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EXPERIMENTAL PATCHING CONCRETE FIELD APPLICATION ON TEST BRIDGE S01 of 33035A (WB M 36 OVER US 127)

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Research Laboratory Section
Testing and Research Division
Research Project 69 NM-251;
71 NM-288; 71 NM-290
Research Report No. R-871

Michigan State Highway Commission
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INTRODUCTION

The application of these patching concretes in the field culminates several years of laboratory work in which many commercial cements and mortars were tested and evaluated. Many of these cements and mortars were formally submitted for consideration through the New Materials Committee while others were tested as control materials. The actual cements used on this deck were a small portion of the total considered; most were eliminated from further consideration because of inferior performances in the laboratory[1].

The bridge deck selected for this field evaluation was S01 of 33035A which carries westbound M 36 over the limited access roadways of US 127, about one mile northwest of the city of Mason. This bridge was selected because of the following considerations:

1) The deck, constructed in 1966, contained many isolated areas of deteriorated concrete, as evidenced by spalling, which made it ideal for this kind of repair; hence, each material could be applied in at least three different locations. This policy of isolating the different patches of the same material makes it impossible for any adverse peculiarities associated with one area of the deck to affect all applications of that particular material.

2) It was on a state trunkline and the interchange of a limited access highway; therefore, it would carry the same type traffic, at a reduced volume, as an Interstate roadway. This was important because these materials must be subjected to the kind of loading and ice removal salting that will be encountered on Interstate highway bridge decks.

3) The deck could be closed to traffic. The bridge's location on a divided highway with cross-over interchange ramps at either end made it possible to close it to traffic and run two-way traffic over its adjacent eastbound structure.

4) The bridge was readily accessible to Lansing.

On July 14, 1972, a planning meeting was attended by S. M. Cardone, D. Kanellitsas, and G. E. Langen of the Maintenance Division and M. G. Brown, W. K. Kruger, and H. L. Patterson of the Research Laboratory.

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[1] Evaluation of Five Commercial Fast-Setting Hydraulic Patching Mortars. MDSH Research Report No. R-715, and Evaluation of Six Commercial Fast-Setting Hydraulic Patching Mortars, A Latex Bonding Agent, and an Epoxy Emulsion Admixture. MDSH Research Report No. R-872.

At this meeting the patching materials and the required work for their application were discussed. The materials included both conventional and fast-setting concretes and were described as follows:

<u>Conventional Hydraulic Cements (four-day cure)</u>

1. Dow "Modifier A" in portland cement (control)
2. Dow "Modifier B" in portland cement (experimental)
3. Portland cement bonded with "Bonding Blend" (71 NM-288)
4. Portland cement bonded with epoxy-polysulfide grout (experimental)
5. Portland cement bonded with cement slurry (control)

<u>Rapid Hydration Cement (24-hour cure)</u>

6. Atlas "Lumnite" bonded with Lumnite slurry (experimental)

<u>Fast-Setting Hydraulic Cements (4 to 8 hour cure)</u>

7. "Duracal A" bonded with Duracal slurry (71 NM-290)
8. "Embeco 411A" bonded with Embeco slurry (experimental)
9. "Regulated-Set" bonded with Regulated-Set slurry (68 NM-251).

Discussion during the meeting established that the work for this project would be divided as follows:

The Research Laboratory would:

a) Sound out the bridge and outline patch locations with paint
b) procure materials
c) monitor the removal of deteriorated concrete
d) measure the components and mix the concrete
e) prime the patch areas
f) measure the slump, entrained air, and make test specimens
g) furnish part of the required equipment.

District 8 Maintenance personnel would:

a) Reroute traffic
b) make perimeter saw-cuts and break out concrete (approx. 900 sq ft)
c) supply part of the required equipment
d) place, vibrate, and screed the concrete.

It was decided to begin work on the bridge shortly before Labor Day so the work could be completed by mid-September. This would allow time for District Maintenance personnel to complete their presently scheduled work, allow adequate time for the procurement of the necessary materials, and permit the work to take place at cooler temperatures, which would be beneficial for the temperature-sensitive Regulated-Set cement.

PATCHING CONCRETE DEVELOPMENT WORK

It was decided that the patching concrete should contain a coarse aggregate, fine enough to allow patching to a minimum depth of 1-1/2 in. All the finer coarse aggregate designations listed in the MDSH Standard Specifications were considered and it was noted that none was ideal for this particular application. The finest gradation specifically intended for concrete (17A) was too coarse, and the finer one, a bituminous mix aggregate (25A), was poorly graded for concrete and allowed too much dust.

The coarse aggregate gradation of the AASHO specifications were consulted and it was found that the size designated as M 43-54 (#7) was the best for patching work with a nominal 5/8-in. top size. The same gradation is also shown as ASTM specification C33-71a (#7). Since this coarse aggregate is ideal for a partial-depth patching concrete, it was recommended that it be included in the MDSH 1973 Standard Specifications. The Grand Rapids Gravel Company produces this size natural gravel and supplied the coarse aggregate for this work.

The patching concretes developed for use in this work are shown in Table 1. They were all developed to contain 7 sacks of cement per cu yd, equal volumes of sand and gravel, a slump ranging between 3 and 5 in., and an air content of 6 percent. Exceptions were made for the two Dow Modifier mixes where the latex admixture made the concrete too rich when equal volumes of sand and gravel were used; therefore, the volume of sand was reduced to 48 percent of the total aggregate. The Embeco 411A was a fully packaged concrete which contained its own cement, aggregate, and admixture.

A water reducer, Pozzolith 200N, and an air-entraining agent, Darex, were used with the Huron Type-I cement of the control concrete. The high aluminate cement, Atlas Lumnite, used only the air-entraining agent (Darex) but required much more of it to entrain the desired amount of air. The two fast-setting concretes, Regulated-Set and Duracal, each required a specialized admixture to retard their set along with the air entraining agent Darex. The Embeco 411A concrete contained all the admixtures it required within the fully packaged mix.

TABLE 1
PATCHING CONCRETE PROPORTIONING PER CUBIC YARD

Patching Concrete	Cement wt, lb	Fine Aggregate (2NS)		Fine Agg. Total Agg. Ratio by Volume	Coarse Aggregate ASTM C33-71a		Net Mix Water, lb	Net W/C Ratio	Total Water, lb	Admixtures	
		Oven Dry wt, lb	Abs. Water, lb		Oven Dry wt, lb	Abs. Water, lb				Darex A-E, fl oz	Other
Portland Cement Type-I (Huron) Control	657	1,457	12	0.50	1,501	16	270	0.41	298	7	Water reducer (Pozzolith 200N) 26 fl oz
Portland Cement Type-I (Huron) with Dow Mod A	657	1,402	12	0.48	1,563	17	62 free 109 Mod A 171	0.26	62 free 29 abs. 109 Mod A 200	--	Dow Mod. A, lb, 208: 99 solids, 109 water
Portland Cement Type-I (Huron) with Dow Mod B	657	1,402	12	0.48	1,563	17	90 free 107 Mod B 197	0.30	90 free 29 abs. 107 Mod B 226	--	Dow Mod. B, lb, 206: 99 solids, 107 water
Atlas Lumnite	657	1,466	12	0.50	1,511	16	263	0.40	291	35	
Embeco 411A	Fully packaged concrete (incl. cement, aggregate, and admixtures = 3,730 lb)								379	--	
Regulated-Set	657	1,449	12	0.50	1,494	16	276	0.42	304	17	Retarder (Citric acid) 112 fl oz [1]
Duracal	658	1,515	13	0.50	1,561	17	225	0.34	255	7	Retarder (Sodium citrate) 10 fl oz [2]

Concentration of Citric Acid solution: 100 gm per 418 ml or 2 lb per gallon.
Concentration of Sodium Citrate solution: 1 gm per 20 ml or 0.42 lb per gallon.

FIELD WORK

Bridge Deck Preparation

The bridge deck was sounded with hammers and areas located where the concrete was deteriorated. These included areas of delamination where the concrete had already spalled off, delaminated areas which produced a hollow sound beneath the hammer, and areas showing cracks and rust stains above the reinforcing bars. These deteriorated areas were then encompassed with black paint stripes which ran transverse or parallel to the main reinforcing steel of the deck. The stripes parallel to the steel were laid out with a Swiss Pachometer such that they ran between two adjacent bars. The Swiss Pachometer is an instrument which, through the employment of a magnetic field, is able to locate the position of reinforcing bars that are embedded in concrete.

In late August, District 8 Maintenance personnel began sawing the perimeters of the patch areas. Our concern was to cut as deep as possible without damaging the main reinforcing steel; hence, all cuts which were parallel to, and between, the main reinforcing bars were sawed to a depth of 1-1/4 in., and all cuts which were perpendicular to, and over, these bars were sawed to a depth of only 3/4 in. This measure was taken for two reasons; to protect the sound concrete outside the patch area from the fracturing action of the air hammer, and to avoid any need for feathering the patching concrete at the perimeter of the patches. Since all saw cuts were run full-depth up to the corner, the leading edge of the saw actually traveled a few inches beyond the corner. These cuts were taped and filled with epoxy mortar after the patch work was completed.

By mid-September the main breaking work was completed in all patch areas and the final chipping work began. It was desired that the patch areas be chipped to an average depth of 2-1/2 in., but it was necessary to go deeper in some areas. On patch No. 23 where lime and salt stains were visible on the underside, it was necessary to chip full-depth in the afflicted area to remove the "punky," deteriorated concrete. In other patch areas, mainly those in span 2, it was noted that the main reinforcing bars had insufficient cover. Two techniques were found to be effective in coping with this problem: in cases where the No. 3 shrinkage bars were sufficiently deep and exposed only a short distance, it was possible to obtain 1-in. minimum cover by tying the No. 6 bars down to them; in other cases where both sets of bars were high, it was necessary to drive them down with sledge hammers after chipping the necessary underclearance.

Upon completion of the chipping, all patch areas were photographed and measured; Table 2 gives the pertinent physical data for each of the 49 patch areas. In this table, the patches are numbered consecutively in the order in which they occur from the northwest abutment; their location is denoted by a curb line numbering system and by the abbreviation "T" or "P" which represent the traffic or passing lane in which they occur. A diagram of the deck and curb line numbering system is shown in Figure 1. The system begins on the NE curb line over the NW abutment reference line and consists of consecutive numbers painted on the curb at 10-ft intervals along the entire length of the bridge. The numbering on the SW curb line is subordinate to that on the NE curb line and bears the same numbers perpendicularly across the bridge.

Figures 2 through 5 are diagrams of each of the four bridge deck spans; they show the location and shape of each of the 49 patch areas.

Concrete Placement Procedure

By mid-September, all the necessary materials and equipment required to pour concrete were located at the bridge site. Because the bridge was closed to traffic, the sand and gravel were piled on the shoulder of the NW approach and the 6 cu ft rotary mixer was located between them but offset so as to sit on the pavement. The cement, admixture, measuring containers, and density kit were located on a stake-bed truck to permit removal from the site during non-working hours. A mobile set of platform scales was located at the site to weigh out the components for the first batch of each of the various concrete mixes; as weighings were completed, the containers were marked to permit subsequent batches to be measured by volume

To insure the concrete patch would bond well to the bridge deck substrate, a bonding agent was brushed into the substrate prior to placement of the patching concrete. To obtain proper mixing of the bonding agent, a Hobart mixer and a portable generator were both located on a platform cart; this permitted the mixer to be moved from patch to patch as work progressed.

