USE OF A SILICONE ADMIXTURE IN BRIDGE DECK CONCRETE
Scotten Ave. over US 12 (Michigan Ave.), Detroit (Mb S04 of 82062C, C3)

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Research Projects R-50 B-49(3) and R-61 B-58
Research Report No. R-463

Michigan State Highway Department
John C. Mackie, Commissioner
Lansing, June 1964

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The use of silicone solutions of various types and concentrations both as a sealant coating on hardened concrete and as an admixture in fresh concrete has been explored by various agencies in recent years. The Dow Corning Corp. of Midland, being a major producer of silicones, has been evaluating both types of applications in concrete construction. The benefits derived from silicone surface coatings in protecting bridge deck concrete from the scaling action of ice removal salts have generally been found to be of short duration or temporary in nature.

More recently, Dow Corning, as well as some other agencies, has been evaluating the properties of concrete containing silicones as an admixture. They have obtained indications that several water soluble silicones, added in small amounts to portland cement concrete, produce unusual delays in setting properties; increases in bond, compressive, and flexural strengths; some reduction in the net water-cement ratio; and finally, increased resistance to scaling on concrete of low or moderate air content when ice removal salts are used.

A group of Dow Corning personnel presented a summary of their recent laboratory studies on concrete with silicone admixtures to Highway Department representatives in Midland on April 25, 1963, and also on May 9, 1963, in Lansing. Their latest studies concern the use of DC-777 silicone liquid added to concrete primarily at the rate of 0.3 percent by weight of cement. The DC-777 silicone is a straw-colored liquid-reactive polysiloxane containing 100-percent silicone and weighs approximately 8.45 lb per gal. As previously mentioned, the 0.3-percent addition of DC-777 to Type I cement in structural concrete alters the initial and final setting properties at various temperatures approximately as follows:

Temp., F	Normal Concrete*		Concrete with 0.3 Percent DC-777*	
	Initial Set, hr	Final Set, hr	Initial Set, hr	Final Set, hr
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

* Typical setting times as determined by ASTM Method C 403.

After Dow Corning's presentations to the Department, the Scotten Ave. structure was selected for an experimental field study of silicone concrete in comparison with conventional air-entrained concrete under normal construction conditions. This report summarizes that study, and includes all related laboratory data obtained on specimens made at the time of construction.

Construction Procedure

The subject structure is a two 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 deck lays primarily in a north-south direction carrying Scotten Ave. over Michigan Ave. (US 12) in Detroit. The original deck was built in 1941 using non-air-entrained concrete and had deteriorated so badly from weathering and de-icing salts that a heavy maintenance contract was set up for removal of the old deck concrete and replacement with air-entrained and silicone concrete. Fig. 1 is a plan view of the deck pours with code designations for the roadway, curbs, sidewalks, and girder encasements. The diagram shows that half of all of these pours were cast with silicone concrete and half with conventional air-entrained concrete.

The contractor on this project, L. A. Davidson, was set up to furnish the 248 cu yd of concrete required for all of the new deck concrete in transit-mix trucks from his batching plant at Columbia and St. Antoine Sts. This consisted of hauling and mixing 5-cu yd loads of concrete approximately 3.1 miles to the project. The concrete was transferred from the transit-mix trucks to the proper pour areas with a 1-cu yd bucket by crane (Fig. 2). The concrete was vibrated with a Stow mechanical vibrator, screeded, and finished using normal hand methods. All finished pours were covered with white polyethylene film for seven days of curing, approximately 2 to 3 hr after finishing (Fig. 3).

The mix proportions and sources of materials are listed at the bottom of Tables 1 and 2. Because the DC-777 acts as an air-entraining agent, Type I cement was required for this project in place of the usual Type IA. The DC-777 silicone liquid was furnished at no cost and added manually to each load of transit-mix concrete, for pours requiring it, at the batch plant by Dow Corning personnel. A liquid air-entraining agent (Ersair) was added to all control pour concrete by normal dispenser equipment during batching. All coordination on the project was under the direction of Robert E. Coe, Department Project Engineer.

