USE OF A SILICONE ADMIXTURE IN BRIDGE DECK CONCRETE
Coe Road Over US 27, North of Alma (Mb S01 of 37013C, C13)

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EFFECTS OF A SILICONE ADMIXTURE IN BRIDGE DECK CONCRETE

This report describes the continuation of a cooperative study which began in 1963 between the Dow Corning Corp., Midland, Mich., and the Michigan State Highway Department to determine the effects of using a silicone admixture in bridge deck concrete. Preliminary laboratory studies were conducted by Dow Corning personnel using a water soluble silicone that they had developed and designated as "DC 777." These studies indicated that by adding 0.3-percent silicone by weight to cement, the freeze-thaw durability of concrete could be improved, a higher early strength could be obtained, and setting would be delayed considerably. The results obtained were conclusive enough to warrant further study in the field. Based on these findings, the Highway Department initiated a field study to determine the effect of the silicone admixture in bridge deck concrete containing the three commonly used coarse aggregates--gravel, limestone, and slag.

The purpose of this study has been to evaluate the effects of the silicone admixtures as compared to a conventional air-entraining agent, under normal construction conditions, on the following properties:

1. Freeze-thaw durability.
2. Resistance to surface scaling.
3. Strength.
4. Concrete uniformity.

Field Test Sites and Construction Details

The first structure in which the Department used the Dow Corning admixture was at Scotten Ave. over US 12 (Michigan Ave.) in Detroit. This bridge (Mb S04 of 82062C, C3) was constructed in 1941, and due to traffic, weathering, and heavy salt concentrations for de-icing purposes, was badly in need of repair. A heavy maintenance contract was set up to remove all deck and walk concrete and replace it with conventional air-entrained concrete and silicone concrete. Blast furnace slag coarse aggregate was used in the deck concrete. The results obtained in this study were discussed in Departmental Research Report No. R-463 (June 1964).

The structure selected for a second study was a four-span, prestressed concrete I-beam bridge carrying Coe Rd. over US 27 about 6 miles north of Alma (Mb S01 of 37013C, C13). This project was designated for particular investigation of the various properties of silicone concrete with limestone coarse aggregate. The overall length is 208 ft, with successive spans (west to east) of 34, 71-1/2, 71-1/2, and 31 ft. The width is 31-1/2 ft with a 24-ft clear roadway, 3-3/4-ft walks, and standard parapet-type railings. This structure, under contract to C. E. Utterback Co., was constructed as part of a plan to modernize US 27 to Interstate standards.

The concrete was purchased from Alma Concrete Products, whose transit mix plant was located about 5 miles from the bridge site. A regular six-sack mix with Type IA cement, 6AA limestone aggregate, and 2NS sand was proposed, but after some preliminary batches were used in diaphragm pours it was found that the silicone additive entrained too much air when used with Type IA cement. This necessitated changing to Type I cement and Darex air-entraining agent, which allowed air content to be adjusted for the subsequent pours. Mix proportions, materials, and sources for the deck pours were as follows:

Air-Entrained
94 lb Aetna Type I cement
211.5 lb Roslund 2NS sand
296 lb Inland Lime & Stone 6AA limestone
44.9 lb water
3 oz Plastiment retarder per sack
0.5 oz Darex air-entraining agent per sack

Silicone
94 lb Aetna Type I cement
211.5 lb Roslund 2NS sand
296 lb Inland Lime & Stone 6AA limestone
44.9 lb water
5 oz Dow Corning DC 777 silicone per sack

The bridge deck was poured in a conventional manner using two portable cranes with 1-cu yd buckets, transverse machine finishing with some hand floating, and white sprayed-on curing membrane. Fig. 1 indicates the boundaries of the silicone and air-entrained concrete pours, and various construction operations are shown in Fig. 2.

