LOW SLUMP PORTLAND CEMENT CONCRETE BRIDGE DECK OVERLAYS

MICHIGAN DEPARTMENT OF STATE HIGHWAYS AND TRANSPORTATION

TESTING AND RESEARCH DIVISION
RESEARCH LABORATORY SECTION

LOW SLUMP PORTLAND CEMENT CONCRETE BRIDGE DECK OVERLAYS

K. H. Laaninen

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Peter B. Fletcher, Chairman; Carl V. Pellonpaa,
Vice-Chairman; Hannes Meyers, Jr., Weston E. Vivian
John P. Woodford, Director
Lansing, January 1978

INTRODUCTION

This is the post-construction report on an experimental project involving the overlay of two bridge structures with low slump, cement-rich concrete. It is a Category 2 project, authorized by a letter of May 8, 1975, from David A. Merchant to John P. Woodford. Future reports will include data on the field performance of these overlays.

The structures selected for overlay were S03 of 33084 and S10 of 47065. S03 of 33084 is a three-span ramp structure, 39.5 ft wide and 239 ft long. It is located near Lansing and carries southbound I 496 to eastbound I 96 over westbound I 96. S10 of 47065 carries I 96 over Grand River Ave near Brighton and consists of two 52-ft wide structures of three spans, totaling 174 ft.

The purpose of this experimental project is to determine whether low slump, cement-rich concrete is an acceptable alternate to latex modified concrete for bridge deck overlays.

Deterioration of concrete bridge decks is a major problem in Michigan and elsewhere. Rusting of the reinforcing steel with subsequent fracture plane development and spalling of the deck concrete are typical of bridge deck deterioration. Temporary measures, such as asphalt patching, do little to retard the rate of deterioration; permanent rehabilitation of the deck is the only real solution.

One acceptable method of permanent rehabilitation is to remove all deteriorated and chloride-contaminated concrete, prepare the deck, and overlay it with a suitable concrete or mortar in a thin bonded overlay. Iowa has reported success in using low slump concrete of 8-3/4 sacks of cement per cubic yard of concrete for overlayment of their bridge decks starting in 1964. Their preparation of the concrete deck is similar to Michigan's practice for latex concrete overlays except they stipulate a surface-dry deck to be brushed with a fluid grout prior to overlay.

DECK PREPARATION, OVERLAY, AND CURING

The concrete decks described in this report were prepared by scarifying to a depth of 1/4 in. and removing all unsound concrete below 1/4 in. with pneumatic hammers. The exposed reinforcing steel was sandblasted to remove rust scale.

The low slump concrete was proportioned and mixed at the project site by the use of two Concrete-Mobiles. The mix design used is shown below and is basically the same as used in Iowa:

Cement	823 lb/cu yd
Fine aggregate (2NS sand)	1381 lb/cu yd*
Coarse aggregate (25A crushed gravel)	1381 lb/cu yd*
Net water	272 lb/cu yd
Water/Cement ratio	0.33
Master Builder's Vinsol Resin (MBVR)	1.5 fl oz/sack
Pozzolith 200N	4.0 fl oz/sack
Slump	1 ± 1/4-in.
Air content	6-1/2 ± 1-1/2 percent

* Based on specific gravity of 2.65

A Gomaco Model F500 finishing machine was used to consolidate and finish the concrete. This machine had two oscillating screeds with four hydraulic vibrators on the front screed and one on the second. The surface weight on the screeds was indicated to be 75 lb/sq ft. Consolidation was achieved by these five surface vibrators operating on the two pan-type screeds. Initial distribution and leveling of the mix was done with hand shovels.

TABLE 1
DATE AND LOCATION OF OVERLAY PLACEMENT

Pour Date	Structure	Pour Location	Direction of Pour
8-14-75	S03 of 33084	Inside 20 ft	East
8-27-75	S03 of 33084	Outside 19.5 ft	West
8-28-75	S10 of 47065	Eastbound outside 16 ft	West
9-2-75	S10 of 47065	Westbound outside 16 ft	East
9-3-75	S10 of 47065	Eastbound center 16 ft	East
9-4-75	S10 of 47065	Westbound center 16 ft	West
10-2-75	S10 of 47065	Eastbound inside 20 ft	East
10-3-75	S10 of 47065	Westbound inside 20 ft	West

A Type I grout (1:1 cement to sand) was broomed on the surface dry deck immediately prior to overlayment. This grout was also used as a wetting agent during hand finishing. No water was allowed to contact the fresh concrete prior to covering with burlap.

A wire comb was used to transversely texturize the fresh concrete after hand finishing.

Curing consisted of 72 hours under wet burlap followed by 48 hours nominal air drying, after which a linseed oil-mineral spirits (50:50) sealer was applied in two coats.

Pour dates, location, and direction of overlayment placement are shown in Table 1. Figure 1 illustrates the various steps in placing, and finishing the low slump overlays.