A four-wheel rubber-tired tractor with a scoop front-end loader was used to transport the fresh concrete from the mixer to the patch area. As the concrete was placed in a freshly primed patch area, it was consolidated by a probe-type electric vibrator. After a patch area was filled with concrete and vibrated, the platform cart was moved to start the next patch while screeding and troweling were completed.

TABLE 2
PHYSICAL DATA OF CHIPPED-OUT PATCHES (S01 of 33035A)

Patch No.	Patch Location: Curb Line No. System	Patch Location: Lane T	Patch Location: Lane P	Patch Area, sq ft	Edge Cond.: Good	Edge Cond.: See Notes	Patch Depth, in.: Min.	Patch Depth, in.: Max.	Patch Depth, in.: Avg.	Patch Depth, in.: No. Meas.	Transverse Reinforcing Bars: No. Bars Across Patch	Transverse Reinforcing Bars: Cond.: Good	Transverse Reinforcing Bars: Cond.: See Notes	Transverse Reinforcing Bars: Splice	Bar Cover: Min.	Bar Cover: Max.	Bar Cover: Avg. all bars	Additional Information
1	2.4	x	x	43		x	2-1/4	3-1/2	2-5/8	10	13	x			1	1-1/4	1	Add. chipping req'd at curb line
2	4.4	x		55		x	2-3/4	3-1/2	3-1/8	11	32	x			3/4	1-1/4	1	Chipped out spot SW side
3	6.2	x		3	x		2-1/2	3-3/4	3	3	3	x		x	1-1/4	1-1/4	1-1/4	Chipped out NE side
4	6.3	x	x	10	x		2-1/4	3-1/2	3	4	4	x			1	1-1/4	1-1/4	Chipped out SW side
5	6.4	x		3			2-1/2	3-1/2	3	3	2	x			3/4	3/4	3/4	
6	7.2	x		4			3	3-3/4	3-3/8	3	3	x		x	1	1	1	All bars spliced
7	8.1	x		13			3	3-3/4	3-1/2	6	6	x		x	1	1	1	1 bar spliced
8	8.2		x	12			3-1/2	4	3-5/8	6	5	x			1	1-1/2	1-1/4	Chipped out spot SE side
9	9.2	x		3			3	3-1/4	3-1/8	2	7*	x			1-1/4	1-1/4	1-1/4	*3 trans, 4 parallel to exp. jt.
10	9.8	x	x	2			2-3/4	3-1/2	3-1/8	2	5*	x			1	1-1/4	1-1/8	*3 trans, 2 parallel to exp. jt.
11	10.4		x	8	x		3	4-1/4	3-1/2	4	14*	x			1-1/2	1-3/4	1-5/8	*12 trans, 2 parallel to exp. jt.
12	12.9		x	10	x		3	3-3/4	3-1/4	6	5	x			1-1/4	1-1/2	1-3/8	
13	12.9		x	4	x		3-1/2	4	3-3/4	3	4	x			2	2	2	
14	13.2		x	22	x		2-3/4	3-1/2	3-1/8	9	11	x			1	1-1/2	1-1/8	
15	14.7		x	79	x		2-1/2	3-1/4	2-3/4	12	13	x			1	1-1/2	1-1/4	
16	15.4		x	6	x		3-1/4	3-1/2	3-1/4	3	3	x			1	1-1/2	1-1/8	
17	15.5		x	85	x		2	3	2-5/8	12	16	x			1	1-1/2	1-1/8	
18	16.4		x	4	x		2-1/2	3-1/4	2-3/4	3	6	x		x	1-1/4	1-1/4	1-1/8	All bars spliced
19	16.7		x	29		x	2-1/2	2-3/4	2-5/8	6	11	x			3/4	1	7/8	Chipped out spot NE & SW side
20	17.3		x	48	x		2-1/2	4-1/2	3-1/8	7	11	x			3/4	1	7/8	
21	17.8	x		7		x	2-1/4	3-3/4	2-1/2	3	5	x		x	1	1	1	Chipped out spot NE & SW side
22	18.0		x	13		x	3	3-1/4	3-1/8	4	4	x			1	1-1/4	1-1/4	Chipped out NE end & S corner
23	18.2	x		20		x	2-1/2	3	2-3/4	5	11	x		x	1/2	1	7/8	Full-depth hole through deck
24	18.3		x	20		x	2-1/4	3-1/4	2-3/4	4	8	x			1	1-1/4	1-1/8	Chipped out spot SW side
25	18.9	x		11	x		2-3/4	3	3	4	9	x		x	1	1	1	All bars spliced

TABLE 2 (Cont.)

PHYSICAL DATA OF CHIPPED-OUT PATCHES (S01 of 33035A)

Patch No.	Patch Location: Curb Line No. System	Lane: T	Lane: P	Patch Area, sq ft	Edge Cond.: Good	Edge Cond.: See Notes	Patch Depth, in.: Min.	Patch Depth, in.: Max.	Patch Depth, in.: Avg.	Patch Depth, in.: No. Meas.	Transverse Reinforcing Bars: No. Bars Across Patch	Cond.: Good	Cond.: See Notes	Splice	Bar Cover: Min.	Bar Cover: Max.	Bar Cover: Avg. all bars	Additional Information
26	19.0		x	73	x		2-1/4	3	2-5/8	12	21	x			3/4	1-1/2	1-1/8	
27	20.4		x	81	x		2-3/4	3-1/2	3-1/8	13	19	x			1	1-1/4	1-1/8	
28	22.6	x		6	x		2-3/4	3-1/2	3-1/8	6	4	x			1	1-1/2	1-1/4	
29	23.2	x		8	x		2-3/4	3-1/2	3-1/8	6	5	x		x	1	1-1/2	1-1/4	Broken out S corner
30	24.3		x	3		x	3	3-1/4	3-1/8	2	3	x			1-1/4	1-1/2	1-3/8	N & S corners broken out
31	24.5		x	7		x	2-3/4	3-3/4	3-1/4	3	3	x			1-1/4	1-1/4	1-1/4	Chipped out spot SW side
32	27.2		x	3	x		3-1/2	4-1/2	4	2	3	x			1-1/4	1-3/4	1-1/2	
33	27.2	x		19	x		3	4	3-1/2	9	12	x		x	1-1/4	1-3/4	1-3/8	All bars spliced
34	27.4		x	55		x	3	3-3/4	3-1/4	15	23	x			1	1-1/2	1-1/8	Hollow spot NE side
35	29.6		x	8	x		2-1/2	3-1/4	2-3/4	6	5	x			1	1	1	
36	30.5	x		8		x	2-1/2	3-1/2	2-3/4	6	4	x		x	1	1	1	All bars spliced
37	30.5		x	20	x		3	4	3-3/8	9	10	x			1-1/4	1-1/2	1-3/8	
38	30.9	x		12	x		2-1/2	3	2-3/4	8	13	x		x	3/4	1-1/4	1-1/8	6 bars spliced
39	31.1		x	32	x		2-1/4	3-3/4	3	12	10	x			1	1-1/2	1-1/4	
40	32.1		x	5	x		2-1/2	3-1/4	2-7/8	6	3	x			1	1	1	
41	33.6		x	6	x		2-3/4	3	2-3/4	3	Bars Below Bottom of Patch							
42	33.8	x		2	x		2-1/2	2-1/2	2-1/2	3	2	x			1	1	1	
43	33.9	x		19	x		2-1/4	3-3/4	3	10	8	x			1-1/4	1-1/2	1-1/4	
44	34.2		x	3		x	2-1/4	2-3/4	2-1/2	3	Bars Below Bottom of Patch							Chipped out SW end
45	36.5		x	13	x		3-1/4	3-3/4	3-3/8	9	5	x			1-1/4	1-1/2	1-1/4	
46	36.9		x	13	x		2-1/2	3-3/4	3-1/8	12	8	x			1	1-1/2	1-1/4	Chipped out SE side & N corner
47	37.5		x	4	x		2-1/4	3	2-7/8	9	3	x			1-1/4	1-1/4	1-1/4	Broken S corner
48	37.9		x	6	x		2-3/4	3-7/8	3-1/4	9	3	x			1	1-1/4	1-1/8	
49	38.5		x	3	x		2-5/8	4-1/4	3-1/4	9	3	x			1-1/8	1-1/2	1-1/4	

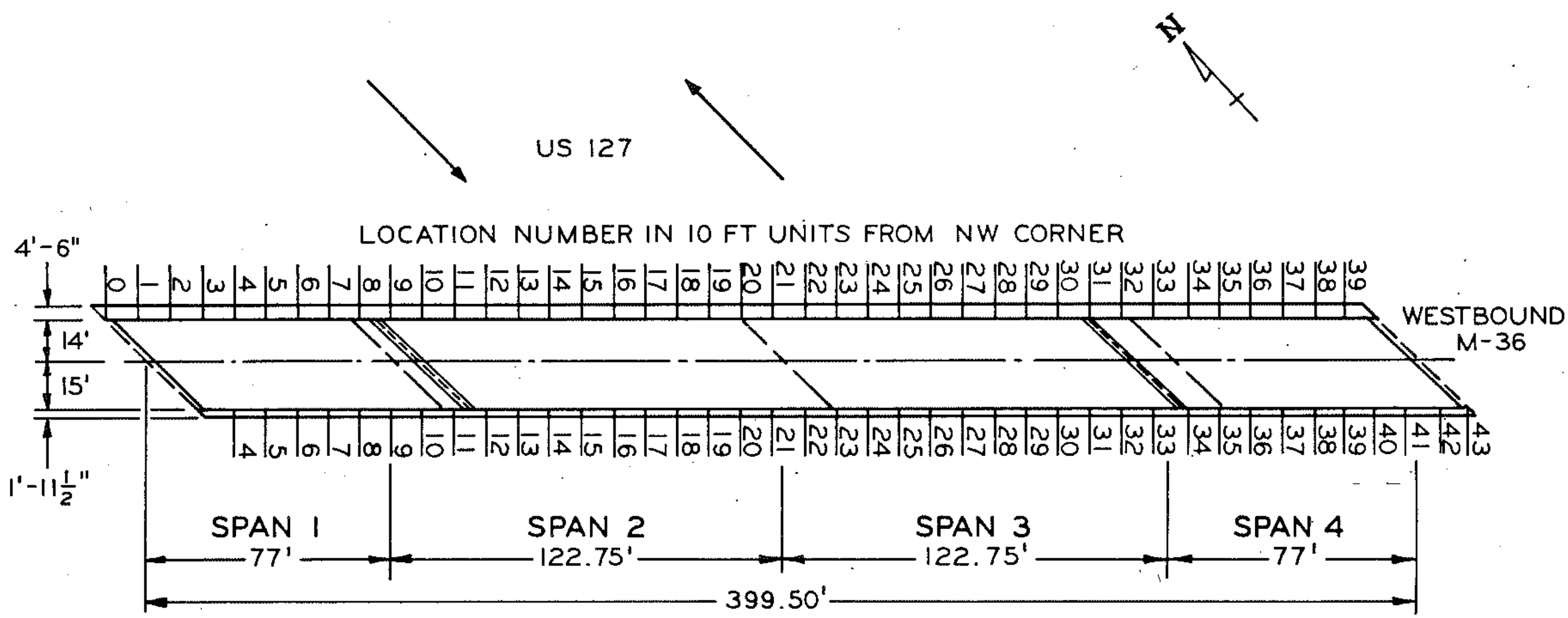


Figure 1. Patching concrete test bridge (S01 of 33035A).