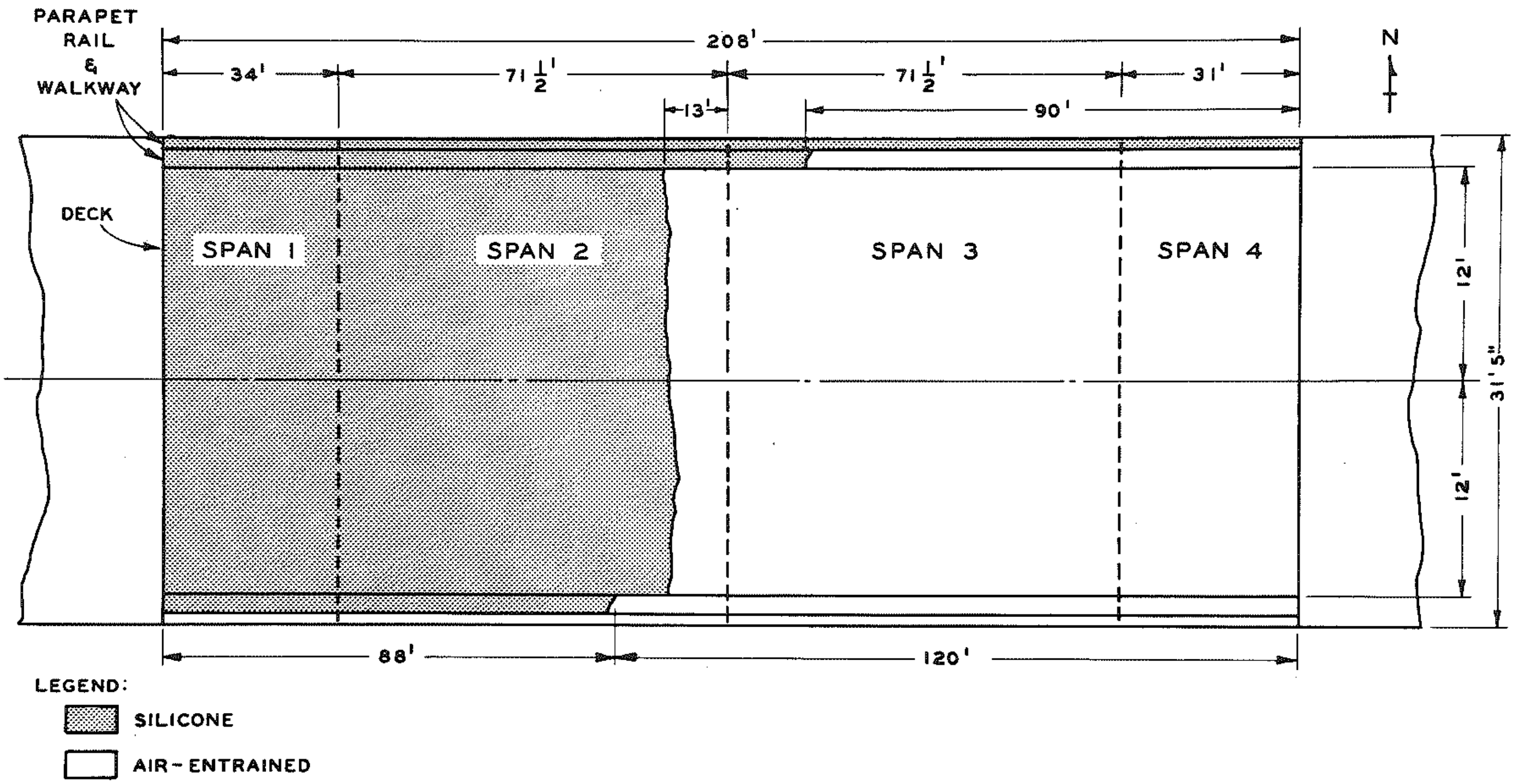

Figure 1. Locations of silicone and conventional air-entrained concrete pours on Coe Rd. structure.

