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Bulletin 260

Repair of Structures and Pavement by Thin Concrete Patching

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Contents

Latex-Modified Mortar in the Restoration of Bridge Structures

S. M. CARDONE, M. G. BROWN, and A. A. HILL, Respectively,
Chief, Maintenance Operations Division and Chemical Engineer, Michigan State Highway Department; and Coatings Technical Service, Dow Chemical Company

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, Mich., 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, 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 incorporated in patching mixes for restoration of a deteriorated bridge deck.

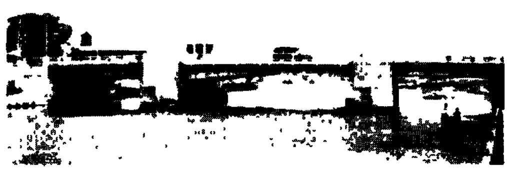

Figure 1. Bascule bridge on US 23, Cheybogan, Michigan.

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, Mich., 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, par-

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.

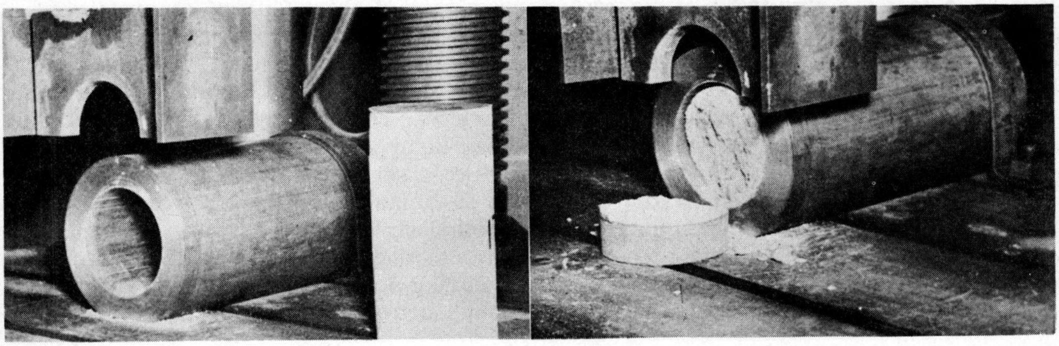

Figure 2. Laboratory equipment for determining shear bond strength of latex-cement mortar patches on concrete cylinders.

Figure 3. Typical scaled and polished concrete deck surface.

Figure 4. Cutting machine used to remove minimum of $\frac{1}{2}$ in. of scaled concrete.

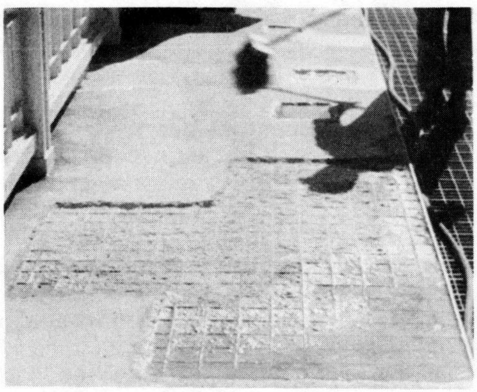

Figure 5. North sidewalk patches chipped to squared edges.

ticularly in shear bond strength. The shear bond tests were run on the various mortar coatings applied to 3⅜-by 6-in. concrete cylinders, cured 14 days prior to capping, and tested as shown in Figure 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 ½-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.

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. Little water was added, because about 6 percent water was contained in the sand. Typical placement and finishing are shown in Figure 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 Figure 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.

All latex-cement mortar mixes were quite fluid, but the net water-cement ratios were fairly low (Table 2). 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 6 days. Upon completion of this 7-day curing period, the resurfaced areas were opened to traffic.

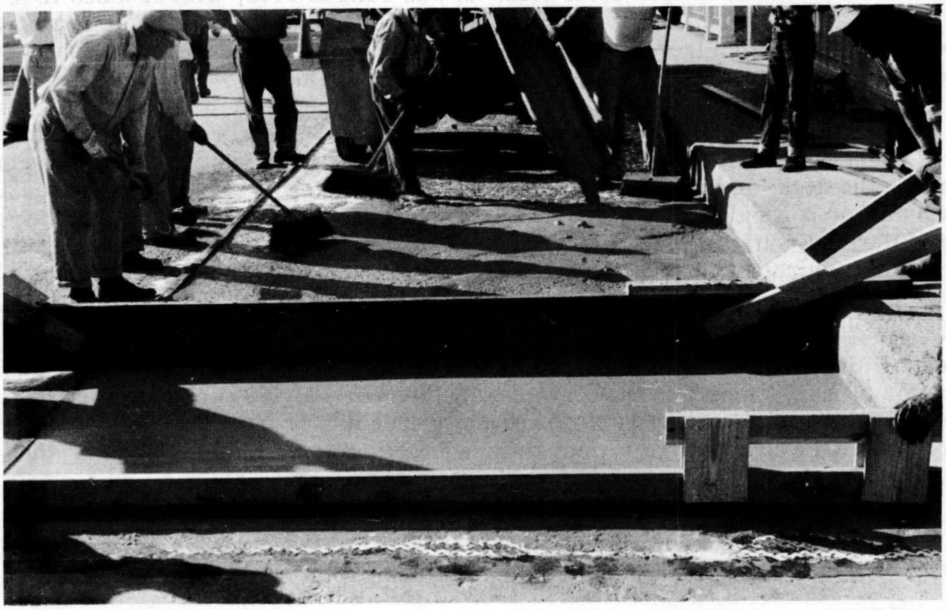

Figure 6. Typical placement and finishing procedure for latex-cement mortar.

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.

