

LATEX MODIFIED MORTAR in the RESTORATION of BRIDGE STRUCTURES

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Synopsis

A synthetic latex emulsion admixture was used with portland cement mortar in thin patching mixtures. Laboratory study showed improvement in shear bond strength, compressive strength, tensile strength, and a reduction of water-cement ratio as compared to regular mortar. The latex emulsion was added in amounts of 10 to 20 percent based on latex solids to cement weight. It was used in mortars having sand-cement ratios of 3:1 and 2:1 by weight.

Thin patching was applied to a bascule bridge deck in Cheboygan, Michigan, during the Fall of 1957. Evaluations of the thin patched deck show that areas where the latex mortar was applied over a sound, wet substrate held up well through two winters. Bond failed during the first year in varying degrees in areas covered dry, with latex-cement slurry, or with a brush coat of the latex emulsion only.

The 1957 areas where bond failed were repaired in late 1958 by applying a different latex mortar over a cleaned substrate soaked with water prior to the patching application. After one winter these areas appear to be well bonded to the old surface. A few areas contain some fine shrinkage cracks but do not appear to be loosening.

The mortar mixes of 1957 contained a water-dispersed resin of a styrene-butadiene copolymer. A new latex emulsion of a Saran type was used in the 1958 patching mortars.

Better and more permanent methods of applying thin patches of mortar or concrete to old, deteriorated concrete surfaces are continually being sought. Representatives of the Michigan State Highway Department and the Coatings Technical Service, Dow Chemical Company, Midland, Michigan, met in August 1957, to discuss the merits of a new additive for portland cement mortar or concrete which was reported to improve,

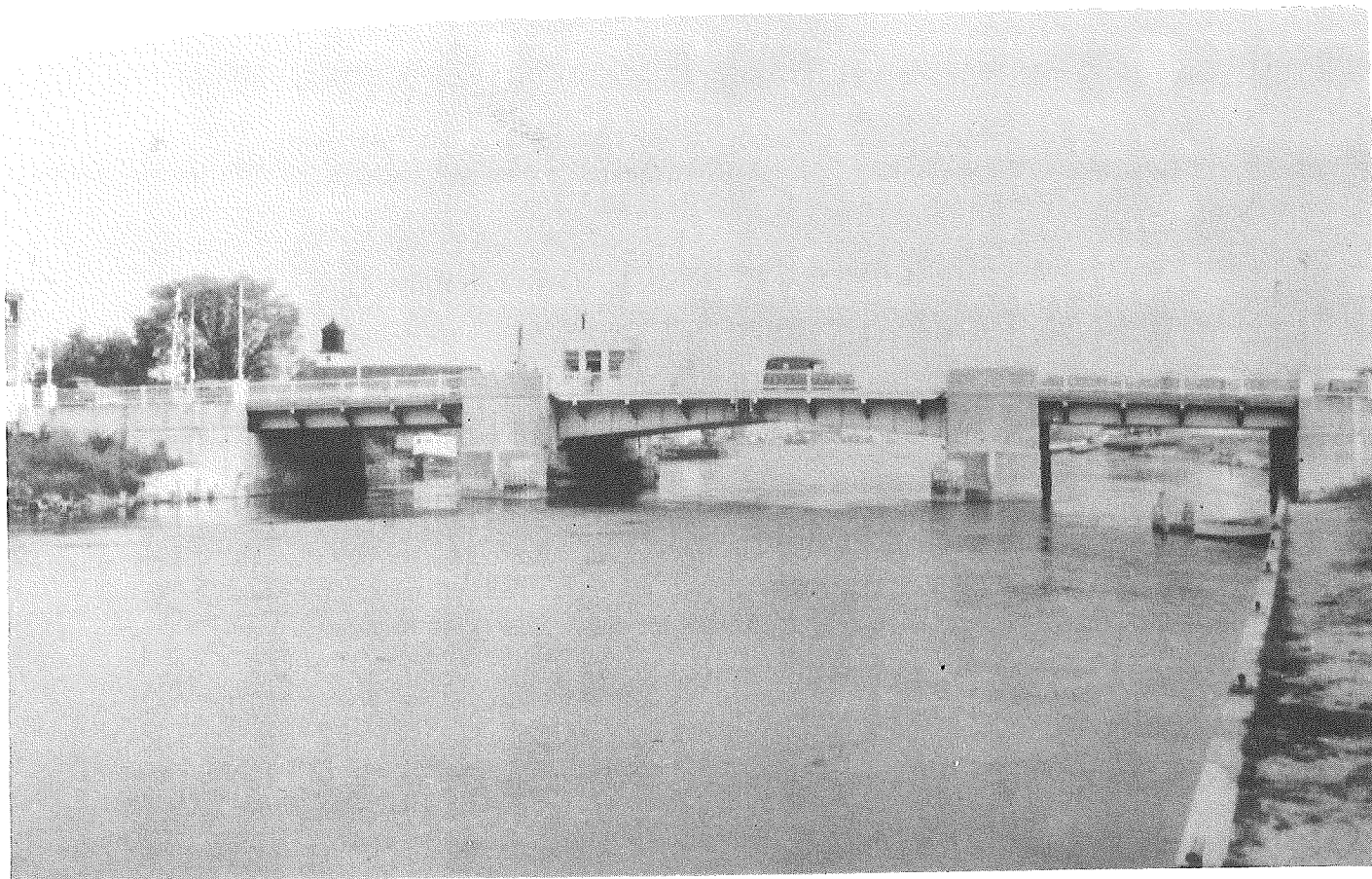
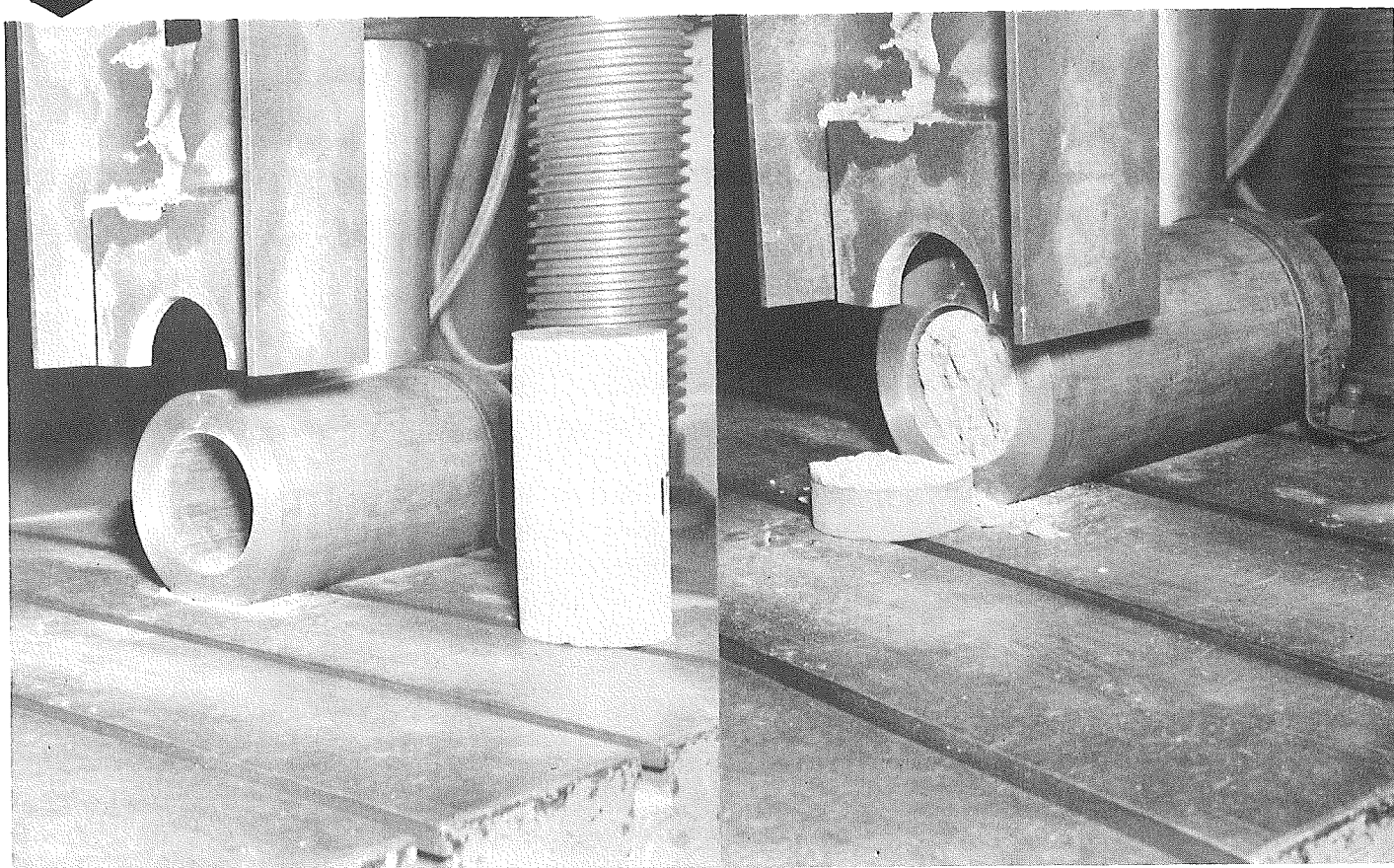