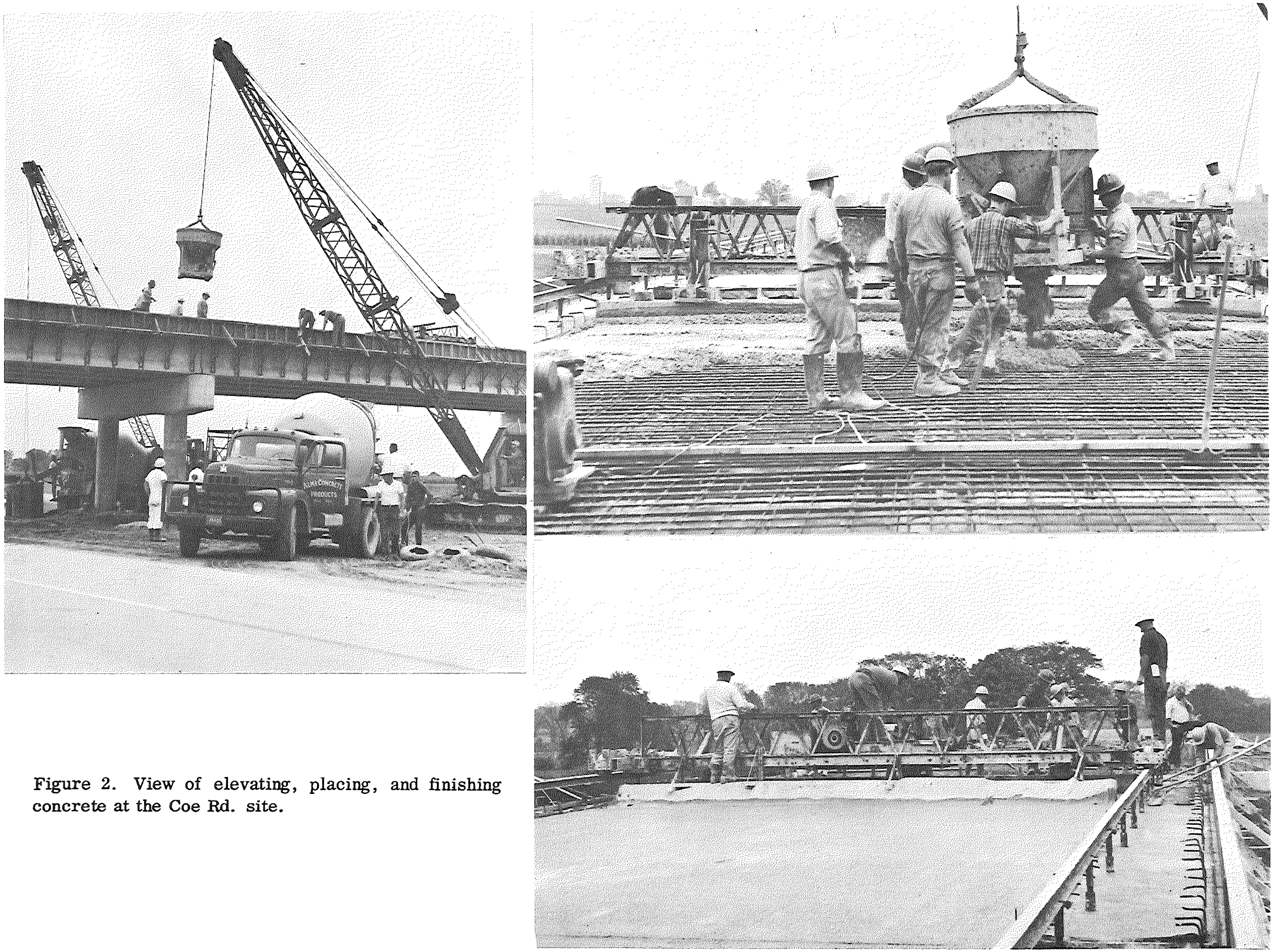

Figure 2. View of elevating, placing, and finishing concrete at the Coe Rd. site.

Sampling and Testing Procedures

A systematic sampling method was planned to measure the properties of fresh and hardened concrete containing DC 777 silicone and the control air-entraining agent. Each 5-cu yd load was subjected to tests and checks, both at the plant and at the site. The sampling was designed to determine within-test variations as well as overall variations. Data obtained for each load included charging time, mixing revolutions, slump, air content, water added at site, unit weight, and discharge time. Field test data on fresh concrete for deck pours are presented in Table 1 and, in less detail, for walk and parapet rail pours in Table 2. Laboratory test data for hardened concrete from the same pours are given in Tables 2 and 3.

Sampling and testing procedures as described in Research Report No. R-463 were used and are shown in Fig. 3. Loads were picked at random for extra tests such as air content (ASTM C 231), slump, and unit weight at the beginning and end of discharge, and for shrinkage beams, freeze-thaw beams, and cylinders for compressive strength. Specimens were made from concrete taken from the middle portion of the load discharged. Six 4- by 8-in. cylinders and three 3- by 4- by 16-in. beams were made from each load sampled. A total of nine shrinkage beams (3- by 3- by 15-in.) with stainless steel end studs were molded from the silicone and control air-entrained concretes. All specimens were cured with white sprayed-on membrane and polyethylene sheets for a minimum of 48 hr before being transported to the Research Laboratory for placement in the moist room where they remained until time of testing.

Compressive strength of all cylinders (capped with hot capping compound) was measured after moist curing for 7 or 28 days. All three beams molded from each load sampled were tested in the automatic freeze-thaw machine using ASTM Method: C 290 (rapid freeze-thaw in water). Six cycles a day were obtained by this method after the beams were moist-cured for 14 days. Shrinkage measurements were made on the smaller beams at the intervals shown in Table 3, using ASTM Method: C 157. An initial 14-day moist curing period was followed by storage in laboratory air. No flexural strength tests were conducted due to a shortage of beam molds at the time of sampling.

Discussion of Results

Relative variations in slump, air content, operating efficiency,

TABLE 1
SUMMARY OF FIELD TEST DATA ON FRESH CONCRETE
Deck Pours of September 22, 1964

