

USE OF SILICONE ADMIXTURE IN BRIDGE DECK CONCRETE



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USE OF SILICONE ADMIXTURE IN BRIDGE DECK CONCRETE

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INTRODUCTION

Previous Reports

This report is the third in a series which resulted from a cooperative study that originally started in 1963 between 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 were as follows: MDSH Research Report No. R-463 (1964), jointly written by M. G. Brown and R. H. Merrill describing the construction and initial inspection of the Scotten Ave bridge over Michigan Ave in Detroit; and MDSH Research Report No. R-529 by R. H. Merrill and C. A. Zapata describing the Coe Rd bridge over US 27 in Isabella County.

Studies by Dow Corning Corporation

The Dow Corning Corporation, a major producer of silicones, has been investigating the effects of silicones on concrete for several years. Initially, their efforts were directed toward hardened concrete sealants; but more recently they have been interested in the use of silicones as an admixture in concrete, thus leading to the development of DC-777. This admixture is a water-soluble straw colored liquid-reactive polysiloxane containing 100-percent silicone and weighing approximately 8.45 pounds per gallon. When added to concrete in the amount of 0.3 percent by weight of the cement, Dow Corning engineers found that 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.

MDSH Test Bridges

Scotten Ave over US 12 (Michigan Ave), Detroit (S04 of 82062): Dow Corning personnel presented a summary of their laboratory studies to MDSH representatives in Midland on April 25, 1963 and in Lansing on

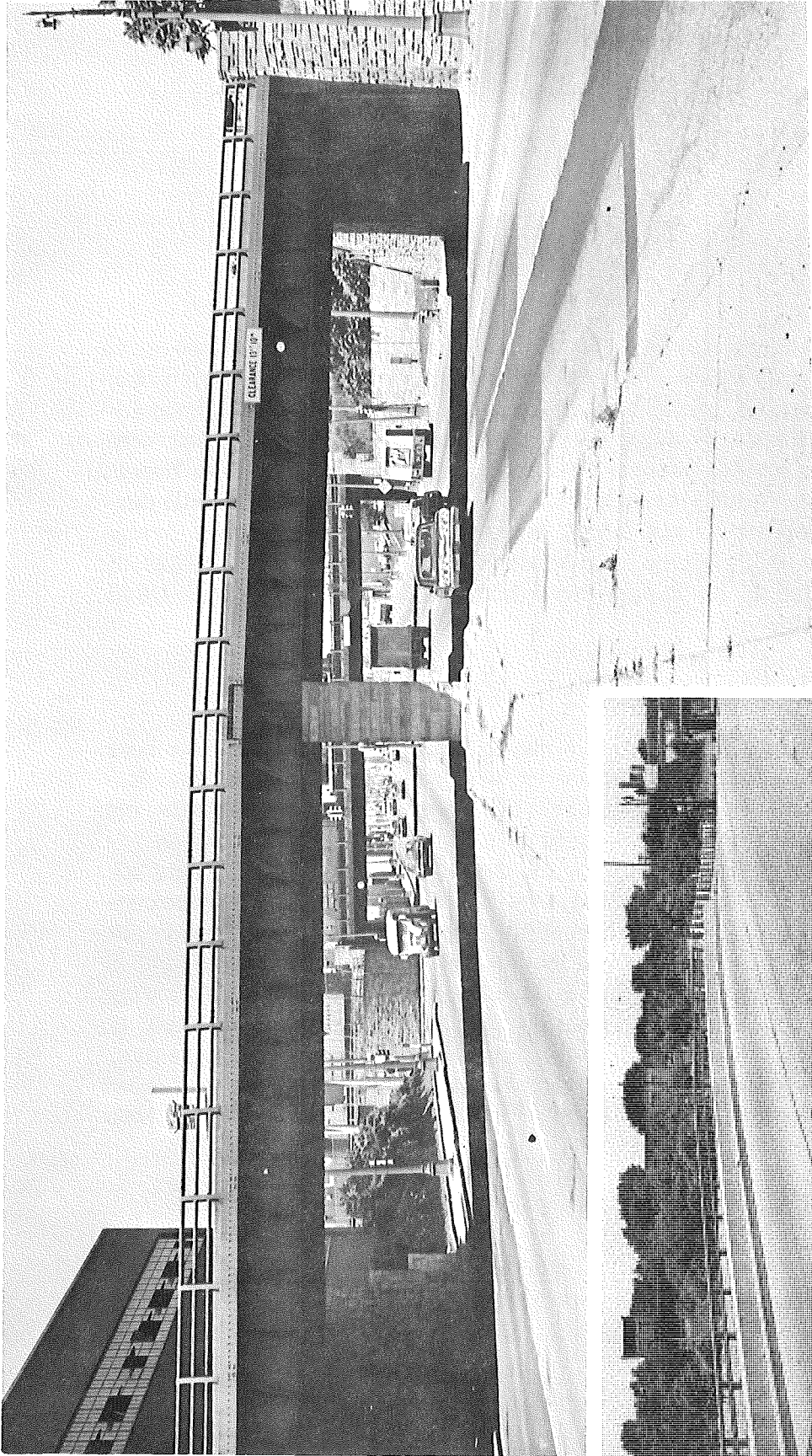


Figure 1. Scotten Ave bridge over Michigan Ave.
General view of bridge deck looking northwest (left)
and profile view looking west along MichiganAve (top).

May 9, 1963. At this time it was decided to select a bridge whose deck would test the effectiveness of the admixture. The Scotten Ave bridge over Michigan Ave in Detroit, originally constructed in 1941, was scheduled to receive a deck replacement under a major maintenance contract. It was decided to use this deck to evaluate the effectiveness of the admixture when used in conjunction with blast furnace slag coarse aggregate.

TABLE 1
SETTING TIME COMPARISON (hours)

Temp., F	Normal Concrete ⁽¹⁾		Concrete With 0.3 percent DC-777 ⁽¹⁾	
	Initial	Final	Initial	Final
40	10-1/2	15-1/2	52	63
60	6	8	31-1/2	37
80	4	5-1/2	23	29
100	2	3	15	24

⁽¹⁾ Determined by ASTM C-403

The subject structure is a two-span, through plate girder design, 141 feet long with a clear roadway of 42 feet. Curb, sidewalk, and girder encasement pours on both sides of the deck result in an overall width of 62 feet, 8 inches. The NE and SW deck pours were to contain the silicone admixture concrete while the NW and SE 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 Rd over US 27, 6 miles north of Alma (S01 of 37013): The second structure selected in the study is a four-span, prestressed concrete I-beam bridge that carries Coe Rd, a rural county road, over US 27, a limited-access divided highway. It was selected to investigate the performance of the silicone admixture when used with limestone coarse aggregate. The bridge has a 24-foot roadway and a total length of 208 feet. All but 13 feet of the west half of the bridge deck was constructed with silicone admixture concrete while 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 profile and approach views of the bridge as it appeared in 1969.

