DEPARTMENT OF MAINTENANCE

Resurfacing and Patching Concrete Pavements with Bonded Concrete

EARL J. FELT, *Manager,*
Transportation Development Section,
Portland Cement Association, Chicago, Illinois

Resurfacing or patching of old concrete pavements with bonded concrete has been extensively studied and found to be feasible. Many factors are involved in developing the good bond between old and new concrete so essential for thin resurfacing and patching.

This report covers laboratory bond tests, experimental field projects, a survey of projects in use, and recommended practices. The laboratory data and field work indicate that bond strengths, as determined by a shear test, may frequently be 400 psi or more, but that strengths of 200 psi or even less may be adequate. The two main factors governing bond are: (1) the strength and integrity of the old base concrete, and (2) the cleanness of the old surface. Mechanical cleaning was found to be essential if a weak surface layer is present, whereas cleaning of sound concrete can be accomplished with hydrochloric (muriatic) acid. Best bond was obtained when the base concrete was dry and grouted. Good compaction of the fresh concrete is also required for a strong bond. Other factors of importance include the precise placement of new joints over old ones, and adequate curing of the fresh concrete.

The performance of experimental projects and other projects in service shows that properly bonded surfaces will withstand extreme climatic conditions and heavy traffic. Thin bonded resurfaces giving satisfactory service date back to 1913.

Recommended practices are given in the last section of the paper. They specify in detail techniques which have proved to be the best for successfully bonding old and new concrete. The need for good workmanship and suitable materials, essential in applying the recommended practices, cannot be overemphasized.

● CONCRETE pavement resurfacing may be either bonded or unbonded, but bond is desirable in many cases and is often essential. Thin concrete resurfaces or patches placed on scaled or worn concrete pavements to restore riding quality must be securely bonded or they would be quickly damaged by traffic. Thicker resurfaces must sometimes be bonded to the base concrete for structural reasons in order that the two-layer system will have approximately the same strength as a single layer of equal total thickness. In other cases it is not necessary to achieve bond, particularly when relatively thick resurfaces are placed to rehabilitate old, narrow pavements. Occasionally, some engineers use special construction procedures to separate the two layers to avoid the reflection of cracks and joints into the new pavement.

This report concerns only the case in which the resurface or patch, whether thin or thick, must be bonded to the old base concrete, and this investigation was initiated to improve methods for carrying out construction of this type. The study included the following phases: (1) literature survey, (2) a laboratory investigation of factors that influence bond, (3) a field survey to study the performance of existing resurfaces and patches and to take cores from representative jobs, and (4) the construction of pilot field projects.

Following the review of the technical literature an annotated bibliography covering some 275 references was prepared. This review indicated that many questions concerning resurfacing or patching pavements and floors could be answered only by further laboratory study of methods of bonding new and old concretes.

While the laboratory study was in progress, several pilot field projects were built to study methods of resurfacing and patching concrete pavements with bonded concrete. In addition considerable information and data were obtained on the performance of a number of resurfaced projects already in service.

The purpose of this report is to present and correlate this information and test data on patching and resurfacing pavements, sidewalks, and floors with bonded concrete, and to provide a recommended procedure for carrying on work of this kind.

LABORATORY INVESTIGATION OF BOND

In practically all previous laboratory work on bond, the base concrete was only a few days to a few weeks old; the data obtained are applicable to new construction of two-course floors and to horizontal construction joints in dams and other structures but are not necessarily applicable to bonding new concrete to pavements or floors where the base concrete may be many years old. Accordingly, this investigation included tests on base concrete 25 or more years old, although in preliminary tests many variables were evaluated using base concrete only a few weeks old.

Description of Tests

The factors that might influence bond were evaluated by a test in which a layer of new concrete was sheared from the old base concrete to which it was bonded. In the first group of tests, laboratory-cast concrete base specimens 9½ inches square and 7 inches high were used. Because of their relatively small size, they were suitable for an exploratory investigation of many variables. The prisms,

Figure 1. Testing prism for bond.

when several weeks old, were "resurfaced" with 2 inches of fresh concrete. After curing, the top layer was sheared from the base in the jig shown in Figure 1 to determine the bond strength.

In a second group of tests 16- by 40- by 7-inch laboratory-cast specimens were resurfaced with 2 inches of concrete when they were several weeks old. These larger specimens permitted a study of variables, such as concrete placement methods, that could not be readily investigated using the 9½-inch specimens. After the resurfaced slabs were cured, 8-inch prisms were sawed and 8-inch diameter cores were drilled for shear testing. The cores were sheared in the jig shown in Figure 1 fitted with curved saddles.

In a third group of tests 16- by 40-inch slabs sawed from 25-year old concrete were resurfaced. These specimens permitted a study of various methods of cleaning the old concrete surface before resurfacing. Methods of grouting and placing the resurfacing concrete found to be practicable and effective in the previous series of tests were used. The resurfaced slabs were cured, then sawed into prisms or cored to provide specimens for shear testing.

Factors evaluated in the tests include smooth and rough surfaces; damp and dry surfaces; cement-sand and neat cement grouts; concrete resurfacing mix design; and method of placing the new concrete, including surface and internal vibration, vacuum processing, mechanical float compaction, and pneumatic pressure application. Proprietary compounds promoted for improving bond between new and old concretes were studied also, but the test data are not included in this report. When the old concrete surface was clean and sound, none of the proprietary materials tested using the methods described herein produced better bond than that obtained by using portland cement grout. However, some of the proprietary materials apparently develop "adequate" bond between new and old concrete, and they may have value in the field under certain construction conditions. Also, some of the bonding materials, when used as a glue between two pieces of hardened concrete, developed bond stronger than the concrete.

Casting, Curing, and Preparing Specimens

Base Specimens. The 9½ by 9½-inch and the 16- by 40-inch base specimens were cast of concrete having a cement content of 6 sk/cu yd with a w/c ratio of 5 gal/sk. Maximum aggregate size was 1½ inches. The concrete, mixed in a pan mixer, had a slump of 1 to 2 inches and contained 1 to 2 percent air. Three 9½-inch blocks and one 6- by 12-inch cylinder for compression tests were cast from a single nix; one 16- by 40-inch base specimen and one test cylinder were cast from a single mix.

The concrete was compacted in the forms with a spud vibrator, and the specimens were wood-floated immediately. They were left exposed to laboratory air for two or three hours after which they were steel-troweled lightly.

The base specimens were cured in the forms under damp burlap overnight and in the fog room at 73° F for 21 days. They were then placed in a room at 50 percent relative humidity and 73° F for at least five days prior to preparing for resurfacing. Many of the base specimens remained at 50 percent relative humidity for several weeks.

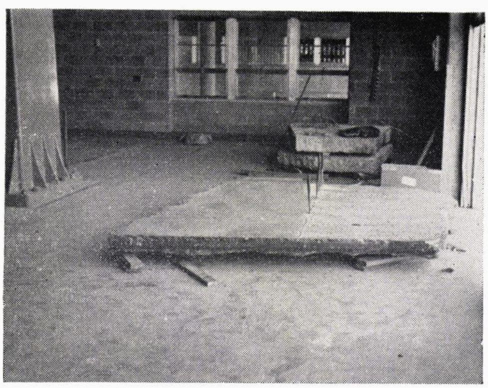

Figure 2. Large slab of old concrete being split in half preparatory to sawing 16- by 40-inch test specimens.

To determine the effect on bond of the moisture condition of the base concrete, the laboratory-cast specimens were resurfaced in either a dry or a damp condition. The "dry" specimens were conditioned at 100° F and 30 percent relative humidity for two days, and the "damp" specimens were conditioned in the fog room for two days immediately before resurfacing. Thus, the surfaces of the base concrete were either definitely dry or definitely moist at the time of resurfacing. There was no free water on the damp specimens, however; they were dull in color and tending to become "surface dry."