Figure 1. Bascule bridge on US 23, Cheboygan, Michigan.

Figure 2. Laboratory equipment for determining shear bond strength of latex-cement mortar patches on concrete cylinders.



among other qualities, the workability and shear bond strength of thin patching mixtures with a lowering of water to cement ratios. This new admixture was a synthetic resinous latex emulsion in water, designated "Dow Latex 560."

It was decided that this latex would be tried in patching mixtures on a regular field maintenance project. It was furnished to a bridge maintenance crew and incorporated in patching mixes for restoration of a deteriorated bridge deck. Technical assistance was given by the manufacturer, and measurements and pictures taken by the Research Laboratory Division of the Office of Testing and Research. The structure chosen for this field test was a three-span bascule bridge over the Cheboygan River on US 23 in Cheboygan, Michigan, Project B1 of 16-3-7 (Fig. 1).

MATERIALS AND APPLICATION

Properties of Latex Modified Mortars

The Latex 560 emulsion is a styrene-butadiene copolymer dispersed in water, containing about 48 percent solids, weighing 8.4 lb per gal, and having a pH of 10.5. A second experimental latex emulsion, used in later repair work, is a Saran type numbered X2130.1 by the manufacturer; it is about 51 percent solids dispersed in water, weighs 10.4 lb per gal, and has a pH of 2.0.

A laboratory evaluation compared the physical properties of mortars using these two latex emulsions with those of regular mortar, after two periods of curing (Table 1). Latex X2130.1 had a considerable advantage over Latex 560 or plain mortar, particularly in shear bond strength. The shear bond tests were run on the various mortar coatings applied to 3-3/8- by 6-in. concrete cylinders, cured 14 days prior to capping, and tested as shown in Fig. 2.

Preparation of Bridge Deck

The Cheboygan bridge has a 40-ft wide four-lane roadway with two 5-ft sidewalks, consisting of about 58 ft of concrete roadway at each end of 38 ft of open steel grid. It was built in 1940, with crushed limestone coarse aggregate, natural sand, and non-air-entrained cement. The roadway had become badly scaled from weathering and de-icing salts, and highly polished from traffic (Fig. 3). The unsound and scaled surface

was removed with a cutting machine (Fig. 4), so that a latex-portland cement mortar layer of 1/2-in. minimum thickness could be applied. Some areas of the filled-grid walk sections were chipped out to squared edges (Fig. 5). Small air chisels and sandblasting equipment were also used to prepare the deck for thin patching. Narrow steel strike-off bars were greased and set with anchor bolts along the edge of each lane, so that the proper depth of patch and crown of the deck surface would be maintained during screeding and finishing operations. These bars were removed after the latex-cement mortar had cured.