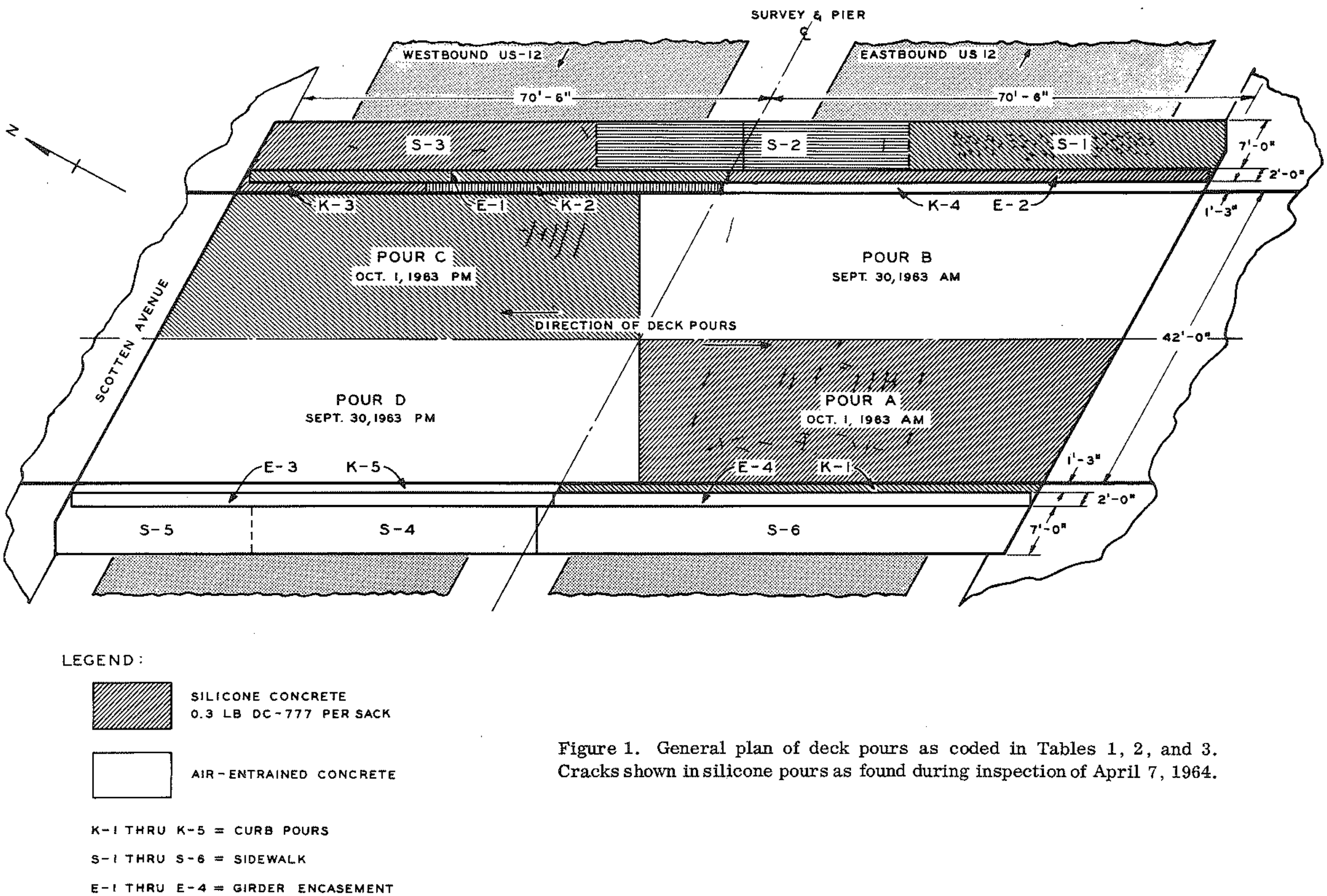

Figure 1. General plan of deck pours as coded in Tables 1, 2, and 3. Cracks shown in silicone pours as found during inspection of April 7, 1964.

Figure 2. Typical procedure for placement of transit-mix concrete showing Stow vibrator at left and hand screed at right (Pour D looking south toward finished Pour A: September 30, 1963).

Figure 3. View toward north, showing Pours B and D covered with white polyethylene; finished silicone Pours A at left and C at right yet to be covered. Note top of plate girder and sidewalk steel at right.