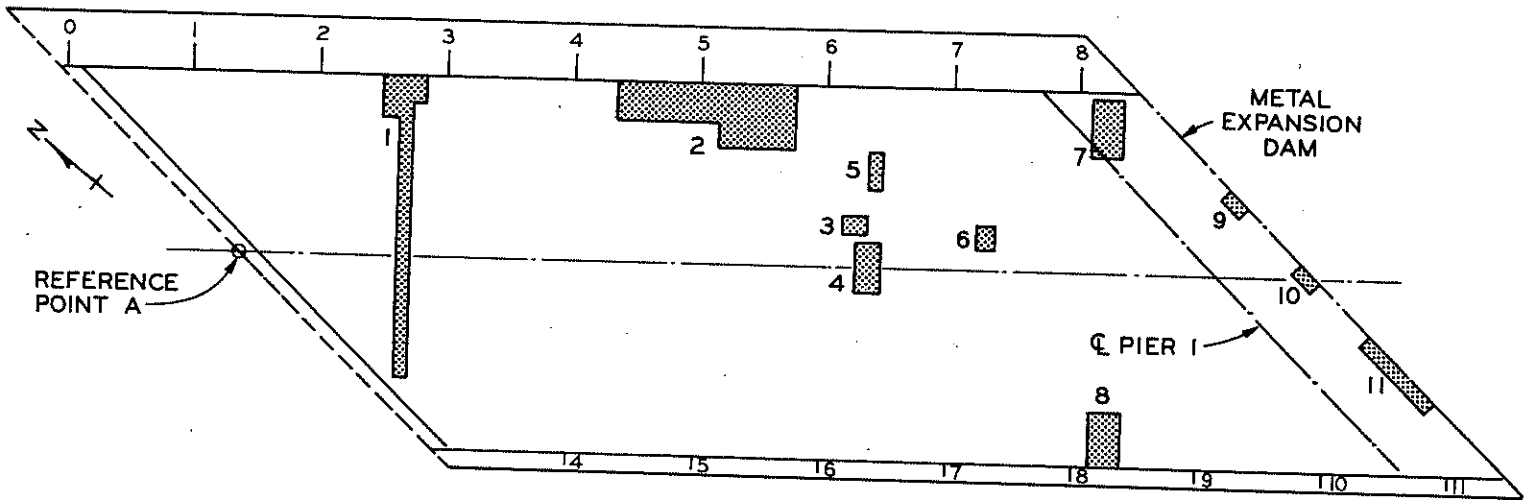


Figure 2. Patch areas in span 1.

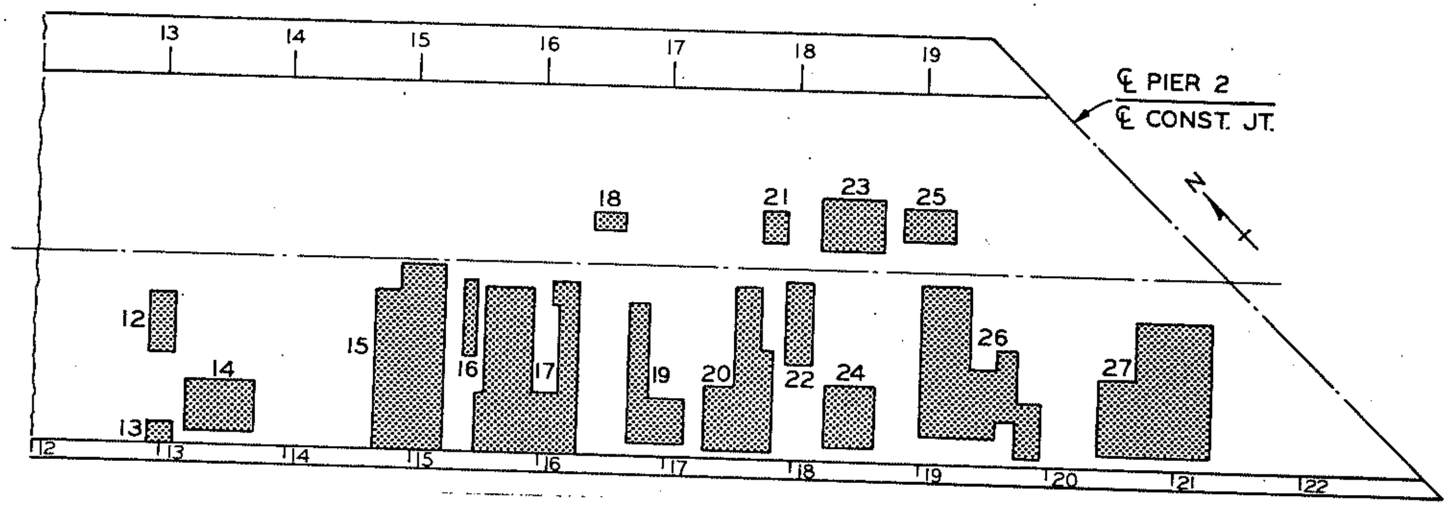


Figure 3. Patch areas in span 2.

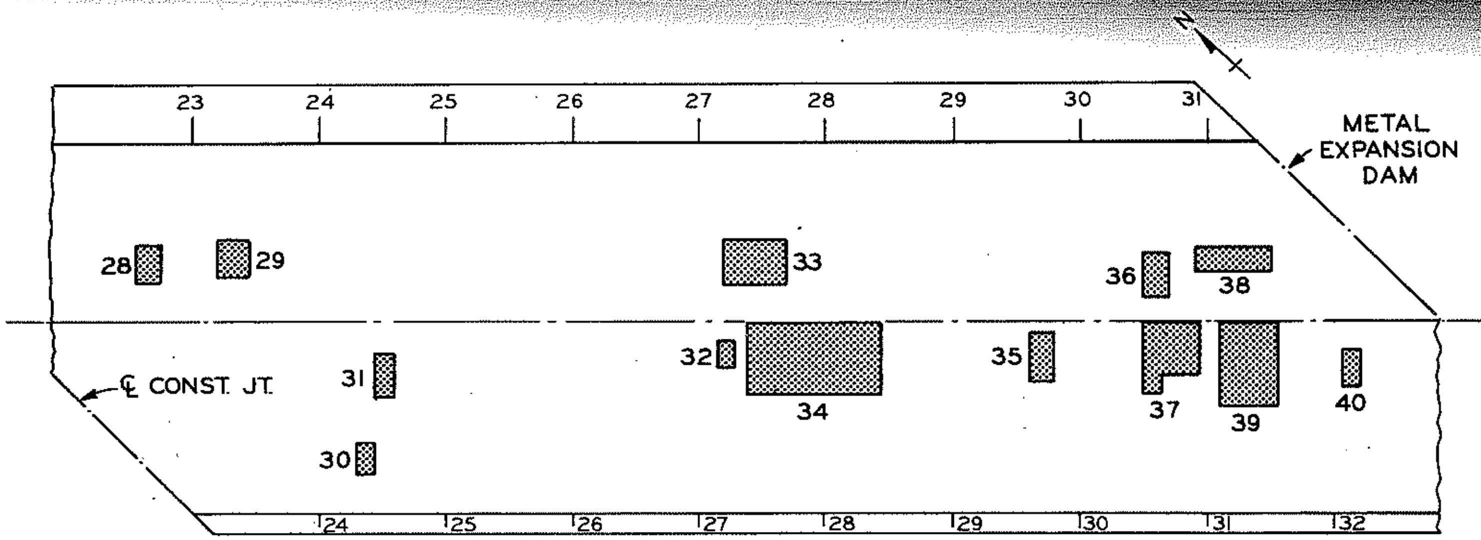


Figure 4. Patch areas in span 3.

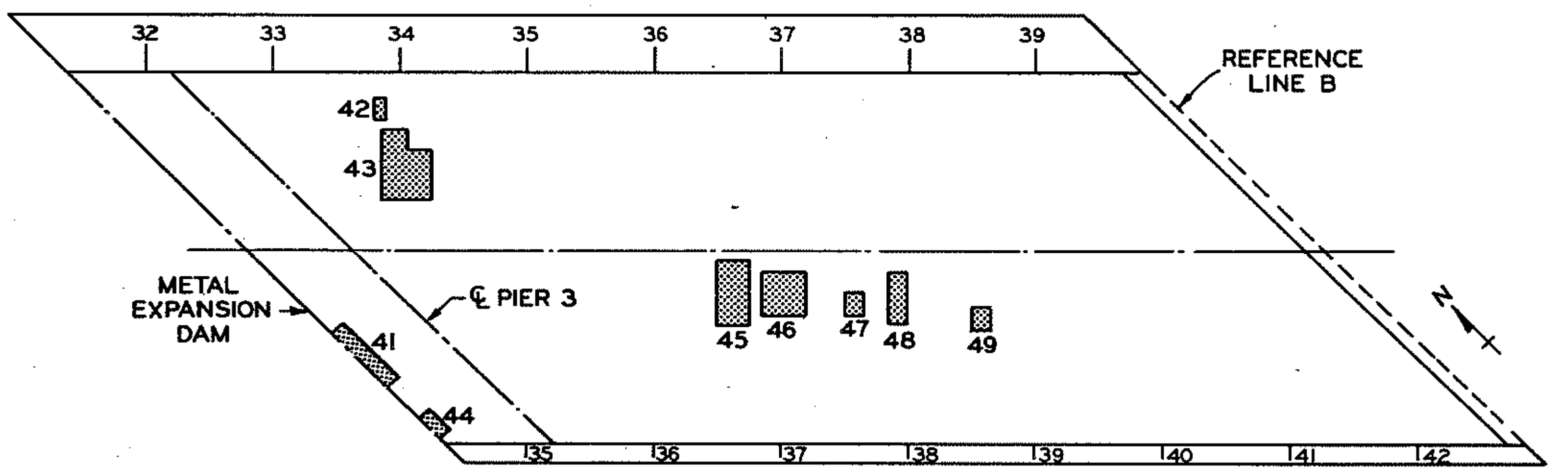


Figure 5. Patch areas in span 4.