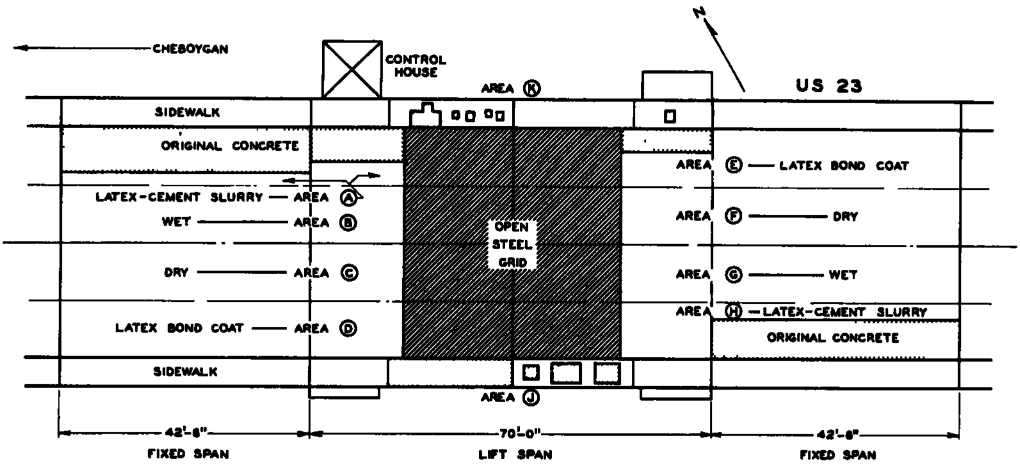

Figure 7. Placement of Latex 560 mortar mixes in September 1957 (see Table 2) with four types of substrate treatment.

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 15-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	
28 days	A-4	2603	A-6	956	2.3
	A-5	2617	A-7	956	2.4
	B-4	2461	B-6	873	2.4
	B-5	2405	B-7	882	2.4
	average	2522	average	917	
90 days	A-3	2977	A-9	689	2.6
	A-7	3246			
	B-7	3091	B-9	767	2.6
	B-8	3055			
	average	3092	average	728	
7 months	A-6	3197	A-3	1033	
	A-8	3296	A-8	900	
	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.

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. Figure 10 is a close-up 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

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).

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; and
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 given in Table 4 and the deck placement is shown in Figure 12. The deck areas to be replaced were cleared of loose patch material and then washed and soaked with water just before resurfacing.

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.

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.

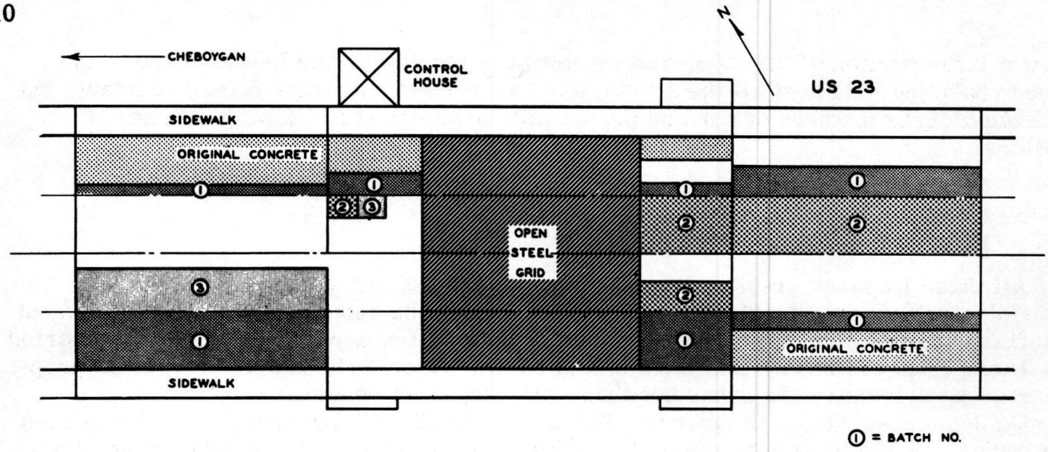

Figure 12. Placement of Latex X2130.1 mortar mixes in October 1958 (see Table 4).

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 2 or 3 hr. Some shrinkage cracks were noted in various areas of this pour. All three pours had a considerable amount of rain during their 7-day curing period.

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 shown in Figure 16.

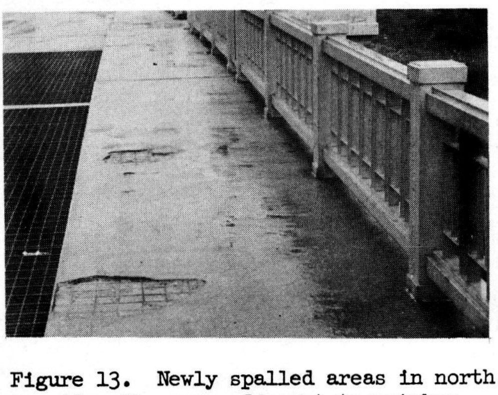

Figure 13. Newly spalled areas in north sidewalk, some adjacent to patches.

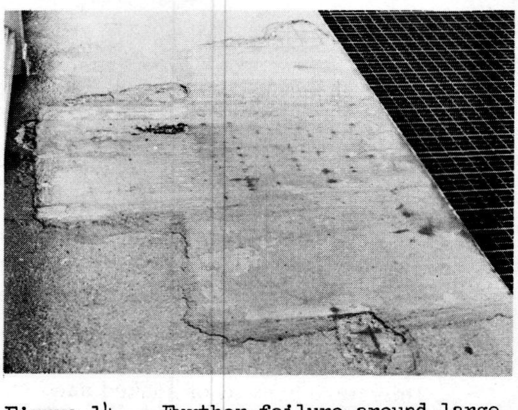

Figure 14. Further failure around large latex-mortar patch in north sidewalk.