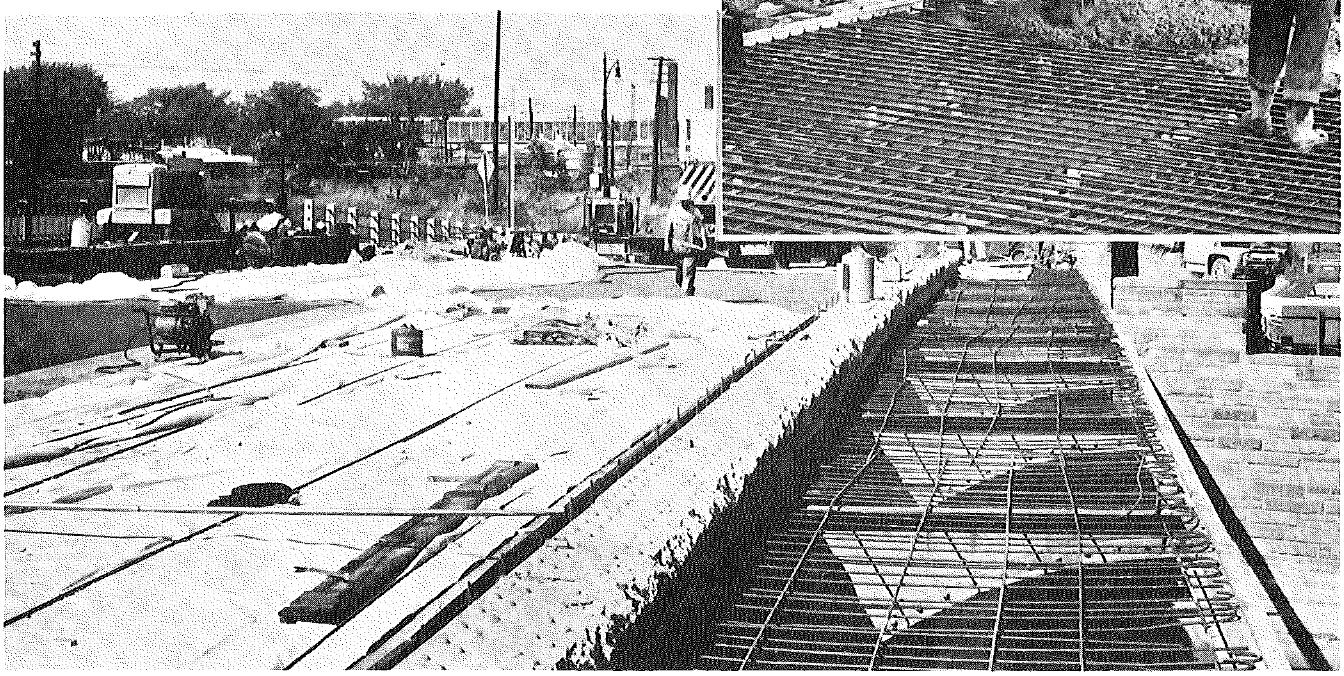

Figure 4. General view (left) of shrinkage cracks in middle portion of silicone Pour A, with close view of typical crack (below).

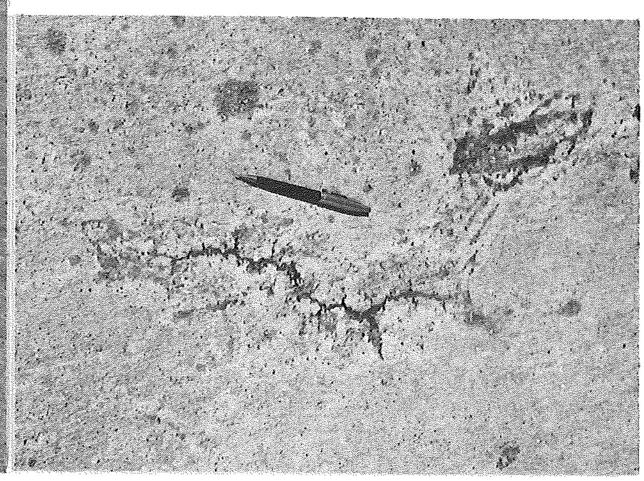

TABLE 1
SUMMARY OF FIELD TEST DATA ON FRESH CONCRETE
Air-Entrained Pours of September 30, 1963