TABLE 3
PATCHING CONCRETE LOCATIONS

Patching Concrete and Pour Date	Patch No.	Patch Location: Curb Line No. System	Lane T	Lane P
Portland Cement Control with Slurry Bond Poured: 9-22-72	3	6.1 - 6.4	x	
	5	6.3 - 6.5	x	
	26	19.0 - 20.0		x
	28	22.5 - 22.8	x	
	32	27.1 - 27.3		x
	33	27.2 - 27.7	x	
	45	36.5 - 36.8		x
Portland Cement Control with Epoxy Bond Poured: 9-27-72	1	2.4 - 2.9	x	x
	13	12.9 - 13.1		x
	15	14.7 - 15.3		x
	18	16.4 - 16.7	x	
	31	24.4 - 24.6		x
	40	32.0 - 32.2		x
	44	34.2 - 34.5		x
Portland Cement Control with Bonding Blend Poured: 9-27-72	4	6.2 - 6.5	x	x
	19	16.7 - 17.2		x
	41	33.5 - 34.0		x
Portland Cement with Dow Modifier A Poured: 9-28-72	11	10.4 - 11.0		x
	16	15.3 - 15.5		x
	24	18.2 - 18.7		x
	25	18.8 - 19.3	x	
	30	24.3 - 24.5		x
	37	30.5 - 31.0		x
	48	37.8 - 38.0		x
Portland Cement with Dow Modifier B Poured: 9-28-72	7	8.1 - 8.4	x	
	9	9.2 - 9.4	x	
	10	9.8 - 10.0	x	x
	12	12.9 - 13.1		x
	23	18.2 - 18.7	x	
	39	31.1 - 31.6		x
	49	38.5 - 38.7		x
Atlas Lumnite Poured: 10-11-72	2	4.3 - 5.8	x	
	17	15.5 - 16.3		x
	34	27.4 - 28.5		x
	47	37.5 - 37.7		x
Duracal A Poured: 10-12-72	14	13.2 - 13.8		x
	21	17.7 - 18.0	x	
	27	20.4 - 21.3		x
	29	23.2 - 23.5	x	
	35	29.6 - 29.8		x
	42	33.8 - 33.9	x	
	43	33.8 - 34.3	x	
Regulated-Set Poured: 10-12-72	8	8.1 - 8.4		x
	20	17.3 - 17.9		x
	36	30.5 - 30.7	x	
	38	30.9 - 31.5	x	
Embeco 411A Poured: 10-12-72	6	7.2 - 7.4	x	
	22	17.9 - 18.2		x
	46	36.8 - 37.2		x

Table 3 shows the various patching concretes used in this work, the date they were poured, the patch areas they occupy, and the location of each of these patch areas. The particular patch areas to be filled with one type of concrete were done in an order such that those patch areas furthest (SE) from the mixer were done first; i.e. in the reverse order as that given in Table 3. This permitted these areas, as they were completed, to set unmolested as work progressed across the deck to the last patch, which was closest to the mixer.

Concrete Placement Details

Portland Cement Control with Slurry Bond - On September 22, preparations were made to pour the first application of control concrete which had the slurry bond. Those patch areas designated for this application were sandblasted and all sand, chips, and dust were blown out. The moistening and priming of the first patch area started at the same time as the concrete mixer.

When the first mix was too fluid and had to be adjusted with additional amounts of cement, sand, and gravel, it was realized that our measurements of aggregate moisture content were not representative. It was discovered that even though the aggregate piles had been covered with tarpaulins, rainwater had run underneath. The moisture content of the gravel remained quite constant throughout the pile, but not the moisture content of the sand; it varied from a minimum at the top of the pile to a maximum at the bottom, and at the bottom it varied from the high crown side to the low crown side of the pile. Subsequent batches, with mix proportions based upon the average of moisture measurements at the middle and bottom of the sand pile, restored the concrete slump to design limits.

After the floating, troweling, and broom finishing were completed on a patch area, the fresh concrete was sprayed with a white membrane curing compound as soon as the surface moisture had evaporated. As shown in Table 4, eight 2-cu ft batches of concrete were used to complete this application. Slump and air measurements were taken on batch Nos. 2 and 6.

Figure 6 shows the Hobart mixer being charged for a batch of bonding slurry as the patch area in Figure 7 is moistened with a garden sprayer. The bonding slurry was spread over the entire patch area with a whisk broom as is shown in Figure 8. Figure 9 shows the patching concrete being placed.

Portland Cement Control with Epoxy Bond - On September 27, rainwater was blown out of the remaining patch areas designated for the portland cement control, and by 10:00 a. m. they were dry enough to begin sandblasting.

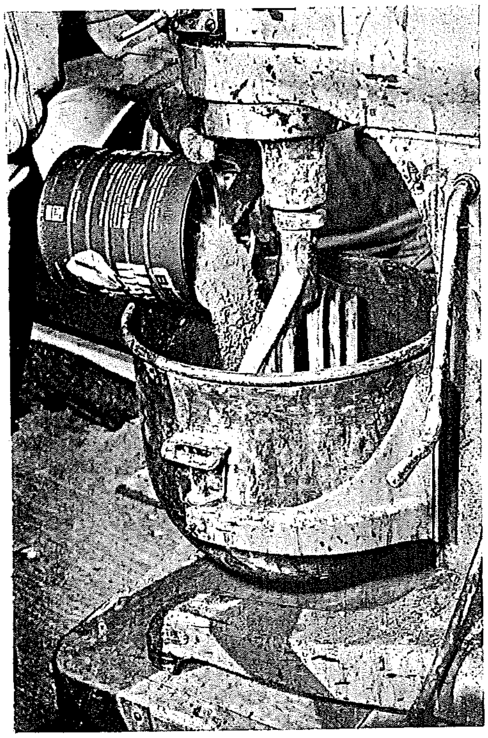
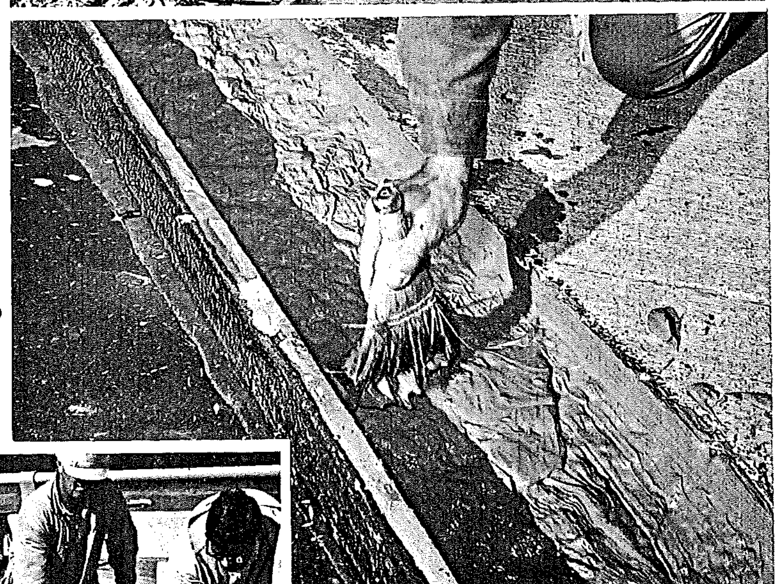


Figure 7. Moistening substrate of patch area No. 19 with sprayer prior to brushing in bonding slurry.

Figure 6. Mortar mixer used to prepare bonding slurry.

Figure 8. Brooming bonding slurry into substrate of patch area No. 41.



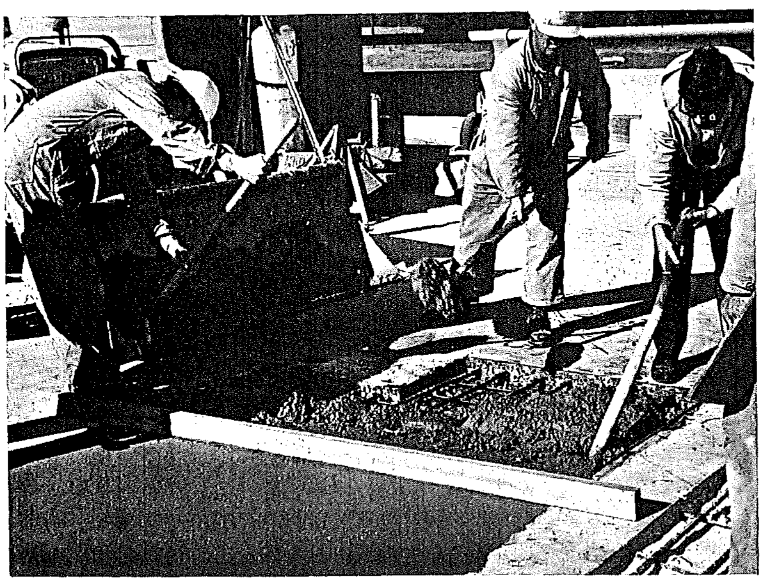


Figure 9. Vibrating and screeding patching concrete in patch No. 15.

TABLE 4
PATCHING CONCRETE POUR DATA

Concrete	Pour Date	Total 4 cu ft Mixes Poured	Mix No.	Time	Weather			Slump, in.	Entr. Air, percent	Test Spec.
					Temp, F	Wind	Sky			
Portland Control w/Slurry Bond	9-22-72	8	2	1:00	56	---	---	4.5	6.5	
			6	2:00				3.5	6.5	
Portland Control w/Epoxy Bond & Bonding Blend	9-27-72	11	1	12:30	59	---	---	3.0	6.5	
			5	2:30				2.8	6.8	
			6	3:00				4.5	8.4	x
Portland Type I w/Dow Mod. A	9-28-72	6	1	12:00	60	SE-15	Cloudy	6.0	3.6	
			5	1:30				6.0	4.0	x
Portland Type I w/Dow Mod. B	9-28-72	6	1	2:30	60	SE-15	Cloudy	4.5	4.2	
			5	4:00				4.5	4.7	x
Atlas Lumnite	10-11-72	13	1	10:30	68	SW-20	Cloudy	4.5	5.6	
			6	12:00				5.5	5.6	x
			10	1:00				4.3	5.3	
			13	1:30				4.0	4.6	
Embeco 411A	10-12-72	2	2	10:30	56	NW-5	Cloudy	2.8	7.0	x
Reg-Set	10-12-72	5	1	12:00	56	NW-5	Cloudy	5.0	7.3	
			5	1:00				6.2	9.0	x
Duracal	10-12-72	10	1	1:30	54	NW-5	Cloudy	3.8	4.9	
			5	2:15				5.2	6.4	x
			10	3:00				4.3	6.2	

The epoxy that was used for bonding this second application of portland cement control was a type-I epoxy-polysulfide grout produced by American Metaseal and designated "P. E. Bonding Compound." It conformed to paragraph 8.16.08, "Epoxy Bonding Agent for Plastic to Hardened Concrete," of the 1970 MDSH Standard Specifications.

In accordance with the specification we diluted the epoxy with 10 percent toluene before brushing it on the bonding surfaces. Since the epoxy sets slowly, and since the volatile toluene must be allowed to escape from the epoxy before the fresh concrete is placed, the bottom and side surfaces of the patch areas were all primed before any concrete was mixed.

Even though a light coat of epoxy was brushed evenly over the entire substrate surface, it was noted that it tended to run off the high spots and puddle in the low spots; it is not known if this build up of epoxy thickness in the low spots will have an adverse effect on the patch durability.

Table 3 shows the seven patch areas which were repaired with this application. Again, the finished surfaces of the completed patch areas were sprayed with white membrane curing compound.

Portland Cement Control bonded with Bonding Blend - Immediately following the completion of the last portland cement control patch bonded with epoxy, the portland cement control concrete was placed in those patch areas which were primed with Bonding Blend (Table 3). Bonding Blend is a latex emulsion that the producer, M. P. S., Inc., recommends should be mixed with Type-I portland cement to make a slurry of medium consistency. It was found in the laboratory that 1-part Bonding Blend to 2.5-parts cement by weight produced an ideal slurry.