It was discovered soon after starting the tests that the steel-troweled specimens had a thin laitance layer on the surface which interfered with evaluation of factors influencing bond. Subsequently, therefore, most of the specimens that were not to be roughened and cleaned mechanically with an electric chisel or with the Tennant[1] machine were surface wetted and treated lightly with commercial hydrochloric (muriatic) acid (27.9 percent HCl) to remove this laitance layer. The acid treatment was generally not continued sufficiently to roughen the surface; instead, the treatment produced a rather smooth surface having a gritty sand texture. Immediately after the acid treatment, the base specimens were placed either in the fog room or the 100° F room for the 2-day conditioning period before resurfacing.

Base specimens of approximately 25-year old concrete were obtained for resurfacing by sawing 16- by 40-inch slabs from large pieces of pavement brought in from the field (see Figure 2). These specimens were stored in the laboratory for several months and were resurfaced in the air-dry condition. Various methods of cleaning and preparing the surfaces of the old specimens were investigated. These included washing with acids and other liquids, roughening and cleaning mechanically with the Tennant machine or with electric chisels, or by sandblasting.

Resurfacing the Base Specimens. Most of the 9½- by 9½-inch base specimens and some

[1] The Tennant machine utilizes rapidly revolving, hardened-steel, gear-shaped cutters for chipping the concrete surface. A "waffle" pattern may be obtained by operating the machine in two directions at 90 degrees.

of the 16- by 40-inch base specimens were resurfaced with concrete having a cement content of 6 sk/cu yd and a w/c ratio slightly over 5 gal/sk. The concrete had a maximum aggregate size of ¾ inch, a slump of 1 to 2 inches and contained 1 to 2 percent air. However, a few of the small base specimens and most of the 16- by 40-inch specimens were resurfaced with concrete of the same mix design but containing 4 to 6 percent air. In addition, a number of special concretes described later were used. Generally a red iron oxide coloring material in the amount of 2 percent by weight of cement was added to the resurfacing concrete to aid in determining the location of bond failure after the specimens were tested.

The 9½-inch base specimens were resurfaced three at a time as shown in Figure 3. The 16- by 40-inch specimens were resurfaced individually (Figure 4) or resurfaced two or four at a time (Figure 5).

Before resurfacing, a bonding coat of sand-cement or neat cement grout was applied to many of the specimens. Generally the grout was brushed on the surface to a thickness of about 1/16 to ⅛ inch, but in some tests the grout was applied by pneumatic pressure. When investigating grouts in the case of the 16- by 40-inch specimens, half of each specimen was covered with grout and the other half was not.

The resurfacing concrete, 2 inches thick, was compacted in place on the 9½-inch base specimens with a small spud vibrator; for the 16- by 40-inch specimens various methods of compaction, some simulating field methods, were utilized.

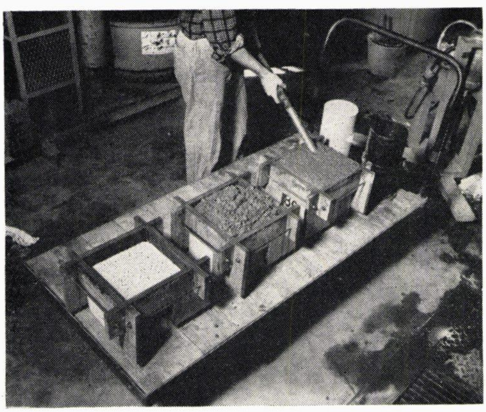

Figure 3. Three 9½-inch base specimens being resurfaced from one batch of concrete.

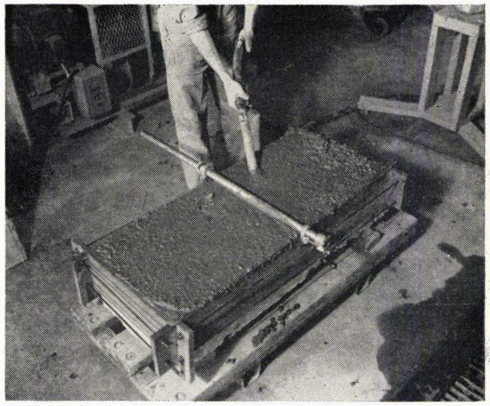

Figure 4. One 16- by 40-inch base slab being resurfaced with concrete placed by internal vibration.

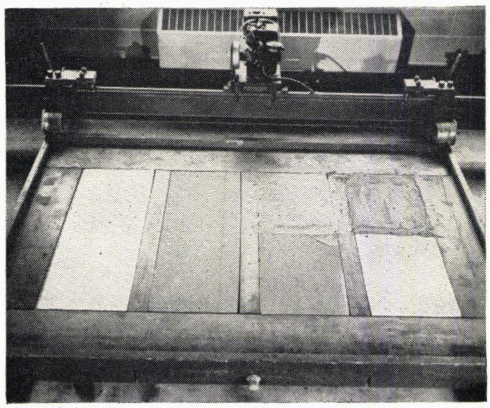

Figure 5. Four 16- by 40-inch base slabs ready for resurfacing. Two middle specimens are dry, two outer specimens are damp; one-half of two specimens has been covered with grout.

The resurfaced specimens were cured in the forms overnight under wet burlap. The 16- by 40-inch specimens that were resurfaced in groups were removed from the casting set-up by sawing around the outside edges of each of the specimens as shown in Figure 6. All specimens were placed in the fog room at 73° F to complete 14 days moist curing. Individual 16- by 40-inch slabs were then cored with an 8-inch diameter core barrel or were sawed into 8-inch prisms. Two cores and two prisms were taken from the grouted half of the slab and two of each from the ungrouted half.

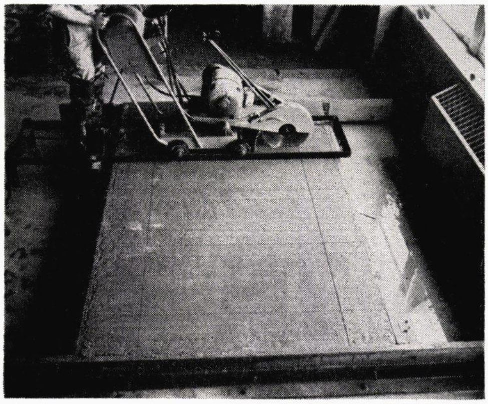

Figure 6. Removing resurfaced specimens by sawing around edges.

All prisms and cores were finally conditioned (after the 14 days damp curing) in the 50 percent relative humidity and 73° F room for 14 days before shear testing. The drying procedure permitted the concretes to develop shrinkage stresses at the bond surface, giving the new layer of concrete an opportunity to loosen from the base. The resurface was then sheared from the base to obtain the bond strength in psi.

Presentation of Data

The test data are summarized in three tables, discussed in detail later in the report: Table 1 for the 9½-inch base blocks, Table 2 for the 16- by 40-inch laboratory-cast base slabs, and Table 3 for the 16- by 40-inch base slabs from the field.

When studying the data in these tables it would be helpful if a criterion were available for evaluating bond strengths in terms of service requirements, but further experimental and analytical studies are needed to determine the maximum bond stresses which must be resisted under various conditions of loading, temperature change, and drying shrinkage. Some data are available indicating that bond strengths of 200 psi or even less may be satisfactory for most resurfacing applications. For instance, at the PCA Laboratories, two-layer concrete beams 60 inches long, 12 inches wide, and 10 to 14 inches deep, when tested in flexure, were practically as strong as monolithic beams of the same total depth, even though the shear strength at the bonding face in some beams was only of the order of 200 psi. Also, tests on a number of cores (to be discussed in detail later in this report) removed from resurfaced pavements that have been in satisfactory service for many years showed some bond strengths less than 200 psi.