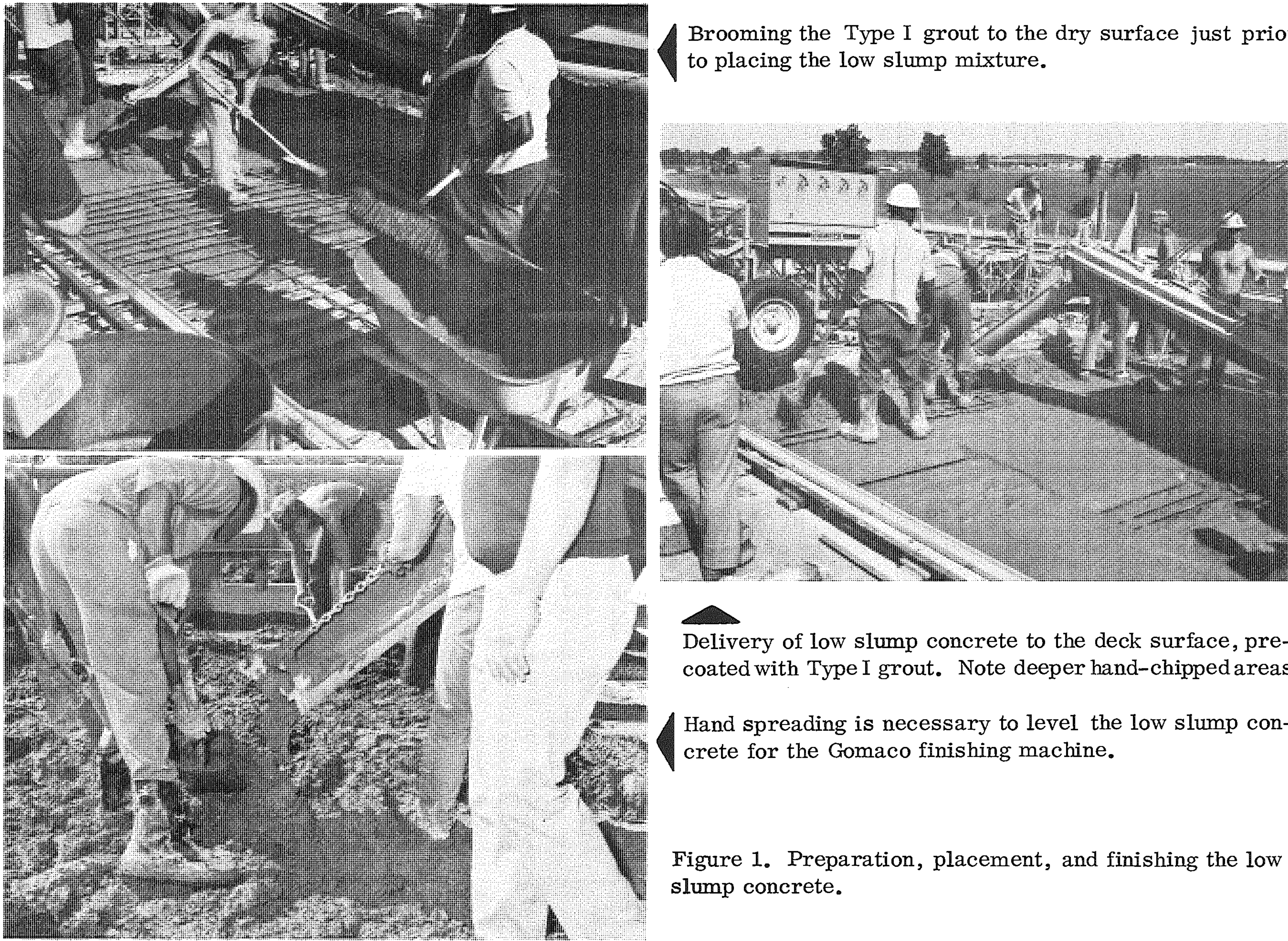
CONTROL AND EVALUATION

On-Site Measurements of Fresh Concrete

Measurements were taken of slump, entrained air, mix temperature, and unit weight on the low slump overlay concrete. The averages of several tests taken during each day's pour are summarized in Table 2. Slump measurements were made in accordance with ASTM C 143-71. Measurements of entrained air were made with a pressure-type air meter as described in ASTM C 231-72T. Standard methods proved inadequate in consolidating the low slump concrete in the air meter pot, however satisfactory results were obtained by using a surface vibrator mounted on a channel iron to strike-off and consolidate the top layer.

The unit weight of the concrete was obtained by weighing the filled air meter pot. This unit weight was used as a reference for subsequent density checks of the in-place concrete overlay. The density of the in-place concrete overlay was obtained through the use of a Troxler Model 2401 Nuclear Moisture/Density gage. The Troxler gage was calibrated and readings taken at a probe depth of 1-1/2 in. for the 2-in. nominal overlay thickness. A correction factor was determined to apply to the indicated Troxler density to give the true density.

Fresh concrete was consolidated in two layers in a calibration box of 20 by 14 by 4 in. by spading with a square shovel. After spading, each end of the box was dropped four times through a distance of 3 in. In addition, the top layer was screeded and further consolidated with the surface vibrator.

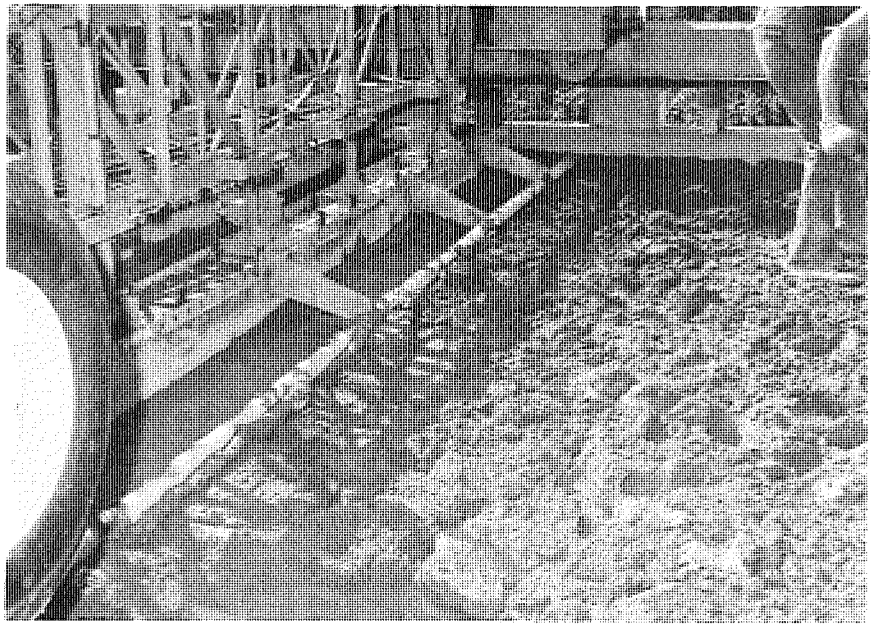


Brooming the Type I grout to the dry surface just prior to placing the low slump mixture.

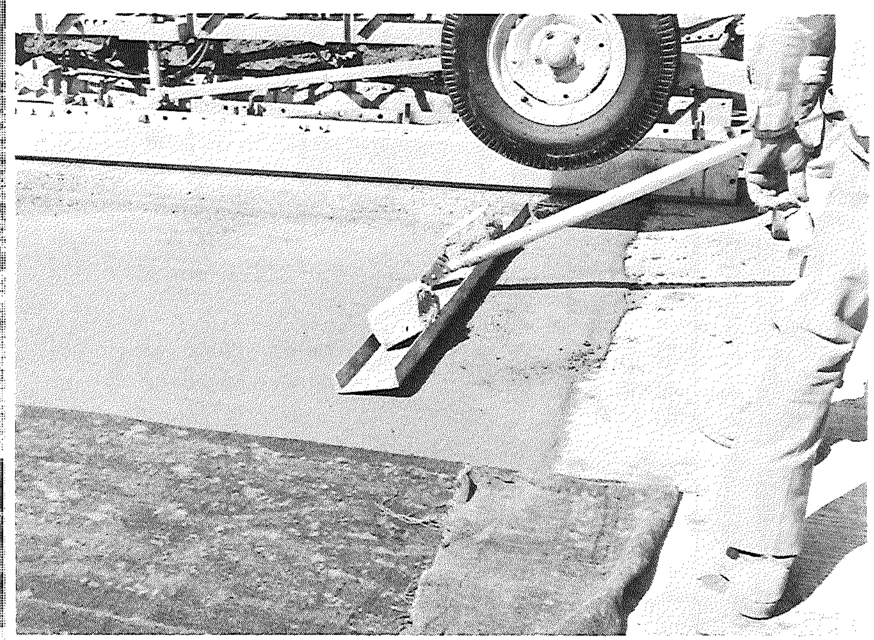
Delivery of low slump concrete to the deck surface, precoated with Type I grout. Note deeper hand-chipped areas.