Pour Code and Load No.	Slump, in.	Concrete Temp, °F	Air Content, percent		Unit Weight, pcf	Mixing Revolutions	Water Added At Project, gal	Water/Cement Ratio (net), gal/sack
			Chace	Rollimeter				
B-1	5	69	8.0	---	---	70	15	5.35
B-2	2-3/4	65	7.0	5.8	---	136	16	5.39
B-3	This load not used due to truck break down.							
B-4	3-1/2	69	7.4	6.6	135.2	142	12	5.25
B-5	5-1/2	69	6.0	7.5	134.2	91	5	5.33
B-6	6	69	8.5	8.8	132.2	96	6	5.37
B-7	5	70	6.0	7.6	132.2	160	30	6.17
B-8	5-1/8	70	7.4	7.6	133.2	58	6	5.37
B-9	3	72	6.0	5.5	137.2	60	9	5.47
B-10	1-1/2	69	6.5	7.0	136.2	95	6	5.37
Average	4-1/8	69	7.0	7.1	134.3	---	--	5.46
D-1	5-1/2	75	5.0	5.5	137.7	---	16	5.70
D-2	3-1/2	76	6.0	4.5	139.7	---	14	5.63
D-3	5	71	7.5	7.0	136.2	---	9	5.63
D-4	2-1/4	72	6.0	6.5	138.2	133	8	5.60
D-5	4-1/4	71	5.5	6.5	135.2	80	4	5.47
D-6	4	72	5.5	4.8	137.7	---	7	5.57
D-7	2-1/2	72	6.5	6.0	137.7	97	11	5.70
D-8	4-1/2	70	8.5	7.3	135.7	104	2	5.40
D-9	4	72	8.5	6.9	134.7	97	10	5.67
Average	4	72	6.6	6.1	137.0	---	--	5.60
Average B&D	4-1/16	71	6.8	6.6	135.7	---	--	5.53

Mix Proportions and Materials, 6.0 sacks/cu yd design

Cement	94	lb	Peerless, Type I
2NS sand	238.5	lb	Walker Supply
6AA slag	236	lb	Levy - Trenton
Water (total)	55.2	lb	
Air-entraining agent	2 to 2-1/2	oz	Ersair

TABLE 2

SUMMARY OF FIELD TEST DATA ON FRESH CONCRETE

Silicone Pours of October 1, 1963

Pour Code and Load No.	Slump, in.	Concrete Temp, °F	Air Content, percent		Unit Weight, pcf	Mixing Revolutions	Water Added At Project, gal	Water/Cement Ratio (net), gal/sack
			Chace	Rollimeter				
A-1	7-1/2	71	8.0	7.8	136.2	97	10	4.65
A-2	6-1/2	72	6.0	9.0	135.3	100	10	4.65
A-3	2-1/2	73	8.0	6.0	140.2	108	5	4.49
A-4	7	74	11.0	8.8	133.7	122	5	4.49
A-5	4-1/2	72	6.5	8.3	135.7	104	3	4.42
A-6	6	76	7.0	9.2	135.7	125	0	4.32
A-7	3-1/2	74	7.0	7.2	138.7	144	1	4.35
A-8	2-3/8	75	7.5	6.0	138.7	103	2	4.38
Average	5	73	7.6	7.8	136.8	---	--	4.47
C-1	7-1/4	74	9.5	11.0	130.7	78	5	4.65
C-2	2-3/4	78	5.0	4.7	139.7	145	5	4.65
C-3	7-1/2	76	9.5	8.2	133.2	96	0	4.49
C-4	4	76	8.0	5.8	139.7	84	0	4.49
C-5	3-1/2	77	5.0	5.5	136.7	---	2	4.55
C-6	3-1/2	77	7.0	6.4	137.2	99	3	4.58
C-7	3-1/4	77	7.5	6.7	137.7	79	0	4.49
C-8	3-1/2	78	8.9	5.0	141.2	120	0	4.49
Average	4-3/8	77	7.6	6.7	137.0	---	--	4.55
Average A&C	4-1/16	75	7.6	7.3	136.9	---	--	4.51