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

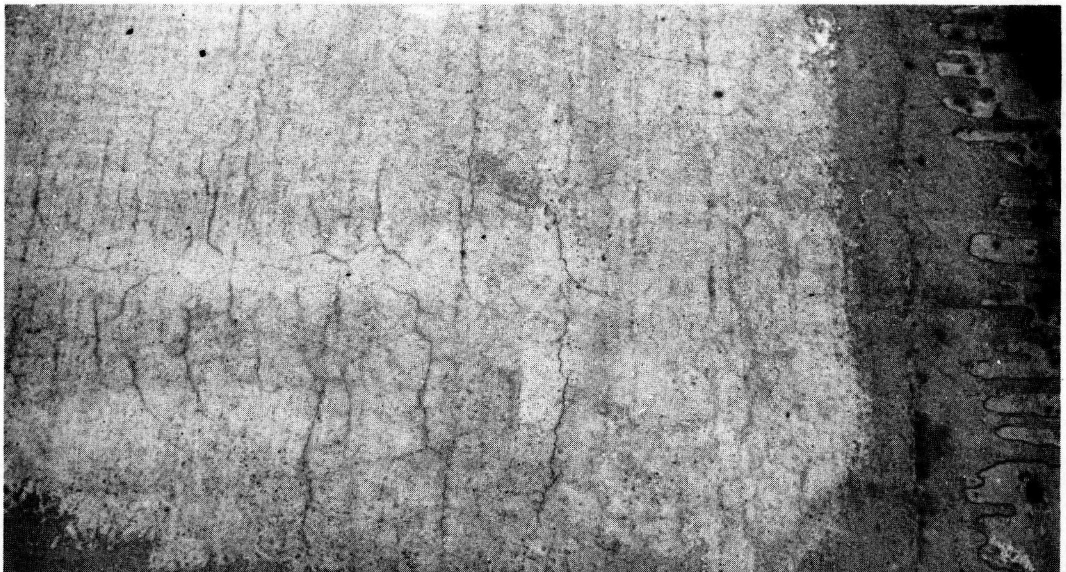

Figure 15. Network of shrinkage cracks in latex-mortar resurfacing on southeast lane, after one winter.

Figure 16. General views of the bridge deck showing over-all sound condition of latex-mortar lanes in August 1959, after two winters; east end (upper) and west end (lower).

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 one 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

The work described in this report was conducted under the general supervision of E. A. Finney, Director of the Research Laboratory Division, Michigan State Highway Department. The Laboratory is a Division of the Department's Office of Testing and Research, headed by W. W. McLaughlin, Testing and Research Engineer.

The authors wish to acknowledge the help of members of the Laboratory staff and, in particular, W. W. McLaughlin and E. A. Finney; and I. J. Cummings and R. B. Drubel of the Coatings Technical Service, Dow Chemical Company, for their initiation of this project and guidance and cooperation. They also wish to commend the Bridge Maintenance crew who did a fine job of preparation and application.

Bonded Resurfacing and Repairs of Concrete Pavement

WILLIAM G. WESTALL, Senior Airfield Engineer, Highways and Municipal Bureau, Portland Cement Association, Chicago, Ill.

● FOR SEVERAL YEARS the Research and Development Division of the Portland Cement Association has investigated methods and materials for bonding relatively thin layers of concrete to old pavements or floors. The latoratory tests were designed to evaluate such factors as surface cleanliness; smooth and roughened surfaces; damp and dry surfaces; cement-sand mortars and neat cement grouts for bonding courses; concrete resurfacing mix designs; and methods of placing the resurfacing concrete, including surface and internal vibration, mechanical float compaction and pneumatic pressure application. Tests were made of the effectiveness of the bond as measured by the load required to shear the concrete along the plane of the junction of the two layers of concrete. These tests indicated that the most important single factor was the condition of the old surface—its cleanness, texture, and strength or soundness. If the surface was clean and free of a weak outer skin, very good bond was generally obtained; otherwise relatively poor bond was obtained.

These laboratory investigations are described in detail by Felt (1).

The purpose of this paper is to discuss bonded concrete construction and its various applications to pavements, to describe projects which have been accomplished, and to illustrate the essential steps in surface preparation and construction. All the jobs discussed were constructed at airports.

THIN BONDED CONCRETE RESURFACING

Although layers of concrete ½ in. thick have been successfully bonded to old pavements in both laboratory and field applications, this paper deals with resurfacings varying in depth from 1 to 4 in. because the projects were within these ranges.

In the past five years there have been five sizable jobs of thin bonded concrete resurfacing on existing concrete at airports. These were Little Rock Air Force Base, Ark., in 1955; Selfridge Air Force Base, Mich., in 1956; Campbell Air Force Base, Ky., in 1957; Bunker Hill Air Force Base, Ind., and Standiford Field at Louisville, Ky., in 1959. All these projects were accomplished under contract conditions.

The Selfridge Air Force Base Project

Though out of chronological order, the Selfridge Air Force Base project will be considered first. It is the largest in area of any project built to date and includes construction techniques common to the other projects plus problem features of its own.

In August and September 1956, a thin bonded resurface was applied to 47,000 sq yd of the aircraft parking apron at Selfridge Air Force Base which is near Mt. Clemens, Mich. Approximately 37,000 sq yd of the project area consisted of 10-in. concrete 14 yr old. The remaining area was 6-in. concrete 27 yr old. The principal defects in the pavement corrected by the resurfacing were surface scaling (Fig. 1), raveling along joints, and surface popouts over unsound particles of aggregate. There was also a considerable amount of random cracking, both transversely and longitudinally.