Hand spreading is necessary to level the low slump concrete for the Gomaco finishing machine.

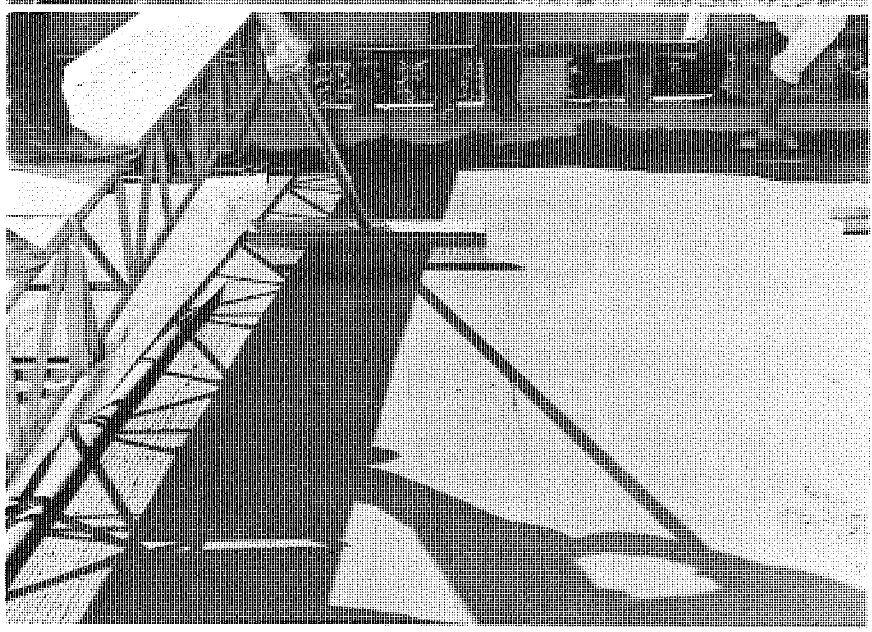
Figure 1. Preparation, placement, and finishing the low slump concrete.



Gomaco finishing machine with strike-off bar and vibratory screed (note surface vibrators).



Hand float with concrete blocks for weight followed just behind the finishing machine. Some hand finishing with wood floats was necessary in harsh or torn areas.



The wire comb texturing of the fresh overlay was done by hand.

Figure 1. (Cont.)

TABLE 2
SLUMP, ENTRAINED AIR, TEMPERATURE, AND UNIT WEIGHT OF FRESH LOW SLUMP CONCRETE

Structure	Date	Slump, in.	Entrained Air, percent	Temperature, F	Unit Weight, lb/cu ft
	8-14-75	7/8	7.3	79	144.4
S03 of 33084	8-27-75	3/8	7.4	--	143.8
	S03 Avg	---	7.4	--	144.1
	8-28-75	1/8	5.5	--	146.1
S10 of 47065	9-3-75	1/2	5.0	74	146.4
EB Deck	10-2-75	1/8	7.0	66	143.7
	EB Avg	---	5.8	--	145.4
	9-2-75	0	5.9	81	144.1
S10 of 47065	9-4-75	7/8	5.8	78	145.4
WB Deck	10-3-75	1/8	6.2	71	144.7
	WB Avg	---	6.0	--	144.7
	S10 Avg	---	5.9	--	145.1

The density of the fresh concrete in the calibration box was determined by weight, and then with the Troxler Nuclear Density gage. Three counts of one minute each were taken with the Troxler gage at each of two locations in the calibration box. The correction factor is defined as the average difference between the density determined by weighing and the density determined with the Troxler gage.

At each station selected for density measurement of the in-place concrete overlay, three or four points were located laterally across the width of the pour. At each point a density determination was made with the Troxler gage using three one-minute counts.

The percent consolidation at each point was determined by the following formula:

$$\text{Percent consolidation} = \frac{(\text{Troxler density} + \text{correction factor}) \times 100}{\text{Reference air pot density}}$$

Results of these density tests are shown in Table 3.

TABLE 3
IN-SITU DENSITY OF FRESH LOW SLUMP CONCRETE OVERLAY
(Percent of Reference Density)

Structure	Span	No. of Points	Density of Overlay, percent			Number Less Than 98 Percent
			High	Low	Avg	
S03 of 33084	1	5	102.0	98.0	100.3	0
	2	9	100.8	98.1	99.6	0
	3	10	101.9	97.1	100.0	2
	Total	24	102.0	97.1	99.9	2
S10 of 47065 EB Deck	1	0	---	--	---	-
	2	21	105.1	97.9	100.9	1
	3	12	104.4	99.0	102.4	0
	EB Total	33	105.1	97.9	101.4	1
S10 of 47065 WB Deck	1	6	101.0	99.4	100.2	0
	2	21	103.6	97.5	100.8	2
	3	6	102.3	99.4	100.8	0
	WB Total	33	103.6	97.5	100.7	2
	S10 Total	66	105.1	97.5	101.0	3

Laboratory Testing of Sampled Concrete

Samples were obtained from each of the two concrete placement dates for Bridge S03 of 33084 designated as mixes B1 and B2. Samples were also obtained from two of the six concrete placement dates for Bridge S10 of 47065 designated as mixes B3 and B4.

The specimens were molded of fresh concrete at the project site, covered with polyethylene sheets for overnight field curing, and were transported to the laboratory the following day for continued curing and testing.

The type of test and number of specimens tested for each of the four designated mixes are described as follows:

1) Compressive Strength - Six, 4 by 8-in. cylinders were tested in groups of three after 7 and 28 days of continuous moist cure in accordance with ASTM C 42-68.