Mix Proportions and Materials, 6.0 sacks/cu yd design

Cement	94	lb	Peerless, Type I
2NS sand	225	lb	New Hudson Sand & Gravel
6AA slag	236	lb	Levy - Trenton
Water (total)	55.5	lb	
Silicone	0.3	lb	DC-777

Sampling and Testing Procedures

To measure the properties of fresh and hardened concrete with DC-777 silicone and air-entrained concrete without silicone, systematic sampling was planned for each 5-cu yd load of concrete at the job site for all four of the roadway pours, totaling 164.8 cu yd. These tests were also to measure the uniformity or batch-to-batch variations encountered with transit-mix concrete under typical job conditions. Enough fresh concrete was taken from the second or third cubic yard being transferred from the transit-mix truck to the deck to run all the required tests and mold the necessary specimens. The tests run on each load of fresh concrete (summarized in Tables 1 and 2) included slump, temperature, unit weight, air content by Chace meter and Rollimeter, additional water added at project, mixing revolutions at time of sampling, and the calculated net water-cement ratios. Six 4- by 8-in. cylinders and three or four 3- by 4- by 16-in. beams were cast from each 5-cu yd load sampled. A total of nine 3- by 3- by 15-in. shrinkage beams with stainless steel end studs were cast from selected loads of both silicone concrete and air-entrained concrete. Test data on these specimens are summarized in Tables 4 and 5. Normal Departmental or standard ASTM test methods were used on the fresh concrete and in molding and testing of specimens. Pours B and D were placed with conventional air-entrained concrete on September 30, 1963, beginning at a center transverse construction joint and working toward each end. The weather was clear and sunny and temperatures ranged from 60 to 74 F during pouring. A total of 18 loads of transit-mix were sampled from this first day's pouring of 89.4 cu yd. Pours A and C, totaling 75.4 cu yd of silicone-admixed concrete, were sampled from 16 loads of transit-mix and tested on October 1, 1963. The weather continued clear and sunny with air temperatures from 68 to 75 F. The remaining curb, sidewalk, and girder encasement pours were placed on six different days later during October. Normal Departmental tests were run on these latter pours and are summarized in Table 3. No test specimens, however, were cast from these pours for laboratory tests.

Test specimens were covered at the job site with white polyethylene approximately the same time as the finished roadway pours, about 2 hr after final finishing. The air-entrained control beams were removed from their molds after 24 hr and placed under polyethylene. The silicone beams were not removed from molds until 48 hr after molding due to the much longer setting times characteristic of the admixed concrete. After a minimum of 48 hr the test specimens were transported to the Research Laboratory and placed in the moist room for curing until time of test.

TABLE 3

SUMMARY OF FIELD TEST DATA ON FRESH CONCRETE

Miscellaneous Pours of October 2 to 25, 1963

	Pour Code and Load No.	Pour Volume, cu yd	Date of Pour	Mix Type	Slump, in.	Concrete Temp, °F	Air Content, percent		Added Water, gal
							Chace	Rollimeter	
Curb Pours	K-1	7.6	Oct. 4	Silicone	4-3/4	67	5.5	---	2
	K-2	7.6	Oct. 4	Silicone	3-5	64	3.0	---	--
	K-3		Oct. 4	Silicone	3	68	6.5	---	--
	K-4	7.6	Oct. 2	AE	3	--	6.0	6.4	Unknown
	K-5	7.6	Oct. 2	AE	4	--	5.5	3.0, 6.5	Unknown
Sidewalk Pours	S-1		Oct. 15	Silicone	5-1/2	78	5.5	5.4	5
	S-2	18.8	Oct. 15	Silicone	5	74	5.5	5.2	5
	S-3		Oct. 15	Silicone	4-3/4	75	10.0	11.8	2
	S-4	9.4	Oct. 18	AE	4	76	10.0	8.0	Unknown
	S-5		Oct. 18	AE	2	80	3.4	2.8	Unknown
	S-6	9.4	Oct. 23	AE*	5	76	7.0	9.0	Unknown
Girder Encasement Pours	E-1	8.1	Oct. 18	Silicone	7-1/2	77	3.5, 7.0**	3.2, 4.5**	Unknown
	E-2	7.2	Oct. 23	Silicone	3	72	4.0	2.8	15
	E-3	7.2	Oct. 23	AE*	4	78	8.3	8.3	Unknown
	E-4	8.1	Oct. 25	AE*	3-1/2	70	8.0	---	Unknown

* Also contained 2 oz of Plastiment per sack of cement.