The Air Force specifications for the bonded resurfacing provided for preparing the surface and placing concrete of a minimum of 1-in. thickness in the following sequence of operations.

The first step in surface preparation was the removal of all bituminous material from joints, cracks and elsewhere on the pavement. The excessive amount of jetfuel resistant sealer which had been applied, the hot weather during removal, and the irregularity of the joints were contributing factors to difficulties encountered in joint cleaning operations. This irregularity also made jointing of the resurfacing more difficult.

TABLE 1

RECOMMENDED TRIAL CONCRETE MIXES FOR THIN RESURFACING

Resurf. Thickness (in.)	Cement Content (lb)	Total Water[1] (lb)	Fine Agg.[2] (lb)	Coarse Agg. Max. Size (in.)	Coarse Agg. Amt.[2] (lb)	Air Content (%)	Cement Factor[3] (s/cy)	Slump (in.)
½	94	42	190	⅜	115	9 to 11	8.5	1 to 4
1	94	42	170	½	170	6 to 8	7.5	1 to 4
2	94	42	190	1	230	5 to 7	7.0	1 to 4
3 (or more)	94	42	180	1½	305	4 to 6	6.3	1 to 4

[1]Including free moisture in the aggregates.
[2]Based on saturated surface-dry aggregate, s. g. 2.65.
[3]Approximate, sacks per cubic yard.

Sealer was removed from the joints by plowing with an improvised "foot" mounted on the front of a light tractor, followed by two or more passes of a Tennant machine adjacent to the joints (Fig. 2), supplemented by hand-operated spud bars. Experience had indicated that sand blasting is also effective for final cleaning of joints after use of the Tennant machine.

Because of surface scale and excessive laitance in many areas it was considered necessary to scarify approximately 80 percent of the pavement surface in order to provide sound, clean concrete for the bonded resurfacing. Scarification was carried out with a fleet of four Tennant machines with heads packed with 4-in. drop forged cutters so arranged as to make a clean cut about 4 in. wide. The debris created by the machines was removed by a combination of means: compressed air and hand push-brooms to clear the immediate working area and a mechanical pickup broom for final disposal.

At this point it should be emphasized that an extremely rough surface is not necessary in order to secure bond. Scarification is used only for the purpose of obtaining a sound surface. Felt's investigations (1) brought out that a slightly roughened

Figure 1. Scaled and raveled pavement at Selfridge Air Force Base.

Figure 2. Tennant machine used for cleaning joints and grinding surface.

surface, such as produced by acid etching, is satisfacory for bonding the resurfacing.

As is frequently the case on old concrete pavements, the areas which were not scarified on the Selfridge project had various substances on the pavement surface which would likely cause bond failure. These included oil and grease, hydraulic fluid, bituminous materials and paint markings. Paint and bituminous materials and the larger grease spots were removed by spot scarification. Areas not scarified were cleaned with a water soluble commercial detergent. The detergent powder (sodium metasilicate with resin soap) was applied to the wetted pavement surface at the rate of 1 to 2 lb per 100 sq ft with a hand-operated distributor similar to a seeder. The moistened detergent was then scrubbed into the surface with a mechanical sweeper and the surface flushed with water until it showed a neutral reaction to pH paper. Thorough flushing is necessary because the alkaline detergent, if it remained on the surface, would partially neutralize the acid subsequently applied for etching the surface.

Prior to acid etching, which is the final step in surface preparation, the pavement surface was cleaned by sweeping and blowing with compressed air.

The commercial muriatic acid (27.9 percent HCl) was delivered to the job by tank truck which was equipped with a 12-ft spreader bar (Fig. 3). A force pump on the truck supplied pressure for distribution which was regulated by the forward speed of the truck to give and application of 1 gal of acid per 100 sq ft on the pavement surface which has been previously wetted. It should be noted that this is a minimum requirement. Felt recommends 1 gal of acid per 60 sq ft of pavement. As soon as all visible etching or foaming action ceased, the pavement was scrubbed with a mechanical broom and flushed with water until it showed a neutral reaction to pH paper. Because the product of acid reaction forms a jell if left long on the concrete, it is important that the surface be cleaned by flushing and scrubbing as soon as the foaming action stops.

Figure 3. Tank truck used for distributing muriatic acid.

The foregoing surface preparation items have been described in chronological order. It should be remembered that several of these operations, as well as paving, must be carried out at the same time in order to obtain good production on a project of this size.

Specially designed wood forms were used along each edge of alternate paving lanes. Paving of the fill-in lanes (approximately one-half of the pavement area) required no forms. The forms were made from 2- by 8-in. fir planks 14 ft long surface dressed down to 1¼ in. These forms were laid flat along each side of the paving lane, parallel to the old construction joints so that the 1¼-in. thickness provided the depth of the form. Each length had four steel flanges which were countersunk and bolted to the bottom face of the form. The flanges extended 3 in. beyond the outer edge of the form and were bored to receive three bolts outside the form and one bolt through the form and countersunk flange. The inner edges of forms were positioned immediately above the longitudinal construction joint and holes drilled in the concrete to receive lead expansion sleeves and lag screws for securing the forms to the old pavement. After the forms were bolted in place they were shimmed to line and grade by means of wood wedges. A steel strip ¼ in by 2 in. was inserted into the longitudinal construction joint and tacked in a vertical position on the forms inner edge to bound the paving lane and to prevent grout and concrete from running under the forms.