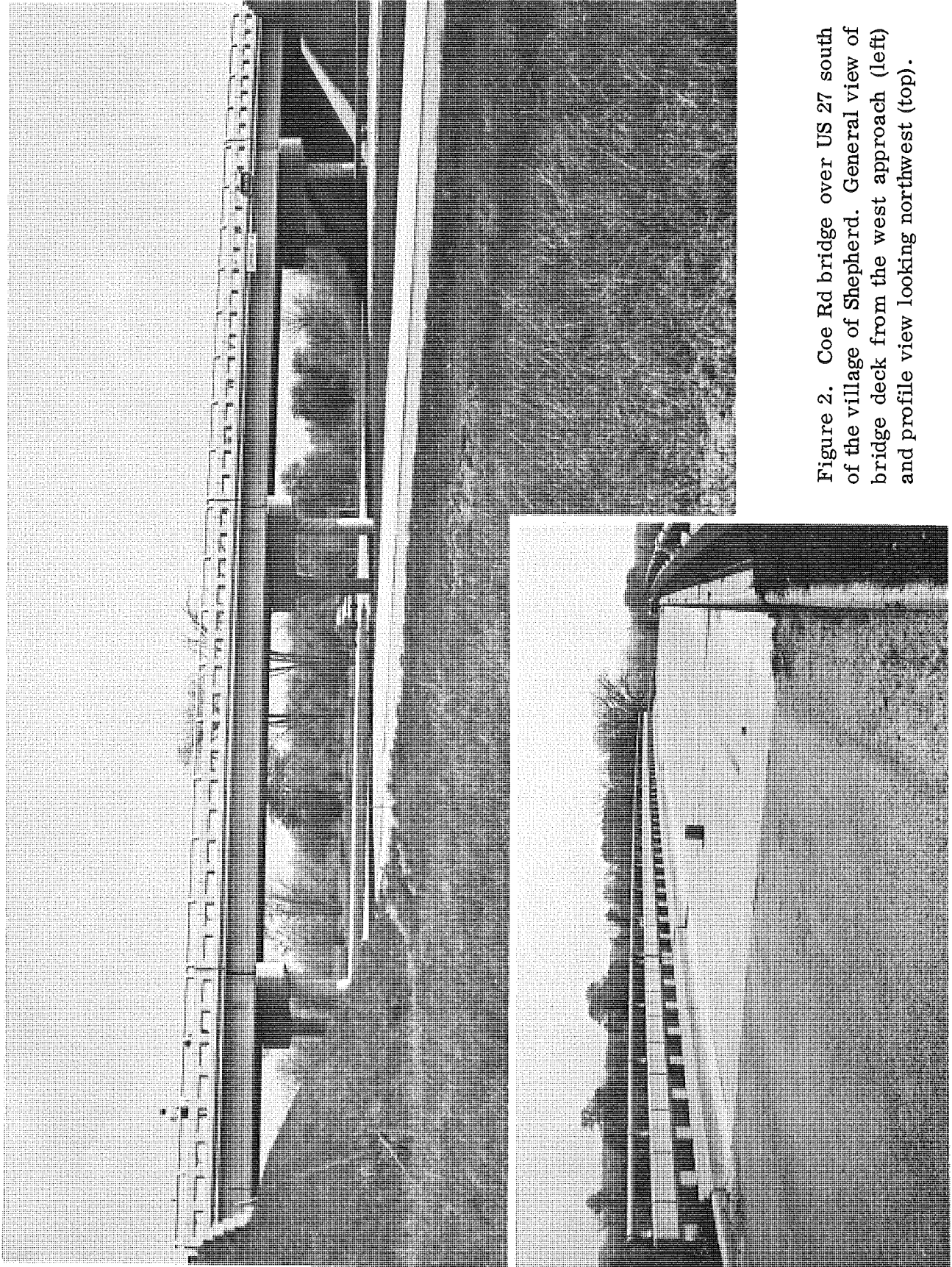


Figure 2. Coe Rd bridge over US 27 south of the village of Shepherd. General view of bridge deck from the west approach (left) and profile view looking northwest (top).

Eastbound M 78 over the Grand Trunk and Western Railroad, south of Flint (X05 of 25042): The third structure selected in the study is a three-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 feet, 6 inches, is 203 feet long, and its end spans cantilever over their piers to support the suspended center span. This bridge was selected to investigate the performance of the silicone admixture when used with concrete containing gravel coarse aggregate. The bridge deck and curb pours of the center span are cast with the silicone concrete, while the end spans have normal concrete. In addition to being air entrained, the normal concrete also contained 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 trunkline traffic with moderate salting for snow removal. Figure 3 shows profile and approach views of the bridge as it appeared in 1969.

EVALUATION

Silicone Admixture with Slag Coarse Aggregate (Scotten Ave)

This urban Detroit deck used a concrete mix containing blast furnace slag coarse aggregate and six sacks of cement per cubic yard. The concrete was mixed in transit by ready-mix trucks, placed by a crane-lifted concrete bucket, and was hand screeded and finished. The deck concrete was cured with 4-mil white polyethylene, 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, it minimizes surface and internal disruptions caused by freeze-thaw vulnerable deleterious materials, and it is 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.

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

It will be noted from Table 2 that the water-cement ratio of the normal concrete was higher than the silicone concrete. This is because the deck