** Two tests.

As shown in Tables 4 and 5, all cylinder and beam strengths were measured after moist curing for 7 or 28 days. Cylinders were capped with hot capping compound prior to test. Beams were broken by third-point loading. One beam was selected from each batch to be tested in the automatic freeze-thaw machine using ASTM Method C 290 (rapid freeze-thaw in water). Six cycles per day were obtained by this method and beams were moist-cured 14 days prior to beginning the test. A similar set of one beam from each mix (34 total) was transferred to the Dow Corning laboratory for a similar rapid freeze-thaw test in a 10-percent sodium chloride solution. Shrinkage measurements were made at the intervals shown in Tables 4 and 5 using ASTM Method C 157, and an initial 14-day moist-curing period was followed by storage in laboratory air. Sections of beams from four batches each of the air-entrained and silicone mixes were cut and polished to measure air void properties by the linear traverse method. Beams were selected from mixes of high and low air contents.

Discussion of Results

Test data for samples taken from 34 loads of fresh transit-mix concrete listed in Tables 1 and 2, with the corresponding data from cured concrete specimens in Tables 4 and 5, contain some informative measures of transit-mix concrete variation under field conditions. As mentioned earlier, all tests and specimens were made from the second or third cubic yard of concrete discharged from the individual 5-cu yd loads.

Only 20 mixing revolutions were applied to each load of concrete at the batch plant, and trucks ran their loads at agitation speeds while traveling the 3 miles to the project. Upon arrival, additional mix water had to be added to most transit-mix loads to obtain a slump of approximately 4 in. The balance of mixing occurred during the addition of this extra water.

The strength properties of each load of transit-mix with and without the DC-777 silicone were measured primarily by means of cylinder compressive strengths. In comparing the compressive strengths of the air-entrained mixes in Table 4 with the silicone mixes in Table 5, a considerable difference is noted. All silicone mixes averaged 50-percent stronger at 7 days and 31-percent stronger at 28 days than the air-entrained mixes. Although test data on flexural strength are more limited, the silicone mixes averaged 24- and 31-percent stronger at 7 and 28

TABLE 4

SUMMARY OF TESTS ON HARDENED CONCRETE

Air-Entrained Pours of September 30, 1963

Pour Code and Load No.	Strength, psi				Freeze-Thaw Tests(c)		Shrinkage, percent (d)				Linear Transverse Data (e)	
	Compressive(a)		Flexural(b)		Durability Factor	Weight Loss, percent	14 day	1 mo.	3 mo.	6 mo.	Air Content, percent	Void Size, in.
	7 day	28 day	7 day	28 day								
B-1	2925	4095		628	77.8	2.6						
B-2	3310	4313	503		19.0	0.2						
B-4	3717	4921	522	698	19.6	0.1	+.008	.015	.043	.043		
B-5	3144	4417			86.5	1.5	+.006	.017	.042	.057		
B-6	2931	4010			86.5	2.0	+.009	.019	.047	.050	9.5; 10.0	.0064; .0059
B-7	2685	3870	477		51.3	3.4						
B-8	3059	4324	424	681	26.6	0.7	+.009	.015	.043	.045		
B-9	3640	5061	523		19.6	+2.2					6.1; 5.4	.0058; .0059
B-10	4108	5387			33.8	1.7						
Average	3280	4489	490	659	46.7	1.1	+.008	.017	.044	.049		
D-1	3201	4361		642	49.5	1.5	No shrinkage beams made from pour D.				5.2; 5.5	.0051; .0054
D-2	3479	5343	620		35.0	0.6						
D-3	3188	4382			41.8	1.5						
D-4	3909	5223	472	666	62.5	7.0						
D-5	3360	4417	577		37.8	2.1						
D-6	3723	5078	598		56.0	3.3						
D-7	3958	5135			24.5	0.7						
D-8	3512	4490			75.7	2.4					6.1; 6.3	.0052; .0056
D-9	2978	4182			70.0	3.8						
Average	3479	4735	567	654	49.8	2.5						
Average B&D	3380	4612	529	657	48.3	1.8						.0057

(a) Each value is average of three cylinders.

