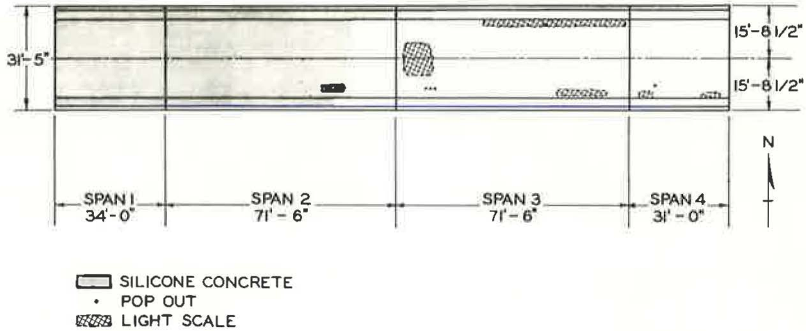

Figure 6. Surface deterioration observed on Coe Road bridge deck containing limestone coarse aggregate.

set-retarding admixture, produced very impressive results, even slightly surpassing the performance of the silicone concrete. The compressive strength and shrinkage measurements were obtained from the 4- by 8-in. cylinders and 3- by 3- by 15-in. prisms cast with stainless steel end studs. No flexure strength beams were cast for this bridge. The complete test data for this bridge are contained in the original MDSH report (2).

A field inspection was conducted 5 years after the bridge was constructed, and showed the concrete to be in excellent condition. Figure 6 shows a diagram of the deterioration features on the deck that were visible at the time of the inspection. The silicone portion of the deck was completely unblemished except for 1 small scale spot. The normal concrete portion of the deck had developed a few areas of light scale and a very few pop-outs. These pop-outs were probably caused by deleterious materials that were introduced at the batching plant of the concrete company.

Gravel Coarse Aggregate

In the limited-access, divided-highway bridge deck on M-78, the concrete mix contained gravel coarse aggregate (6AA) and 6 sacks/cu yd of cement. The concrete was mixed in transit by ready-mix trucks, placed by a crane-lifted concrete bucket, and

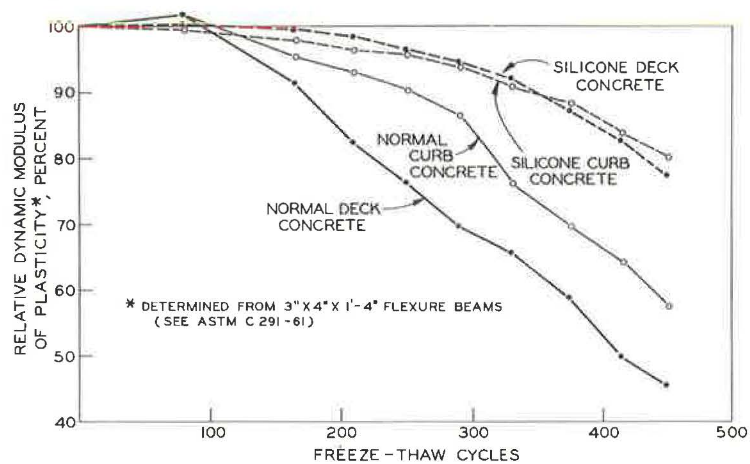

Figure 7. Internal freeze-thaw durability of beams cast from gravel coarse aggregate concrete used in M-78 bridge.

finished by a longitudinal screeding machine. The concrete was cured with a white membrane curing compound applied at 200 sq ft/gal.

Gravel has the advantage of being readily available, relatively cheap, and composed of an assortment of smooth rounded stones that will produce a very workable mix. Because of its workability, the percentage of fine aggregate can be minimized and produce a strong rich mortar. Gravel has the major disadvantage of being composed of a random assortment of rock types, some of which are considered to be deleterious.

Because freeze-thaw susceptible aggregates generally have low specific gravities, the quality of gravel can be improved by the heavy media process that separates the lighter particles from the heavier ones. Although this process improves the aggregate, it by no means makes it ideal because some stones of marginal quality are retained. When freeze-thaw conditions cause these frost-susceptible particles to disintegrate, they disrupt the concrete that surrounds them and make it vulnerable to further damage.

In 1967, when this deck was poured, the Dow Corning Corporation had incorporated a defoaming agent into its silicone admixture that allowed it to be used with conventional air-entrained cement. This modified version of the original admixture was designated DC-777B. Thus, all the cement used in this bridge was Type IA.

Table 2 gives the important properties of the fresh concrete used throughout the deck and curb pours of this bridge. The silicone concrete data are from span 2, and the normal concrete data are from spans 1 and 3. Little difference exists between the properties shown for the 2 types of concrete.