2) Flexural Strength - Six, 3 by 4 by 16-in. prisms were tested in groups of three after 7 and 28 days continuous moist cure. Third-point loading was used in accordance with ASTM C 78-64.

3) Shrinkage - Three, 3 by 3 by 15-in. prisms, as described in ASTM C 157-69T, were weighed and measured periodically during a 13-week special cure consisting of one week continuous moist curing, three weeks air drying, three weeks moist room recovery, three weeks air drying, and three weeks moist room recovery. Following the 13-week special cure the prisms were subjected to six months of air drying during which they were weighed and measured after 1, 3, 7, and 28 days and three and six months. Following the six months of air drying the prisms were placed in the moist room for 28 days during which time they were weighed and measured after 1, 3, 7, and 28 days.

4) Internal Freeze-Thaw Durability - Three, 3 by 4 by 16-in. prisms, were given a simulated bridge deck cure consisting of 7 days in the moist room, 14 days air drying, and 7 days in the moist room. At 28 days the prisms were weighed and the fundamental transverse frequency (NVF) measured. The prisms were placed in the rapid freeze-thaw machine, six cycles per day, corresponding to ASTM C 666-73, Procedure B.

The beams were weighed and the fundamental transverse frequency measured at intervals of 42 freeze-thaw cycles during the 336 freeze-thaw cycle duration of the test. After weighing and measuring the frequency at 336 freeze-thaw cycles the beams were tested in flexure by third-point loading.

The internal freeze-thaw durability factor is equal to the relative dynamic modulus of elasticity at 336 cycles. The relative dynamic modulus of elasticity at each test is expressed as a percent of the 28-day value in accordance with the following formula:

$$\text{Relative dynamic modulus of elasticity, percent} = \frac{(\text{NVF})^2 \times 100}{(\text{initial NVF})^2}$$

5) Surface Durability in Freezing and Thawing - One composite block was used to evaluate the surface and bond durability of the low slump overlay concrete in freezing and thawing.

A well cured, precast and surface dry block 12 by 10 by 4 in. composed of seven-sack concrete containing a 6 by 8 by 1-1/2 in. depression centered in the top was utilized for this purpose. An etching compound was used while the concrete was fresh in order to expose the aggregate at the bottom of the depression. This, combined with sandblasting, was done to simulate a concrete bridge deck prepared for overlayment. The block was taken to the job site where a slurry of cement and water was brushed on prior to placement of the low slump concrete into the depression.

This composite block consisting of the cured seven-sack concrete and fresh low slump overlay concrete was moist cured 7 days and then air dried for 7 days.

At 14 days age the composite block, hereafter referred to as 'the block,' was photographed, ponded with fresh water, and placed in the walk-in freezer at 0 F.

The block was subjected to a repeating routine of freezing and thawing. The block was removed from the freezer each morning to thaw at laboratory temperature. At 4 p.m. each day the block was returned to the freezer where it remained overnight and on non-working days.

One cycle of freezing and thawing is defined as freezing from a completely thawed condition to 0 F and subsequent complete thawing at laboratory temperature.

To simulate the weathering and exposure to chloride that bridge decks experience through the winter, the block was alternately ponded with a 4-percent solution of rock salt and fresh water. Fresh water remained on the block for four cycles of freezing and thawing after which it was replaced with a 4-percent solution of rock salt. The salt solution remained on the block for three cycles of freezing and thawing after which it was replaced with fresh water.

This routine of alternating a salt solution and fresh water was repeated throughout the test. At intervals of 21 cycles of freezing and thawing the block was washed, scrubbed, and set to dry for at least 24 hours. After air drying, the block was photographed and then returned to the freezer with fresh water ponded. The procedures previously described were then resumed. After being photographed at 105 cycles of freezing and thawing the block was prepared for freeze-thaw bond durability tests.

6) Bond Durability in Freezing and Thawing - After the surface durability test, the block was sawed into two, 3-1/2 by 4-in. pieces. Each piece was subsequently tested in single shear at the bond line of the overlay to the substrate.

Field Evaluation of Hardened Low Slump Concrete Overlay

After being opened to traffic, the skid resistance of the low slump concrete overlay was determined. The Department's skid trailer applies a flow of water over the deck just ahead of the skid tires at a speed of 40 mph to simulate wet weather driving conditions. The test trailer basically meets the requirements of ASTM E 274. A rapid travel profilometer survey of each deck was also run.

Subsequent testing of the low slump concrete overlay will include obtaining cores to determine density, bond strength of the overlay to the original concrete, and chloride ion concentration at different depths. In addition, the overlay will be electrically measured with a copper sulfate half-cell to determine if active corrosion is continuing in the reinforcing steel. The overlay will also be measured with a delamination detector to determine if any delaminations exist in the original concrete or if the overlay has become unbonded at any point. Results of these tests will be contained in a subsequent report which will also include condition survey data after two years of traffic and weather.

Results of Laboratory Testing of Sampled Concrete

Properties of the field sampled batches which were subsequently tested in the laboratory are shown in Table 4. The slump, entrained air, mix and air temperatures, and unit weight are as noted. Although mix B2 exceeded the specified entrained air content, it was felt the testing of this mix would yield significant data on the basic properties of the low slump concrete. These data could have a bearing on any proposed upward revision of specified entrained air.

TABLE 4
PROPERTIES OF PLASTIC FIELD CONCRETE
FOR LABORATORY TEST SPECIMENS

Mix Code[1]	Date of Pour	Slump, in.	Entrained Air, percent	Temperature, F		Unit Weight, lb/cu ft
				Air	Concrete	
B1	8-14-75	1/8	7.2	75	79	146.0
B2	8-27-75	1/2	8.8	80	--	142.2
B3	10-2-75	0	6.0	41	65	145.4
B4	10-3-75	0	5.7	60	69	145.0

[1] Mixes B1 and B2 were obtained from S03 of 33084, mixes B3 and B4 were obtained from S10 of 47065.

TABLE 5
SUMMARY OF LOW SLUMP CONCRETE STRENGTH, COMPRESSIVE AND FLEXURAL
(All specimens except freeze-thaw beams cured in moist room until time of test)

Mix Code	Compressive Strength, psi[1]		Flexural Strength, psi[2]		
	7-Day	28-Day	7-Day	28-Day	After 336 Freeze-Thaw Cycles
B1	4960	5870	768	852	877
B2	4750	5870	790	832	855
B3	5900	6420	818	970	881
B4	5350	5770	918	1036	859
Avg	5240	5980	824	922	868

[1] Each value is average of three 4 by 8-in. cylinders.
[2] Each value is average of three 3 by 4 by 16-in. beams.