The wood forms used at Selfridge could not be considered an unqualified success. With occasional readjustment and additional shimming during construction, they did serve to provide an acceptably smooth surface. Recognizing the limitations of comparatively thin wood boards when used as forms, the U.S. Air Force has specified a minimum thickness of 2 in. for thin bonded concrete resurfacing. This 2-in. minimum, instead of 1-in., will result in only slightly higher cost for material and will permit the use of sections of steel channel for forms or provide wood of a dimension that will have better rigidity.

After the forms were in place, the prepared surface was given a final cleaning. Any grease or oil spots from leaking equipment were removed with the Tennant machine. The pavement was then blown clean with an air jet.

Just ahead of placing concrete, a 1 to 1 sand-cement grout was applied to the old pavement surface (Fig. 4). The sand used in this mixture had been screened to remove the plus ⅛ particles. The grout was mixed to a heavy paint consistency in a paddle-type mixer, carried to the paving lane in buckets and scrubbed onto the damp but not wet surface with rattan stable brooms. A coating of about 1/16 in. was left on the surface. Any excess grout in transverse and longitudinal joints was redistributed with a warehouse broom. It should be mentioned that the pneumatic method of placing bonding grout has been successfully used. This method of application requires expert operation in order to control rebound and accumulation of the coarser sand particles along the form lines in a concentration likely to prevent bond. The lack of skilled operators and of proper pneumatic equipment dictated the use of hand methods of grout application on the Selfridge project.

Figure 4. Spreading bonding grout.

Ready-mix concrete was delivered to the site by transit mixers, two scheduled to arrive on the job and place concrete at the same time from each edge of the paving lane (Fig. 5). Each mixer carried 5 to 6 cu yd of concrete made from ½-in. maximum size crushed dolomite, 60 percent by weight of natural sand and 7½ bags of portland cement per cu yd. Mixing water was proportioned to give a net water content of 5 to 5.1 gal per bag of cement and a slump of 4 to 5 in. which was necessary for discharging from the mixer and for placing and finishing the resurfacing concrete. Sufficient air-entraining agent was added at the batching plant to produce an air content of 7 to 8 percent.

After a limited amount of hand spreading, the concrete was further spread during the first pass of a two-screed self-propelled finishing machine. A second pass struck and consolidated the concrete to final grade. The finishing machine was equipped with offset rubber-tire wheels which traveled on the old pavement outside the forms. This worked quite satisfactorily because it resulted in the wood forms supporting only the buoyant weight of the screeds.

After the two passes of the finishing machine, the pavement surface was given final finish with hand floats and straightedges. Surface texture was provided with a burlap drag. The resurfacing was cured with white pigmented curing compound. This method of curing was selected because it could be applied early to prevent the rapid loss of water and because it simplified subsequent joint sawing operations.

In bonded concrete resurfacing it is necessary to match exactly the joints in the old pavement both in location and kind. Longitudinal and transverse expansion joints were formed in place using wood strips which were inserted in the joint crevice of the old

Figure 5. Concrete delivered to both sides of paving lane by transit mixers.

pavement. These strips marked the location of expansion joints during paving and served as a filler in the finished resurfacing.

Transverse contraction joints were sawed with abrasive-type blades. To saw through the resurfacing and directly over the joint in the old pavement, it was necessary to carefully mark these joint locations on side forms or on the surface of adjacent paved lanes and snap a line on the finished surface of the plastic concrete to mark the exact location of the saw cut. Sawing had to be done early in order to prevent precracking over joint locations. It was done from 5 to 12 hr after paving depending on temperature and relative humidity. During cool weather the joints were sawed dry which permitted earlier sawing with a minimum of raveling along the cut.

To meet the grade of the adjacent pavement, a 3-ft ramp was built around the resurfaced area. The ramp area was routed out to a minimum depth of 1 in. and the concrete for the ramp was placed by the same procedure as the other resurfacing. Planes can enter the resurfaced area under their own power without any difficulty.

To check the thickness of the resurfacing and to provide specimens for testing the strength of bond between the resurfacing layer and the old pavement, cores were drilled from the finished pavement (Fig. 6). By its appearance, the resurfacing layer is easily distinguished from the basic concrete. Fifteen of the cores showed an average bond strength of 323 psi when tested by shear stress in the laboratory. Felt's investigations led him to the conclusion that bond strength on the order of 200 psi is generally sufficient to insure adequate performance of bonded resurfacing.

After more than three years of service, the resurfacing at Selfridge Air Force Base is showing good performance. Most of the random cracking of the old pavement has appeared in the resurfacing layer. These cracks are generally close and tight and have not required grouting and sealing.

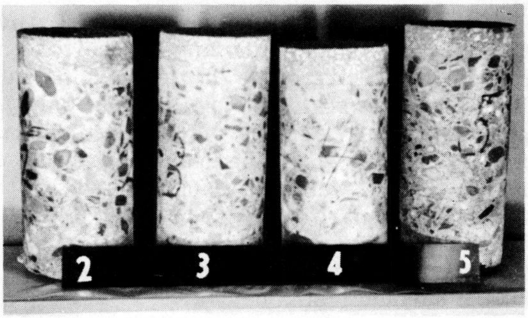

Figure 6. Cores taken from resurfaced concrete at Selfridge Air Force Base.

The Little Rock Air Force Base Project

The bonded resurfacing at Little Rock Air Force Base, placed in early October 1955, was done to repair the surface of concrete pavement placed several months before which had frozen immediately after placing. The pavement involved was about 700 ft of a 25-ft wide paving lane. Only the immediate surface of the pavement was damaged to a depth of about ½ in. The Army Corps of Engineers held the contractor responsible for replacement of the damaged concrete which was 15 in. thick and part of an aircraft parking apron.