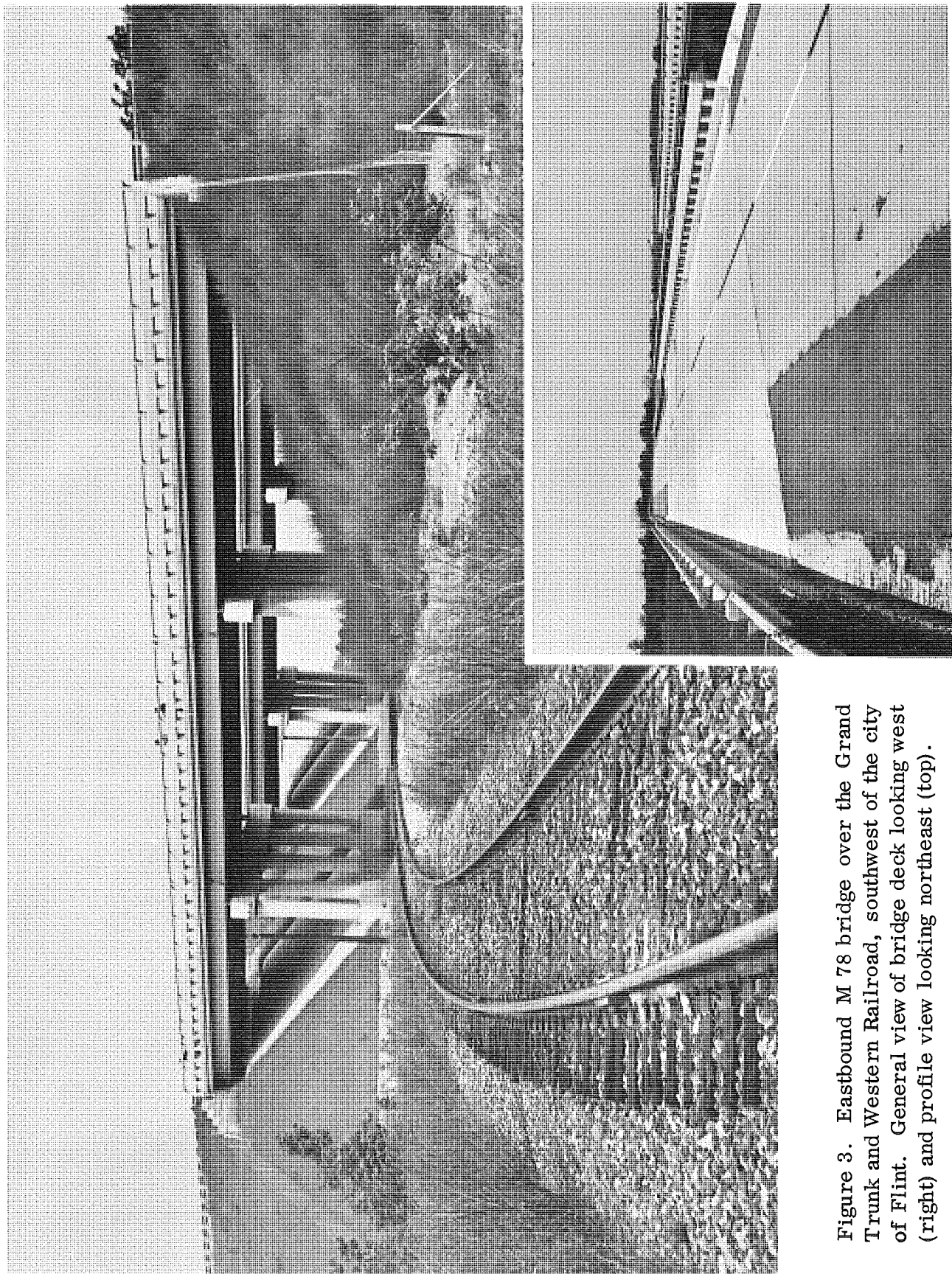


Figure 3. Eastbound M 78 bridge over the Grand Trunk and Western Railroad, southwest of the city of Flint. General view of bridge deck looking west (right) and profile view looking northeast (top).

was constructed before the Department adopted water-reducing and set-retarding admixtures for use in bridge deck concrete to accommodate machine finishing. To achieve a 4-in. slump, the water-cement ratio of the normal concrete had to be significantly higher than 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. The deck concrete was cured with 4-mil white polyethylene, applied as soon as surface moisture was gone.

TABLE 2
FRESH CONCRETE DATA (SLAG COARSE AGGREGATE)
(Scotten Ave Structure)

Concrete	Type I Cement, sacks/ cu yd	Net W/C Ratio	Fine Agg. Total Agg., percent	Slump, in.	Air, percent	Admixture per sack
Normal AE ⁽¹⁾	6	0.49	50	4.1	6.6	2-1/2 oz AE agent
Silicone	6	0.40	49	4.7	7.3	0.3 lb DC-777

⁽¹⁾ Air-entrained

In the laboratory, the performance of the silicone concrete field specimens was superior to those of the normal concrete in both strength and shrinkage measurements (Table 3). This could have been the combined effect of two 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 which were sampled at various times during the pour. The compressive strength, flexure strength, and shrinkage measurements were measured respectively from 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 MDSH report.⁽¹⁾

⁽¹⁾ Brown, M. G. and Merrill, R. H., "Use of a Silicone Admixture in Bridge Deck Concrete," MDSH Research Report No. R-463, June 1964.

TABLE 3
FIELD SPECIMEN TEST DATA (SLAG COARSE AGGREGATE)
(Scotten Ave Structure)

Concrete	28 Day Strength, psi		Shrinkage, percent	
	Compression	Flexure	28 Day	3 Mo.
Normal AE ⁽¹⁾	4610	660	0.017	0.044
Silicone	6080	860	0.009	0.036

⁽¹⁾Air-entrained

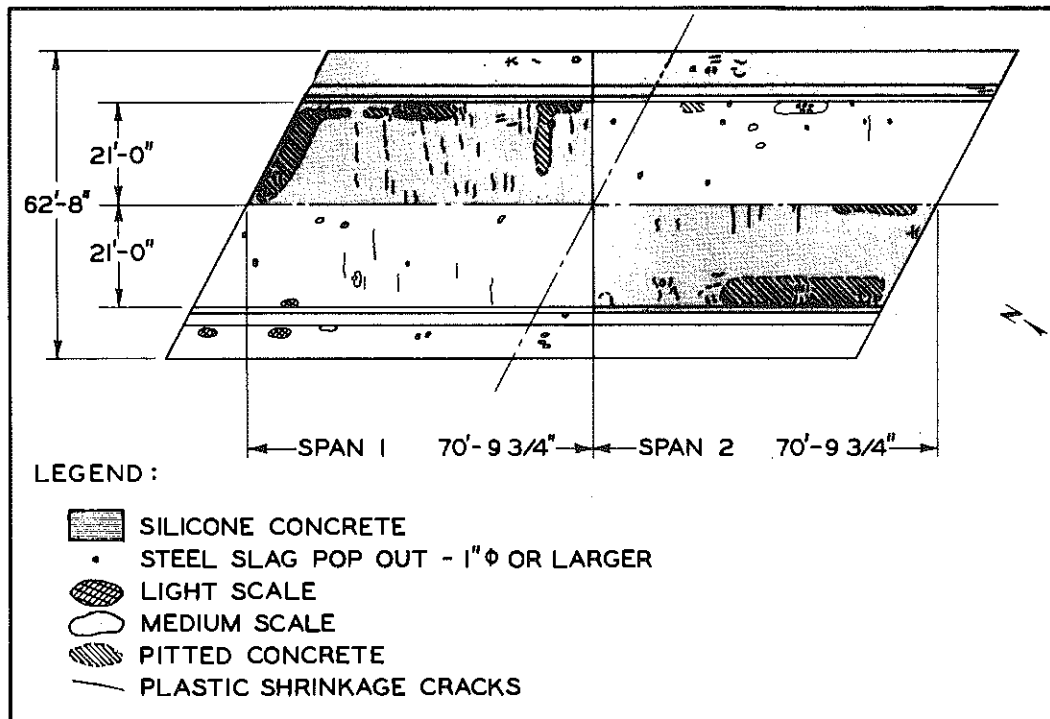


Figure 4. Surface deterioration observed on urban Detroit deck containing slag coarse aggregate (Scotten Ave structure).

Last summer, six years after the deck was poured, a field inspection showed the entire deck to be functioning well. Figure 4 is a diagram of the bridge deck showing all the deterioration features that were visible at the time of inspection. The plastic shrinkage cracks and large pitted areas were generally confined to the silicone concrete while the scaled areas and rusted iron popouts 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: first, the silicone concrete took 36 hours to set; second, the slag aggregate, with its great absorption potential, had adequate time to absorb a significant amount of mix water; and third, the polyethylene sheeting, with which the deck was cured, could have allowed air movement underneath if not properly sealed around its perimeter. The first two 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 popouts 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 (Coe Rd)

In the rural county road deck, the concrete mix contained limestone coarse aggregate and six sacks of cement per cubic yard. 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 crushed limestone's irregular angular shape and can only be rectified by increasing the percentage of fine aggregate in the mix. This increased the volume of the mortar, dilutes its cement content, and increases the water-cement ratio. The softness of the limestone makes it vulnerable to traffic abrasion.