TABLE 1
PHYSICAL PROPERTIES OF LATEX MODIFIED MORTARS
Laboratory Mixes (Type I Cement and Ottawa Sand)

	Latex 560	Latex 2144*		Regular Mortar
Sand-cement ratio	3:1	2:1	3:1	3:1
Latex solids-cement ratio	0.20	0.15	0.20	---
Water-cement ratio	0.35	0.34	0.46	0.45
Shear bond strength, psi (Lateral cylinder method)				
2 weeks dry	400	800	1000	50
2 weeks dry, 2 weeks wet	325	650	780	250**
Compressive strength, psi (ASTM C 109, 2-in. cubes)				
2 weeks dry	4000	7500	4930	2500
2 weeks dry, 2 weeks wet	3300	6000	3550	3500***
Tensile strength, psi (ASTM C 190, briquettes)				
2 weeks dry	550	1000	900	180
2 weeks dry, 2 weeks wet	440	650	400	400***
Flexural strength, psi (ASTM C 192 and C 293)				
2 weeks dry	900	2100	1360	500
2 weeks dry, 2 weeks wet	550	1200	770	800***

* Same polymer composition as the Latex X2130.1 used in 1958 on the Cheboygan bridge.

** After 14-day moist cure.

*** After 28-day moist cure.



Figure 5. North sidewalk patches chipped to squared edges.



Figure 4. Cutting machine used to remove minimum of 1/2 in. of scaled concrete.

Figure 3. Typical scaled and polished concrete deck surface.



Figure 6. Typical placement and finishing procedure for latex-cement mortar.

Application of Latex-Cement Mortar

When all the preparatory work on the bridge deck had been completed, mixing and application of latex-cement mortar began on September 18, 1957. Laboratory tests showed promising bond strengths for latex mortar on dry or latex coated bases. To explore the bond characteristics, four different methods were used in treating the cleaned deck surfaces:

1. Surface wet thoroughly with water.
2. Left dry and untreated.
3. Bond coat of straight latex emulsion brushed into surface and dried until tacky.
4. Slurry of Latex 560 and cement at a ratio of 1:1 broomed into the deck.

The latex-cement mixes were made in a standard transit mix truck with moist sand (2NS) weighed and loaded first. The necessary bagged Type I cement was added as the drum continued to rotate. After mixing the sand and cement for 10 to 15 min, the Latex 560 was added from 55-gal drums, using a hoist truck. Mixing continued while the transit mix truck was traveling the few blocks from plant to bridge site. Very little water was added, since about 6 percent water was contained in the sand. Typical placement and finishing are shown in Fig. 6.

During the four days in September 1957 when thin patching was applied, a total of six loads of transit mixed latex-cement mortar were used. Data on these mixes are summarized in Table 2. The locations on the bridge, coded by letters, and the surface preparation where these mixes were placed are shown in Fig. 7. Small cylinders and beams were made from the first batches of September 18 and 19; strength and durability results for these specimens are given in Table 3.

A nominal sand-cement ratio of 3:1 and a latex solids content of 20 percent, based on the cement weight, were used for all batches. During mixing, trouble was encountered with the moist sand balling up with the cement. Most of the large sand and cement lumps were screened out as the mortar was placed, but some smaller ones were finished into the thin surfacing. Shrinkage cracks appeared through a few of these lumps soon after finishing (Fig. 8).

The latex-cement mortar tended to form a surface skin which produced shrinkage cracks (Fig. 9), if not immediately covered with wet burlap. This was especially true when the weather was sunny and windy.

TABLE 2
LATEX 560 MORTAR DATA
September 1957 Field Mixes

Batch No.	1	2	3	4	5	6
Pour date area* time	9-18-57 G 11:30-1:00	9-18-57 E 3:00-4:00	9-19-57 A & C 3:15-4:15	9-25-57 B & J 9:45-10:25	9-26-57 F & H 8:50-11:00	9-26-57 D & K 12:00-12:20
Sand (2NS)**						
wet, lb	6000	4500	6000	6000	7500	3000
dry, lb	5650	4240	5650	5660	7040	2815
Type I cement	1974	1504	1927	1974	2444	987
Latex 560 (48 percent solids)						
lb	900	675	900	675	1125	450
solids, lb.	432	324	432	324	540	216
Additional water, lb	108.0	66.6	50.0	42.0	----	----
Air content, percent	13.1	11.2	13.2	11.1	6.5 & 8.1	8.2
DC Antifoam B, lb***	9.00	6.75	9.00	6.75	11.25	4.50
Net water-cement ratio	0.434	0.416	0.414	0.336	0.392	0.390
Dry sand-cement ratio	2.860	2.820	2.930	2.870	2.870	2.850
Latex solids-cement ratio	0.219	0.215	0.224	0.164	0.221	0.219

* Areas identified in Fig. 7

** Absorption of 2NS sand = 1.23 percent; specific gravity, saturated surface dry = 2.63; met ASTM concrete sand gradation.

*** Added to latex emulsion before use.

TABLE 3
COMPRESSIVE AND FLEXURAL STRENGTH OF LATEX CEMENT MORTAR
September 1957 Field Mixes (Latex 560 and 3:1 Mortar)

Age at Test	Compressive Strength 3- by 6-in. cylinders		Flexural Strength 3- by 3- by 16-in. beams		Dynamic Modulus of Elasticity x10 ⁶ psi
	Specimen No.*	Comp. strength psi	Specimen No.*	Flex. Strength psi**	
9 days	A-1	2115	A-4	744	2.2
	A-2	2228	A-5	822	2.3
8 days	B-1	2228	B-4	667	2.3
	B-2	2122	B-5	722	2.3
	average	2173	average	739	
	A-4	2603	A-6	956	2.3
	A-5	2617	A-7	956	2.4
28 days	B-4	2461	B-6	873	2.4
	B-5	2405	B-7	882	2.4
	average	2522	average	917	
	A-3	2977	A-9	689	2.6
	A-7	3246			
90 days	B-7	3091	B-9	767	2.6
	B-8	3055			
	average	3092	average	728	
	A-6	3197	A-3	1033	
	A-8	3296	A-8	900	
7 months	B-3	3168	B-3	1000	
	B-6	3182	B-8	1040	
	average	3211	average	993	

* Series A specimens molded 9-18-57 and Series B 9-19-57. All specimens cured outdoors until time of test.

** Third point loading method

After 300 cycles of freeze-thaw in air-water between 0 and 40 deg F, beams A1 and A2 and B1 and B2 showed practically no change in weight, length, or dynamic modulus.

All latex-cement mortar mixes were quite fluid but, as Table 2 shows, the net water-cement ratios were fairly low. Air entrainment was held to a moderate amount by adding to the latex drums before use, 0.2 percent DC Antifoam B solids based on the latex solids. The Antifoam B is a solution of 10 percent solids. Even with Type I cement, latex emulsions entrain considerable amounts of air unless a defoamer is used.