The contractor broke out part of the concrete which proved difficult and costly because the damaged area was on a 1111-1n lane bounded on both sides by concrete. An agreement was reached permitting the contractor to restore the surface of the remainder of the pavement with a bonded layer of 1 in. thick.

Preparation of the pavement required scarification to a depth of 1 in. This scarification, on a fully matured slab with large sized natural aggregate, proved somewhat tedious and relatively costly. A total of 575 lin ft of 25-ft paving lane, approximately 1,600 sq yd, was prepared for resurfacing.

No forms were necessary on the Little Rock project since the adjacent paving lanes bounded the work and provided grade and elevation for the finished resurfacing. The prepared surface was etched with muriatic acid by use of an improvised dispenser. This device was made by fastening a coiled plastic garden hose on a square of plywood which was equipped with a carrying handle. Three loops of hose on the bottom of the board were perforated and the acid forced through the hose by hand pump from glass containers mounted on the bed of a pickup truck. Acid was applied at the approximate rate of 1 gal per 100 sq ft to the wetted pavement. Workmen equipped with goggles and protective clothing spread the acid over the pavement with pushbrooms (Fig.10). When the acid reaction ceased, the pavement was scrubbed and flushed with water until it showed neutral reaction to pH paper.

The placing of bonding grout and concrete followed the procedure described for Selfridge Air Force Base except that concrete was provided by a dual drum job mixer instead of transit mixer and that the two-screed finishing machine had two spud vibrators mounted on the front screed. The concrete was made from 45 percent ½-in. maximum size crushed aggregate and 55 percent natural sand with 7¼ bags of cement per cu yd and approximately 8 percent entrained air.

Using standard metal inserts, the joints in the resurfacing were hand formed in such manner as to provide continuity through the resurfacing layer of the joint openings in the basic pavement. The resurfaced concrete was cured with wet burlap for three days followed by an application of white pgmented curing compound.

After more than four years of service, this section of thin bonded resurfacing shows no defects of any type and is, in fact, indistinguishable in appearance from the adjoining pavement on the parking apron. This pavement has been put to a somewhat severe test by the 50,000-lb individual wheel loads of the jet bombers based at Little Rock.

The Campbell Air Force Base Project

Portions of two hardstand areas at Campbell Air Force Base, Ky., were given a 2-in. bonded resurface during the summer of 1957. The resurfacing was placed on 500 lin ft of the 25-ft center lanes of the hardstands, a total of approximately 1,400 sq yd. This was new 17-in. concrete which did not meet the finish and surface requirements of the Corps of Engineers' job specifications. Agreement was reached to permit the contractor to correct the construction deficiency by placing a 2-in. bonded resurfacing.

Paving of the outside lanes of the hardstands was deferred until after the resurface was placed on the center lanes. The construction situation allowed a raise in elevation of 2 in. to accommodate the resurfacing on the 400-ft center lane of one of the hardstands This area was scarified to a depth of only ⅛ to ¼ in. in order to remove curing compound and faulty surface. The entire area of the other 100-ft center lane was cut 2 in. in depth so the resurfaced pavement would conform to the elevation of the original pavement. Forms were set along the sides of the 25-ft lanes and graded to an elevation 2 in. above the prepared surface.

The scarified surface was etched with muriatic acid by means of a plastic hose device similar to that used at Little Rock and the acid residue was then flushed away until the surface tested neutral.

A 1 to 1 sand-cement grout was spread on the dampened surface with pushbrooms. The resurfacing concrete was made from 50-50 crushed limestone of 1-in. maximum size and stone sand, with 7 bags of cement per cubic yard and approximately 7 percent entrained air. This low slump mixture was placed on the grout-coated surface and vibrated by conventional hand-type vibrators which were pulled through the plastic concrete in a longitudinal direction ahead of the two-screed finishing machine. A mechanical longitudinal float was used behind the transverse finisher and final finishing was by hand floats and scraping straightedges. Surface texture was provided by a burlap drag.

Joints in the resurfacing layer were located exactly over original joints by use of a transit line and sawed to a depth of 3 in. The extra inch of saw cut was to provide assurance that joint openings in the basic concrete were cleared of grout or concrete. The resurface was cured with wet burlap.

After more than two years trafficking by heavy aircraft the resurfacing at Campbell Air Force Base shows no defects of any type.

The Bunker Hill Air Force Base Project

During the early summer of 1959 a 3-in. bonded concrete resurface was placed on 45,000 sq yd of the aircraft parking apron at Bunker Hill Air Force Base, Ind. The old pavement was 8-in. concrete constructed during World War II which had developed surface defects consisting of popouts, scaling and minor spalling plus a few broken slabs requiring removal and replacement. Furthermore, the pavement required some strengthening to support the load imposed by the aircraft scheduled to use it. A design analysis indicated a requirement for a slab thickness of approximately 11 in. It was assumed that a 3-in. layer bonded to the existing 8-in. pavement would provide the required capacity and avoid the necessity for a considerably thicker unbonded overlay.

Construction procedures followed closely those previously described. Loose and damaged material was removed from the surface by mechanical scarification followed by treatment with muriatic acid. The laminated wood forms fabricated by the contractor were of sufficient rigidity to support the vibrating screed used for mechanical finishing and a level true surface was achieved. Transverse joints were formed by the use of paper inserts vibrated into the plastic concrete over the old joint locations. These inserts provided positive crack control until they were later sawed out just prior to sealing the joints. Longitudinal center joints were sawed after the concrete had hardened sufficiently to prevent raveling. The crushed limestone used for coarse aggregate served to facilitate the sawing operations.