Table 4 shows that 11 batches of portland cement control concrete were mixed for the combined epoxy and Bonding Blend application. Of the 11 batches, slump and air measurements were made on batch Nos. 1, 5, and 6, and the laboratory test specimens were made from batch No. 6.

Portland Cement Type-I with Dow Modifier A - Since the concretes containing Dow latex admixtures have a much lower water-cement ratio than conventional concrete, it was necessary to use aggregates with very little adsorbed water; this necessitated air drying the sand several days prior to pouring the latex concretes and storing it under a tarpaulin cover to keep it dry. By mid-day on September 28, all preliminary work was completed. It had been planned to prime the patch areas with a latex-cement slurry, but Neil Foor, a Dow Chemical Co. representative, recommended that the patch substrate simply be moistened and some of the concrete broomed in prior to filling the patch. He also recommended that the concrete be mixed without an air-entraining admixture.

As noted in Table 4, the weather was cloudy, cool, and windy, and by the time work was in progress on the third patch, it was discovered that the moisture was evaporating so rapidly from the first patch (No. 48) that plastic shrinkage cracks had already occurred. After covering the first patch, it was discovered that the second patch (No. 30) had also started cracking, and it was evident that the freshly patched areas would have to be sealed beneath polyethylene immediately after the screeding and floating were completed. Upon recommendation from Mr. Foor, the plastic shrinkage cracks in patch area Nos. 48 and 30 were sealed with a pentrating epoxy as soon as curing was complete.

To prevent an excessive build-up of latex mortar in the mixer while successive batches were being mixed, the mixer was charged in the following manner: immediately after a batch was discharged, the mixer was charged with aggregate for the next batch; when the scoop loading tractor started back for another load, the cement was added at the same time the Dow

Modifier was drawn from the drum; it was then added to the mixer and mixed for one minute while the mix water was added continuously so as to not exceed the desired slump. After all the components had been added, the concrete was mixed for approximately four minutes. The Dow Modifier was not drawn from the drum until ready for use because it skinned over if allowed to sit for a few minutes in the air.

As shown in Table 4, a total of six batches of the Dow Modifier A concrete were mixed and slump and air measurements were made after batch Nos. 1 and 5, laboratory specimens were made from batch No. 5.

The polyethylene sheeting covering the patch areas was removed after two days of curing and the latex concrete was allowed to air dry.

Portland Cement Type-I with Dow Modifier B - Immediately after completing the Dow Modifier A concrete pours, the work on the Dow Modifier B concrete began. The same procedures were employed as before; like the Modifier A concrete, no air-entraining admixture was used and the patch substrates were merely wetted and the latex concrete broomed into the surface before the patch was filled. Six batches of Dow Modifier B concrete were mixed, and slump and air were measured on batches Nos. 1 and 5, and laboratory test specimens were cast from batch No. 5 (Table 4).

In general, these latex modified concretes were sticky to work with, difficult to float and trowel, and difficult to remove from tools that were not cleaned immediately.

Atlas Lumnite with Slurry Bond - Lumnite is different from Type-I portland cement in the following ways; it is a high aluminate cement; it nearly completely hydrates in 24 hours; it has a lower water-cement ratio; it produces a slightly harsher mix; and it requires more admixture to entrain air. During initial stages of rotary mixing, when the correct proportioning of mix water and air-entraining admixture are present, the concrete looks very dry and harsh. More mix water must not be added, because as mixing continues and more air is entrained, it gradually loses its dry, harsh appearance and begins to roll and fold like well-proportioned portland cement concrete. Lumnite concrete has the advantage of good workability, easy clean-up, lower shrinkage upon curing, and near maximum strength in 24 hours. When hydration starts, it occurs rapidly and proper curing is very important; the manufacturer prefers moist curing[2]: but suggests that a resin-base curing compound may be used as an alternate method.

[2]By sprinkling after initial set; sprinkled water carries away intense heat of hydration and keeps surface wet -- impractical for bridge decks.

On October 10, rainwater was blown out of all the remaining patch areas, and on the following morning the preliminary work began. By midday, priming of the patch substrate areas with a Lumnite cement slurry began at the same time as the mixing work. Each batch of Lumnite concrete was mixed for five minutes.

As shown in Table 4, a total of 13 batches were poured and slump and air measurements were taken on batch Nos. 1, 6, 10, and 13. Laboratory test specimens were made from batch No. 6.

An otherwise excellent application of Lumnite concrete was debilitated when a concrete surface hardening compound was inadvertently used as a curing compound; this material did not seal the surface against moisture loss. On the following morning, it was discovered that the surface mortar was soft and that it dusted badly under foot. A laboratory evaluation revealed that the weakening effect of the improper curing produced soft mortar to a depth of 1/8 in. The mortar deeper than this was harder and seemed to be more normal. It was concluded that this debilitated application might not be capable of representing correctly cured Lumnite concrete in a long-term field evaluation study. It appeared that the best course of action was to try to prevent unknown limits of disintegration by coating the surface with a penetrating epoxy. On November 6, the Lumnite patch areas were sealed with a Type-II[3] epoxy binder, Meta Bond 200, which was diluted 25 percent with toluene to give it better penetration. Sufficient epoxy was available to cover all the Lumnite patch areas except the northwest half of patch No. 17; this portion was left unprotected. At the time the sealant was applied, those portions of the patch areas under traffic had abraded down to a harder surface. Figure 10 shows a view of patch No. 17; the unsealed portion of the patch in the foreground is quite distinct from the sealed portion in the background.

Fast-Setting Patching Concrete - Mix development work in the laboratory established that the set time for each of these concretes was from 10 to 15 minutes at room temperature. It also established that the set time varied with the mix temperature, being faster when warm and slower when cool.

The rotary mixer was not ideally suited for the mixing of these concretes; it was remotely located from the patch areas and required three minutes of mix time to entrain the necessary air. To cope with this problem, chemical retarders were employed for use with both the Regulated-Set and Duracal concretes; they would retard the set about five minutes

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[3]MDSH 1970 Standard Specification 8.16.06.

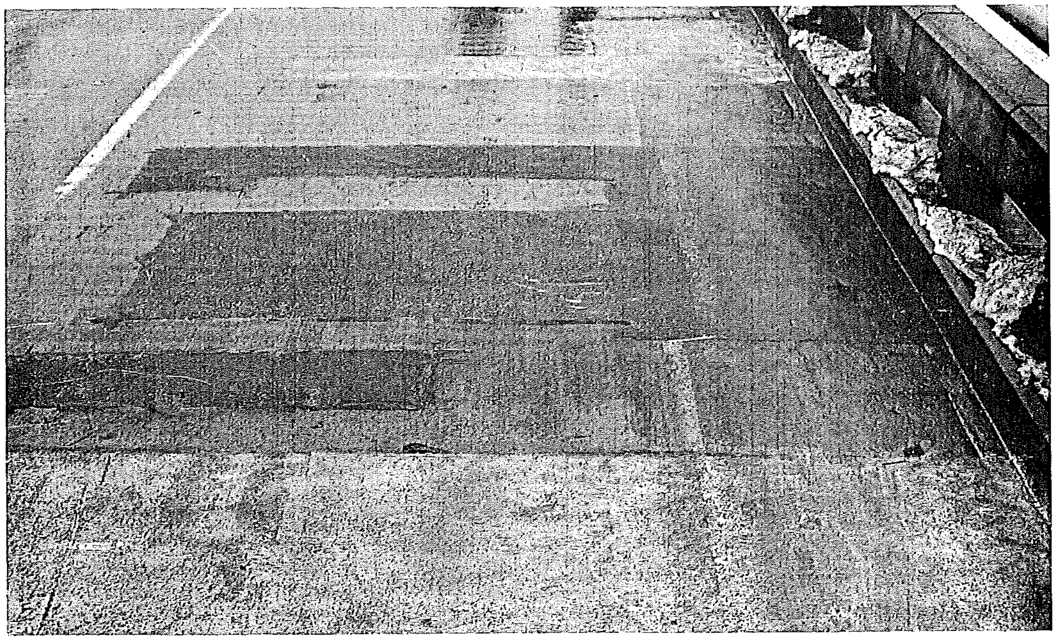

Figure 10. View of patch No. 17 containing Lumnite Concrete. Note that furthest portion of patch has been sealed with a penetrating epoxy.

which hopefully would permit enough total time to mix, transport, place, screed, and finish the concrete.

The weather was ideal for mixing and placing these fast-setting concretes. The most critical timing would occur on the larger patches where one batch of concrete would have to remain plastic until the next batch was placed in order to avoid the formation of cold joints.

About 10:00 a.m. the pouring of Embeco 411A was started with J. E. Flanagan, a Master Builder's technical representative, on hand to view the work. The three patch areas shown in Table 3 were filled with two full-sized and one partial batch of this material. As shown in Table 4, slump and air measurements, and the laboratory specimens, were made from batch No. 2. Mr. Flanagan requested that the patch areas be covered with wet rags upon completion of floating and then later sprayed with Master Builders' Curing Compound MB-429, which he furnished. The set time for the concrete was about 30 minutes.

At noon, the work with Huron Cement Company's "Regulated-Set" concrete began. Five pours were made in the patch areas shown in Table 3; Table 4 indicates that slump and air measurements were made on batch Nos. 1 and 5, and that laboratory specimens were cast from batch No. 5.

The cool weather plus the citric acid retarder extended the concrete set time to about 30 minutes which was ample time to complete the finishing. After the patch areas had been floated, they were sprayed with the remainder of the MB-429 to effect proper curing.

At 1:30 p.m., work began on the Duracal A concrete patches (Table 3). Slump and air measurements were made on three of the ten batches, and laboratory test specimens were cast from batch No. 5 (Table 4). As with the other fast-setting concretes, Duracal set in approximately 30 minutes; this allowed ample finishing time. Arthur Grant, from the U.S. Gypsum Co., stated that his company had not recommended that a curing compound be used on Duracal patches.

Following the pouring of the Duracal patches, the patching work was complete except for sealing the saw cuts past the corners of the patch areas. On October 13, the saw cuts were repaired, and by evening the bridge was reopened to traffic.

FIELD SPECIMEN TEST RESULTS

For each different concrete poured in the field, samples were taken for laboratory control. The specimens cast included six 4 by 8-in. compression cylinders, three 3 by 4 by 16-in. freeze-thaw beams, three 3 by 3 by 14-in. shrinkage prisms, and three 9 by 12 by 2-1/2-in. freeze-thaw scaling slabs. The specimens were cast at the mixing site and were cured under polyethylene sheeting. In all cases, after the specimens had set, they were returned to the laboratory before they were stripped from their forms.

Compression Cylinders

All concrete cylinders were cured in polyethylene bags until their test time. The testing included measurements for calculating their specific gravity, ultimate compressive strength, an approximate measurement of their compressive modulus of elasticity, and determination of their moisture content. The test times and test result values are shown in Table 5.