Table 3 gives the results of some of the laboratory tests run on field specimens. The silicone concrete in every case tested higher in both compression and flexure. In shrinkage, however, the normal concrete shrank less than the silicone concrete.

For this bridge, scaling slabs and freeze-thaw beam specimens were cast in addition to the compression (4- by 8-in. cylinders), flexure (4- by 4- by 16-in. beams), and shrinkage (3- by 3- by 15-in. prism) specimens. They were all covered with polyethylene film at the bridge site and allowed to harden before being moved to the moist-curing room in the laboratory.

By means of dynamic testing apparatus, the fundamental transverse vibration frequencies of the 3- by 4- by 16-in. freeze-thaw beams were measured initially and at subsequent regular intervals throughout the rapid freeze-thaw testing. Figure 7 shows the relative dynamic modulus of elasticity plotted against freeze-thaw cycles. The results of this testing indicate the silicone concrete to be superior to normal concrete in resisting internal freeze-thaw damage; this apparently was the result of a resistance to absorption that the silicone furnished to deeply embedded deleterious particles.

The scaling slabs were 9 in. wide, 12 in. long, and 2½ in. thick and had a 1-in. high mortar dike around the perimeter to retain water. During the testing procedure, the slabs were placed on a mobile rack and pushed into the freezer at night. They were withdrawn in the morning, thus giving a freeze-thaw cycle per day (about 0 to 70 F). At the end of each 15 cycles, the slabs were returned to the concrete laboratory, scrubbed under running water, and set up to dry; their surface condition was then studied, evaluated, and photographed. On alternate days during the first 60 cycles, the slabs were placed in ponds of water and a 3 percent salt solution. Figure 8 shows the scaling slabs of silicone deck concrete before and after 45 freeze-thaw cycles. Although the slabs developed several pop-outs, they developed only light scale.

Figure 9 shows scaling slabs cast of normal concrete before and after 45 freeze-thaw cycles. The surface not only developed many pop-outs but also developed extensive medium scale. Figure 10 shows the observed severity of the scale on all of the normal and silicone concrete scaling slabs through 200 freeze-thaw cycles. The evaluating rating system ranges from 1 to 5, where 1 represents no scale and 5 represents heavy scale. The values shown are the average ratings for 3 specimen slabs of each concrete pour. A comparison of Figures 8 and 9 shows that the silicone concrete has much more resistance to frost-inflicted scaling than the normal air-entrained concrete. It would appear from Figure 8 that frost-susceptible particles lying close to the top surface of the concrete receive little protection, but the same type lying slightly deeper appear to be better protected.

The field inspection of this bridge made 2 years after the bridge was completed showed some contrasting features with the other bridges described in this report.