	Load No.	Slump, in.	Concrete Temp, F	Air Content, percent	Unit Weight, pcf	Mixing Revolutions at Discharge	Water Added at Site, gal	Water/ Cement Ratio (net), gal/sack
Silicone	1	3-1/4	77	7.2	146.8	242	0	4.30
	2	4-1/2	74	6.6	149.5	96	0	4.40
	3(a)	9	76	7.7	143.0	94	0	4.20
	4	5	75	7.6	145.8	116	7	4.43
	5	5-1/4	75	7.3	145.5	74	0	4.30
	6	3-3/4	74	7.0	147.1	110	4	4.33
	7	4-1/4, 5-3/4(b)	76	9.0, 14.2(b)	140.5	95	6.5	4.27
	8	3-1/4	77	6.9	147.1	200	8	4.47
	9	5, 7(b)	76	7.0, 8.4(b)	144.3	96	0	4.37
	10	4-3/4	76	8.9	142.2	134	0	4.37
	11	5-3/4	76	9.4	141.8	106	3	4.47
	12	2	75	5.3	149.5	102	0	4.37
	13	2-3/4	77	6.8	145.5	117	0	4.20
	14	3	77	4.0	152.0	91	0	4.37
	15	3, 2-3/4(b)	77	15.7, 15.6(b)	139.3	102	0	4.20
	16	1-1/2	76	4.6	150.7	168	10	4.53
	17	2-3/4	78	7.3	144.3	140	3	4.30
	18	3	76	3.9	150.5	92	9	4.50
	19	4	78	8.6	143.4	140	9	4.50
	Average	4-1/8	76	8.1	145.7	122	2.66	4.36
Air-Entrained with Plastiment	20	3-1/2	79	6.5	145.3	85	8	4.21
	21	2-1/2	77	6.0	148.3	142	17	4.51
	22	3	77	1.5	152.8	91	19	4.58
	23	2-3/4	77	1.6	154.4	160	24	4.91
	24	2-3/4, 2-3/4(b)	79	5.8, 5.8(b)	146.5	92	10	4.44
	25	2-3/4	78	6.0	148.3	139	20	4.78
	26	6-1/4	78	7.1	144.0	71	9	4.58
	27	4-1/2	76	7.9	144.6	104	5	4.44
	28	5, 5-1/2(b)	77	6.9, 7.5(b)	143.4	70	5	4.44
	29	4	77	7.5	145.8	102	4	4.41
	30	4-1/2	76	6.2	147.8	154	10	4.49
	31	5-1/2	75	7.2	145.8	81	0	4.28
	32	4-1/2	76	6.7	147.5	121	16	4.81
	33	6	77	6.0	146.0	96	6	4.48
	34	4-1/4	76	6.0	147.1	82	10	4.61
	35	4-1/2, 4(b)	76	6.3, 6.4(b)	147.2	70	4	4.41
	36	3	75	5.7	148.3	177	0	4.28
	37	3-1/2	76	6.7	145.3	77	8	4.54
	38	3-3/4	75	7.3	149.0	94	5	4.44
	39	3-1/2	73	7.1	140.9	110	4	4.41
	Average	4-1/8	76.5	6.2	146.9	106	9.2	4.50

(a) Load not used.

(b) Two tests. Sampled after first yard and before last yard of load.

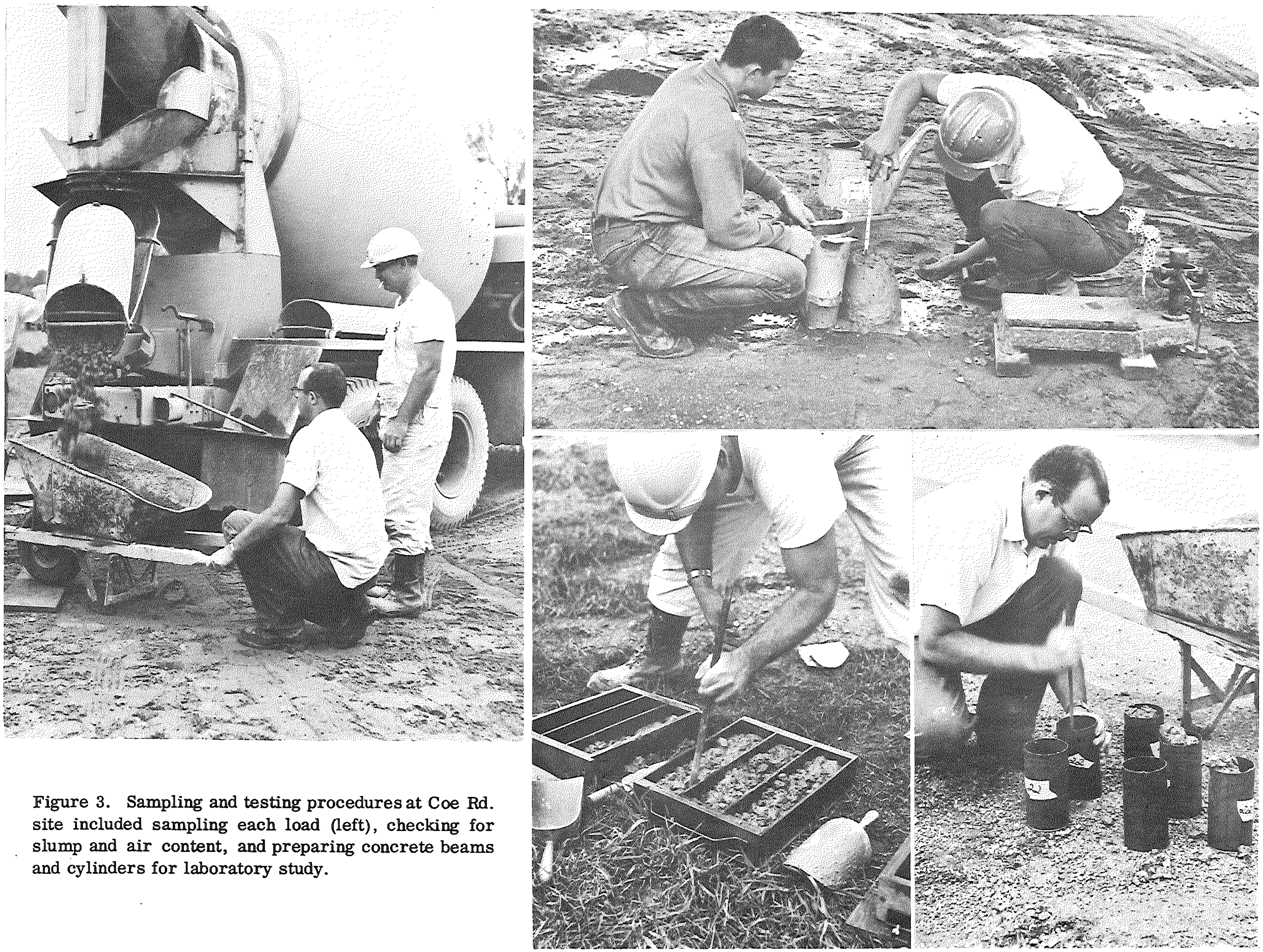

Figure 3. Sampling and testing procedures at Coe Rd. site included sampling each load (left), checking for slump and air content, and preparing concrete beams and cylinders for laboratory study.