Freeze-Thaw Beams

All freeze-thaw beams were cured 14 days in the moist curing room prior to the beginning of freeze-thaw testing. At the beginning, and periodically throughout the testing program, the resonant vibration frequency was determined on a "sonometer" instrument and the relative dynamic modulus

TABLE 5
PATCHING CONCRETE CYLINDER DATA

Concrete	Pour Date	Concrete Age	Wet Bulk Specific Gravity	Moisture Content, percent	Compression Test	
					Strength, psi	Modulus of Elasticity at 1000 psi (psi)
Portland Control	9 27-72	3 Days	2.33	6.2	3070	1.02×10^6
		7 Days	2.34	4.7	4190	1.11
Portland Type I w/Dow Mod A	9 28-72	3 Days	2.43	3.1	3390	1.01×10^6
		7 Days	2.43	3.0	4090	1.16
Portland Type I w/Dow Mod B	9-28-72	3 Days	2.43	3.5	4630	1.03×10^6
		7 Days	2.42	3.4	5550	1.41
Atlas Lumnite	10-11-72	24 Hours	2.37	4.3	4620	1.11×10^6
		7 Days	2.38	4.3	5810	1.26
Embeco 411A	10-12-72	8 Hours	2.32	6.2	1330	0.44×10^6
		24 Hours	2.32	5.9	3520	1.18
Reg-Set	10-12 72	8 Hours	2.28	5.3	1580	0.78×10^6
		24 Hours	2.28	5.4	1910	0.78
Duracal	10-12-72	8 Hours	2.35	6.3	950	----
		24 Hours	2.34	6.1	1220	0.51×10^6

of elasticity calculated. The values of this modulus, expressed as a percentage of the initial value, are shown in the graphs of Figures 11 and 12. The sonometer instrument enables the deterioration of the beams to be periodically monitored without actually breaking them in flexure. After 336 cycles of continuous testing, the beams were tested in flexure (Table 6).

The only concrete to not complete this freeze-thaw test with excellent performance was Duracal which failed before the 84 cycle test.

Shrinkage Prisms

All shrinkage prisms were cured 14 days in a polyethylene bag prior to air drying in the laboratory. Their initial length and weight measurements were made immediately after being removed from their molds and subsequent measurements were made periodically throughout the phases of

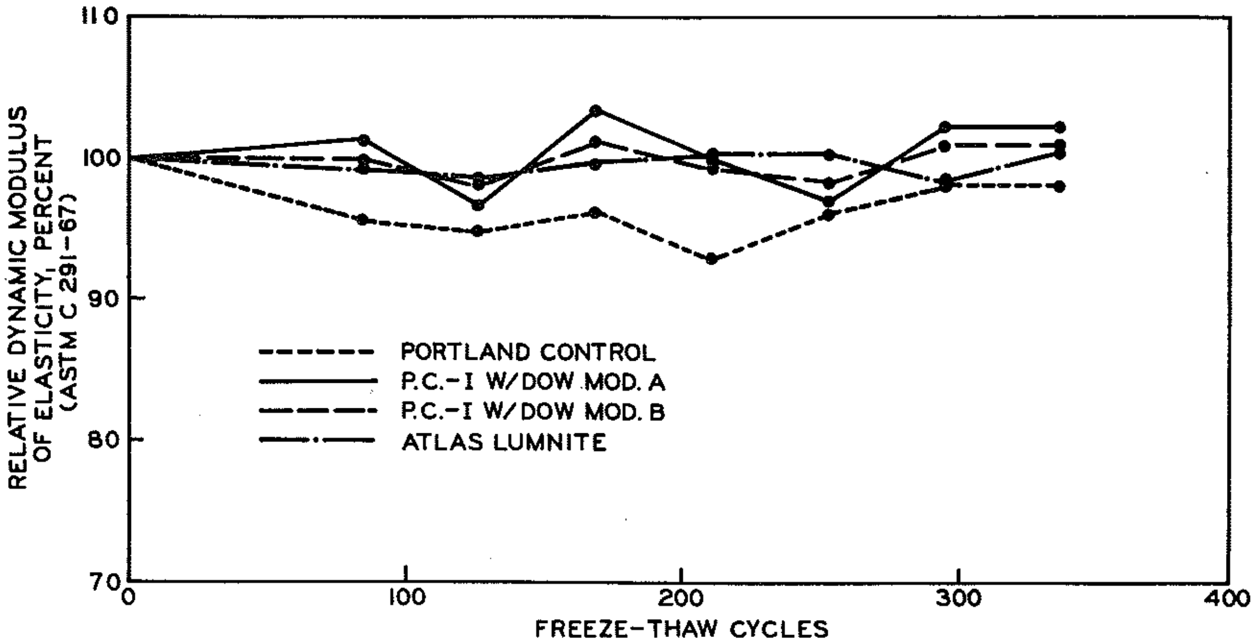

Figure 11. Internal freeze-thaw durability of conventional concrete beams (3 by 4 by 16-in.) tested immediately following the 14-day cure.

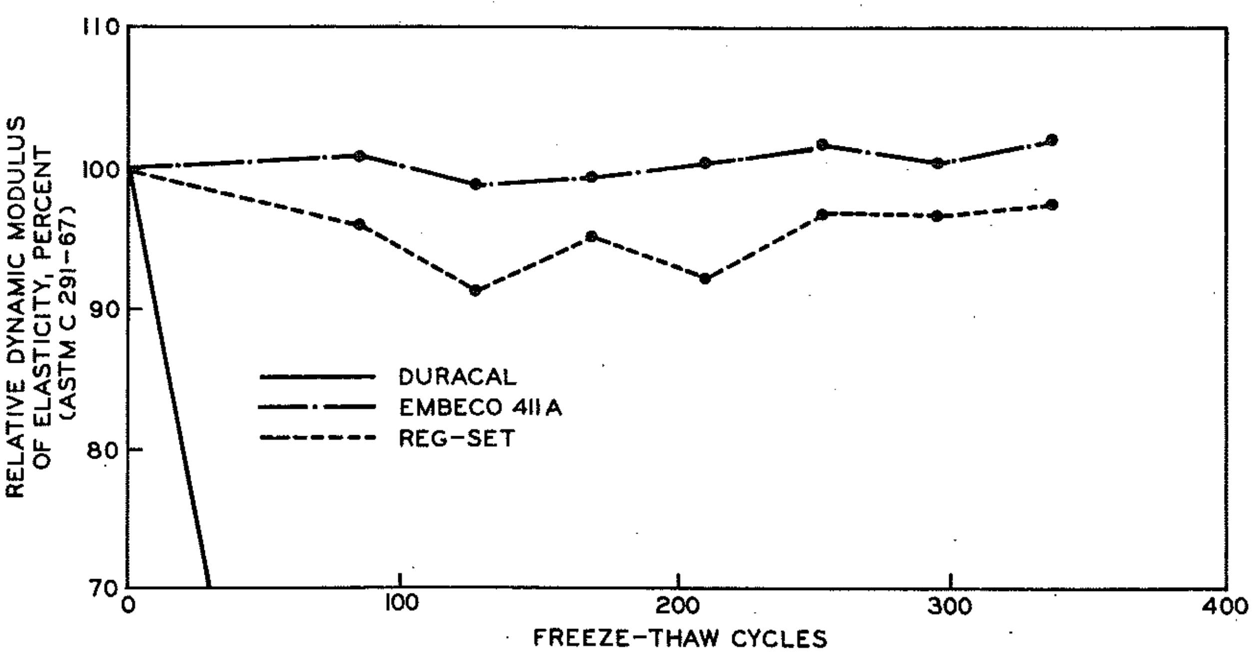

Figure 12. Internal freeze-thaw durability of fast-setting concrete beams (3 by 4 by 16-in.) tested immediately following the 14-day cure.

curing and drying. The graphs in Figures 13 and 14 show the length variations of these prisms through six months of air drying and one month of moist room recovery. The graphs in Figures 15 and 16 show the weight variations that correspond to the length measurements.

TABLE 6
FREEZE-THAW BEAM FLEXURAL STRENGTH AFTER 336 F-T CYCLES

Concrete	Pour Date	Avg. Flexural Strength, psi
Portland Control	9-27-72	824
Portland Type I w/Dow Mod. A	9-28-72	1,240
Portland Type I w/Dow Mod. B	9-28-72	986
Atlas Lumnite	10-11-72	933
Embeco 411A	10-12-72	989
Reg-Set	10-12-72	821
Duracal	10-12-72	---

Scaling Slabs

When the scaling slabs were returned to the laboratory, mortar dikes for water retention were molded around their perimeter with an epoxy bond. Curing took place under polyethylene through seven days and was followed by air drying in the laboratory through 14 days. At this point freeze-thaw testing began at one cycle per day and ran through six 20 cycle sets; each set started with fresh water ponded on the surface for four cycles and then alternated between salt and fresh water every third or fourth cycle. At the end of each 20 cycle set, the surfaces of the slabs were scrubbed off, allowed to air dry, visually rated, and photographed. The ratings were based on a "1 to 5" scale where "1" represented an unscaled condition and "5" represented a heavily scaled condition. The graphs in Figures 17 and 18 show the visual rating of the slabs through six sets of 120 cycles of testing.

DISCUSSION

Portland Cement with Dow Modifiers - Because of the nature of the latex in the Dow Modifier concretes, when the concrete sets, no substantial strength can develop until the cement hydrates and the latex loses its emulsifying moisture; therefore, it is recommended that moist curing be applied for two days only and then removed. The slow rate at which the latex concrete loses its water will leave sufficient moisture to continue the hydration of the cement past the second day. Once the latex concrete dries and loses its emulsifying moisture, it will not re-emulsify in the presence of water and it will re-admit moisture as slowly as it lost it. This makes air dried latex concrete very resistant to freeze-thaw breakdown.

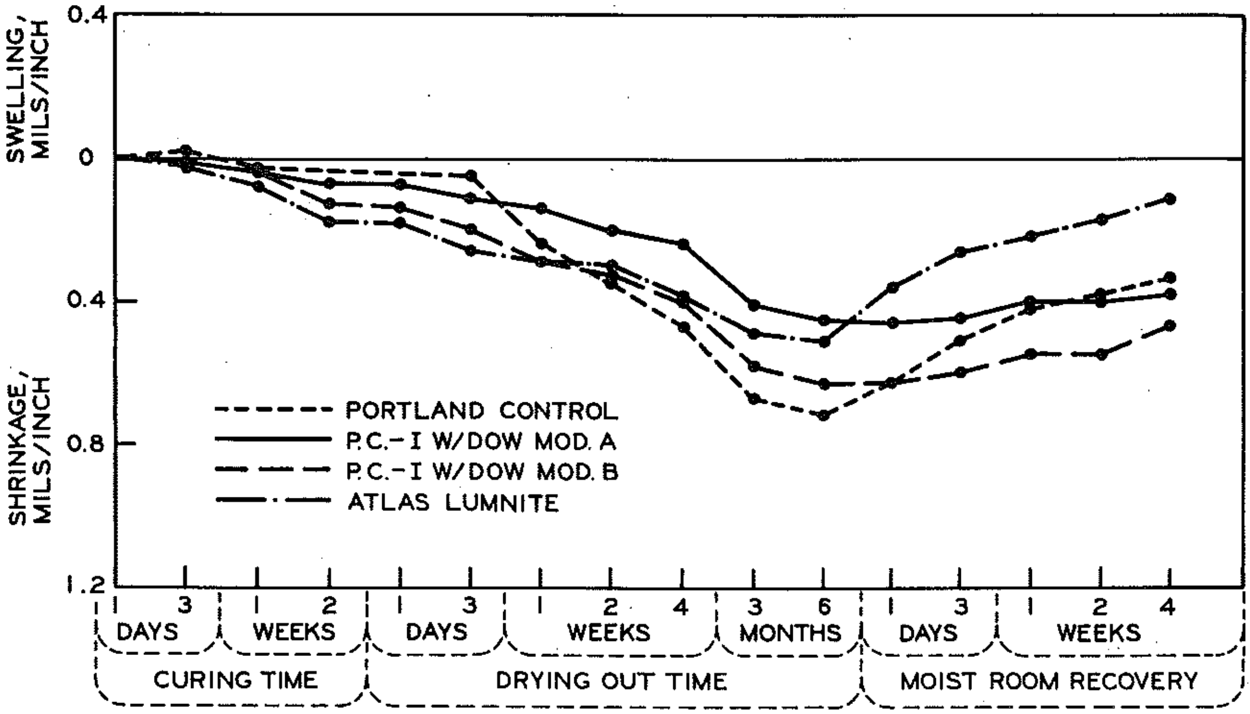

Figure 13. Shrinkage prism length variation. Conventional concrete.