The resurfaced lanes were covered with wet burlap for 24 hr, and then allowed to air cure for six days. Upon completion of this seven-day curing period, the resurfaced areas were opened to traffic.

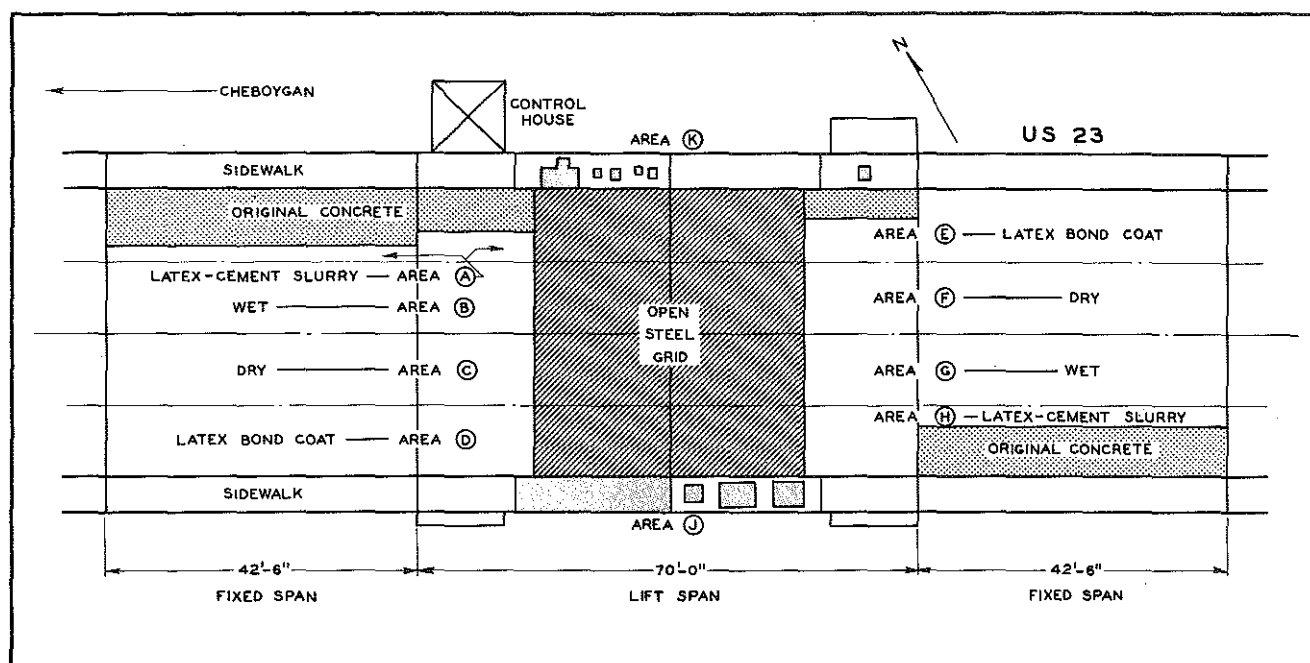


Figure 7. Placement of Latex 560 mortar mixes in September 1957 (see Table 2) with four types of substrate treatment