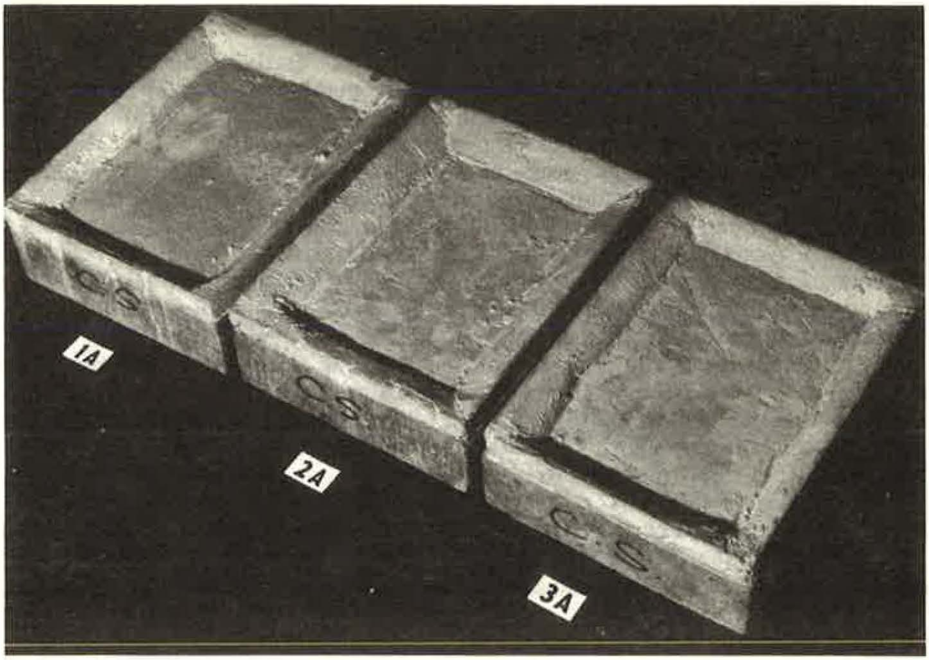

Figure 8a

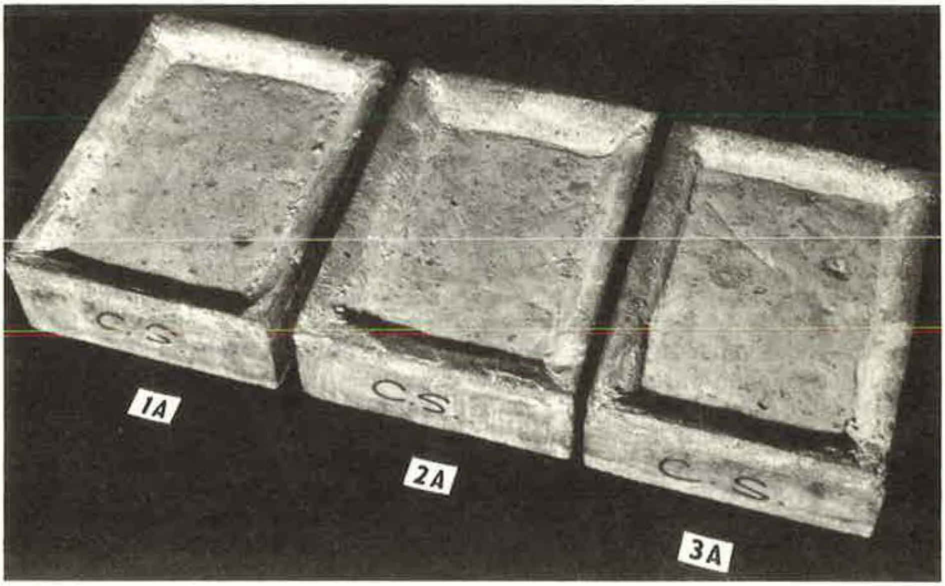

Figure 8b

Figure 8. Laboratory scaling slabs cast from silicone deck concrete used in span 2 of M-78 bridge (a) before testing and (b) after 45 freeze-thaw cycles.