(b) Beams tested by third-point loading (ASTM Method C 78).

(c) Durability factor and weight loss figured at 70 percent of original modulus or 300 cycles.

$DF = \frac{PN}{M}$ where P = relative modulus at N cycles, N = cycles to failure, M = 300.

(d) Fourteen-day plus-values indicate expansion during moist curing.

(e) Measurements made on vertical slices 1-1/2 in. from each end of test beam.

TABLE 5

SUMMARY OF TESTS ON HARDENED CONCRETE

Silicone Pours of October 1, 1963

Pour Code and Load No.	Strength, psi				Freeze-Thaw Tests(c)		Skrinkage, percent (d)				Linear Traverse Data(e)	
	Compressive(a)		Flexural(b)		Durability Factor	Weight Loss, percent	14 day	1 mo.	3 mo.	6 mo.	Air Content, percent	Void Size, in.
	7 day	28 day	7 day	28 day								
A-1	4719	5675	599		35.7	0.3						
A-2	4305	5609		798	40.8	0.6						
A-3	5617	7283	772		35.9	0.6						
A-4	4576	5576		834	36.6	1.1	+.004	.020	.045	.049	6.5 7.5	.0067 .0073
A-5	5320	6484	728	865	62.5	2.4	+.010	.007	.035	.036		
A-6	4938	5907	592	841	70.6	2.7	+.013	.002	.031	.031		
A-7	5723	6453	739		69.5	2.0						
A-8	6034	6561	675	967	58.3	1.3	+.010 +.012	.007 .004	.035 .029	.038 .033	6.1 5.0	.0071 .0066
Average	5140	6194	684	861	51.2	1.4						
C-1	3472	4211	538		72.9	3.8					11.1 9.3	.0072 .0070
C-2	6417	7038		967	32.2	0.1					3.1 3.5	.0062 .0063
C-3	3673	4488	566		77.7	2.4						
C-4	4700	5463		772	77.7	2.7						
C-5	5363	6616	704		40.4	0.3	+.010	.007	.034	.040		
C-6	5210	6360		866	27.5	+0.8	0	.015	.039	.041		
C-7	5303	6351	704		51.8	1.1	+.007	.013	.036	.038		
C-8	5792	7220		840	25.0	0.4						
Average	4991	5968	628	861	50.6	1.3						
Average A&C	5066	6081	656	861	50.9	1.4	+.008	.009	.036	.038		.0068

(a) Each value is average of three cylinders.
(b) Beams tested by third-point loading (ASTM Method C 78).
(c) Durability factor and weight loss figured at 70 percent of original modulus or 300 cycles.

$DF = \frac{PN}{M}$ where P = relative modulus at N cycles, N = cycles to failure, M = 300.

(d) Fourteen-day plus-values indicate expansion during moist curing.
(e) Measurements made on vertical slices 1-1/2 in. from each end of test beam.

days, respectively. A major portion of this strength difference was undoubtedly due to the lower average net water-cement ratio of 4.5 gal per sack for the silicone mixes as compared to 5.5 for the air-entrained mixes.

Considerable variation can be seen in the compressive strengths of individual loads of both the 18 air-entrained mixes and the 16 silicone mixes (Tables 4 and 5). However, none of the 28-day averages fell below the design value of 3500 psi. These variations would reflect corresponding variations in air content, net water-cement ratio, and slump. A contributing factor to these measured test variations would be the number and type of transit-mix trucks involved. A total of four different mixing trucks were involved with the 18 loads of pours B and D on September 30 and three different trucks for the 16 loads used in pours A and C on October 1. However, all these trucks were of the inclined-drum type, 6-cu yd rated capacity, and operated at a mixing speed of 10 rpm. The variability of the silicone loads does not appear to be appreciably different from the air-entrained loads.