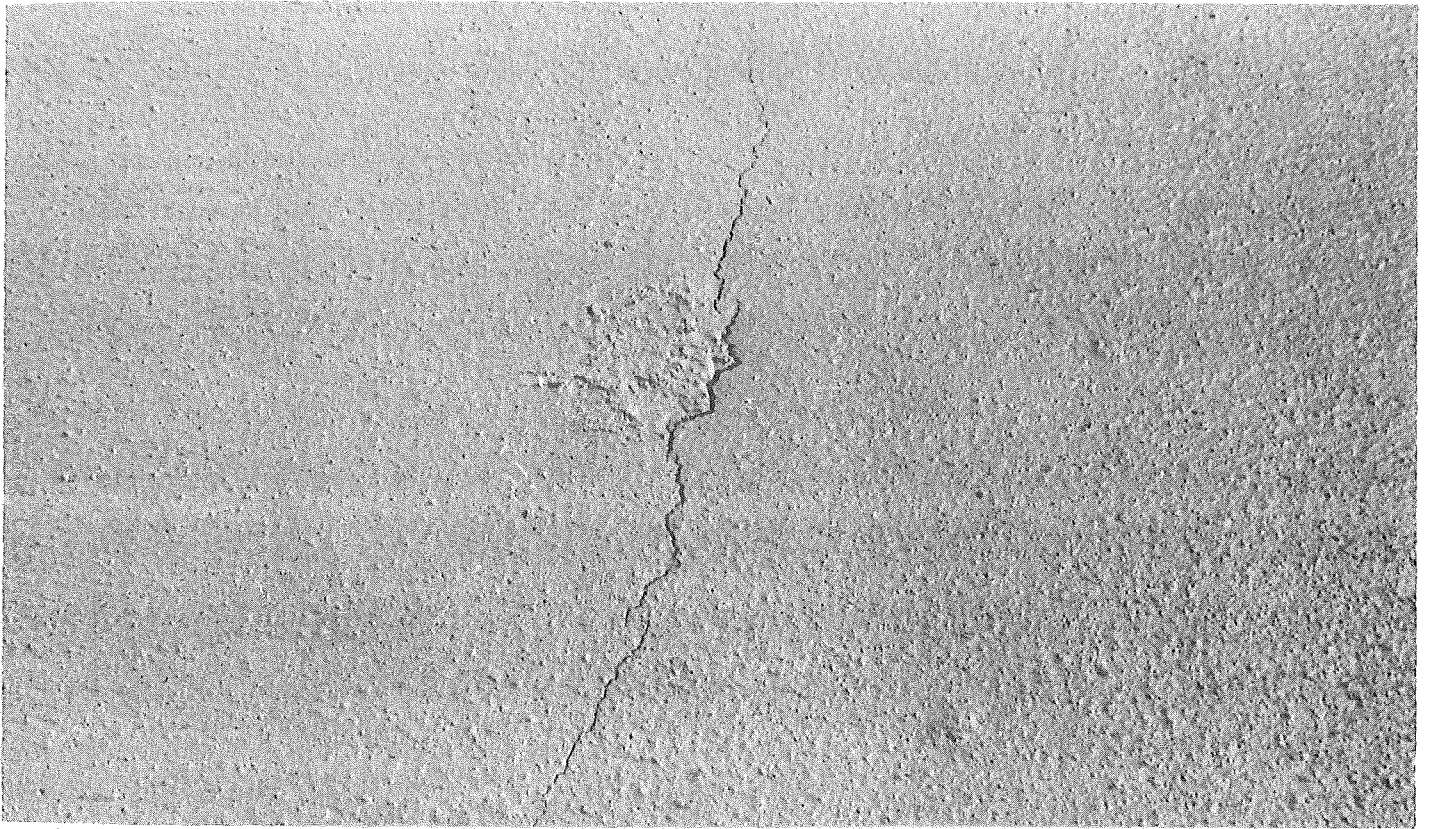
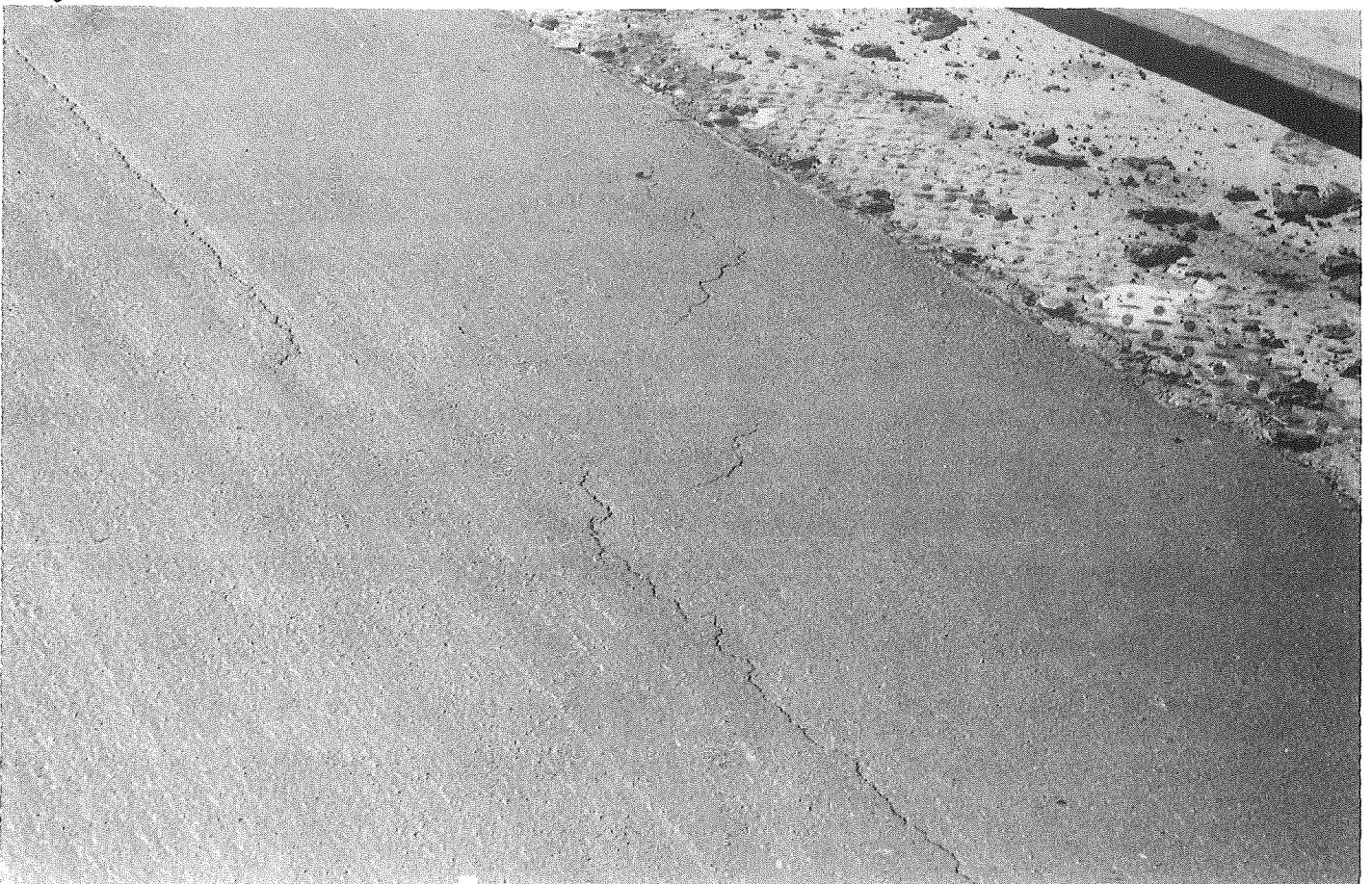


Figure 8. Shrinkage crack adjacent to sand-cement lump.

Figure 9. Shrinkage cracks in latex mortar surface on west end of Lane D when not quickly covered with wet burlap.