In an effort to obtain some means of evaluating the importance of the various factors studied in Table 1, all the data were plotted to give a frequency-distribution curve. A skewed curve was obtained which rose rapidly from values in the range of 100 to 200 psi and trailed off gradually for values near 600 psi. The peak of the curve, that is the bond value corresponding to maximum frequency, occurred at about 325 psi. On this basis it appears reasonable arbitrarily to designate as "superior" those treatments which produced bond strengths greater than about 400 psi. Solid blocks of laboratory-cast concrete, when tested in the same way as the resurfaced blocks (shear plane established 2 inches from surface of specimen), showed shear strengths 700 to 900 psi, and two blocks of the 25-year old concrete showed strengths of 760 and 940 psi.

In studying the tables, some indication as to the reliability and reproducibility of the data is also of value. An analysis of certain comparable data in Table 1 shows that the average shear strength of 57 sets of tests (three specimens per set) was 375 psi; the average low strength of the three prisms in these 57 sets was 309 psi, and the average high strength 442 psi, giving an average range between high and low strengths in a set of three specimens of 133 psi.

Similar variations were obtained in the data in Table 2 for prisms and cores taken from 16- by 40-inch laboratory-cast base specimens. The average bond strength of 19 sets of two prisms each (each set from the same 16- by 40-inch base) was 472 psi, the average low of the two prisms was 423, and the average high 520, giving an average range between the high and low of 97 psi. The average bond strength of 19 sets of two cores each (each set from the same 16- by 40-inch base as the prisms) was 553 psi, the average low 459, the average high 648, and the average range 189 psi. The above data show that the bond strengths obtained with cores are higher than those indicated by the prisms. A reason for this is that the strength recorded is the average shear stress at the interface at the instant of failure. Anal-

TABLE 1

EFFECT OF SURFACE TREATMENT AND VARIOUS TYPES OF GROUT ON BOND

9½- by 9½-inch prisms resurfaced with 2 inches of concrete containing 2 percent red iron oxide pigment by weight of cement. Unless otherwise noted: Resurfacing concrete was 6 sk/cu yd, 1- to 2-inch slump, compacted by internal vibration, compressive strength 5000 to 7000 psi; surface of base block was light steel-troweled; data are average of three tests; grout had w/c ratio of 0.46.

Entry No.	Treatment Given Specimen Surface, or Type of Grout, or Resurface Mix	Bond Strength, psi					
		Damp base			Dry base		
		Grouted		No grout	Grouted		No grout
		1:1	Neat		1:1	Neat	
1	None (little laitance effect)	216	239	254	264	253	308
2	None (laitance effect)		121*			113*	
3	None (wood-float finish, laitance effect)	136		152	153		140
4	Smooth-sawn surface					201	
5	HCl	339	232	295†	625‡	408	353†
6	HCl not flushed			93*			106*
7	Glacial acetic acid			296			369
8	Glacial acetic acid, not flushed			93*			332*
9	Electric chisel—light chipping			369			369
10	Tennant—shallow waffle (slightly rough)	415	345	366	388	410	543
11	Tennant—deep waffle (rough)					500	
12	Tennant—shallow waffle, 2% $CaCl_2$ in grout					428	
13	Tennant—shallow waffle, retempered mix						318
14	HCl—wood-floated	216		266	328		278
15	HCl—2% $CaCl_2$ in grout	295	229		452	503	
16	HCl—2% $CaCl_2$ in grout and mix	149	253*	258	387	564*	632
17	HCl—Retempered grout§	620	317‡		517	403‡	
18	HCl—Cement dust grout		547			519	
19	HCl—Grout-sprayed at 26 psi		392			564	
20¶	HCl—Grout on surface 1½ hr. before resurfacing	353	259		440	437	
21¶	HCl—Temperature of base about 120°F‖				326		
22¶	HCl—Temperature of base about 120°F**	323					
23	HCl—9 sk/cu yd concrete, 2½-in. slump, 5% air, 6400 psi	510	404	281	454	556	365

* One test specimen.
† Average of 12 test specimens.
‡ Average of 6 test specimens.
§ Grout was mixed, then permitted to set undisturbed one hour, then remixed.
¶ Air-entraining cement in grout, and 5 percent air in resurfacing concrete; 2 to 3-inch slump, and about 5000 psi.
‖ Grout at w/c ratio of 0.80 placed directly on hot base specimen.
** Surface wetted and grout at w/c ratio of 0.46 placed on damp surface.

yses based on elastic performance indicate that the maximum shear stress of a prism of square cross-section is equal to 3/2 the average stress; whereas for a cylinder, the maximum shear stress is equal to only 4/3 the average. Thus, if we assume that the maximum shear stress in both specimens is the same, the average stress of the prisms should be less than that of the cores.

In Table 3 the average bond strength of 29 sets of four prisms each (each set from the same 16- by 40-inch specimen) was 238 psi, the average high of the four prisms was 283 psi, the average low 192 psi, and the average range from high to low was 91 psi. (These average bond strengths are low because they include the data from a number of surface-cleaning treatments that were ineffective and yielded low strengths.)

Thus, it is apparent that the average test values in the tables, although given to the nearest psi, include experimental variations of considerable magnitude. Other investigators studying bonding of new and old concretes have reported a considerable range in bond strength values also.

As the number of tests increased, it became apparent that factors influencing bond of new and old concrete were not easily isolated and controlled. The most important factor was the condition of the old surface—its cleanness, roughness, and strength or soundness. If the surface was clean, slightly rough, and free of a weak outer skin, good bond was generally obtained; otherwise relatively poor bond was obtained.

Discussion of Laboratory Test Data

Tests on Laboratory-Cast Base Concrete. The data in Tables 1 and 2 show that good bond may be obtained by many different procedures. Although considerable variation was

TABLE 2

EFFECT OF SURFACE TREATMENT, CONCRETE CONSISTENCY, AND PLACEMENT PROCEDURE ON BOND

16- by 40-inch slabs resurfaced with 2-inch concrete of type and strength indicated, containing 2 percent red iron oxide pigment by wt. of cement. Resurfaced slabs were either cored or sawed into prisms for testing. Slabs surface-treated with HCl (except where noted) to remove light laitance layer. Data are average of 2 cores and 2 prisms; except for 4 prisms where no data are shown for cores. Grout is a 1:1 mix, w/c ratio of 0.46 except as noted.