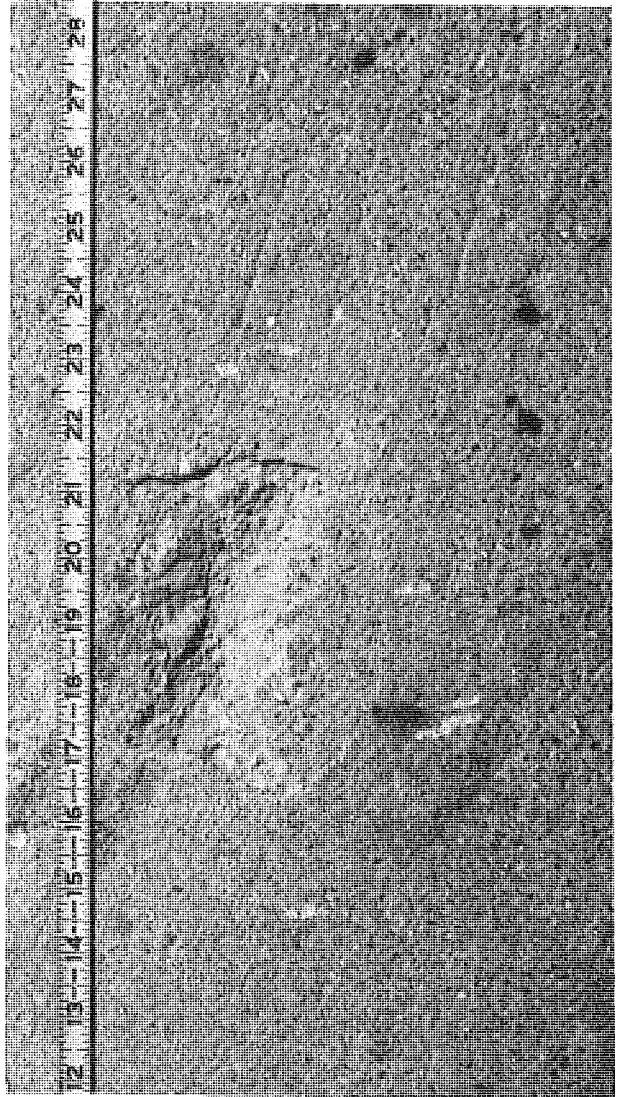
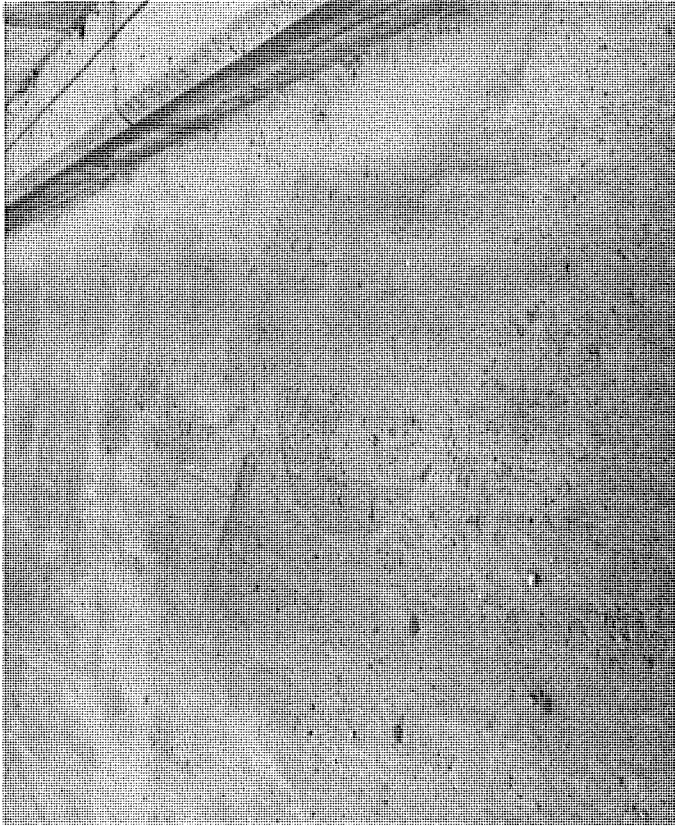


Figure 5. Deterioration on the Scotten Ave bridge. Typical plastic shrinkage cracks found in silicone concrete (top left); light pitting to which slag aggregate concrete appears vulnerable (top right); and a 3- by 5-in. scale spot caused by the volume expansion of rusting iron (bottom left).

As with the Detroit bridge, Type I cement was used throughout the deck since the silicone admixture entrained 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 was finished by a transverse screeding machine. The concrete was sprayed with a white curing membrane applied at 200 sq ft per gallon soon after finishing.

Table 4 shows that the water-cement ratio, the rest of the mix proportioning, and the slumps 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 4
FRESH CONCRETE DATA (LIMESTONE COARSE AGGREGATE)
(Coe Rd Structure)

Concrete	Type I Cement, sacks/ cu yd	Net W/C Ratio	Fine Agg. Total Agg., percent	Slump, in.	Air, percent	Admixture per sack
Normal	6	0.40	42	4.1	6.2	$\left\{ \begin{array}{l} 3 \text{ oz WR}^{(1)} \text{ and SR}^{(2)} \\ 1.5 \text{ oz AE agent} \end{array} \right.$
Silicone	6	0.39	42	4.1	8.1	

⁽¹⁾ Water reducing agent

⁽²⁾ Set retarding agent

Table 5 shows the results of the field specimens that were cured and tested in the laboratory. The normal concrete, aided by its water-reducing 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 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⁾

⁽²⁾ Merrill, R. H. and Zapata, C. A., "Use of a Silicone Admixture in Bridge Deck Concrete," MDSH Research Report No. R-529, September 1965.