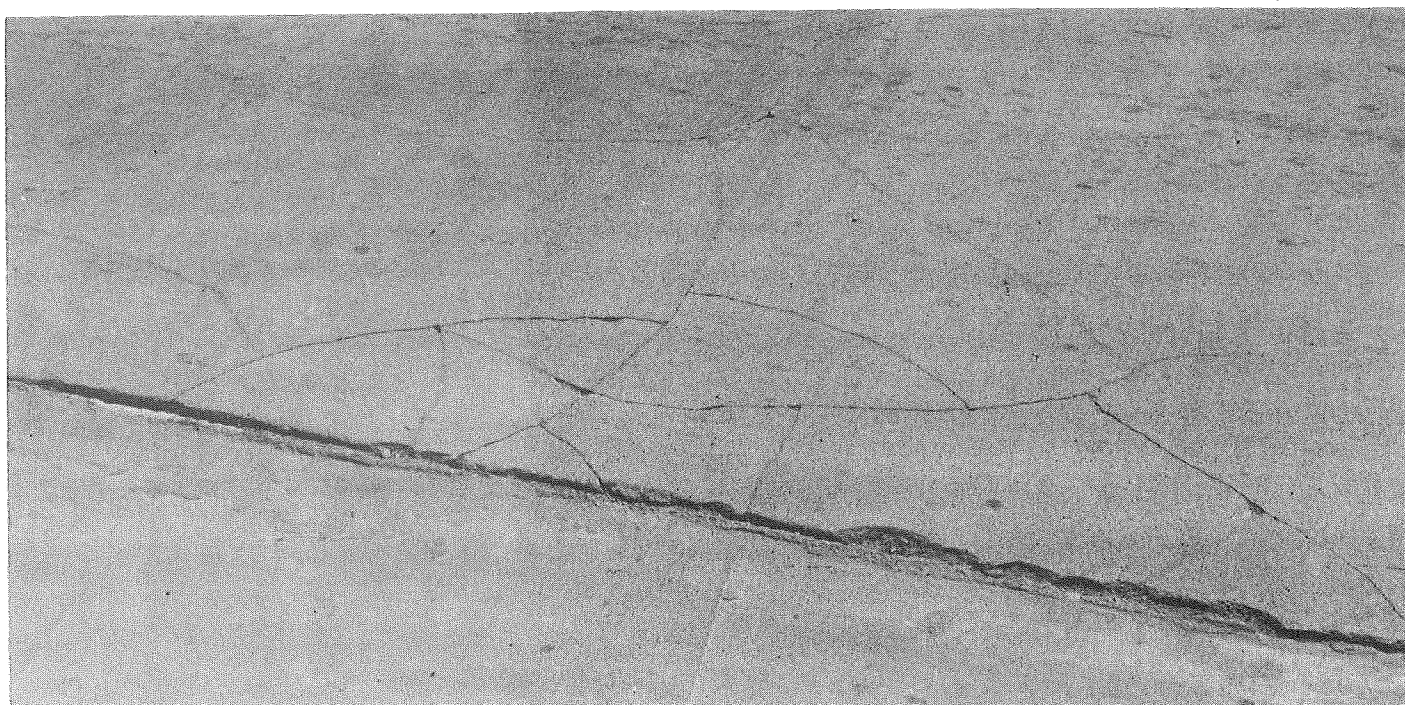


Figure 10. Extensive cracking and loose latex mortar on east end of Lane F after one winter. April 1958.

Figure 11. Cracking and loose mortar in west end of Lane D after one winter. April 1958.



EVALUATION AND REPAIR

Evaluation: 1958

On April 15, 1958, the latex-cement mortar thin surfacing on the Cheboygan bridge was appraised after exposure to its first winter. Two quite extensive areas were badly cracked and loosened from the substrate. Fig. 10 is a closeup of the east end of Lane F, containing cracked and loosened latex-cement mortar which had been applied over a dry substrate. A similar failure of the latex-cement mortar was found at the west end of Lane D, where the prepared base had been broomed with a straight solution of Latex 560 emulsion (Fig. 11). Only these two test areas appeared to be losing bond in April 1958.

Repair: 1958

By September 1958, it was apparent that a large portion of the latex-cement mortar resurfacing had loosened and would need replacing. Almost all the area applied over a wet substrate remained intact, but the other three methods of surface preparation exhibited the following degrees of failure:

Dry and untreated - 80 percent
Latex bond coat - about 50 percent
Latex-cement slurry - 100 percent

All these loosened areas were removed and cleaned with pneumatic chisels and sandblasting. It was decided that these areas should be repaired using a latex-cement mortar containing the newer X2130.1 experimental latex emulsion. The tests reported in Table 1 had shown that this latex emulsion was superior to Latex 560 in some properties; in particular, the shear bond strength was about double.

On September 27 and October 6, 1958, the Latex X2130.1-cement mortar was used to replace all the loosened areas. The materials were handled and mixed essentially the same way as in September 1957. Mix data for the three mortar batches involved are presented in Table 4 and the deck placement in Fig. 12. The deck areas to be replaced were cleared of loose patch material and then washed and soaked with water just before resurfacing.

TABLE 4
LATEX X2130.1 MORTAR DATA
September-October 1958 Field Mixes

Batch No.	1	2	3
Pour date	9-27-58	10-6-58	10-6-58
Sand (2NS)*			
wet, lb	5280	5280	2640
dry, lb (approx.)	4950	4950	2475
Type I cement, lb	2726	2726	1410
Latex X2130.1 (51 percent solids)**			
gal	77	77	38
lb	801	801	395
solids, lb	408	408	202
Additional water, lb	250	250	125
Diethylene glycol, gal	6.75	6.75	3.25

Dry sand-cement ratio = 1.82
Water-cement ratio = 0.31
Latex-cement ratio = 0.15
Diethylene glycol-cement ratio = 0.05 (approx.)

* Soaked by two days rain; dry weight obtained assuming 6.5 percent water (moisture content of soaked sand on 9-26-57).

** Contained 0.2 percent DC Antifoam B solids based on latex solids.

The new mortar differed from that placed a year earlier in that a nominal sand-cement ratio of 2:1 was used, with a latex solids to cement fraction of 15 percent. About 5 percent diethylene glycol was added to the mortar to increase the finishing time and reduce the tendency of the latex mortar to skin over and produce shrinkage cracks. The glycol reduced but did not entirely eliminate this tendency.

The pour of September 27, 1958, was placed and finished during intermittent rain and the surface required some refinishing after two or three hours. Some shrinkage cracks were noted in various areas of this pour. All three pours had a considerable amount of rain during their seven-day curing period.