The results of the compressive and flexural strength tests are shown in Table 5. The flexure strength after 336 cycles of freeze-thaw testing is also included.

The results of the shrinkage prism tests are shown in Figures 2 and 3. The shrinkage values in mil/in. as shown are generally good except for mix B2 which contained a high percentage of entrained air.

The results of the test of internal durability in freezing and thawing are shown in Figure 4. All sampled concrete showed excellent durability. The results of the flexure test performed after 336 cycles of freeze-thaw exposure as shown in Table 5 also indicates excellent durability.

Results of the test for surface durability and bond in freezing and thawing are shown in Figures 5 and 6. The photograph of concrete test blocks (mixes B3 and B4) after 105 cycles of freezing and thawing (Fig. 6) indicates excellent surface durability. This was true for all four of the sample mixes.

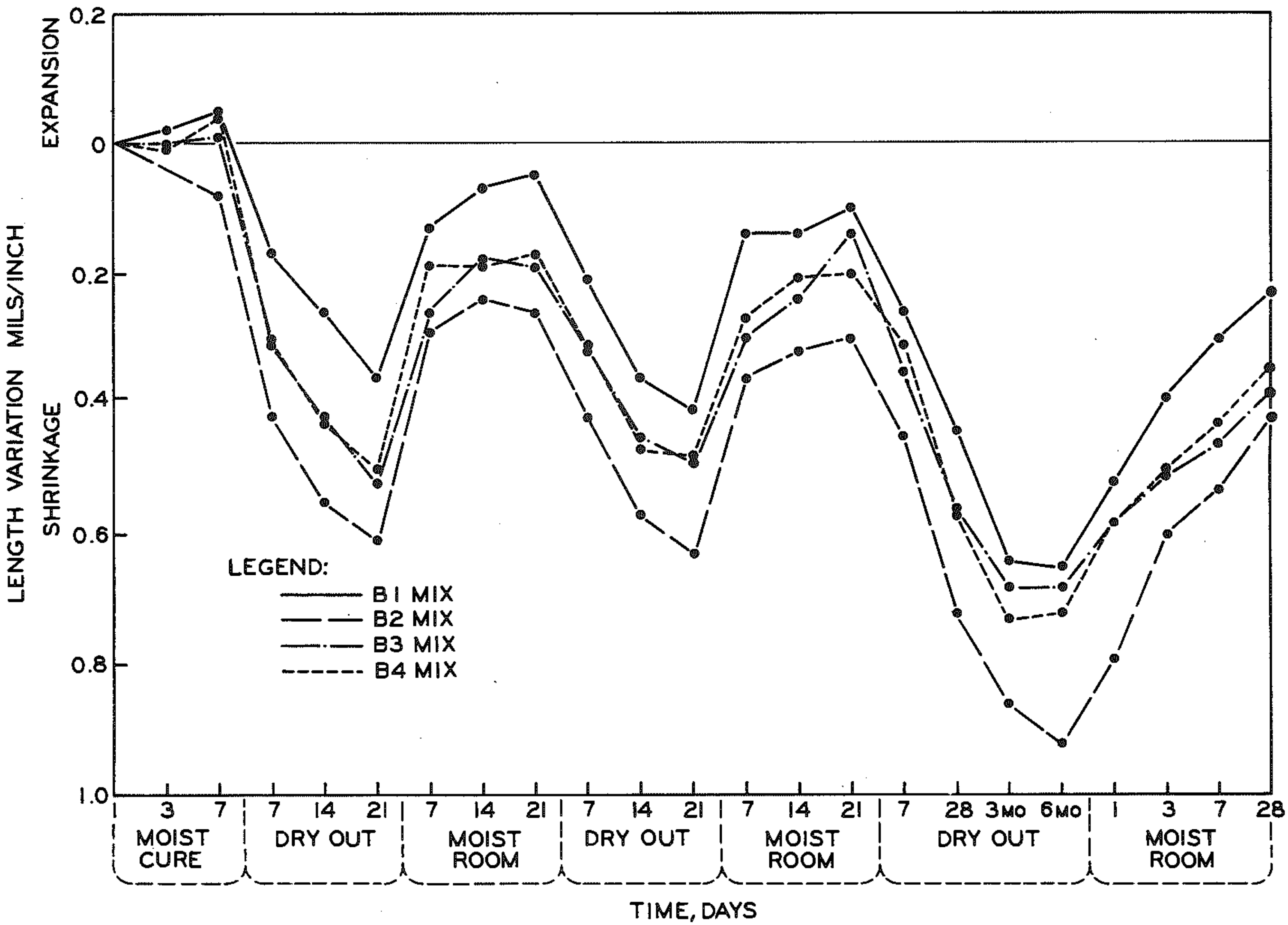


Figure 2. Shrinkage prism length variation, low slump concrete.