Test No.	Method of Placement, Type and Strength of Resurface Concrete	Bond Strengths, psi				Type of Test Specimen
		Damp base		Dry base		
		Grout	No grout	Grout	No grout	
1	Surface vibration, 6 sk/cu yd, 3″ slump, 6% air, 6100 psi	297	194	521	167	8″ prisms
2	Surface vibration, (no HCl), rough chisel surface, water in hollows, 6 sk/cu yd, 3″ slump, 4% air, 5200 psi	301	207			8″ prisms
3	Surface vibration, rough chisel surface-damp, same mix as above	326	292			8″ prisms
4	Internal spud vibration, 6 sk/cu yd, 3½″ slump, 4½% air, 6300 psi			363	212	8″ prisms
5	Compactor float, after hand tamping. 7 sk/cu yd, 0″ slump, with iron oxide in mix, 8700 psi	579	397	598	0*	8″ prisms
		640	468	687	0*	8″ cores
6	Same as above but no iron oxide in mix, 7000 psi	565	357	556	0*	8″ prisms
		570	555	663	0*	8″ cores
7	Internal spud vibration and compactor float 2 hours later. 7 sk/cu yd, 2½″ slump, 4% air, 7700 psi	437	350	659	449	8″ prisms
		620	430	816	657	8″ cores
8	Internal spud vibration and compactor float 2 hours later. 7 sk/cu yd, 5″ slump, 10% air, 4600 psi		234		654	8″ prisms
			217		701	8″ cores
9	Shotcrete 1:3 mix, 6300 psi, specimen vertical	289	434	428	301	8″ prisms
		124†	350	151†	553	8″ cores
10	Shotcrete 1:3 mix, 10,600 psi, specimen horizontal	251	354	536	590	8″ prisms
		135	214	373	577	8″ cores
11	Shotcrete 1:3 grout only. Resurface mix 6 sk/cu yd 1½″ slump, 1½% air, 6300 psi. Internal vibration	477	269	574	481	8″ prisms
		820	235	820	472	8″ cores
12	Surface vibration followed by vacuum process. 6 sk/cu yd, 3″ slump, 6% air, 6100 psi	189	166	456	272	8″ prisms
13	Surface vibration, vacuum process, and compactor float. 6 sk/cu yd, 3½″ slump, 6.7% air, 4800 psi	440	219	387	237	8″ prisms

* Resurface came off during coring and sawing.
† Sand pockets apparent.

obtained in the test results, the data show that better bond was generally developed with a dry-base concrete than with a damp base. When considering this conclusion it should be remembered that the base concrete was of good pavement quality having relatively low water-absorption characteristics. This conclusion agrees with that of Withey (*1*), who found that concrete specimens that had dried three days generally developed better bond with fresh concrete than specimens that had dried only one day; of Thornton (*2*), who found that with smooth brick of low suction, good bond was obtained with dry brick; moistening the surface did not help, and in some cases reduced bond; and of Waters (*3*), who found that tensile strength of joints was highest when the old concrete was dry at the time the new concrete was placed.

Representative figures obtained by averaging comparable data in Table 1 under "Damp Base" and under "Dry Base" show an average bond strength of 322 psi for the damp base and 432 psi for the dry base. Furthermore, when all the data in Table 1 are separated on the basis of 400 psi, it is found that for damp bases only 5 out of 33 tests fall in the superior class, while for dry surfaces 18 out of 37 fall in this class. Thus it appears that when plastic concrete is being bonded to high-quality base concrete, a dry surface is better for developing bond than a damp surface; however, under suitable conditions good bond can be obtained either way.

The data in Tables 1 and 2 show also that grout frequently increases bond. Other investigators (*4*, *5*) have found similar evidence. According to Table 1, when grout was not used, only 2 tests in 23 showed superior bond (over 400 psi); whereas when grout was used, 21 treatments out of 47 showed superior bond. The data indicate little difference between a sand-cement grout, a neat cement grout, a retempered grout, a grout containing $CaCl_2$, or a grout formed by spreading dry cement on a damp surface. Furthermore, grouts may be brushed on or sprayed on pneumatically; they may be mixed for a considerable time before using; and they may be spread for some time before concreting, but not so far in advance that they dry out excessively.

Tests were made to determine the influence on bond of the surface roughness of the base. Surfaces roughened to various degrees were prepared with an electric chisel, with the Tennant machine, and with HCl. These tests show that surface roughness influences bond, but the effect is neither great nor consistent. Apparently, little is to be gained by roughening a sound surface to an extent greater than that produced by the HCl treatment.

Most of the tests reported in Table 1 were made using 6-sk non-air-entrained concrete, but some were made with 6-sk and 9-sk air-entrained concrete. The test data indicate that neither the variation in cement content nor in air content had an important effect on bond.

As seen in Table 2, good bond was obtained with surface-vibrated concrete, with internally vibrated concrete, with concrete that was permitted to set for two or three hours before final compaction, with shotcrete, with vacuum-processed concrete, and with concrete compacted with a mechanical float.

All these data explain why successful bond has been reported by many investigators using entirely different methods. The most important single factor that influences bond is the surface condition of the old concrete. The surface must be clean and the concrete must be sound. A slight degree of roughness is desirable, but extremely rough surfaces are not required.

Tests on Old Concrete from the Field. In these tests, methods of cleaning and preparing base concrete approximately 25 years old were given major attention. The test data in Table 3 show that the bond obtained is greatly dependent upon the method used.

Cleaning and very slight roughening of the old surface with HCl (entries 1, 2, 3, 15, 16, 17, 18, 20, and 21) developed acceptable bond in the range of 300 to 500 psi. In fact, many of the specimens that had been cleaned with HCl developed bond strength greater than the strength of the surface of the old concrete, resulting in shear failures about ¼ to 1 inch down in the old concrete. It is significant that Clemmer (*6*) and Ungar and Barentzen (*7*) have found by experience that HCl is an effective cleaning agent for preparing old concrete surfaces for patching and resurfacing. Glacial acetic acid (entry 4) was not very effective.

TABLE 3

EFFECT OF SURFACE TREATMENT OF OLD CONCRETE ON BOND

16- by 40- by 7-inch slabs, sawed from panels of concrete removed from pavement 25 years old, resurfaced with 2 inches of new concrete containing 2 percent red iron oxide pigment by weight of cement. Data are average of tests on four 8-inch prisms, sawed from test slabs. Resurface concrete 6 sk/cu yd, 2- to 4-inch slump, 5- to 6- percent air, compressive strength about 6000 psi, compacted by surface vibration except where noted.

Test No.*	Method of Treating Old Surface. All Base Slabs* in Air-Dry Condition When Resurfaced Except Entry 2	Bond Strength, psi	
		1:1 Grout	No grout
1	HCl	301†	228†
2	HCl, damp condition	355	152
3	HCl, internal vibration	363	212
4	Glacial acetic acid	52	68
5	Sandblasted, torpedo sand, shotcrete gun	102	88
6	Sandblasted, silica sand, commercial gun	48	64
7	Tennant machine, smooth surface	174	181
8	Tennant machine, slightly rough waffle surface	283	326
9	Electric chisel, light chipping	163	162
10	50% sodium hydroxide		7
11	Saturated solution $CaCl_2$		44
12	25% tetrasodium salt of ethylene-diamine tetraacetic acid		89
13	Brushed and washed with water	21	4
14	Thoroughly brushed and washed with water and an earthenware cleaner (resurfaced with 6-inch concrete, internally vibrated)	239‡	
15	HCl (resurfaced with 6-inch concrete internally vibrated)	396‡	
16	HCl—7 sk/cu yd concrete (internally vibrated) compressive strength = 6000 psi	525	327
17	HCl—11 sk/cu yd concrete (internally vibrated) compressive strength = 7600 psi	425	418
18	HCl—7 sk/cu yd concrete (scaled but sound base)		
	(a) neat cement grout	423	
	(b) 1:1 grout	358	
19	Tennant machine 7 sk/cu yd (scaled but sound base)		
	(a) neat cement grout	422	
	(b) 1:1 grout	407	
20	HCl—7 sk/cu yd concrete; specimens broken after 28 days moist curing	484	
21	HCl—7 sk/cu yd concrete with 2% $CaCl_2$; specimens broken after 28 days moist curing	656	

* Base specimens for entries 1 to 13 were from a 28-year old highway in Cook County, Illinois; compressive strength of air-dry 6- by 6-inch cubes = 9300 psi. Base specimens for entries 14 to 17 and 20 and 21 were from a 26-year old street in Milwaukee, Wisconsin; compressive strength of 6- by 6-inch cubes = 12,000 psi. Base specimens for entries 18 and 19 were from a scaled part of this same street in Milwaukee, Wisconsin; compressive strength of 6- by 6-inch cubes = 9400 psi.