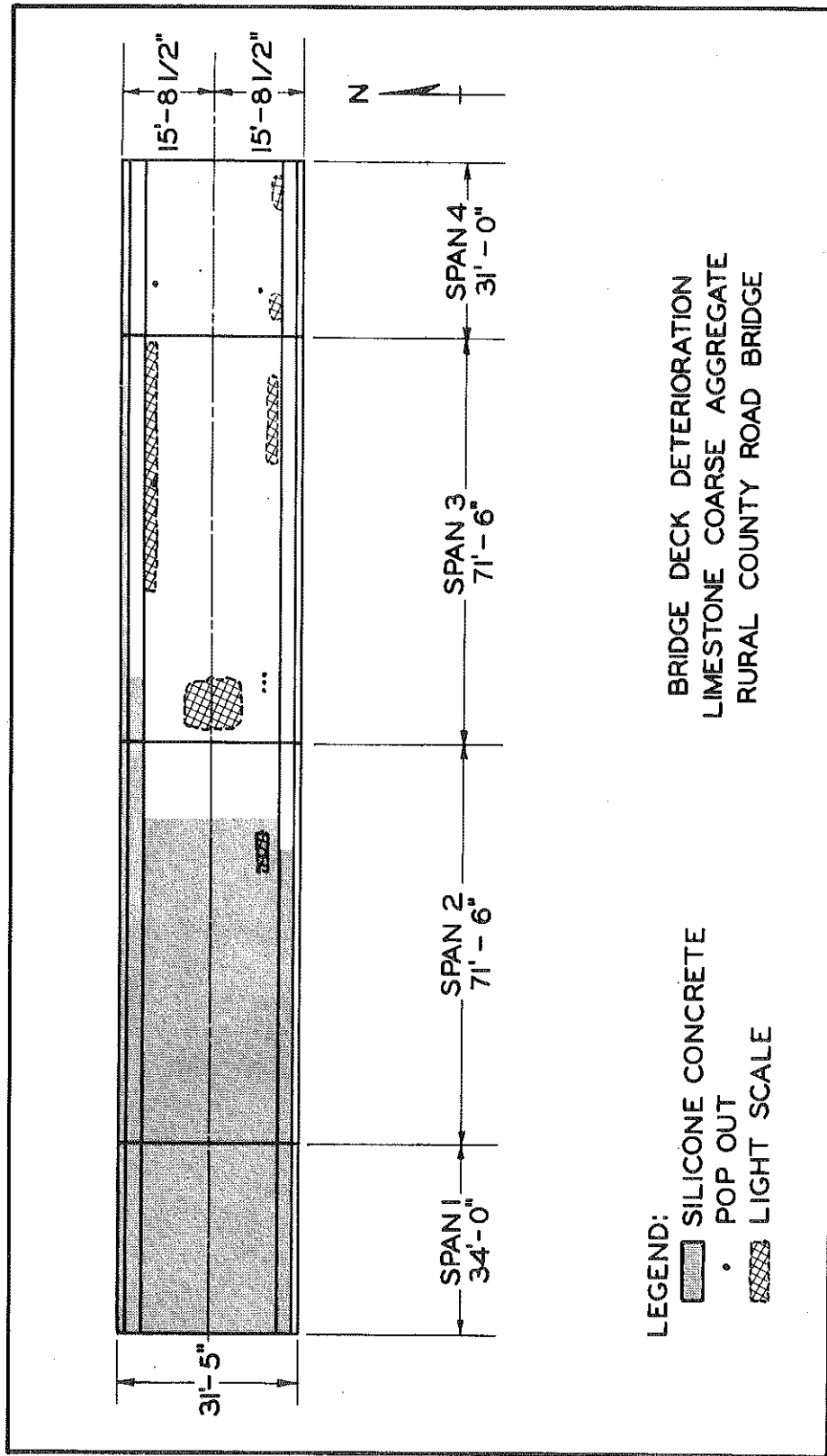


Figure 6. Surface deterioration observed on rural county road bridge deck containing limestone coarse aggregate (Coe Rd structure).

Last summer, five years after the bridge was constructed, a field inspection showed the concrete to be in excellent condition. Figure 6 is a diagram of the bridge deck showing the deterioration features on the deck that were visible at the time of the inspection. The silicone portion of the deck is completely unblemished except for one small scale spot. The normal concrete portion of the deck has developed a few areas of light scale and a very few popouts. These popouts were probably caused by deleterious materials that were introduced at the batching plant of the concrete company.

TABLE 5
FIELD SPECIMEN TEST DATA (LIMESTONE COARSE AGGREGATE)
(Coe Rd Structure)

Concrete	28 Day Strength, psi		Shrinkage, percent	
	Compressive	Flexure	28 Day	3 Mo.
Normal	5800	----	0.008	0.030
Silicone	5420	----	0.010	0.033

Gravel Coarse Aggregate (M 78)

In the limited-access divided highway bridge deck, the concrete mix contained gravel coarse aggregate (6AA) and six sacks of cement per cubic yard. The concrete was mixed in transit by ready-mix trucks, placed by a crane-lifted concrete bucket, and was finished by a longitudinal screeding machine. The concrete was cured with a white membrane curing compound applied at 200 sq ft per gallon.

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; thus producing 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 which separates the lighter particles from the heavier ones. Although this process improves the aggregate, it by no means makes it ideal, since some

TABLE 6
 FRESH CONCRETE DATA (GRAVEL COARSE AGGREGATE)
 (M 78 Structure)

Concrete	Pour Date	Span No.	Type IA Cement, sacks/cu yd	Net W/C Ratio	Fine Agg. Total Agg., percent	Slump in.	Air, percent	Admixture/sack	
Deck Concrete	Normal	8-14-67	1	6.0	0.43	0.35	4.0	6.5	4 oz WR and SR ⁽¹⁾ 0.5 oz AE agent ⁽²⁾
	Silicone	8-11-67	2	6.0	0.43	0.35	4.0	7.5	0.25 lb DC-777B 0.25 oz AE agent
	Normal	8-16-67	3	6.0	0.42	0.35	4.5	7.1	4 oz WR and SR 0.5 oz AE agent
Curb (brush block) Concrete	Normal	8-25-67	1	6.0	0.44	0.33	3.0	8.5	3 oz WR and SR 1.38 oz AE agent
	Silicone	8-30-67	2	6.0	0.44	0.33	3.3	7.6	0.25 lb DC-777B 0.25 oz AE agent
	Normal	8-29-67	3	6.0	0.44	0.33	3.0	7.9	3 oz WR and SR 1.25 oz AE agent

⁽¹⁾ Water reducing agent

⁽²⁾ Set retarding agent

⁽³⁾ Air-entrained

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 makes it vulnerable to further damage.

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

Table 6 shows 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. No significant difference exists between the properties shown for the two types of concrete.

Table 7 shows the results of some of the laboratory tests run on field specimens. It shows that the silicone concrete tested significantly higher in both compression and flexure. In shrinkage, however, the silicone concrete was out-performed by the normal concrete which shrank less.

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.

TABLE 7
FIELD SPECIMEN TEST DATA (GRAVEL COARSE AGGREGATE)
(M 78 Structure)

	Concrete	Span No.	Avg Compressive Strength, psi		Avg Flexural Strength, psi		Shrinkage, percent	
			7 Day	28 Day	7 Day	28 Day	7 Day	28 Day
DECK	Silicone	2	3670	4200	710	880	0.035	0.051
	Normal	3	3450	3980	610	720	0.036	0.049
CURB	Normal	1	3240	3350	640	800	0.024	0.050
	Silicone	2	3450	3860	710	830	0.042	0.059

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 is a graph showing 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 undoubtedly was the result of a resistance to absorption which the silicone furnished to deeply imbedded deleterious particles.