water-cement ratio, and compressive strength were evaluated using the expression

$$V = 100 \frac{S}{\overline{X}} \qquad (1)$$

where

V = coefficient of variation or relative variation
S = sampling variability or standard deviation
$\overline{X}$ = mean value or average of the set of measurements (sampling average)

TABLE 2
SUMMARY OF TEST DATA
ON FRESH AND HARDENED CONCRETE
Walk Pours (10-1-64) and Parapet Rail Pours (10-29-64)

	Load No.	Slump, in.	Concrete Temp, F	Air Content, percent	Compressive Strength, psi[a] 7-day	Compressive Strength, psi[a] 28-day
Air-Entrained	1	4	63	9.3	----	----
	2	2-1/2	62	8.7	2501	3612
	Walk 3	2-3/4	62	8.7	2539	3813
	9	3-1/4	69	10.3	2363	3010
	10	4	67	10.0	----	----
	Avg.	3-1/3	65	9.4	2468	3478
Silicone	4	3-1/2	64	9.2	----	----
	5	3	66	8.1	4531	5877
	Walk 6	4-3/4	68	9.3	3761	4665
	7	4-3/4	68	9.5	3748	5041
	8	4-1/4	68	9.1	----	----
	Avg.	4	67	9.0	4013	5194
	Rail 1	4	--	9.0	----	----
	2	4-1/2	--	9.0	----	----

(a) Each test value is average of three cylinders.

The larger the value of V, the less uniform are the experimental data, and vice versa. Thus, this expression is useful for indicating the degree of uniformity of the field data, when they approximate the normal distribution curve.

Freeze-Thaw Durability and Scaling Resistance

For this report, the evaluation of freeze-thaw durability is confined solely to laboratory samples (3- by 4- by 16-in. beams) obtained from the bridge deck concrete. Nine beams from each pour (silicone and control air-entrained) were tested in accordance with ASTM Method: C 290 (rapid freeze-thaw in water), with the results given in Table 3.

TABLE 3

SUMMARY OF LABORATORY TEST DATA ON HARDENED CONCRETE

Deck Pours of September 22, 1964

	Load No.	Compressive Strength, psi(a)		Freeze-Thaw Tests(b)		Shrinkage, percent		
		7-day	28-day	Durability Factor	Weight Loss percent	14-day(c)	1 mo	3 mo
Silicone	5	3870	5113	52.1	4.03	+.010	.007	.028
	7	4098	5219	----	----	+.012	.012	.036
	11	4045	5318	45.9	4.87	+.012	.013	.035
	13	4486	5763	----	----	----	----	----
	15	3997	4821	----	----	+.012	.011	.034
	19	5159	6273	38.2	2.46	+.012	.009	.031
	Avg.	4276	5418	45.4	3.79	+.0116	.0104	.0328
Air-Entrained	22	5512	7069	----	----	----	----	----
	24	4716	5378	37.1	2.85	+.012	.006	.027
	26	4451	5305	----	----	+.010	.010	.032
	30	5098	6366	43.1	2.83	+.009	.008	.033
	35	4380	5232	----	----	+.009	.007	.028
	37	4685	5444	49.2	3.73	----	----	----
	Avg.	4807	5799	43.1	3.14	+.010	.0078	.030

(a) Each value is average of three cylinders.

(b) Durability factor and weight loss figured at 70 percent of original modulus or at 300 cycles. $DF = \frac{PN}{M}$ where P = relative modulus at N cycles, N = cycles to failure, and M = maximum cycles specified before ending test (300). Each value average of three beams.

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

These results show no significant difference in durability between the two concretes. Periodic inspections of the bridge deck concrete will provide additional information for further evaluation of relative durability and scale resistance.

Compressive Strength

Results from the Coe Rd. project show that the retarded air-entrained control deck concrete averaged about 10-percent higher in strength than the silicone deck concrete, with both mixes requiring approximately the same water-cement ratio of about 4.5 gal per sack (Table 4). This can probably be attributed to the combined effect of adding the retarder and water reducer to the control concrete.

The silicone walk pours attained 62 and 49 percent higher compressive strengths at 7 and 28 days, respectively, than the conventional control air-entrained concrete. Here, the high air content reduced the strength of the non-retarded conventional concrete to the point that the design strength of 3500 psi was barely attained at 28 days.