† Average of two slabs, 4 prisms in each slab test.

‡ Average of two 60-inch slabs each, 6 or 7 prisms in each slab test.

Washing the old surface with brush and water, sodium hydroxide solution, and calcium chloride solution (entries 13, 10, and 11) did not prove of value; however, in the case of entry 14, fairly good bond was obtained with concrete that had been scrubbed thoroughly with a compound used for cleaning porcelain and earthenware. Cleaning with a solution of the tetrasodium salt of ethylene-diamine tetra-acetic acid (a sequestering agent) had some value (entry 12), although HCl was much more effective.

In these tests, sandblasting the old surface was not particularly effective (entries 5 and 6). The sandblasted surface appeared clean, but all projections were rounded, which may have had some effect on bond. These results are in agreement with results of Carlson's tests (*8*). However, the Bureau of Reclamation (*9*) has found that wet sandblasting is beneficial in cleaning newly hardened concrete at horizontal construction joints in dams.

Chipping the old surface with an electric chisel had value (entry 9) but the most effective tool for mechanical cleaning was the Tennant machine (entries 8 and 19). This machine can remove as little as an eighth inch or so of old concrete in one pass or a thicker layer in several passes (*10*). The chipping or scarifying process, which is carried on with little chance of fracturing the concrete below, is effective in removing incipient scale formation, bituminous materials, and heavy grease layers that are not removable with HCl.

Data are presented in entries 18 and 19 comparing the effect of the Tennant machine and of HCl in cleaning the surface of a concrete base that had scaled considerably from salt applications but was otherwise sound. The test results indicate that there is little difference in the effectiveness of these treatments in preparing the old scaled surface, provided it is sound and reasonably free from incipient scale (as was the case in these tests).

TABLE 4
RATE OF GAIN IN BOND STRENGTH

Specimen Identification	Bond Strength, psi							
	Age of specimen when tested, days							
	Plain concrete				Concrete with 2% $CaCl_2$			
	3	5	7	28	2	4	6	28
Old Wisconsin base...	318	302	300	484	345	347	384	656
Lab cast base.........	311	532	492	—	423	500	533	—

The average bond strength of the grouted specimens in Table 3 is 234 psi and of the ungrouted specimens (where comparable data are available) is 186, indicating again that a grout is beneficial.

Some data on the effect upon bond of the cement content of the resurfacing concrete are given in entries 16 and 17. In these tests, using 7-sk and 11-sk concrete, there was no consistent difference in bond due to the variation in cement content.

Rate of Gain in Bond Strength. Several tests were made to determine the rate at which bond strength increases with time of curing. Two 16- by 40-inch slabs of Wisconsin unscaled concrete were acid-treated, coated with a 1:1 grout, and resurfaced in the usual way, placing the concrete by internal vibration. A 7-sk mix containing 5 percent air was used, with a w/c ratio of 0.38, and a slump of 3 inches. The concrete on one of the specimens contained 2 percent $CaCl_2$ by weight of cement. Each resurfaced slab was cured under wet burlap for two days and was then sawed into eight prisms. Two prisms with plain concrete topping were broken at ages of 3, 5, 7, and 28 days, and two with the $CaCl_2$ topping at ages of 2, 4, 6, and 28 days. The prisms, except those broken at an age of two days, were cured continuously in the moist room until they were tested. A few single 9½-inch prisms of laboratory-cast concrete were resurfaced using the same concretes. They were broken at the same ages as the other specimens except that no 28-day tests were made. The data obtained in these tests, given in Table 4, indicate that bond strengths exceeding 300 psi develop rapidly. In the case of the specimens of the old Wisconsin base concrete, most of the shear failure was due to "pull-out" or failure of the old surface concrete. The laboratory-cast concrete had a stronger surface, and failure was generally at the bonding surface with some slight pull-out and some new concrete transfer to the base.

CONSTRUCTION OF EXPERIMENTAL BONDED RESURFACES

Concurrently with the laboratory investigation, five experimental pilot study field projects were built during the period 1951–1954.

These projects permitted not only a study of methods of cleaning and of bonding techniques but also a study of semi-full-scale construction procedures.

Wauwatosa, Wisconsin

An experimental 2-inch concrete resurface was placed in July 1951 on approximately 4000 square feet of a 21-year old concrete street (Martha Washington Drive) in Wauwatosa, Wisconsin. Considerable rambling longitudinal and transverse cracking had occurred, and in addition the concrete was severely scaled and raveled. Consequently the project presented a very severe test condition.

The concrete surface was prepared by removing old bituminous patches, and in some areas by a light once-over with the Tennant machine. This was followed with washing with water under pressure.

A 1:1 sand-cement grout was used on some areas. Three different concrete mixes were used in resurfacing.

A 5½-sk concrete having a 2- to 4-inch slump was vacuum processed; a 6-sk concrete having a 2- to 4-inch slump was placed with a surface vibratory screed, and an 8-sk concrete having a 0- to 1-inch slump was compacted with a Kelley compactor float. Wire mesh reinforcement fastened to the old concrete with powder-driven anchors was used on part of the project. All the concretes were cured under vaporproof paper for seven days.

When the project was a year old, 8-inch diameter cores were drilled from the test panels and tested in shear. Much of the old concrete was of poor quality, and the shear break frequently took place in the old concrete rather than at the bond surface. This made it difficult to evaluate the influence of the variables included in the study, but strikingly illustrated the importance of the strength of the old concrete surface in controlling bond.

The average bond strength of 10 cores taken from sections where the old base was grouted was 275 psi, whereas the average bond for eight cores taken from ungrouted sections was 197 psi. Bond values varied owing to the inferior condition of the old base, but little variation could be attributed to a damp or to a dry old surface, to the cement content of the concrete mixes, or to the method of placement of the concrete.

The condition of this experimental section when four years old was only fair, as many cracks had developed. Most of them occurred over cracks in the old road and developed in a month or two after construction. Some loosening of bond had occurred adjacent to the cracks.

Figure 7. Minneapolis street before resurfacing.

Minneapolis, Minnesota

An experimental concrete resurface from ½ to 2 inches thick was placed in June 1952 on a heavily traveled street in Minneapolis, Minnesota. The 13-year-old non-air-entrained concrete pavement on Second Avenue North, between Third Street and Washington Avenue, had severely scaled, as can be seen in Figure 7.

A Tennant machine was used to remove a thin surface layer of dirty concrete. Final cleaning was with compressed air and with water under high pressure.

The concrete was permitted to air-dry, and then a 1:1 sand-cement grout was thoroughly brushed on the surface before resurfacing with concretes having cement factors of 8 and 9 sk/cu yd. Maximum aggregate size was ⅜ inch; water-cement ratio, 4 to 4¾ gal/sk; and air content, 8 to 9.5 percent. Part of the concrete was compacted with a vibratory screed and part with a compactor float. The concretes were cured for four days, using wet burlap for one day and vaporproof paper for three days. A membrane curing compound was then applied and the section opened to traffic. Contraction joints were sawed in the resurface at 10-foot intervals directly above the joints in the base when the concrete was 24 to 48 hours old.

Figure 8. Minneapolis street, one-inch resurfacing when three years old.

When the project was a year old, seven 8-inch diameter cores were drilled and tested for bond. The average bond strength of the cores was 565 psi, the minimum 408 psi, and the maximum 836 psi. Differences in strengths could not be attributed to concrete mix design or to method of placement.

In 1955, at the age of three years, the resurface as seen in Figure 8 was in good condition, although a number of cracks, principally over those in the old slab, had developed. Secure bond existed between the new and old concretes except in a number of small areas adjacent to boundaries and at crack intersections. Some spalling and evidence of structural damage over an area of 2 or 3 square feet had occurred at each end of the test section. Poor base concrete was the principal cause of these minor failures.