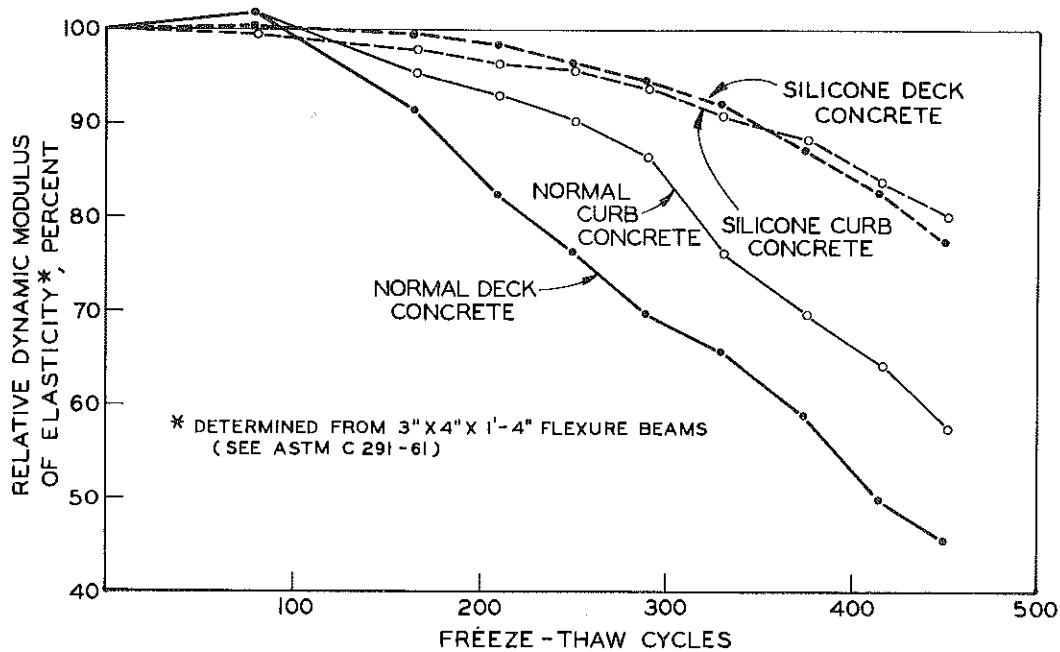


Figure 7. Internal freeze-thaw durability of the gravel coarse aggregate concrete. These beams were cast from concrete used in the limited access divided highway bridge (M 78 structure).

The scaling slabs were 9 in. wide, 12 in. long, and 2-1/2 in. thick, with 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 one freeze-thaw cycle per day (about 0-70 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. During the first 60 cycles, the slabs were ponded on alternate days with 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 popouts, 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 popouts but also developed extensive medium scale. Figure 10 is a graph showing 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 between the numbers 1 and 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. From this figure it is obvious that the silicone concrete has much more resistance to frost-inflicted scaling than the normal air-entrained concrete. It is evident 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 last summer, two years after the bridge was completed, showed some contrasting features with the other bridges described in this report.

Figure 11 is a diagram of the deck showing the deterioration features which were visible at the time of inspection; included are popouts, craze cracking in all three spans, and light scale in span 3. The most obvious of these were the numerous popouts which developed uniformly over the entire deck surface. It was obvious that the silicone admixture provided little protection for the frost-susceptible particles in the gravel lying close to the top surface of the concrete.

The figure also shows that both types of concrete developed large areas which 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; confined mainly to the south curb-line in span 3 where the longitudinal screeding machine left the heaviest concentration of laitance. Since 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 above.

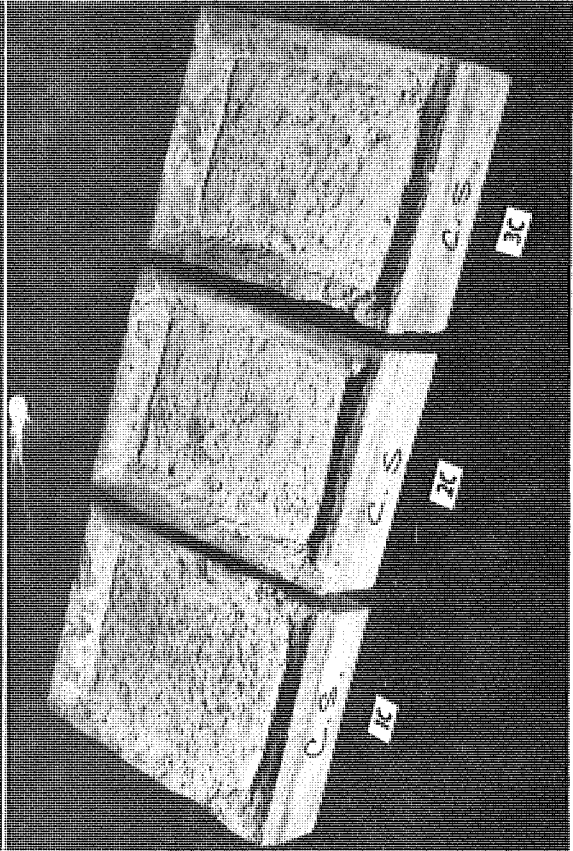
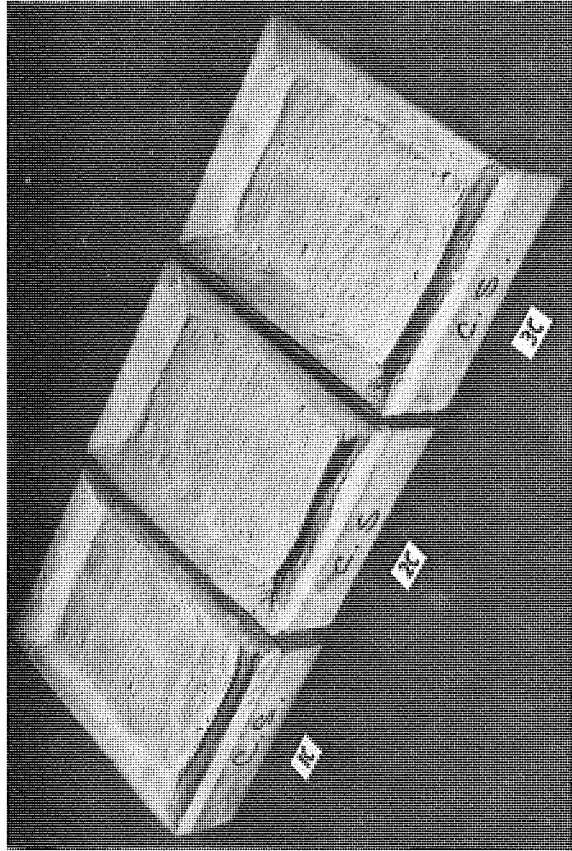


Figure 9. Laboratory scaling slab specimens cast from the normal deck concrete used in span 3 of the M78 bridge before testing (top) and after 45 freeze-thaw cycles (bottom).