The degree of concrete uniformity depends upon the relative variations of processing, handling, and testing the fresh concrete. Since the relative variation V is expressed as a percentage of the sample average X (Eq. 1), the computed values can be compared with similar terms from the field data. The relative variations or coefficients of variation for compressive strength are shown in Fig. 4. Standard statistical tests indicate that the differences in relative variations among cylinders for the two concretes are within experimental error, and therefore these differences can be expected even in controlled conditions.

Since water-cement ratio is an important factor affecting concrete strength, computed values of relative variations for this factor are shown in Table 4 and Fig. 4. Water-cement ratio is computed by combining data on water content of aggregates, plus water added at the plant and the job site, with total cement used for each batch. The higher the ratio (i.e., the more water used per unit of cement), the weaker the concrete will be. The lower the ratio of the workable mix, the stronger the concrete will be. Fig. 4 and Table 4 show that relative variations of the water-cement ratio for conventional concrete greatly exceeded the values obtained for silicone concrete. Therefore, increase in strength with reduction of water-cement ratio is expected for silicone mixes.

Concrete Slump

Analysis of the slump test data reveals that consistency of fresh concrete was significantly affected by the degree of mixing control provided in transit mixers during job operations. In particular, as shown in Fig. 5, prolonged mixing and agitation reduced slump and increased strength. While these properties generally would have been desirable, it was noted in this experiment that unsatisfactory consistency resulted, perhaps because of the condition of the mixer, influence of the operator, or both.

TABLE 4
SUMMARY OF TEST DATA ON TRANSIT-MIXED CONCRETE

Test Factor	Silicone Pours	Air-Entrained Pours
7-Day Compressive Strength		
Total Tests	18	18
Avg. Strength, psi	4276.0	4807.0
Relative Variation, percent		
Overall	11.7	10.2
Within-Test	5.5	6.3
28-Day Compressive Strength		
Total Tests	18	18
Avg. Strength, psi	5418.0	5799.0
Relative Variation, percent		
Overall	9.7	13.5
Within-Test	4.4	6.6
Slump		
Total Tests	19	20
Avg. Slump, in.	4.1	4.0
Relative Variation, percent	42.4	27.8
Air Content		
Total Tests	19	20
Avg. Air, percent	7.6	6.1
Relative Variation, percent	35.3	27.5
Performance Ratio		
Total Tests	19	20
Avg. Ratio, percent	96.0	107.0
Relative Variation, percent	25.8	15.1
Water-Cement Ratio		
Total Tests	19	20
Avg. gal per sack	4.4	4.5
Relative Variation, percent	22.7	40.0