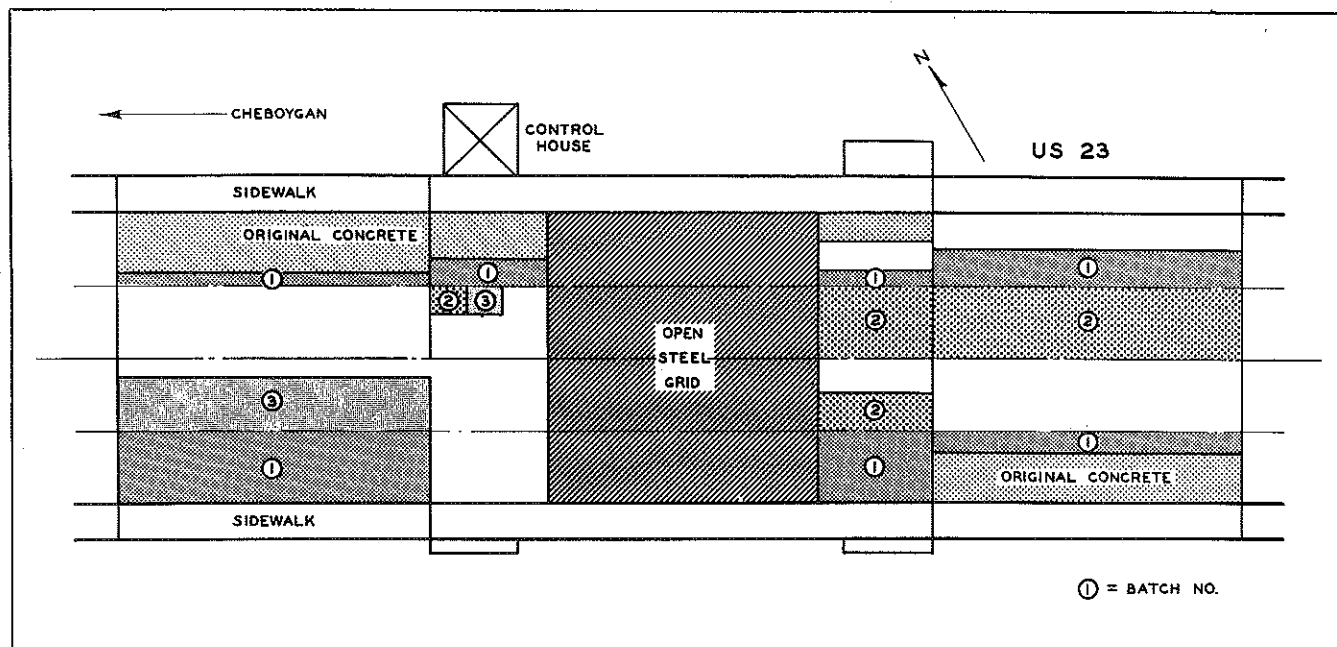


Figure 12. Placement of Latex X2130.1 mortar mixes in October 1958
(see Table 4)

Evaluations: 1959

On April 14, 1959, another inspection trip was made to the bridge site. The remaining 1957 sections and those reapplied in 1958 were still bonded to the old bridge deck. A few newly spalled areas were found in the old concrete surface of sidewalk areas J and K, bordering some of the 1957 latex-mortar patches (Fig. 13). However, all the latex mortar areas appeared sound.

The bridge was examined again on August 7, 1959. The sidewalk spalling in the original concrete around the latex mortar patches observed in April was spreading even farther (Fig. 14). This breakdown of old concrete over the filled grid sidewalk may gradually loosen the adjacent latex-mortar patches. Surface dampness because of rain during this inspection made the fine crack network in the September 1958 repair work especially clear (Fig. 15), but patches seemed to be bonded to the concrete. General views of the sound latex mortar resurfaced lanes after two years of exposure are presented in Fig. 16.



Figure 13. Newly spalled areas in north sidewalk, some adjacent to patches.

Figure 14. Further failure around large latex mortar patch in north sidewalk.

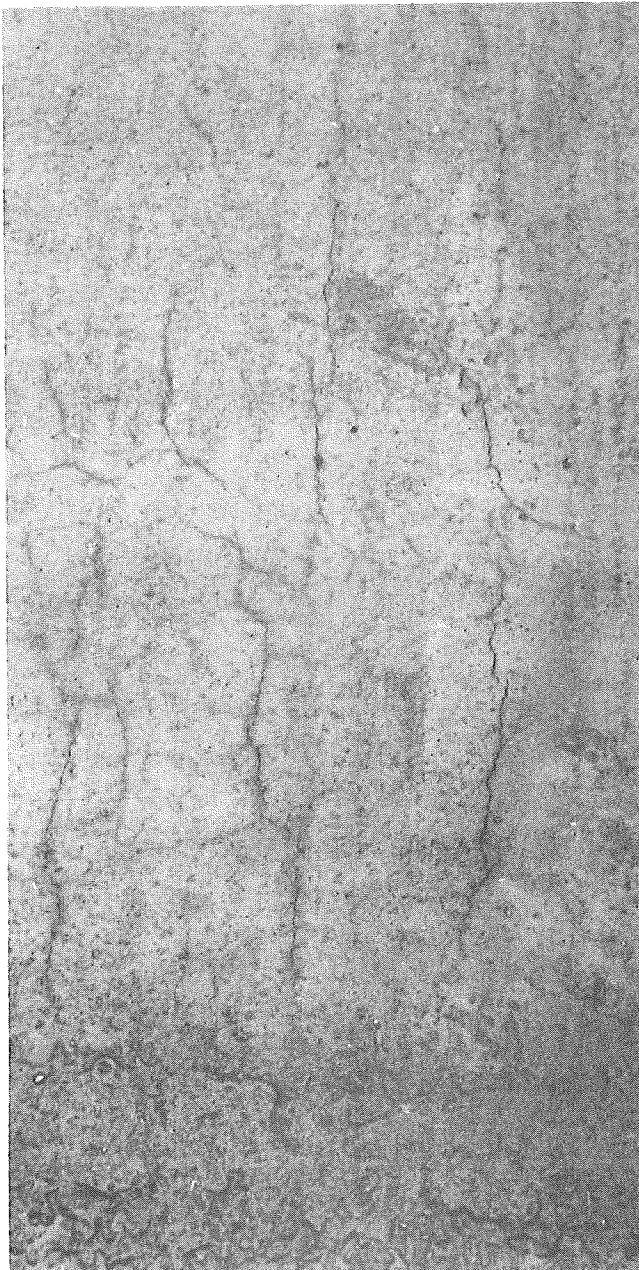


Figure 15. Network of shrinkage cracks in latex mortar resurfacing on southeast lane, after one winter.