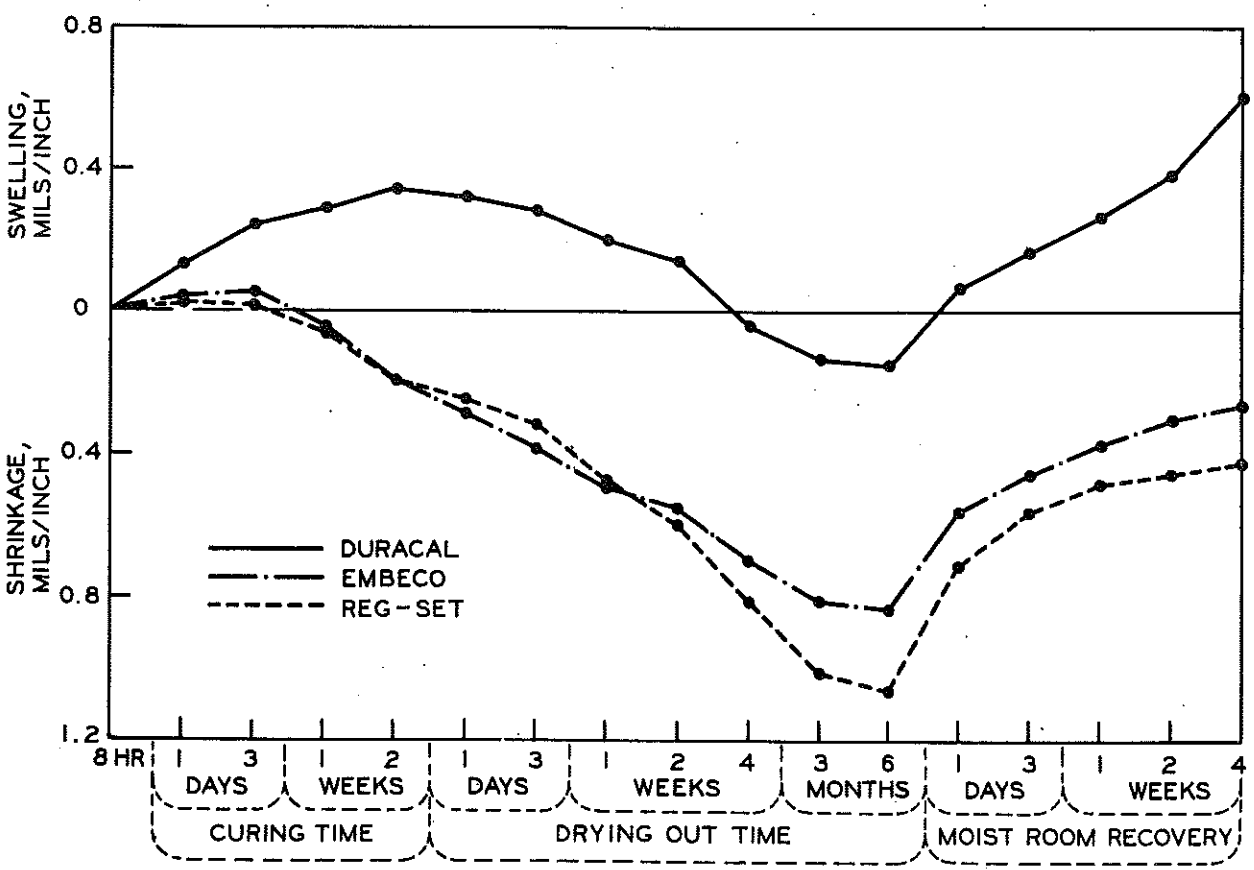

Figure 14. Shrinkage prism length variation. Fast-setting concretes.

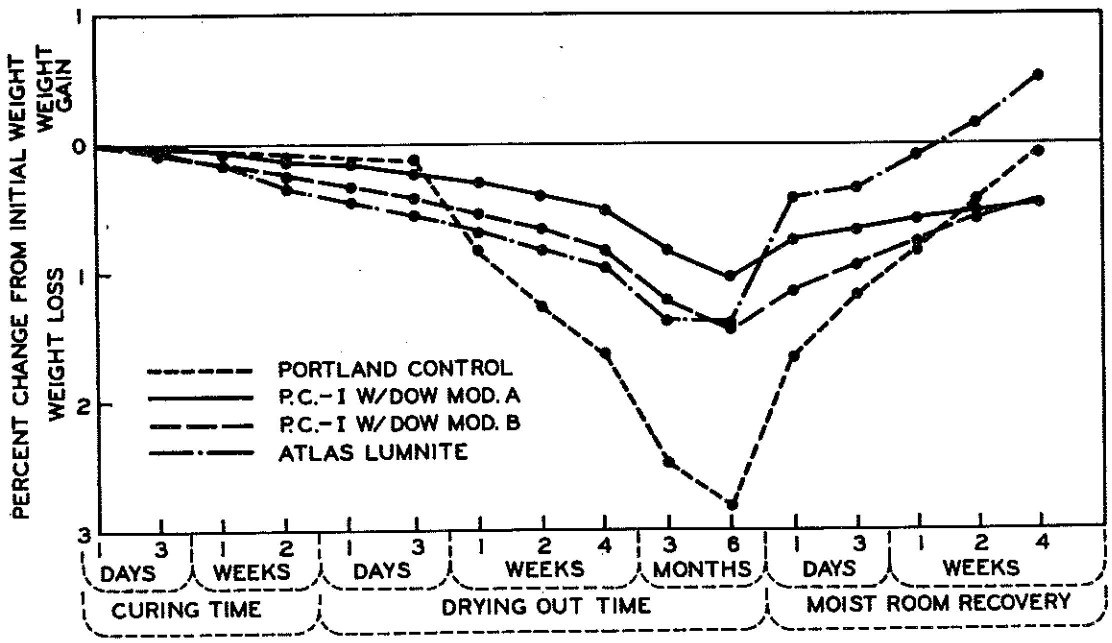

Figure 15. Shrinkage prism weight variation. Conventional concretes.

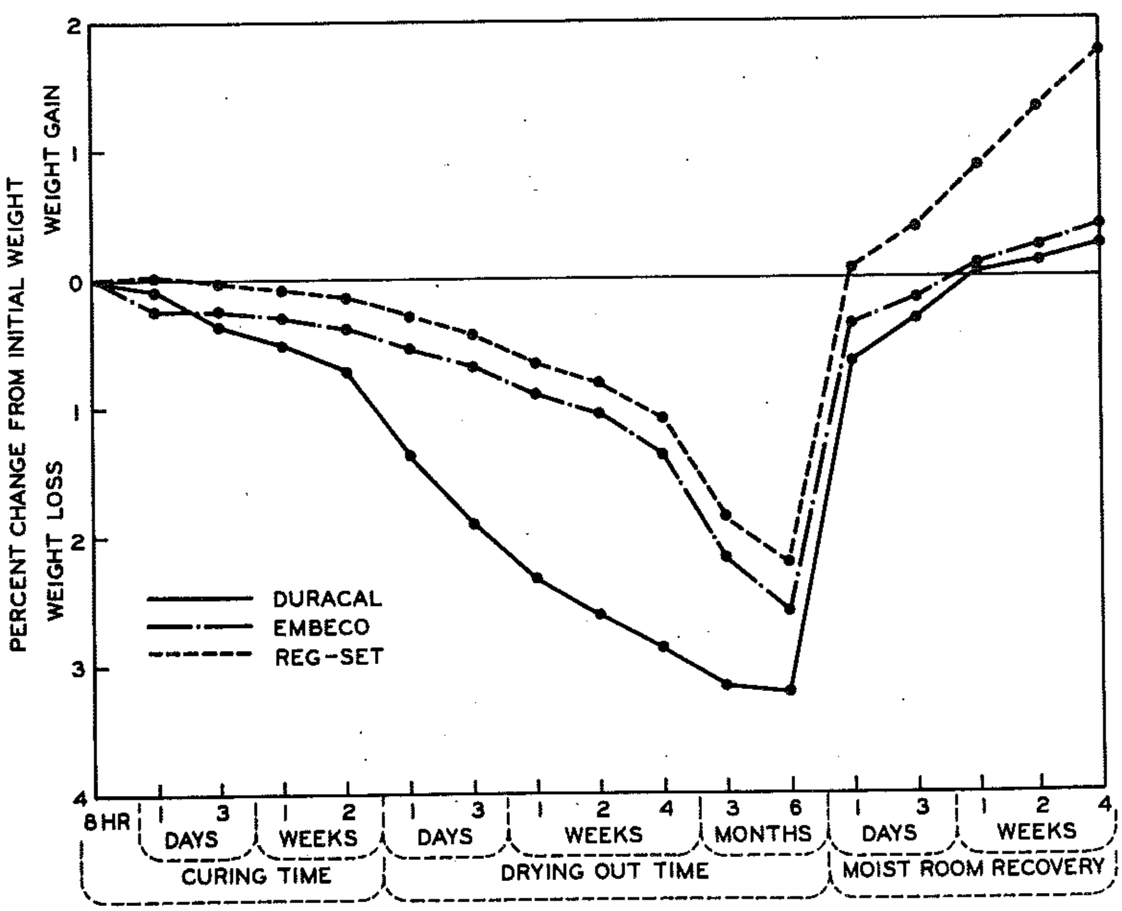

Figure 16. Shrinkage prism weight variation. Fast-setting concretes.