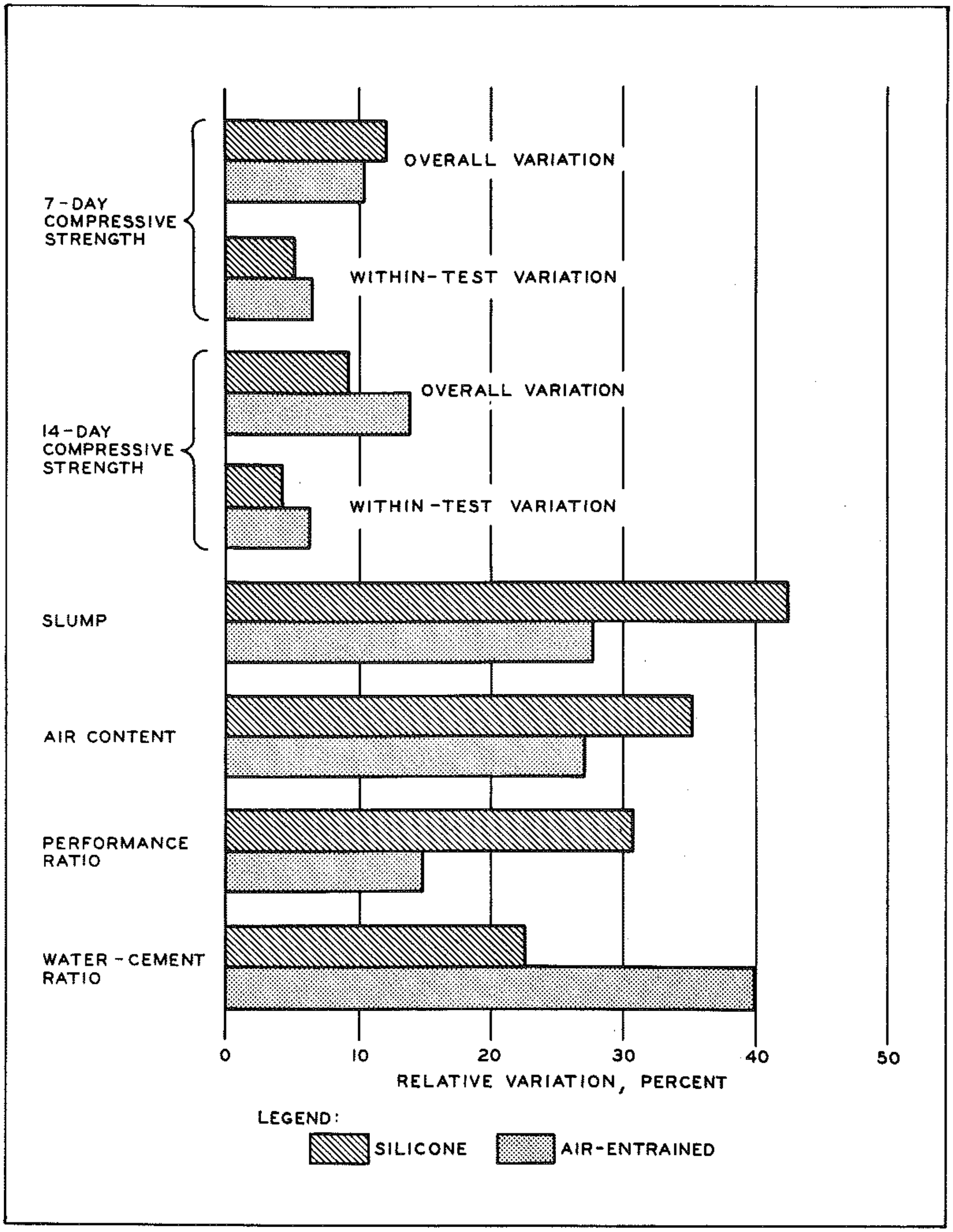

Figure 4. Comparison of relative variations among several field tests on transit-mix concrete.

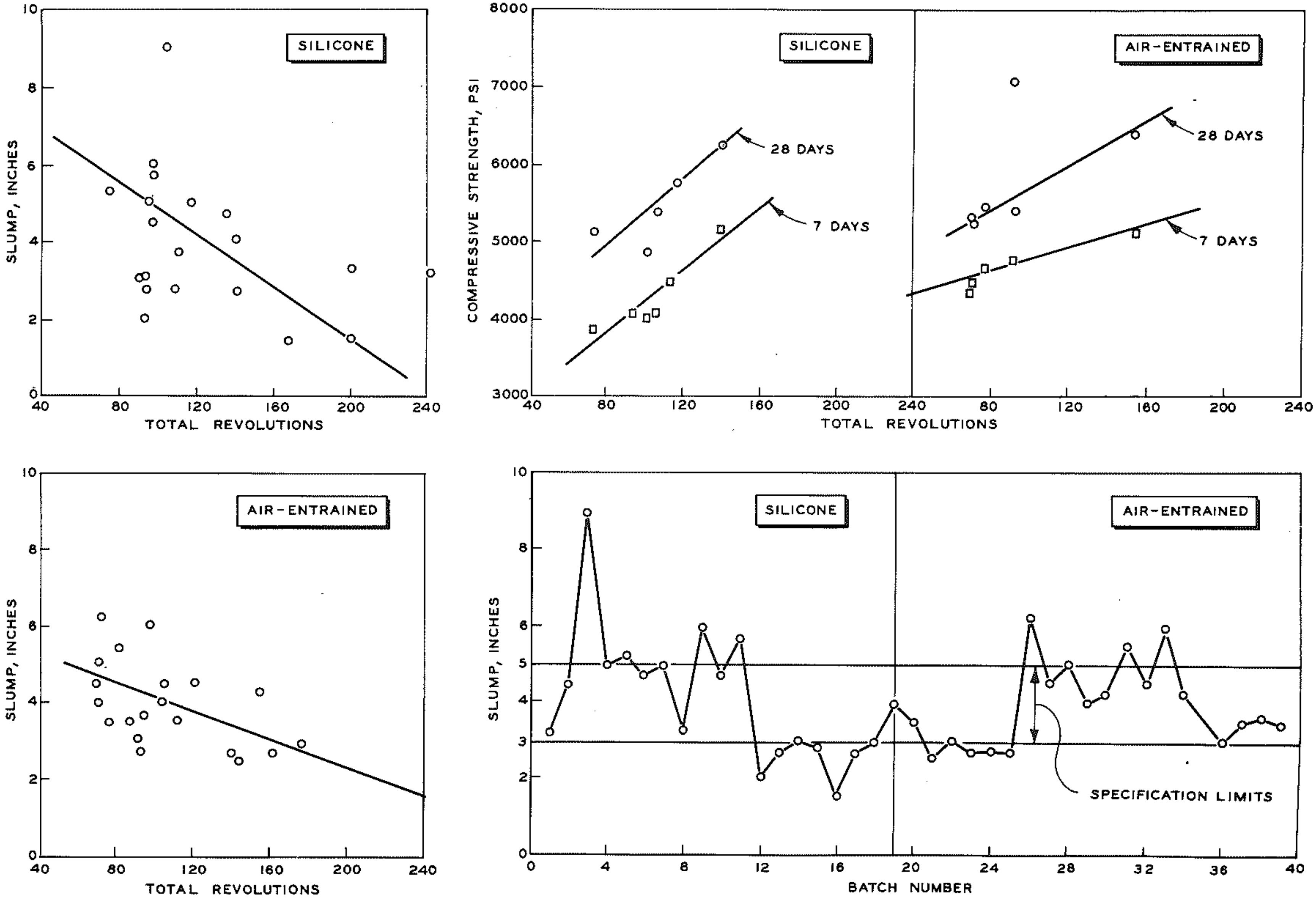

Figure 5. Relationship of total mixing revolutions to slump and compressive strength (slump tests showing lack of control). Coe Rd. project.