Figure 9. Area prepared for thin patching at Rhode Island State Airport (Theodore Francis Green Airport, Hillsgrove, Rhode Island).

Rhode Island State Airport

Approximately 1800 square feet of thin concrete patching were placed in July and September 1953 at the Rhode Island State (Theodore Francis Green) Airport south of Providence at Hillsgrove. The 18-year-old non-air-entrained concrete had scaled in a number of areas near the west end of the east-west runway.

The surface of the old concrete was prepared with an air hammer and a Tennant machine, since mechanical cleaning was required to remove incipient scale that had formed but had not completely loosened from the surface. Final cleaning was with compressed air followed by water under pressure. One of the areas ready for patching is shown in Figure 9.

When the concrete was practically air dry, a 1:1 sand-cement grout was brushed on the surface just before resurfacing with concrete having a maximum aggregate size of ¼ inch, a cement factor of 8 sk/cu yd and a w/c ratio of 5.2 gal/sk. The air content was approximately 10 percent and the slump ranged from 2 to 4 inches. The concrete on part of the patching was compacted by a surface vibratory screed and on part by screeding and tamping with a wood strike off. Where joints were required, they were sawed. Curing was with vaporproof paper for seven days.

Three 8-inch diameter cores were drilled from the patches when they were about a month old. Two of the cores had bond strengths of 184 psi and 308 psi; the other core was not tested. Failure in these cores occurred 80 and 95 percent in the old base concrete, indicating that the bond was stronger than the old base.

In 1955, after service for two years, the patches were in very good condition (Figure 10) although some hair checking and a few fine cracks had developed. The only indication of definite bond failure discovered by sounding was adjacent to a transverse joint over an area of less than 1 square foot.

Skokie, Illinois

A 20- by 100-foot section of a street in Skokie, Illinois, was resurfaced to a thickness of ¼ to 2 inches with pneumatically placed concrete in November 1954. The 25-year-old non-air-entrained concrete pavement which had several longitudinal and transverse cracks was severely scaled as seen in Figure 11. Commercial hydrochloric acid (27.9 percent) applied at the rate of about ⅙ gal/sq yd was used to clean most of the old surface. The Tennant machine was used around the boundaries of the area. Final cleaning was with compressed air, and water under pressure.

Sand, cement, and water for the concrete were mixed in two pug mill mixers in series, the first operating under atmospheric pressure, and the second under a pressure of about 60 psi. From the second mixer the concrete was forced by pressure to the nozzle where an auxiliary air supply aided in the application. The dry surface was lightly fogged with water and given a thin spray-crete grout coat several minutes before the resurface was sprayed to final thickness. The spray-crete had a cement content of 8 sk/cu yd, a water content of 5 gal/sk, a slump of 4 to 7 inches, and an air content of about 3 percent, the maximum that could be obtained with Type IA cement or Type I plus an air-entraining agent.

This resurface after going through two winters was in good condition (see Figure 12) although, as expected, a few fine cracks had developed directly over cracks in the old slab.

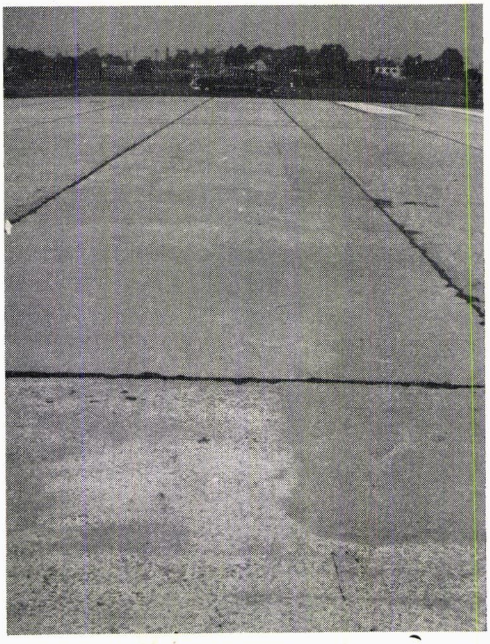

Figure 10. Area at Rhode Island State Airport patched with ¼- to ½-inch concrete. Patch is two years old.

Figure 11. Scaled area of twenty-five year old Skokie street before resurfacing.

Experimental Slabs on PCA Laboratory Grounds

Bond Tests. To obtain exploratory information on "thick" bonded resurfacing a 6-inch by 8-foot by 16-foot slab was resurfaced with a 6-inch layer of concrete. The base slab of 6-sk concrete was built on the laboratory grounds in July 1953, moist-cured seven days, then exposed to the air for approximately two months. Before resurfacing, half the slab was surface wetted and then treated with hydrochloric acid applied at the rate of ⅙ gal/sq yd; the other half was left untreated. When the slab had dried, a 1:1 sand-cement grout was broomed over the surface, and 6-sk resurfacing concrete with 5 percent air and 5-inch slump was placed by surface vibration. Curing was with wet burlap for seven days. In December 1953 when the resurface was three months old, 14 cores were taken, several from two opposite corners and several from the interior portion of the slab, to determine the effectiveness of acid cleaning and to see if the bond at the corners was less than at the center. The cores were dried in the laboratory for six weeks when most of them were tested in shear.

The bond strengths of the acid-treated section were very good: three cores drilled near a corner showed an average of 420 psi, and two cores from the interior showed an average of 590 psi. In comparison, three cores from a corner of the section not acid-treated had an

Figure 12. Skokie street after resurfacing with ½-inch concrete.

average bond strength of 277 psi. Two cores from the interior of this section fell apart during handling at the time shear tests were to be made (apparently owing to drying shrinkage stresses), and a third core showed a bond strength of 296 psi.

In the spring of 1954, one core drilled from the center portion of the acid-treated section had a bond strength of 650 psi. In June 1955, two more cores were drilled from the center portion and from a corner area of both the untreated and acid-treated sections. After air drying at 50 percent relative humidity for two weeks, the cores from the interior area had average bond stengths of 110 psi and 795 psi, respectively, for the untreated and acid-treated areas; and the cores from the corner area had bond strengths of 142 psi and 448 psi for the untreated and treated areas.

These data show the great value of hydrochloric acid cleaning and corroborate data obtained in laboratory tests. The data also show that relatively thick layers of concrete can be securely bonded, and that bond at the corners and at the interior of a pavement slab may be of the same order of magnitude.

Load Tests. Following this work, two 24-foot by 12-foot by 6-inch concrete slabs were built on the laboratory grounds on a clay soil subgrade having a Westergaard subgrade modulus of approximately 100 psi per inch. During the summer of 1955 these slabs were loaded at the corners and edges, and load-deflection-strain relationships were established. The slabs were then sawed and cracked to form four 12-foot by 12-foot by 6-inch panels, although two panels in each case were held together with tie bars across the joint. The four panels were resurfaced with 6 inches of concrete in such a way that the bond between the layers varied from "no bond" to "secure bond." Secure bond was achieved by wetting and acid-treating the surface, followed by grouting and resurfacing when the old concrete was dry. When the resurface concrete was approximately 28 days old, the load tests were repeated to evaluate the structural effect of the 6-inch overlay. It is significant to report that the strength of the 12-inch two-layer slabs where secure bond was obtained was equal to the theoretical strength of a monolithic slab of 12-inch total thickness. This work substantiates laboratory studies which showed that two-layered bonded beams had bending strength approximately equal to full depth beams of the same total thickness.