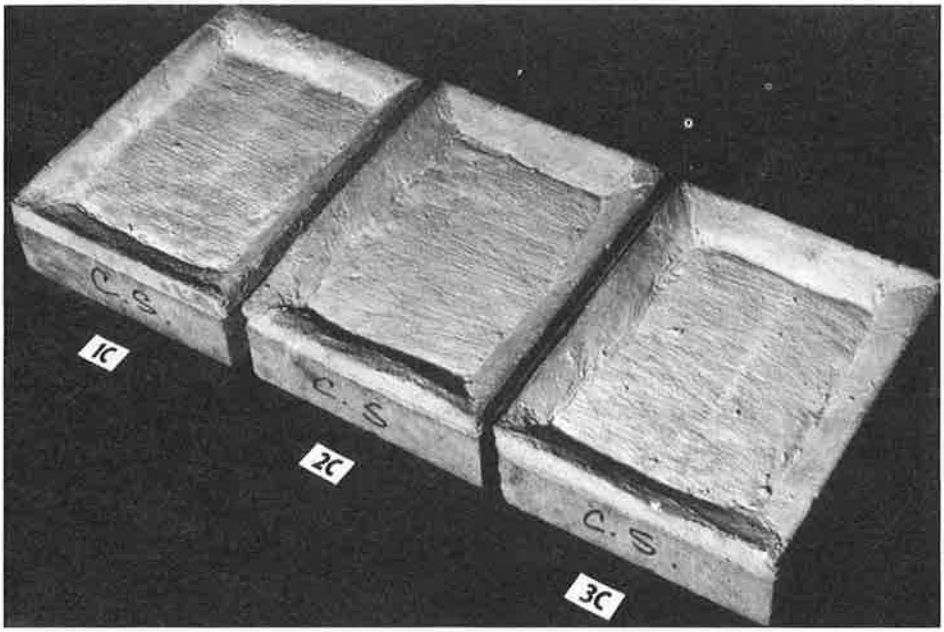

Figure 9a

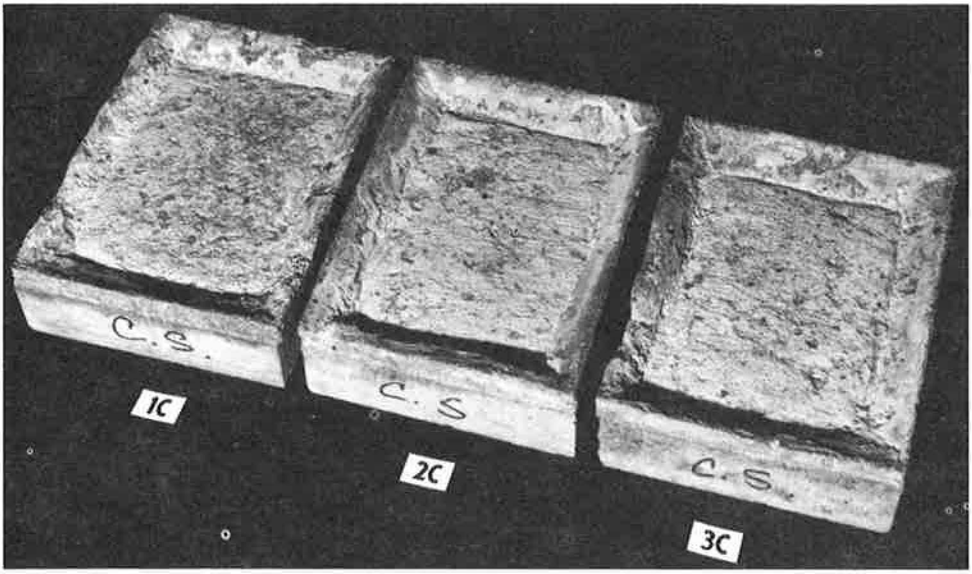

Figure 9b

Figure 9. Laboratory scaling slabs cast from normal deck concrete used in span 3 of M-78 bridge (a) before testing and (b) after 45 freeze-thaw cycles.

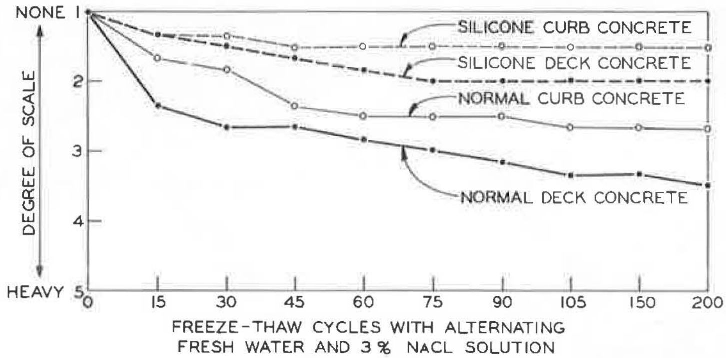

Figure 10. Surface freeze-thaw durability of scaling slabs cast from gravel coarse aggregate concrete used in M-78 bridge.

Figure 11 shows a diagram of the deterioration features that were visible at the time the deck was inspected; included are pop-outs and craze cracking in all 3 spans and light scale in span 3. The most prominent of these were the numerous pop-outs that developed uniformly over the entire deck surface; they developed in a pattern consistent with laboratory observations and suggested that the silicone admixture provided little protection for the frost-susceptible particles in the gravel lying close to the top surface of the concrete. Figure 11 also shows that both types of concrete developed large areas that were craze cracked. This type of cracking is generally the result of early surface shrinkage and could be caused by conditions similar to those that produce plastic shrinkage cracks.

Scaling is minor on this deck, being confined mainly to the south curb line in span 3 where the longitudinal screeding machine left the heaviest concentration of laitance. Because this thin layer of silt and cement was weak and brittle, it was soon removed by weathering and traffic abrasion and now gives the specious impression that the rapid destruction of the concrete is imminent; however, the concrete below laitance generally presents a more formidable surface. Figure 12 shows some of the prominent deterioration features described previously.

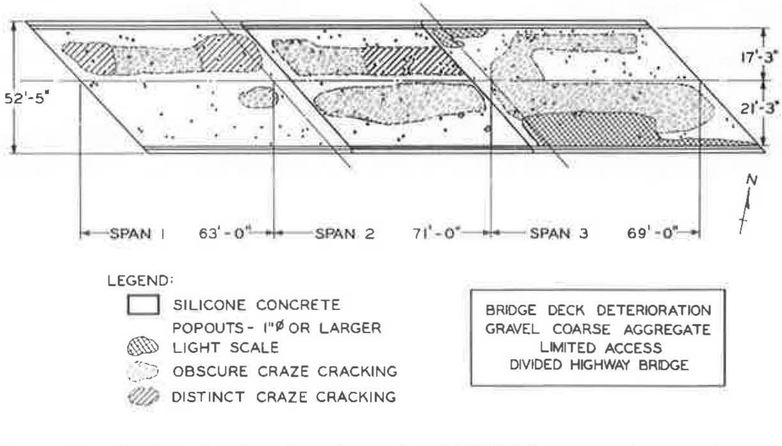

Figure 11. Surface deterioration observed on M-78 bridge containing gravel coarse aggregate.