Here, 40 to 50 percent of the slump tests failed to meet the specification of 3- to 5-in. slump. Fig. 4 also shows that the tendency toward lack of control in slump was stronger for silicone than control air-entrained mixes.

Air Content

A comparable lack of uniformity of fresh concrete is also observed in the air content data (Fig. 6) from Coe Rd. deck pours. In fact, for silicone mixes it was found that 8 of the 19 tests (approximately 42 percent) failed to meet specified tolerances of 5- to 8-percent air content.

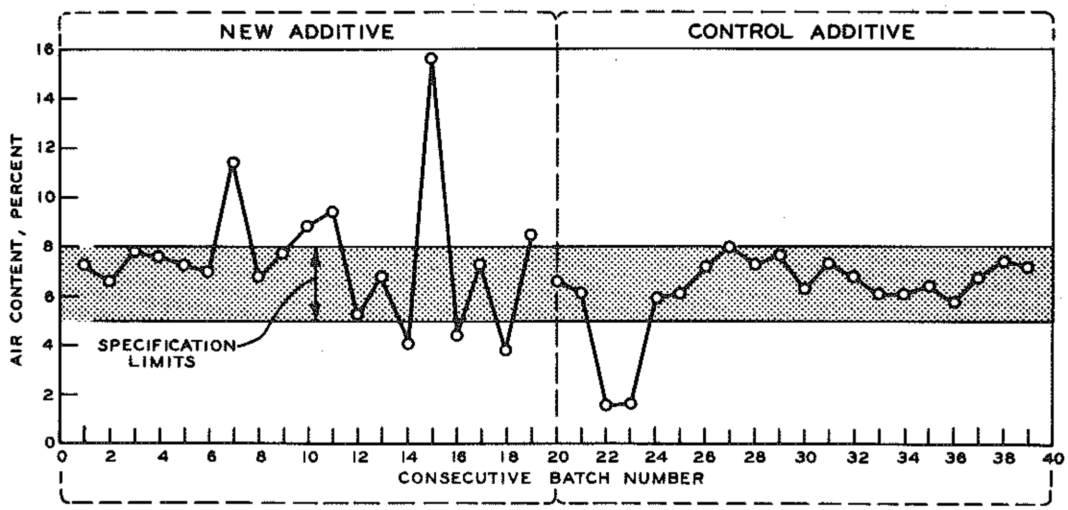

Figure 6. Air content tests on fresh concrete showing wide variability. Coe Rd. project.

However, for air-entrained concrete only 2 of the 20 tests (or 10 percent) were outside specified tolerances. This evidence of lack of control suggests that the air-entraining agents (especially the DC 777 silicone) were not uniformly dispersed throughout the batch and that the control problem was more critical for silicone mixes than for conventional or control air-entrained concrete.

Performance Ratio

To assure an efficient and uniform operation with transit mixers, it is good practice to control the batching sequence of fresh concrete.

Therefore, all major factors that entered into the operation of transit-mixed concrete were related according to the following modified formula:[1]

$$E = \frac{60 \dfrac{V}{t_1 + t_2 + t_3}}{A} \qquad (2)$$

where

$E_1 \ldots E_n$ = performance ratio or operating efficiency, percent
V = batch size, cu yd
t_1 = charging time per batch, min.
t_2 = traveling time per batch, min.
t_3 = discharging time per batch, min.
A = average discharge, cu yd per hr (as averaged upon completion of the job).

Although the field data were insufficient to provide reliable checks on the operating efficiency of transit mixers, the results did show some evidence of lack of relative uniformity, especially for silicone loads (Fig. 4), as indicated by twice as much variation for silicone concrete as for control concrete.

Conclusions

The analysis of this experimental work indicates the following conclusions:

1. Proper control was not attained in producing fresh concrete in transit mixers. The tendency toward lack of control in slump and air content was greater for silicone mixes than for control air-entrained mixes, but the reverse was true for water-cement ratio.

2. The retarded air-entrained mixes averaged about 10-percent higher in compressive strength than the silicone concrete. The sidewalk pours, however, produced a higher compressive strength for silicone than air-entrained concrete without retarder. The relative variations in compressive strength between the two types of concrete mixes fell within the experimental error.

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[1] From "Analysis of Concrete Haul and Cost," Roads and Streets (July 1964) p. 45.

3. The wide fluctuations of test results for slump and air content made it difficult to evaluate the significance of the relationship between water-cement ratio and freeze-thaw durability. However, comparison of average values indicates that the durability factor for silicone beams was slightly better than that for control air-entrained beams.

4. The silicone concrete appears to be about the same in shrinkage properties as the conventional or control air-entrained concrete, up to ages of six months.

5. Placing and finishing of the silicone concrete was comparable to that of the air-entrained concrete. However, slightly better relative uniformity was observed for the latter.

6. Relative resistance of the silicone and air-entrained deck pours to the action of ice removal salts in the field will require later evaluations after extended exposure to winter maintenance.