The bonded resurfacing at Bunker Hill served the dual purpose of restoring the surface and strengthening the pavement with only a small increase in the pavement elevation

The Standiford Field Project

During the summer of 1959 a 4-in. bonded concrete resurface was placed on 500 ft of a runway end at Standiford Field, Louisville, Ky. This resurfacing was built for the dual purpose of correcting surface defects and raising the grade of the runway end to conform to the elevation of a 4-in. bituminous overlay placed over an adjacent portion of the runway. Concrete was required on the runway ends because of utilization of the runway by the Kentucky National Guard for flight training in jet aircraft and the probability of future use by commercial jet transports.

The approximately 8,000 sq yd of bonded resurfacing was constructed using the techniques previously described. Defective surface material was removed from the old concrete by mechanical means and the prepared surface was etched with muriatic acid. Four-inch metal sidewalk forms were used on the 12½-ft paving lanes as the contractor elected to set forms to conform to the longitudinal joints in the old pavement. The concrete was struck off and consolidated by use of a hand-operated vibrating screed (Fig. 7).

Longitudinal joints were formed by a full depth fiberboard insert which was tacked to slab edges prior to placement of the alternate fill-in lanes (Fig. 8). About 1 in. of the insert was later sawed out to form a reservoir for joint sealer. Expansion joints were formed over existing expansion joints by use of a nonextruding joint filler. Contraction joints were sawed at the joint locations in the old pavement.

Figure 7. Hand-operated vibrating screed used at Standiford Field, Louisville,

PATCHING AND REPAIR OF CONCRETE PAVEMENT WITH BONDED CONCRETE

Patching and repair of concrete pavement can be effectively accomplished by the use of bonded concrete. Preparation for patching must be with the same care and attention to detail as required in bonded resurfacing and the base concrete must be structurally adequate, after removal of defective areas, to provide a sound clean surface for the bonded patch.

One recent project at a U.S. Air Force base, which included a variety of types of repairs, will serve to illustrate the essential principles of placing bonded patches.

The Seymour-Johnson Air Force Base Project

Due to the development of a considerable amount of joint spalling on some 11-in. concrete resurfacing at Seymour-Johnson Air Force Base, Goldsboro, N.C. a program of repairs to the pavement was carried out in August 1957.

The pavement involved was on an aircraft parking apron which had been strengthened by concrete overlay about a year before the repairs were made. It is not the purpose of this report to state the reason for the spalling. Similar conditions have been observed on other projects where the steel inserts for forming joints were not removed early enough and the concrete next to joints was split horizontally when inserts were pulled out. At Seymour-Johnson, when concrete was sawed preparatory to patching, the sawed face revealed horizontal laminations extending back as

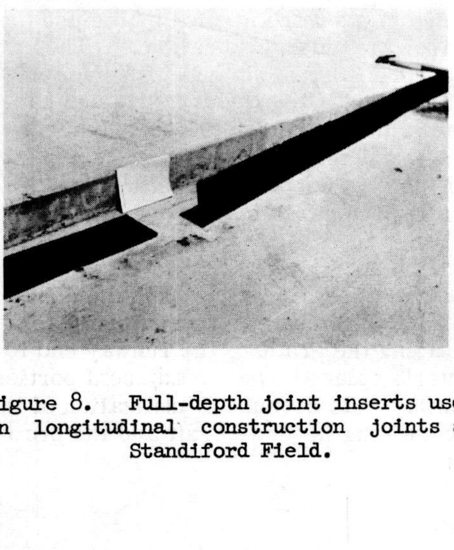

Figure 8. Full-depth joint inserts used in longitudinal construction joints at Standiford Field.

far as 10 in. from the joint. The depth of spalls indicated that the laminations occurred at depths of less than 2 in.

Figure 9. Removing concrete adjacent to joints at Seymour-Johnson Air Force Base.

Although most of the patches were to repair joint defects, there was one defective area of approximately 100 sq ft in the center of a slab which was repaired. Another area (12 by 48 ft) of sound concrete was sawed out and replaced by bonded patch in order to correct an unsatisfactory drainage condition.

The defective concrete along joints was removed by use of a diamond blade concrete saw and penumatic paving breaker. A saw cut was made to a depth of 2 in. parallel to the joint at 6-in. spacing. The 6 in. of concrete between the joint and saw cut was then broken out with pneumatic tools. If the face of the saw cut showed completely sound concrete, the patch was placed at 6-in. width. If the face of the saw cut showed one or more horizontal cracks, another 6-in. section was sawed and removed (Fig. 9). This process of removing 6-in. increments was continued until a sound vertical face was obtained. Some irregular patches were formed inasmuch as pavement was sawed out only as necessary to remove the loosened surface (Fig. 10). Concrete was removed from the large areas by the same methods. Saw cuts were made 2 in. deep, 12 in. apart, and concrete was broken out with pneumatic tools.

After excavations were cleaned, each area was thoroughly checked to insure removal of any loosened or fractured concrete that might remain. Due to the difficulty of cutting to a uniform thickness, the average depth of the patches was approximately 3 in.

Prior to acid etching, all dust was blown out with compressed air. The surface was then wetted. Acid was applied through a plastic hose apparatus from a glass carboy of muriatic acid (Fig. 10). It was difficult to broom acid uniformly on the irregular surface, consequently more than the usual amount was used. Applied at the rate of approximately 2 gal per 100 sq ft, the acid was broomed about until adequate coverage was assured. Brushes with fiber bristles were used to apply acid to the cut faces of the concrete.

Figure 10. Prepared patch receiving acid treatment. Note improvised acid dispenser at right.

Figure 11. Applying bonding grout prior to placing patch.

Acid was removed from the excavations by first filling the depression with water then applying a high pressure jet to blow out the acid water and clean the surface. This was contiuned until a neutral reaction to litmus paper was obtained. A 1:1 sand-cement grout was brushed into the surface, indlucing the vertical faces of saw cuts (Fig. 11).