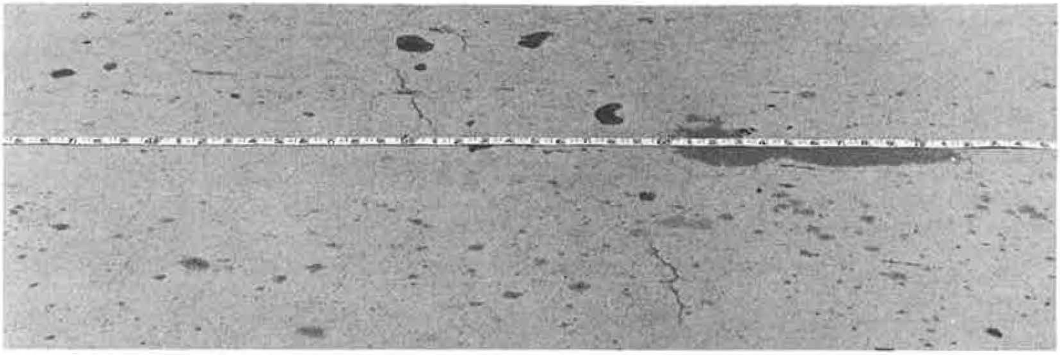

Figure 12a

Figure 12b

Figure 12c

Figure 12. Deterioration on M-78 bridge included (a) pop-out concentration in traffic lane of span 2 and typical across entire deck, (b) distinct craze cracking area in traffic lane of span 2, and (c) light scaling of thin laitance coat along south curb line in span 3.

CONCLUSIONS

The basic liquid silicone admixture DC-777, which was developed by Dow Corning, altered the properties of plain concrete in the following ways:

1. It entrained air;
2. It excessively retarded the set;
3. It served as an internal lubricant, permitting a reduction in mix water;
4. It raised the unit strength; and
5. It increased the resistance to freeze-thaw deterioration.

The basic admixture was later modified and designated DC-777B for use with regular air-entrained cement.

When compared with normal air-entrained concrete to which water-reducing and set-retarding admixtures have been added, the strength advantages of the silicone admixture concrete are somewhat reduced but still include greater resistance to freeze-thaw deterioration.

The silicone admixture seems to function equally well with any of the 3 coarse aggregates described in this report; blast-furnace slag, limestone, and gravel. Although it offers excellent protection to the concrete against scaling, it affords less protection to frost-susceptible particles found in gravel and the iron particles found in slag. The deleterious particles that appeared to be particularly susceptible were those lying immediately at the surface; those embedded deeper in the concrete appeared to receive some protection. This conclusion is based on the superior performance of the silicone concrete in the dynamic modulus freeze-thaw testing conducted in the laboratory.

Although two of the bridges developed some type of shrinkage cracks in the silicone concrete, it was not conclusive that the admixture's set retardation was the main cause; however, it could have contributed significantly in the high-porosity slag concrete that was cured with polyethylene film. The limestone concrete developed no shrinkage cracks, and the craze cracking in the gravel concrete was common to both the silicone and the normal concrete.

In general, the liquid silicone admixture DC-777B could be described as being beneficial to the concrete, particularly in retarding the formation of scale as observed on all 3 test bridges. Rapid freeze-thaw testing conducted in the laboratory revealed the treated concrete to have a superior resistance to internal freeze-thaw breakdown. Whereas the test bridges have shown the silicone concrete to be somewhat superior to normal concrete, they are not old enough at this time to establish a substantial superiority.

The quantity price of the admixture is about $3.50 per pound and would add $6.00 to the cost of a cubic yard of concrete containing 6 sacks of cement, when used at the recommended rate of 0.3 pound of silicone per sack of cement.

REFERENCES

1. Brown, M. G., and Merrill, R. H. Use of a Silicone Admixture in Bridge Deck Concrete. Michigan Department of State Highways, Res. Rept. R-463, June 1964.
2. Merrill, R. H., and Zapata, C. A. Use of a Silicone Admixture in Bridge Deck Concrete. Michigan Department of State Highways, Res. Rept. R-529, Sept. 1965.