Batch-to-batch variations are also reflected in the durability factors and weight loss figures of individual freeze-thaw beams. Comparison of group averages indicates the silicone beams held up slightly better than the air-entrained beams in the freeze-thaw test. The silicone concrete appears to be about the same as the conventional air-entrained concrete in shrinkage properties up to ages of six months. A slight difference was noted in the air void size from cut sections of four silicone beams as compared to similar sections from four air-entrained beams. Air entrainment by the DC-777 silicone produced an average void size of 0.0068-in. diam as compared to 0.0057-in. average for voids entrained by the conventional liquid air-entraining agent Ersair.

First Field Inspection

An inspection was made by R. H. Merrill on April 7, 1964, to assess the general condition of the deck concrete after the first winter of exposure. A number of short shrinkage cracks in the silicone pours noticed during the first few days after finishing last October were found to be primarily in an unchanged condition. These cracks are shown diagrammatically in Fig. 1 and also in Fig. 4. The majority of the short, fine cracks were transverse and in the middle half of pour A, the southeast corner of pour C, and the south quarter of the east sidewalk. All the deck concrete appeared to be in good condition, except for these fine shrinkage cracks.

Conclusions

Based on the described tests on fresh and hardened concrete systematically sampled from individual transit-mix trucks on September 30 and October 1, 1963, and on observations made at the time of construction, the following conclusions may be made:

1. Considerable increases in compressive and flexural strengths at 7 and 28 days were realized from the DC-777 silicone mixes as compared to the air-entrained control mixes. The increases were 50 and 31 percent for compressive and 24 and 31 percent for flexural strengths, respectively. This is substantially more than the 10-percent minimum indicated for Type D Admixtures in ASTM Specification C 494-63T.

2. DC-777 when used at the rate of 0.3 percent by weight of Type I cement produced slightly higher air contents (7.3 percent) than Ersair (6.6 percent) added at the rate of 2 to 2-1/2 oz per sack. Average void size was slightly larger for the silicone concrete--0.0068 in. compared to 0.0057 in. for air-entrained concrete.

3. Batch-to-batch variations were slightly higher for silicone concrete than for air-entrained concrete with respect to strength, but about the same for air content, slump, and net water-cement ratio. For the air-entrained concrete of pours B and D, high and low batch strengths were +22 and -20 percent from the average at 7 days, and +17 and -16 percent at 28 days. The silicone pours A and C produced strength variations of +27 and -31 percent at 7 days, and +20 and -31 percent from the average at 28 days. The minimum strength values of the silicone mixes occurred in the first load of pour C when the highest air content of all mixes (11 percent) was produced.

4. A major cause of the variations measured for all mixes may be the addition of water near the end of the mixing period at the job site to obtain a working slump of 4 in. In some cases, not enough mixing was done after water addition to obtain homogeneity within the batch, and in many cases too much mixing occurred, producing higher air contents. These mixing difficulties point out the need for two-way radio contact between the job site and batch plant so that instantaneous adjustments in mix water or any other mix component can be made quickly, at the point of batching. All projects using transit-mix concrete could benefit by the use of radio communication. The Scotten Ave. project did not have this radio contact between job site and batch plant.

5. Placing and finishing of the silicone concrete was comparable to the air-entrained concrete. Batch variations occasionally caused trouble in screeding and finishing of stiff or low slump concrete in both types of mixes.

6. The shrinkage cracks produced in silicone pours A and C may possibly be attributed to the high absorptivity of the slag coarse aggregate, in conjunction with the long plastic period (greater than 24 hr) for the silicone mixes. The slag aggregate had an absorption of about 4.0 percent and only contained 1.8 percent water at time of mixing for pours A and C. Slag aggregate may induce plastic shrinkage cracking in any bridge deck concrete where prolonged set retardation is used. This would be more probable if the slag were dry or below saturation at time of mixing.

7. The durability of the silicone concrete of pours A and C will have to be compared to that of pours B and D after additional winters of exposure to ice-removal chemicals. After one winter there is no indication of pitting or light scale on any of the concrete. Durability should be good on all roadway concrete since the air content was within specification limits (5 to 8 percent) for most of the 34 loads of concrete involved.