Patches were placed with properly proportioned concrete containing 1-in. maximum coarse aggregate, 7 bags of cement per cubic yard, and 5 percent entrained air. Water-cement ratio was maintained at not more than 5 gal per bag of cement. Concrete was placed at 1¼-in. slump and vibrated for leveling and consolidation with a portable vibrator (Fig. 12). After vibration the concrete was struck-off with a wood 2x4 and hand-floated (Fig. 13). The large areas were finished with a 10-ft straightedge. Surface texture was provided by brooming.

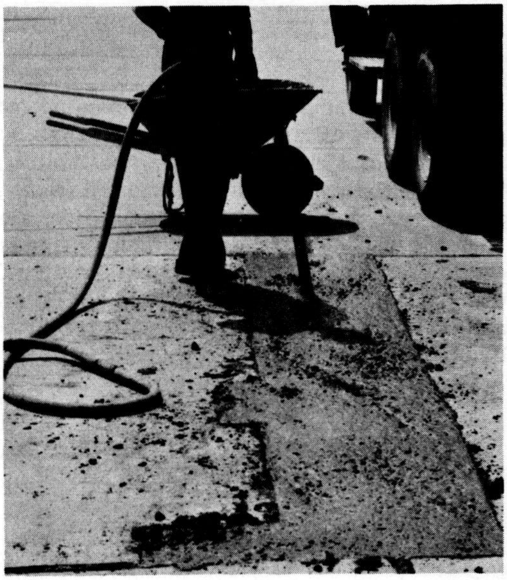

Figure 12. Hand vibrator used to consolidate concrete in patch.

During patching operations no attempt was made to keep existing joints open. Instead, joints were reformed by sawing some 7 or 8 hr after the patches were placed (Fig. 14).

Wet burlap cure was applied for three days followed by application of white pigmented compound. Patches were allowed to cure for 2 weeks before plane traffic was resumed.

After more than two years of service under heavy bomber traffic, these bonded patches show no defects of any kind.

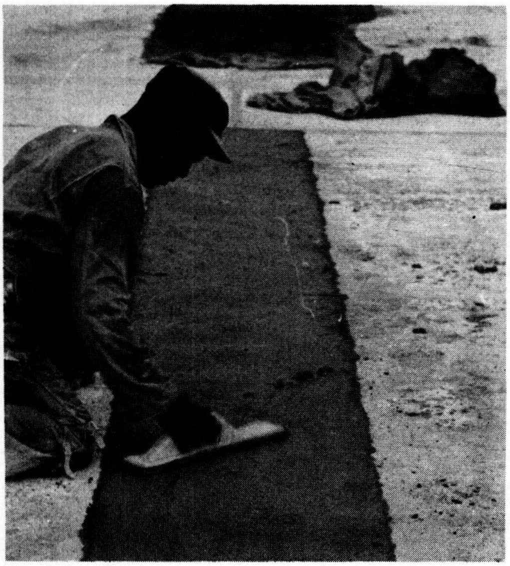

Figure 13. Finishing patch with hand float.

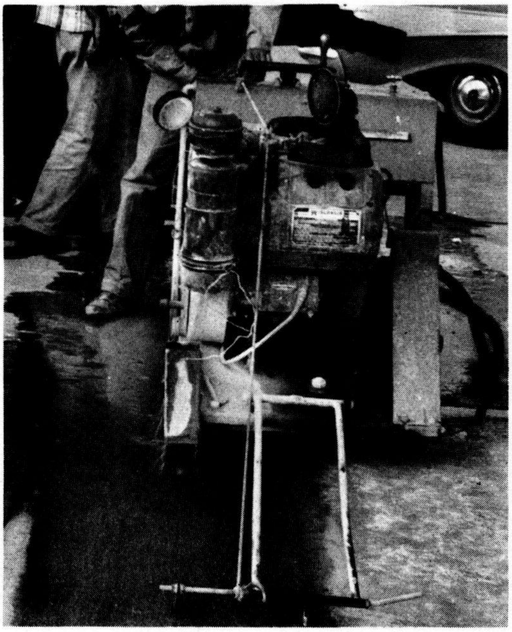

Figure 14. Sawing patch placed on both sides of joint.

CONCLUSIONS

Resurfacing or patching of concrete pavements with bonded concrete has been proved feasible in both laboratory investigations and field construction projects.

When the purpose is only to even up rough surfaces, a thin resurfacing layer will perform as well as, and in many cases better than, a thicker slab, provided that adequate bond is obtained between the old and new concrete. In many cases, especially when the concrete to be resurfaced is part of a larger area, use of the thinner overlay avoids the problem of adjustment of grades on the perimeter of the resurfacing.

If the satisfactory performance of resurfacing or patching with bonded concrete depends on the securing of adequate and uniform bond between the two surfaces. If the essential operations are carried out on a clean sound surface with good workmanship and high grade materials, the degree of bond essential to satisfactory performance can be obtained.

REFERENCE

1. Felt, E.J., "Resurfacing and Patching Concrete Pavements with Bonded Concrete." HRB Proc., 35:444 (1956).

HRB:OR-354

THE NATIONAL ACADEMY OF SCIENCES—NATIONAL RESEARCH COUNCIL is a private, nonprofit organization of scientists, dedicated to the furtherance of science and to its use for the general welfare. The ACADEMY itself was established in 1863 under a congressional charter signed by President Lincoln. Empowered to provide for all activities appropriate to academies of science, it was also required by its charter to act as an adviser to the federal government in scientific matters. This provision accounts for the close ties that have always existed between the ACADEMY and the government, although the ACADEMY is not a governmental agency.

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