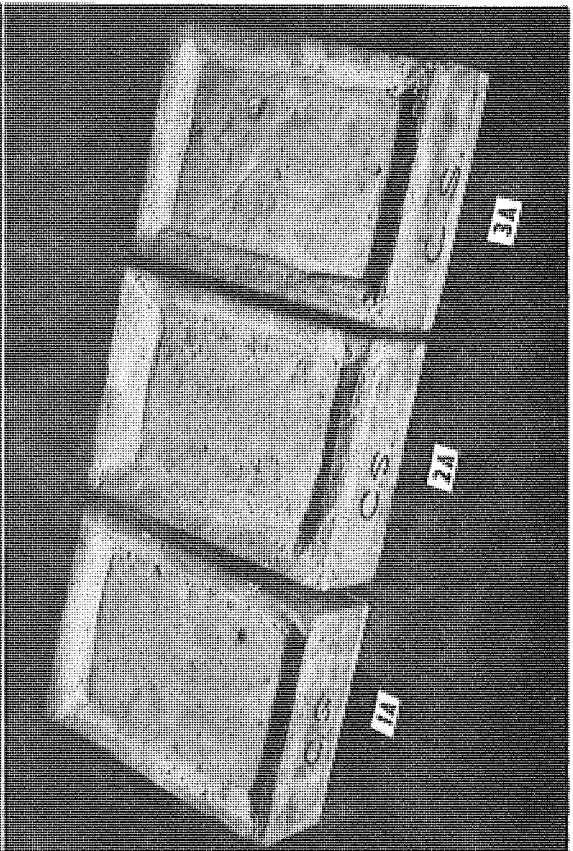
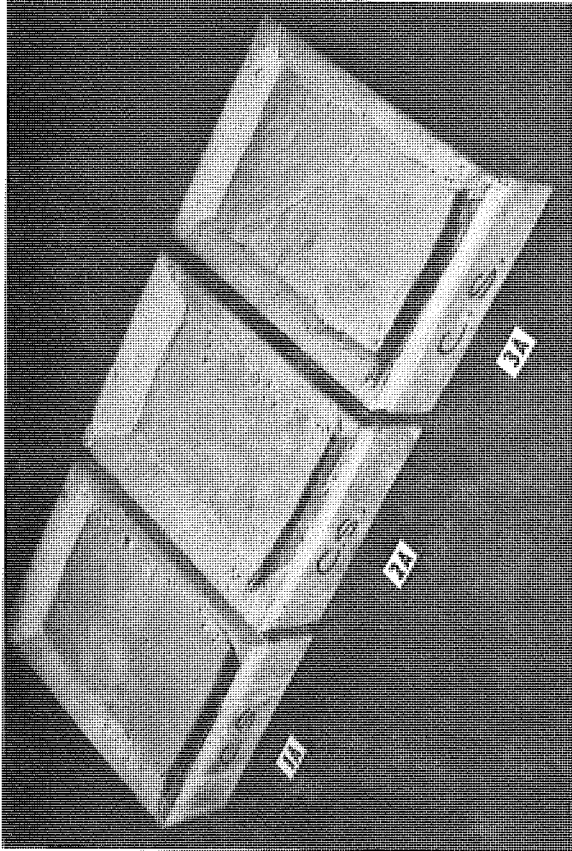


Figure 8. Laboratory scaling slab specimens cast from silicone deck concrete used in span 2 of the M78 bridge before testing (top) and after 45 freeze-thaw cycles (bottom).

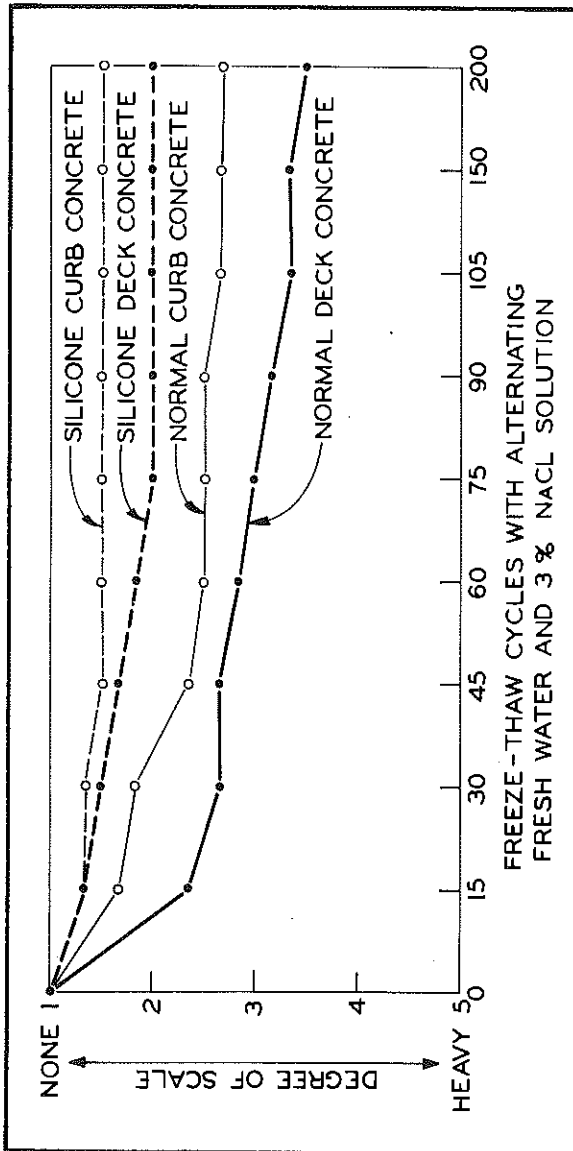
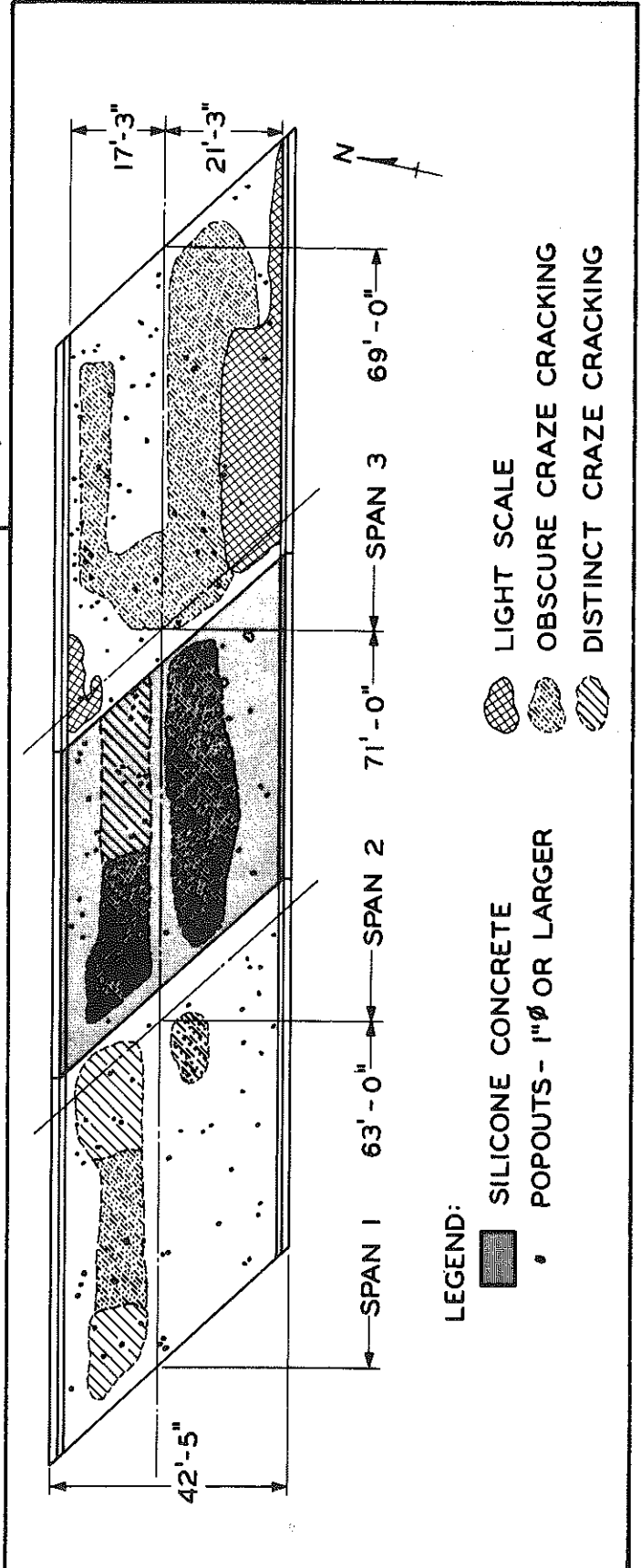


Figure 10. Surface freeze-thaw durability of gravel coarse aggregate concrete scaling slabs. These slabs were cast from concrete used in the limited access divided highway bridge (M 78 structure).