STUDY OF FIELD PROJECTS IN SERVICE

Information on durability and strength of bond obtained in the field is available from performance records of the pilot field projects and also from other resurfacing projects some of which have been in service for many years. Some of these latter projects were discussed by Fleming (*11*) in 1932. The oldest jobs studied, in Savannah, Missouri, and Toledo, Ohio, are 40 years old. During a study of the projects, evidence became available that the performance of some of the resurfaces was adversely affected by the relatively poor durability of the old non-air-entraining concrete. These observations are in agreement with those of Lewis (*12*), who noticed in a survey of resurfaced concrete pavements in Indiana that the resurfacing sometimes exhibited inadequate durability.

The following jobs, in several eastern and midwestern states, were inspected and cored during the summer of 1953. In addition, some of them were inspected in 1954 and 1955.

Michigan

In September 1950 part of the west half of Ilene Street in North Detroit, from Pickford to Margareta Streets, a distance of more than 500 feet, was resurfaced with shotcrete. The old concrete, which had raveled and scaled, was prepared for shotcreting by cleaning with a street broom and compressed air. Shotcrete (cement and sand mixed with water at the nozzle) was applied to the dry surface to a depth of about 1/8 to 1/2 inch. Sand rebound was floated into the mix. The new surface was not moist-cured and was opened to traffic after three days. Local scaling of the resurface started in the spring of 1951; however, in the summer of 1954 considerable areas of resurface still remained intact even where the shotcrete was feathered out. Three cores were drilled from the job in 1953 and one of these tested in the laboratory had a bond strength of 256 psi. A 1/4-inch resurface on another of the cores was broken loose by hitting the edge with an upward blow of a hammer; the break occurred in the old concrete, showing that the bond was stronger than the upper part of the old base.

This job is not considered satisfactory; nevertheless, the performance of the thin shotcrete resurface is encouraging. It is probable that the performance would have been much improved if incipient scale on the old surface had been removed and the new topping had been properly cured.

Minnesota

Tennant Company, Minneapolis. A concrete driveway at the G. H. Tennant Company approximately 2,700 square feet in area, 12 feet wide and 180 feet long, was resurfaced in November 1952 with a 1-inch topping of new concrete. The old pavement was scarified with the Tennant machine, broomed clean, maintained in the moistened condition several hours, then coated with a neat cement grout. A 1:2:3 concrete mix containing 5½ gallons of water per sk producing a 3-inch slump was then placed and finished by hand. Because of cold weather, the concrete was protected with hay and tarpaulins for 10 days.

In the spring of 1953 the resurface over two areas totaling approximately 160 square feet had loosened; it is believed that the concrete had frozen in these spots. Subsequently the topping in these areas was removed and patches placed.

In 1953, three 8-inch diameter cores drilled from the project were tested, and bond strengths of 316, 424, and 596 psi were obtained. The breaks occurred partly in the old concrete and partly in the new.

An inspection of this project in 1955 showed that secure bond existed except in several small areas totaling perhaps 30 square feet. Soundings indicated that the greatest bond failure had occurred near the boundary of one of the patches that had been placed in the spring of 1953. Other areas of looseness and some spalling had developed along cracks and tight joints in the resurface where they occurred over old expansion joints in the base. In these cases, no space for expansion was provided for in the topping over 1-inch wide expansion joints in the base concrete. Expansion of the pavement during warm weather resulted in excessive compressive stress in the thin resurface causing the spalling.

Bridge Deck Patching. Two bridge decks in northern Minnesota on Route 73 in the vicinity of Hibbing, both 30 feet wide and 198 feet long, were built in 1948 with non-air-entrained concrete. Local areas scaled during the following winters, necessitating some maintenance which was done by the Minnesota Highway Bridge Department during the summer of 1953 when approximately 20 patches, ranging in size from about 1 square foot to almost 300 square feet, were placed. Patching totaling 534 square feet was placed on bridge No. 6503 and 1332 square feet on bridge No. 6528.

The areas to be patched were outlined by making a saw cut around the boundaries to a depth of about 1 inch. A Tennant machine was used to rout out the old concrete to a depth of about 1¼ inches. The base was maintained in a damp condition for two hours, blown free of water, and then coated with a neat cement grout thoroughly brushed into the surface. The resurfacing concrete, which had an air-entraining agent and 1 percent calcium chloride added at the mixer, had a cement factor of approximately 10 sk/cu yd, a maximum aggregate size of ½ inch, a slump of 2½ inches, and was placed and finished by hand. After service for two years, all patches were securely bonded and were in perfect condition.

Missouri

Resurfaced concrete streets in several cities in Missouri, where records had indicated that resurfaces 2 to 4 inches thick had been giving good service for many years, were cored in 1953.

Cape Girardeau. Portions of three streets, Spanish, Independence, and Themis, were resurfaced in the early 20's with 4-inch nominal thickness of mesh-reinforced concrete. Little

Figure 13. Cape Girardeau. Themis Street, resurfaced in 1924, looking east from Spanish Street.

specific information is available on the construction. The old concrete base was built in about 1910, and a wood block surface was in place for 10 or 12 years before its removal when the concrete resurface was built. The resurfaced streets (Figure 13 shows Themis Street) have all given excellent service for the past 30 years. Three cores taken from Spanish Street showed no bond between the two layers of concrete, and two cores taken from Themis showed bond in only one. In this case the base, of rather poor-quality concrete, was 4 inches thick, and the resurface was $5\frac{1}{2}$ inches. The bond strength was 291 psi, which is rather high considering the quality of the base. Independence Street was not cored.

Liberty. Harrison Street from Mill Street to the city limits, a distance of 835 feet, was originally paved with 4 inches of concrete in 1913. Some time later it was covered with an inch of black top; then in 1939, a 3- to 4-inch concrete resurface was built on top of the asphalt surfacing. The concrete topping, reinforced with 42-pound mesh, was placed in three 8-foot lanes with transverse joints at 16 feet. Two cores were taken from the job. One showed no bond between the concrete resurface and the black top, but the other showed good bond between the black top and both the base and the resurface. The bond strength between the base and the black top was 220 psi and between the topping and the black top 176 psi. As can be seen in Figure 14, the street, which is used by city busses and Route 10 traffic, is in very good condition after 15 years' service.

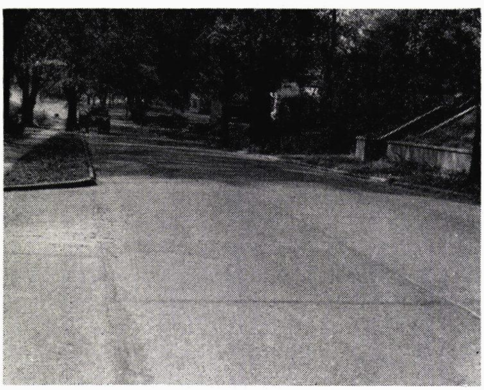

Figure 14. Liberty. Harrison Street, resurfaced in 1939, looking in direction of city limits.

Savannah. Market Street from 5th Street to 6th Street, a distance of 420 feet, was built of concrete 4 to 5 inches thick in 1913. Because the surface was rough, it was topped with 2 to 3 inches of 28-pound mesh-reinforced concrete in 1914. Information is not available on the bonding technique, but apparently bond was obtained over much of the area. Three cores were taken showing a base thickness of about $4\frac{1}{2}$ inches and a topping thickness of $2\frac{1}{2}$ to $3\frac{1}{2}$ inches. Bond strength was 86 psi in one core, and 208 psi in another; the third core was not bonded. The 27-foot wide resurface was built without a longitudinal joint but has transverse expansion joints at 40-foot intervals.

The Market Street concrete resurface has given service for 40 years and, as seen in Figure 15, it is still in usable condition, although considerable transverse and longitudinal cracking has occurred as well as some surface scaling.