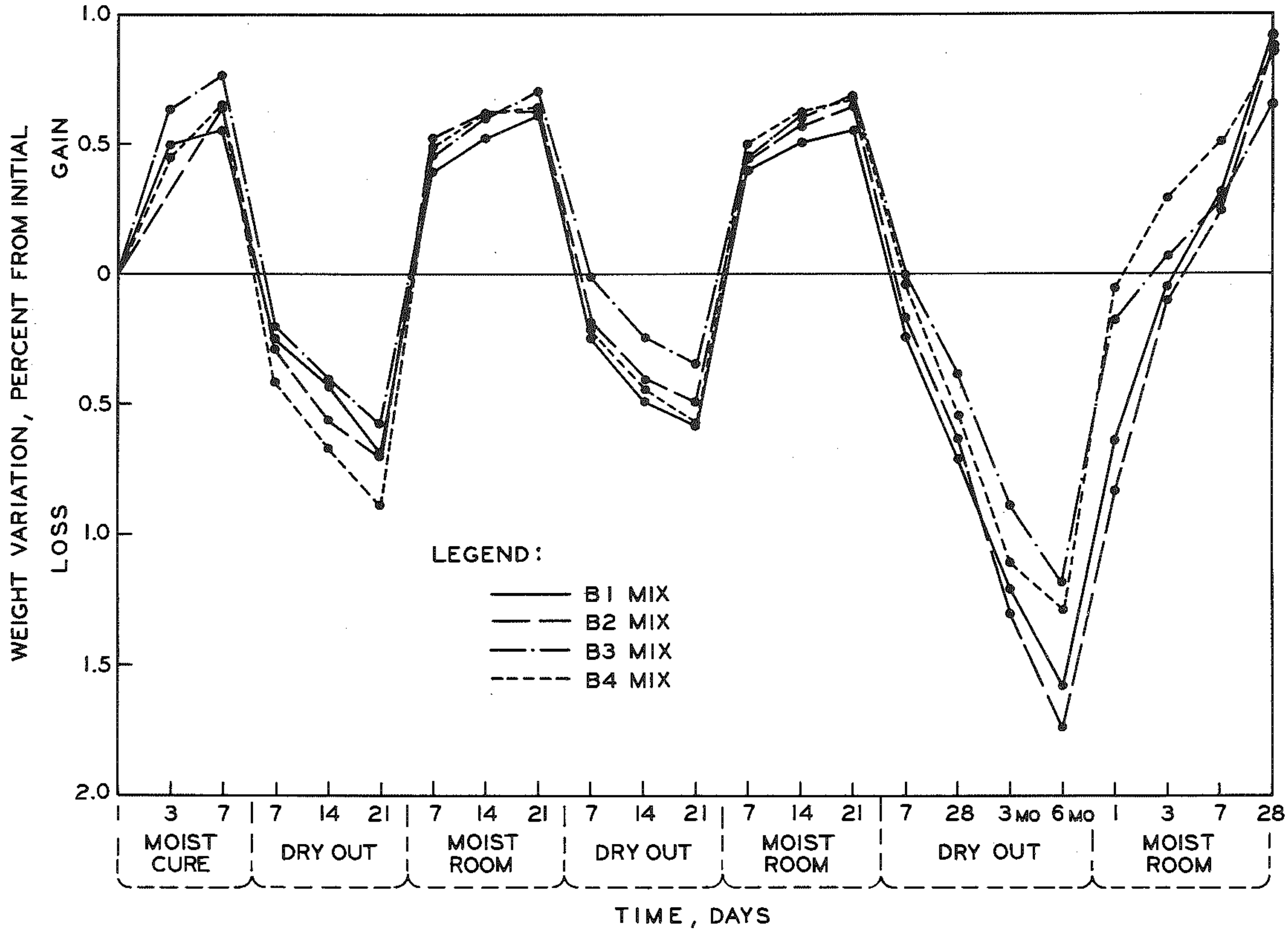


Figure 3. Shrinkage prism weight variation, low slump concrete.

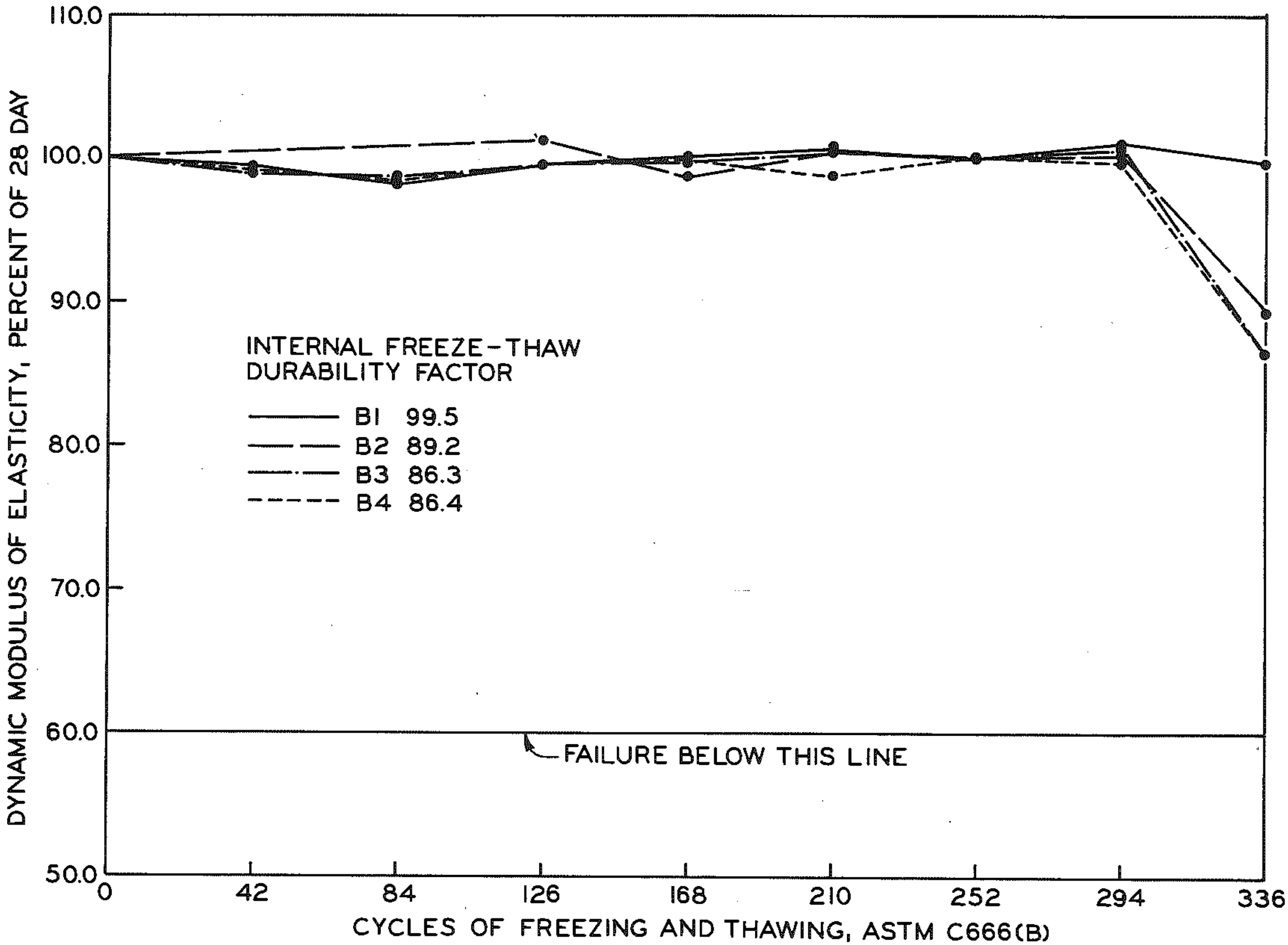


Figure 4. Relative dynamic modulus of elasticity in freezing and thawing.