Figure 11. Surface deterioration observed on the limited access divided highway bridge which contains gravel coarse aggregate (M 78 structure).



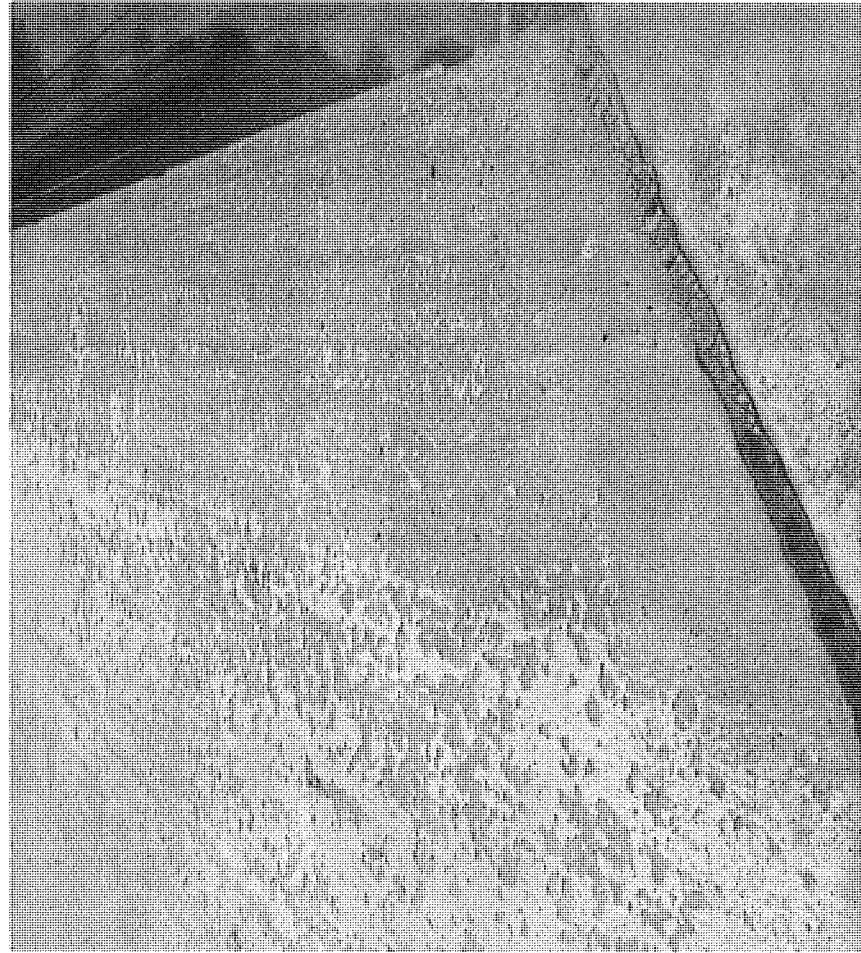
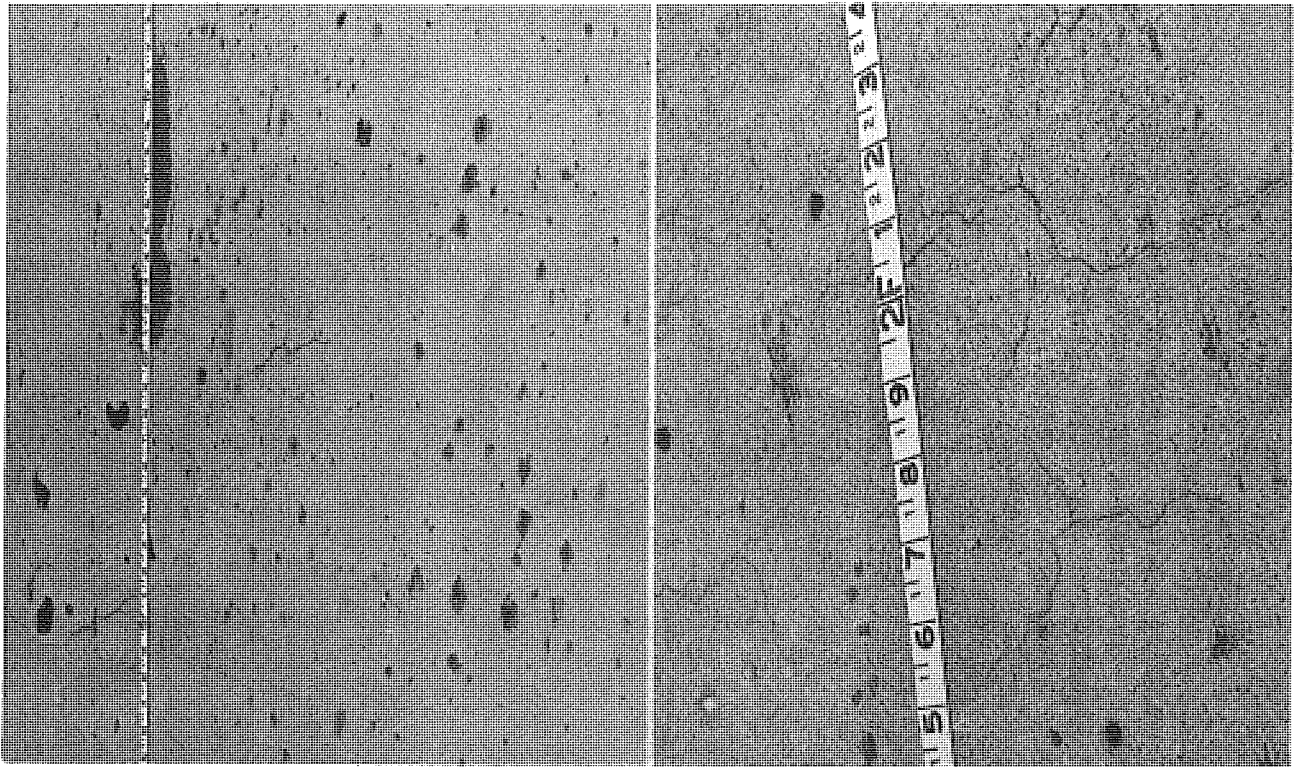


Figure 12. Deterioration on the M 78 bridge. The popout concentration, shown for the traffic lane of span 2, was typical across the entire deck (top left); distinct craze cracking area in the traffic lane of span 2 (bottom left); and light scaling of the thin laitance coat along the south curb-line in span 3 (top right).



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.
5. It increased the resistance to freeze-thaw deterioration.

A later modification of the admixture, designated DC-777B, was developed to adapt it for use with regular air-entrained cement.

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

The silicone admixture seems to function equally well with any of the three coarse aggregates described in this report; blast furnace slag, limestone, and gravel. Whereas 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 particularly susceptible were those lying immediately at the surface; those imbedded 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 which 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 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 three test bridges. Rapid freeze-thaw testing conducted in the laboratory, showed it 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 which 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