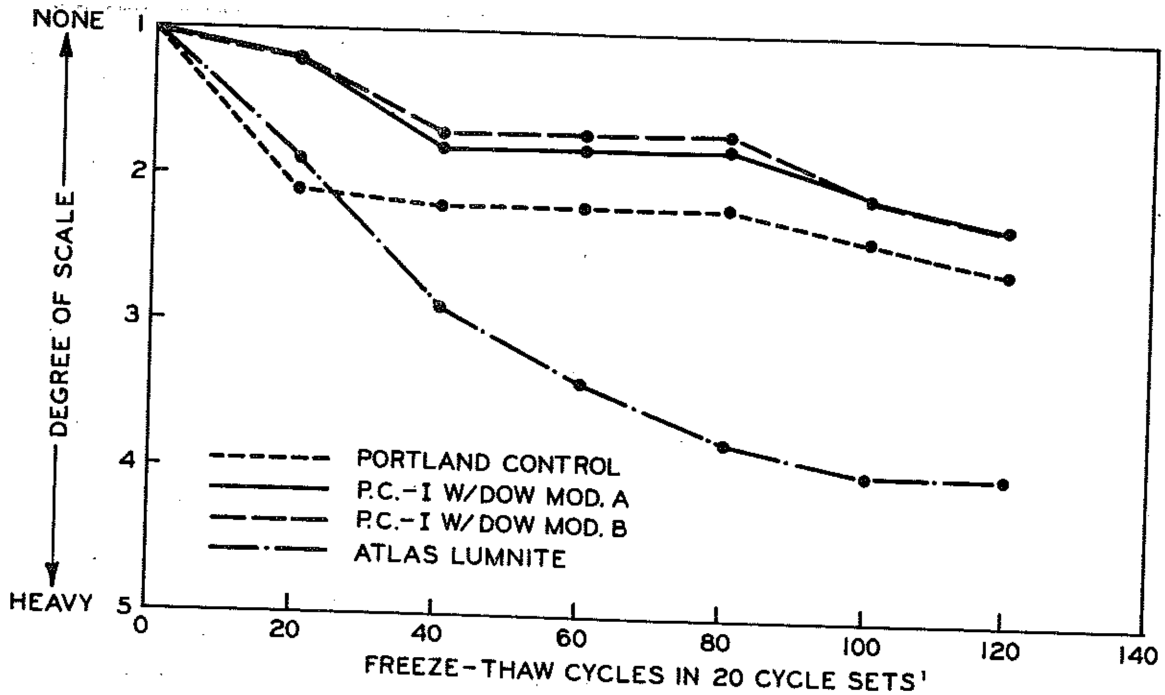

Figure 17. Surface freeze-thaw durability for conventional concrete scaling slabs cured 7 days and air dried 7 days prior to freeze-thaw testing.

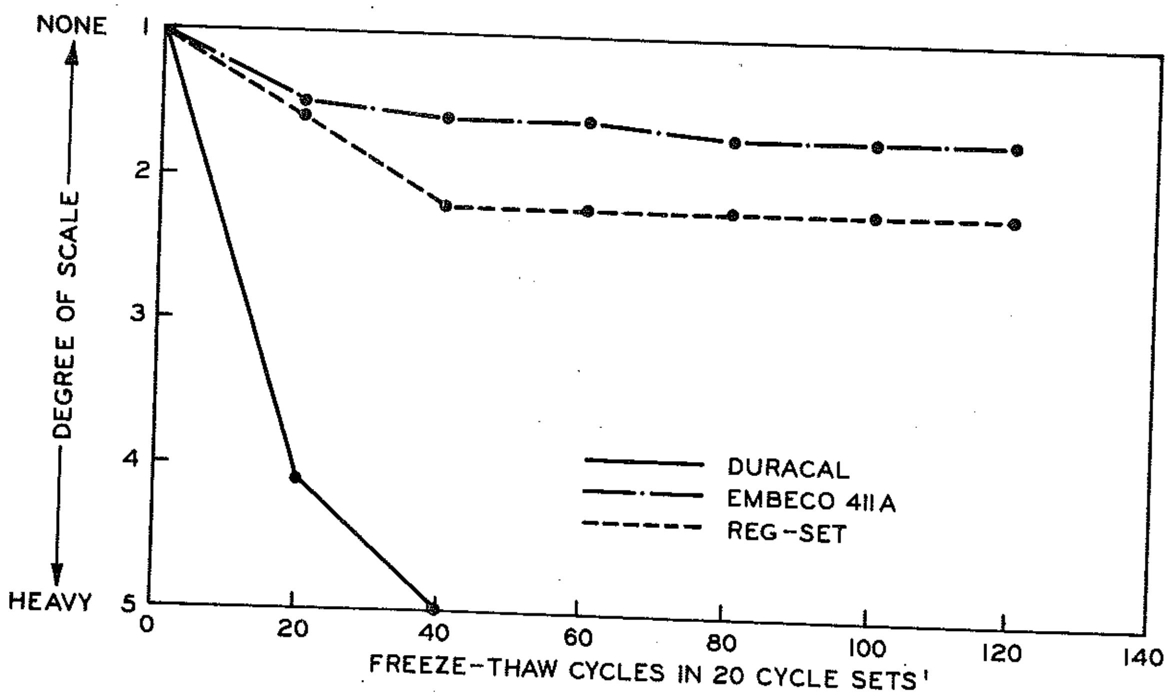

Figure 18. Surface freeze-thaw durability for fast-setting concrete scaling slabs cured 7 days and air dried 7 days prior to freeze-thaw testing.

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[1] Each set includes 4 cycles fresh water, 3 cycles 3 percent salt water, 4 cycles fresh water, 3 cycles 3 percent salt water, 3 cycles fresh water, 3 cycles 3 percent salt water.

The test results of the Dow Modifier A concrete as shown in the graphs and tables indicates that it does not have as high a strength as the Modifier B concrete, but it shrinks at a slower rate. Both seem to have excellent resistance to freeze-thaw breakdown, and both seem to outperform the portland cement control concrete in every test.

Atlas Lumnite - The Atlas Lumnite concrete, which built up such a high 24-hr strength, outperformed the control concrete in every respect except for its resistance to freeze-thaw scaling; in this test it demonstrated a unusual characteristic. After 40 freeze thaw cycles, the slabs scaled to a depth of 1/16-in.; below this depth, however, the mortar was much more resistant and the rate of scaling decreased rapidly. The reason for this seemed, again, to be the debilitation caused by improper curing. These scaling slabs were cured under polyethylene which slowed the escape of the intense heat of hydration which tended to vaporize and drive off the surface moisture.

Fast-Setting Concretes

Laboratory test results on the fast setting concretes show that none at the 8-hr test, and only Embeco 411A at the 24-hr test, have adequate compressive strength to safely carry live load stresses in maximum bending moment areas of bridge decks.

Embeco 411A - The test results on the Embeco 411A indicates it to be superior to any other fast-setting concrete. These same test results also show it to be superior to the portland cement control in every respect except shrinkage; however, this may not be a problem in the field where long periods of air drying rarely occur.

Regulated-Set - The Regulated-Set concrete's resistance to freeze-thaw deterioration was very impressive, but its 24-hr compressive strength and shrinkage after six months of air drying were disappointing. The 9 percent entrained air was certainly a big factor in the favorable freeze-thaw performance, but was detrimental to the strength levels. Another factor which undoubtedly retarded the strength gain was the cool weather in which the concrete was exposed for the first six hours after it was poured. The set retarding effect of this temperature was certainly welcome, but not its retarding effect on the rate of strength development.

To check the test results of these field specimens, a subsequent mix of the same proportioning was poured in the laboratory; the sand, gravel, and mix water for this mix were stored overnight in a 40 F cooler to retard the set long enough to make the necessary slump and air measurements and to fill the various specimen molds. The immediate hydration of this mix was so completely retarded that it had an 8-1/2-in. slump and a 30 minute set time; at normal laboratory temperatures, there would have been no more than a 4-in. slump and a 15 minute set time. The entrained air level was measured and was found to be at 8 percent. As the concrete test specimens sat in laboratory air, their temperature and rate of strength development rose rapidly; the compressive cylinder test values were 1,670 psi at 8 hr, 2,510 psi at 24-hr, 3,410 psi at 3 days, and 3,980 psi at 7 days. These values showed that with favorable curing conditions, the 24-hr strength was substantially improved, but was still far from being ideal for use on bridge decks. Perhaps an eight or nine sack mix would substantially improve these compressive values.

The freeze-thaw and shrinkage values of this laboratory mix compared very closely with the values of the field specimens.

Duracal A - The overall performance of the Duracal test specimens in the laboratory was poor. The compressive strengths were disappointingly low for both the 8 and the 24-hr tests, the freeze-thaw beams had partially disintegrated by the end of 84 cycles, and the freeze-thaw slabs had scaled to a "4" rating by the end of 20 cycles. The only commendable performance was recorded by the shrinkage prisms which swelled during the curing period and remained in a swollen state throughout the first 28 days of air drying; however, moist room recovery measurements indicated an excessive degree of swelling.

Because an obviously inferior material had passed through the mortar evaluation study without detection, Research Laboratory personnel reviewed the mortar test results. They showed a normal weakening in shear bond and compressive strengths during 200 cycles of freeze-thaw, but no sign of physical disintegration.

Immediately, a full set of test specimens was cast in the laboratory with the same Duracal cement which had been used in the field. It conformed to the manufacturer's recommended mix proportions which consisted of equal parts of cement, sand, and gravel by weight. This proportioning was shunned as a field mix because it was sticky and difficult to finish. This laboratory mix had 6.3 percent entrained air, and because of its excessive richness, a 10-in. slump. Test results showed a substantial, but still inadequate improvement in its compressive strength and freeze-thaw beam performance. The resistance to freeze-thaw scaling showed no improvements over the field specimen performance.

The freeze-thaw beam performance of this latter mix was very interesting; sonic measurements indicated that the beams lost 45 percent of their internal strength after 126 cycles, but no physical disintegration occurred until after 250 cycles. This explained its apparently successful freeze-thaw performance during the mortar tests.

Patching Concrete Material Costs

Although the cost of these patching materials will be secondary to their performance, it must be considered at the time a final selection is made. Table 7 lists the various patching concretes used in this work and shows their material cost. The costs of mixing and placement are not included in this figure as they will be approximately the same for each of the materials.

TABLE 7
PATCHING CONCRETE
MATERIAL COST

Patching Concrete	Cost per cu ft
Portland Control	$ 0.80
P. C. with Dow Mod A	5.25 (Est.)
P. C. with Dow Mod B	4.50 (Est.)
Atlas Lumnite	1.60
Embeco 411A	$15.90
Regulated-Set	1.40
Duracal	2.00

These figures include the cost of fine and coarse aggregates, cement, and admixtures. The Embeco 411A is a pre-mixed material that contains all aggregates, admixtures, and cement in the packaged product.

Bonding Agent Material Costs

Although it is impossible to compare the cost of the bonding agent "Bonding Blend" to any of the patching concretes, it can be compared to the cost of the epoxy grout which was used as a bonding agent for several of the control patches. Calculations showed that 1 gal of epoxy grout and the Bonding Blend slurry, which is made by mixing 1 gal of Bonding Blend with 21 lb of portland cement, would both prime 50 sq ft of patch substrate. The unit costs of these materials are 19-cents per sq ft for the Bonding Blend slurry and 25-cents per sq ft for the epoxy grout.

Comments

This report on patching concretes is concerned only with their field application and laboratory test results on specimens obtained from the field. Because of its limited scope, we cannot make any firm recommendations as to which patching concrete should be specified for general usage; these will be forthcoming based on current field performance tests.

It can be stated, however, that the two fast-setting materials, Regulated-Set portland cement and Embeco 411A, are superior to any others previously tested by the Research Laboratory and should be used preferentially until a more comprehensive recommendation can be made. Because of the expense of the Embeco 411A material, its use should be confined to small isolated jobs where it is impractical to haul in aggregate to a drum type mixer.

The bridge adjacent to the subject bridge, which carries eastbound M 36 over US 127 (S10 of 33035), is similarly afflicted by spalling concrete over high reinforcing steel bars. Because of its ideal location it is recommended that this bridge be reserved for future application of experimental patching concretes.