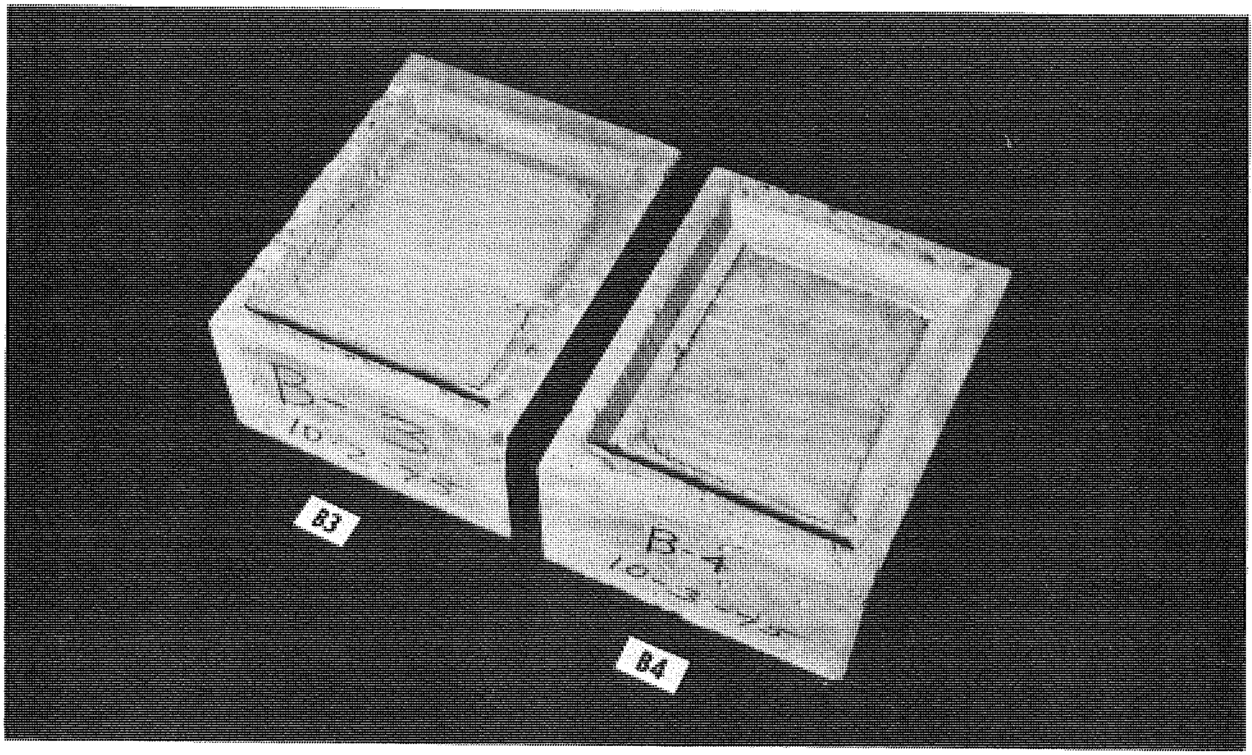


Figure 5. Mixes B3 and B4 after seven days moist cure and seven days air drying, prior to freeze-thaw exposure.

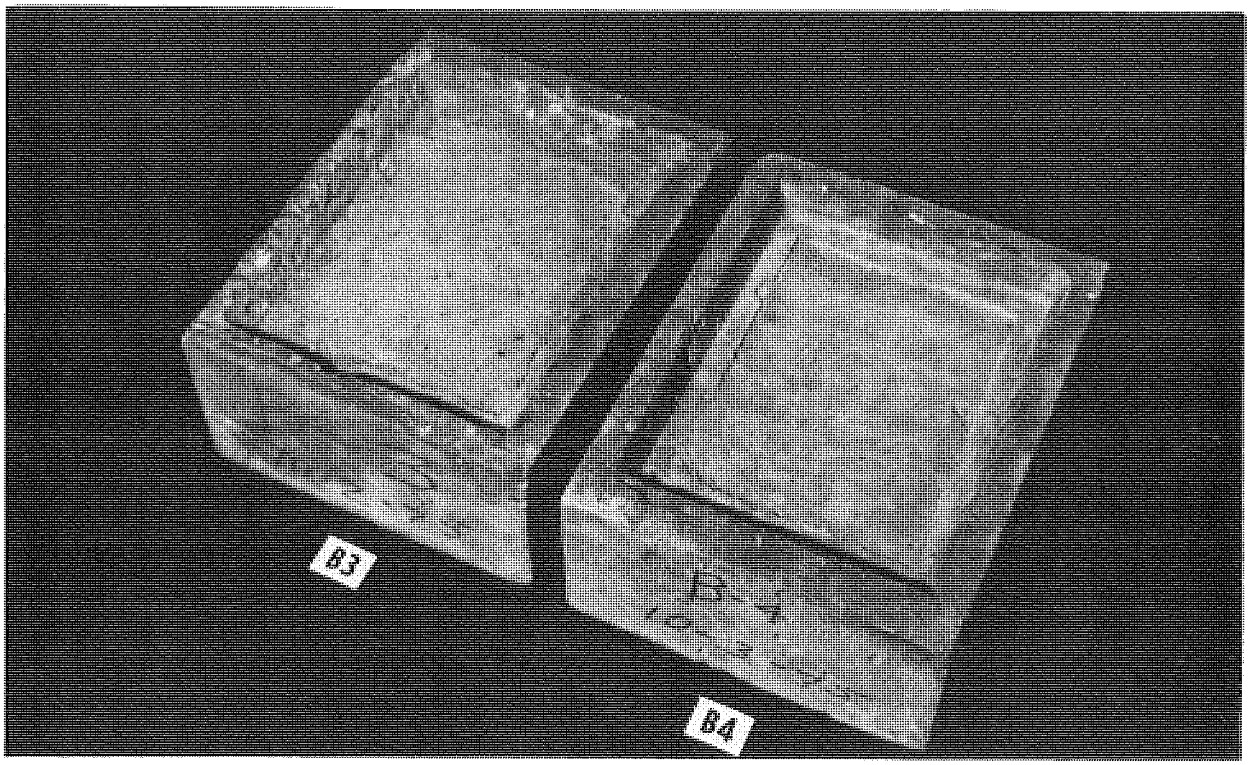


Figure 6. Mixes B3 and B4 after exposure to 105 cycles of freezing and thawing. This is typical of all four batches sampled, indicating no damage from freeze-thaw exposure.

The results of the test for bond durability in freezing and thawing are shown in Table 6. The shear tests were performed on two pieces cut from each block after the test for surface durability in freezing and thawing. For each piece the size, ultimate load, and shear stress are shown. All shear values shown indicate excellent bond strength. The overall average shear stress was 478 psi which was similar to values a good latex modified concrete overlay would show.