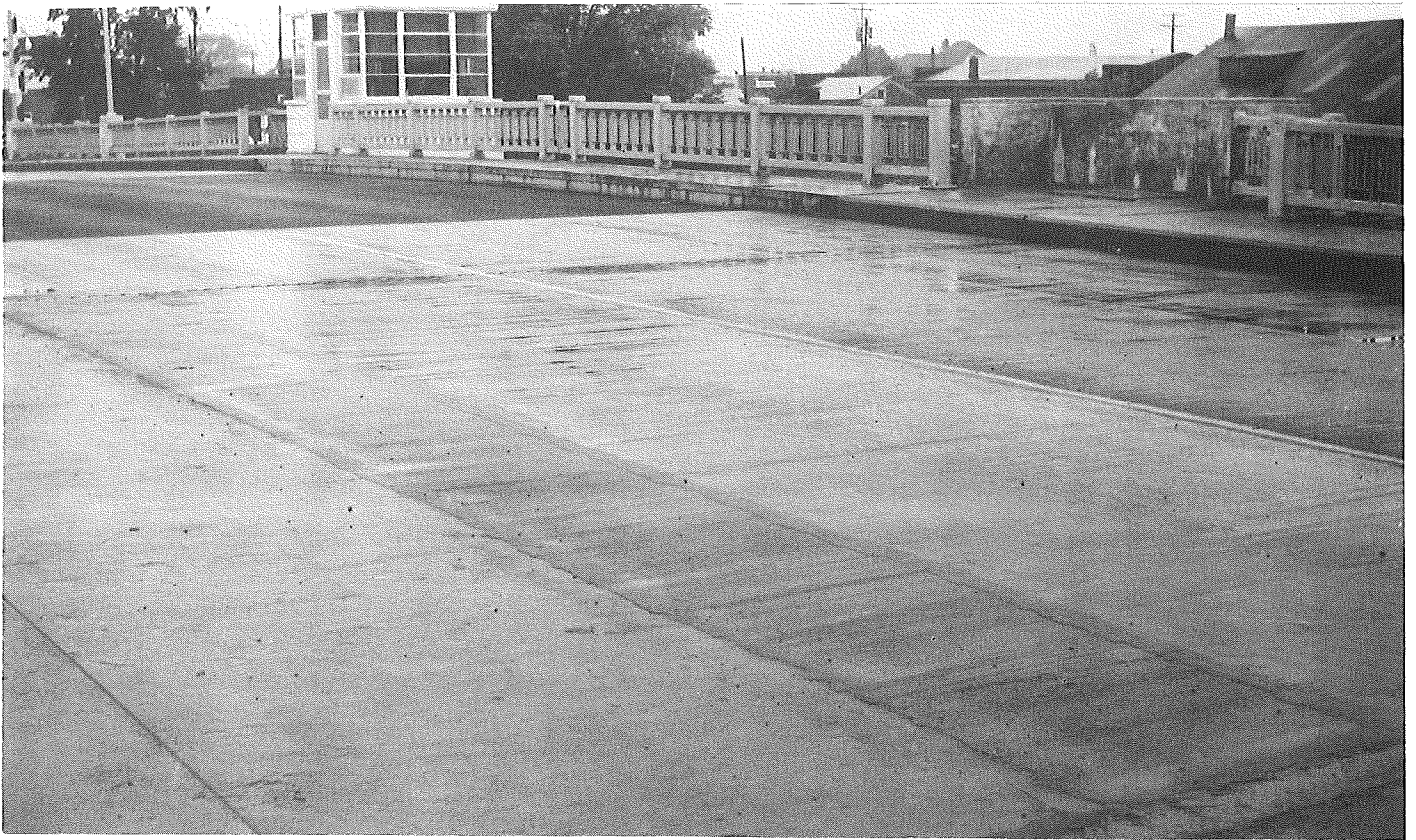


Figure 16. General views of the bridge deck showing overall sound condition of latex mortar lanes in August 1959, after two winters; east end (top) and west end (bottom).

DISCUSSION AND SUMMARY

Laboratory Study

Compressive strength data for the Latex 560 specimens in Tables 1 and 3 differ, but it may be noted that field specimens were 3- by 6-in. cylinders, and laboratory specimens were 2-in. cubes; curing conditions were also different. The field mixes undoubtedly contained more air from entrainment, even though Type I cement and an antifoamer were used. However, their air contents were not abnormal and the performance of freeze-thaw beams through 300 cycles showed good durability.

The low values of dynamic modulus for the Latex 560 field beams illustrate the greater flexibility of latex modified mortars. Regular mortar would have a dynamic modulus of 5 to 6 million psi as compared to the 2.2 to 2.6 million for the latex mortar. This greater flexibility undoubtedly would enhance the bonding properties and subsequent durability of latex mortar patches in the field. It is anticipated that this flexibility will be retained even after years of exposure.

The drop in 90-day flexural strength in Table 3 is thought to be due to the moist condition of the beams from outdoor curing at the time of the test. Dry specimens show recovery and additional gain at seven months testing age. The adverse effect of moisture on flexural strength is more pronounced for Latex 560 than for Latex X2130.1.

Field Application

The two-winter exposure on the Cheboygan bridge shows that the original Latex 560 mortar has maintained bond without any failure on the substrate washed and soaked with water prior to patching. This is in accord with experience in conventional patching and repair work in the field.

It is evident from the Cheboygan bridge experience with placing and finishing latex modified mortars that greater fluidity can be obtained with fairly low water-cement ratios. It is also apparent that the latex mortar is very susceptible to skinning over and shrinkage crack formation if not covered immediately after final finishing operations. This is particularly true when the weather is sunny, warm, and windy. The use of diethylene glycol in mixes of October 1958 reduced but did not eliminate this tendency. The unusual bonding property of latex mortar was evident

in the way it stuck to wood and metal finishing tools and steel joint plates on the deck.

The patching mixes of Fall 1958 may have been too rich in cement, having a sand-cement ratio of 1.8:1 as compared to the ratio of 2.8:1 used in September 1957. Excessive refinishing necessitated by considerable rain during placement may have promoted the extensive crack formation which occurred in the areas patched September 27, 1958. Similar Latex X2130.1 mixes placed under more normal conditions one week later showed no cracks after a year of exposure.

The two lanes of Latex 560 mortar placed over a wet substrate are intact after two years, and the Latex X2130.1 mortar areas are sound after one year. These lanes will be examined and evaluated after additional winters of exposure. Further field exposures using latex modified mortar would be valuable, preferably using the Saran type emulsion and employing higher sand-cement ratios or leaner mixes with several latex-cement ratios.

ACKNOWLEDGMENTS

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