TABLE 6
SHEAR BOND STRENGTH AFTER
105 FREEZE-THAW CYCLES

Mix Code	Size, in.	Load, lb	Shear Stress, psi	Average Shear Bond Strength, psi
B1-1	3-9/16 x 4-1/16	7750	536	468
B1-2	3-1/2 x 3-15/16	5525	401	
B2-1	3-3/4 x 4-1/4	7075	444	406
B2-2	3-3/4 x 4-1/8	5700	368	
B3-1	4 x 3-11/16	5925	402	591
B3-2	3-5/16 x 3-7/16	8875	780	
B4-1	3-1/4 x 4	5600	431	445
B4-2	3-3/16 x 4	5850	459	

Results of Field Evaluation of Hardened Low Slump Concrete Overlay

The results of the skid resistance survey are shown in Table 7. Also shown in Table 7 are values obtained from several different structures overlayed in 1975 with latex concrete or mortar for comparison. The values indicate surface friction properties of the low slump overlays to be fairly similar to the latex overlays.

Table 7 also includes a "Riding Quality Index" for these structures which was obtained by the use of a Rapid Travel Profilometer. Values of the Riding Quality Index of 0 to 30 indicate good ridability, 31 to 70 is average, and 71 to 100 is considered poor. It is evident that the two values of 87 for S03 of 33084 and the values of 75 and 81 on the inside pours of S10 of 47065 indicate a poor or rough riding deck. Much of this could be attributed to the finishing machine rising off the rails when mixes approaching a 0-in. slump were encountered.

TABLE 7
SUMMARY OF SKID AND PROFILOMETER TESTS, LATEX AND LOW SLUMP OVERLAYS
(All overlays placed in 1975 and textured with transverse wire comb)

Structure	Type of Overlay	Lanes	Coefficient of Wet Sliding Friction[1]			Profilometer Riding Quality Index[2]
			Low	High	Avg	
X01 of 33034	Latex Mortar	NB and SBOL	0.49	0.53	0.51	56
X01 of 33034	Latex Concrete	NB and SBIL	0.52	0.56	0.53	55
S16 of 41131	Latex Concrete	6	0.56	0.64	0.59	62
S17 of 41131	Latex Concrete	6	0.53	0.63	0.58	62
S18 of 41131	Latex Concrete	6	0.55	0.62	0.59	60
S03 of 33084	Low Slump Concrete	SBOL	0.53	0.56	0.54	87
S03 of 33084	Low Slump Concrete	SBIL	0.63	0.65	0.64	87
S10 of 47065	Low Slump Concrete	EBOL	0.44	0.48	0.46	67
S10 of 47065	Low Slump Concrete	EBIL	0.57	0.60	0.58	75
S10 of 47065	Low Slump Concrete	WBOL	0.47	0.49	0.48	48
S10 of 47065	Low Slump Concrete	WBIL	0.58	0.60	0.59	81

[1] Skid tests run in July 1976, at 40 mph with an ASTM E 274 type two-wheeled trailer on wet surface.

[2] Values determined from Rapid Travel Profilometer tests run in November 1976.

SUMMARY

Deck Preparation, Overlay, and Curing

In general, the low slump overlay concrete is not easy to apply or finish. Weather is more of a factor than with latex modified concrete, as the prepared deck must be surface dry prior to brushing in of the slurry. Hot, windy weather compounds the consolidation and finishing problems of 1-in. slump mixes by speeding up slump loss.

Low slump concrete on this project was spread and leveled by hand with great difficulty before consolidation by the finishing machine. If the slump of the concrete is variable, the finishing machine will alternately ride up and then sink on the fresh concrete resulting in a wavy finished surface. This wavy surface produces a rough and unpleasant ride.

If the slump of the concrete approaches 0-in. the finishing machine will tear the surface and this necessitates considerable hand manipulation to correct.

The crew applying a low slump concrete overlay on this first contract consisted of 12 workers; a latex modified concrete overlay application will generally require about six workers. In addition, the low slump concrete will require more time to apply than a latex modified concrete. Wet curing time is also longer than that required of latex modified concrete, three days as compared to two for latex.

Results of Laboratory Tests

In general, the laboratory tests of the low slump concrete showed good results. Generally the shrinkage shown for the low slump concrete is about 0.50 mil/in. in 21 days of air drying, while a good latex modified concrete of similar fine aggregate to total aggregate (FA/TA) ratio would show 0.30 mil/in. shrinkage under the same conditions. Bond strength, however, was quite good indicating the shrinkage rate is not detrimental to the bond, at least in the small bond durability test specimen.

The low slump concrete showed about 1.3 percent moisture loss in 21 days of air drying while a good latex modified concrete of similar FA/TA ratio would show 0.9 percent moisture loss under the same conditions. This indicates the low slump concrete is more permeable than latex modified concrete. To ensure the same protection against chloride ion penetration as the latex modified concrete the low slump cement-rich concrete would have to be thicker. The Department currently requires 2-in. low slump as an alternate to 1-1/2 in. of latex concrete.

Results of Field Evaluation

The skid resistance survey indicates a generally lower surface friction between respective outside and inside lanes of both bridges. Outside lanes on S10 of 47065 receive more traffic, and especially more commercial traffic, than do the inside lanes.

Although the general surface profile was rough, the surface texture was quite smooth in comparison to latex modified concrete overlays. When the surface protrusions caused by combing are worn down by traffic the resultant surface friction probably will be lower than a comparable latex modified concrete overlay.

The riding quality of both pours of S03 of 33084 and the inside pours of S10 of 47065 are considerably rougher than other latex concrete decks. This reflects the low slump control problems and the lack of enough weight and possibly vibratory energy, of the particular Gomaco F500 model finishing machine.

Recommendations

The results of laboratory testing indicate an examination of the actual overlays should be continued in more detail to determine whether the shrinkage rates will produce cracking in the overlay. A brief visual inspection of the decks indicates some shrinkage or flexural cracking is apparent, primarily in the inside lanes on S10 of 47065 and in the southerly pour on S03 of 33084.

The Research Laboratory has obtained 4-in. cores through the overlay to evaluate overlay density, bond strength of the overlay to the substrate, and to determine chloride ion penetration after one and two winters of exposure. A delamination survey and a half-cell corrosion survey have also been run.

A report on the field performance of the low slump concrete overlays after two years exposure will be submitted in the future. This will include data from the above mentioned specific tests.