Nebraska

Superior. Although two cores removed from Central Avenue in Superior indicated that the resurface was not bonded to the base, the job is of interest because of its relatively good performance. The old concrete base, 4 to 5 inches thick and 65 feet wide, was built in 1914 and had a 2-inch black top surface which was removed in 1931 when a 4-inch, 42-pound mesh-reinforced concrete resurface was placed. After being in service for almost 25 years, the street is in good condition, with only random longitudinal and transverse cracking marring its appearance.

Hastings. Three resurfaced streets, West

First Street and West 7th Street both from Kansas Avenue to Colorado Avenue, and South Street from Minnesota Avenue to the U.P.R.R. tracks, were cored.

The old concrete base on First Street, built in 1913, 3½ inches thick and 30 feet wide, had a 3-inch black top which was removed in 1948 when a 4-inch plain concrete resurface was constructed. The surface of the old base was swept clean and coated with a cement slurry before resurfacing. Contraction joints were placed transversely at 10-foot intervals and longitudinally to form 10-foot wide lanes. These joints have not controlled the random cracking, indicating that the resurface is bonded and that cracks in the base are now reflecting through the topping. Three cores were taken from the job: two were bonded, having bond strengths of 348 and 308 psi, and one was unbonded.

The old concrete base on 7th Street, built in 1911, 4 inches thick and 26 feet wide, had a 3-inch black top which was removed in 1948 when a 4-inch plain concrete resurface was constructed. The surface of the old base was swept clean and coated with a cement slurry before resurfacing. Contraction joints were placed transversely at 10-foot intervals, and longitudinally at the center line. Two cores were taken from the job: one had a bond strength of 186 psi; the other was unbonded. In 1953, except for some longitudinal cracking, the street was in good condition, as can be seen in Figure 16.

The old concrete base on South Street, 4 inches thick and 26 feet wide, had a 3-inch black top surface until 1949 when it was removed and a 4-inch plain concrete resurface was placed. The old surface was swept clean and coated with a cement slurry before resurfacing. A longitudinal joint was placed at the center line, and transverse contraction joints were spaced at 12 feet. Two cores were taken: one had a bond strength of 168 psi, and one was unbonded. Except for random longitudinal cracking, and some local distress where multiple cracking has occurred, the street was in good condition when cored in 1953.

New York

Rochester. Two thin bonded concrete resurfaces placed in 1942 in Rochester were cored: a Main Street bus stop, 3½ inches thick, 11 feet wide, and 35 feet long; and Meadowbrook Road, 1 to 1½ inches thick, 26 feet wide, and 230 feet long. The old surfaces, prior to resurfacing, were cleaned with star drills mounted in air hammers; the surface was then blown clean, washed with water, and coated by thorough brushing with a 1:1 sand-cement grout (*13*). The resurface concrete had a cement factor of 7 sk/cu yd, and water to make a zero slump. This material was hand tamped into place and finally compacted with a Kelley compactor float. Curing was for seven days with damp sand.

Performance of the Main Street bus stop has been good; two cores taken from the job had bond strengths of 444 and 480 psi.

The Meadowbrook Road job has not performed as well; after 11 years, considerable cracking has occurred, and failure in bond

Figure 15. Savannah, Missouri. Market Street resurfacing placed in 1914. Bond still exists between the base and resurface concretes although the surface shows considerable cracking and erosion.

Figure 16. Hastings, Nebraska. West 7th Street resurfaced in 1948, looking from Colorado to Kansas Avenue.

Figure 17. Core from Meadowbrook Road, Rochester, N. Y., when 11 years old.

along cracks and along boundaries of the resurface is common. Four cores were taken from the better areas; one had no bond and the other three had bond strengths of 520, 396, and 120 psi. One of the cores is shown in Figure 17.

Suffolk County. The old pavement on this job on N.Y. Route 27 for five miles between Amagansett and Montauk, Long Island, built in 1927, was 7 inches thick and 20 feet wide. During the war, heavy traffic caused considerable faulting and cracking, necessitating reconstruction in 1947. This included a 63-pound mesh-reinforced 5-inch resurface with integral widening 9 inches thick.

The old surface was prepared for resurfacing by filling all transverse cracks and joints with mortar to make a so-called monolithic base.

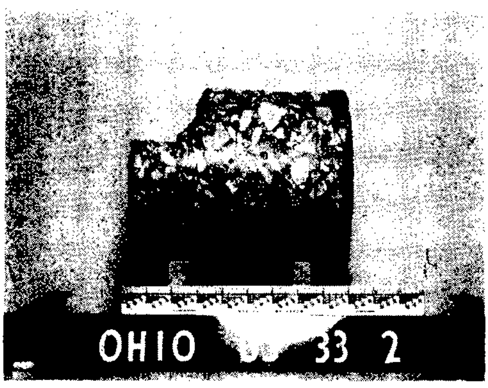

Figure 18. Core from Dublin Bridge sidewalk; ½-inch patch when eight years old.

As an expedient for setting forms for paving a lane at a time, the contractor removed the old concrete along center line in the westbound lane for a width of 15 inches. The inner form was then set in this area for resurfacing the eastbound lane. The westbound lane was resurfaced using the edge of the eastbound lane concrete as a form. No transverse joints were installed in the resurface.

The new pavement is in very good condition although many transverse cracks have developed. In the eastbound lane cracks generally are about 8 to 16 feet apart, whereas in the westbound lane they are about 15 to 24 feet apart. Three cores removed from the job had bond strengths of 500, 504, and 524 psi.

Ohio

Dublin Bridge. This bridge on U.S. 33, built in 1935 in Franklin County, crosses the Scioto River at Dublin. In 1945 part of a sidewalk where severe scaling had occurred was repaired by patching with about 1 inch of bonded concrete.

The areas to be patched were prepared by removing all old concrete that could be loosened readily; this was followed by washing with water, and the concrete was kept wet overnight. Then a cement grout was brushed on, and the resurfacing concrete (one part non-air-entraining cement and two parts sand with water to make slightly plastic) was placed and compacted with a surface vibrator. The concrete was moist-cured for three days.

Two cores were drilled from the patched sidewalk: one had a bond strength of 448 psi; the other, shown in Figure 18, was not tested. In 1953 the thin patches were still giving good service. Figure 19 shows a patched area after eight years of service as contrasted with the original concrete.

Stratford Bridge. The Stratford Bridge in Delaware County on U.S. 23, where it crosses the Olentangy River, was built in 1931; the sidewalk was resurfaced with 2 to 3 inches of bonded concrete in 1949.

The old surface was prepared and resurfaced using the same procedures used on the Dublin Bridge, except that air-entraining cement was used and the surface vibrator was not used.

Four cores were removed from the sidewalk in 1953: three were tested and showed bond strengths of 416, 456, and 210 psi. The resurfaced sidewalk in 1953 was giving good service although the appearance was marred by tight cracks covered with dark-colored exuded material.

This bridge has now been rebuilt as part of the improvement of U.S. 23 between Columbus and Delaware.

Toledo. Warsaw Street was paved in the fall of 1912, and the surface for two blocks north from Streicher Street was damaged by freezing. In 1913 the damaged concrete was removed, the surface swept clean and washed with water. Dry cement was spread on the wet surface as a grout coat before placing a 1- to 2-inch layer of light mesh-reinforced concrete. As late as 1948 the resurface was reportedly in good condition; however, in 1953, although it was still usable as a city street, the over-all appearance was not attractive because of many cracks and considerable patching. Nevertheless, the fact that this thin bonded resurface has remained intact for 40 years is a remarkable record. Figure 20 shows the present surface condition in one of the better areas. Three cores removed from the job had bond strengths of 484, 320, and 188 psi.

Figure 19. Dublin Bridge sidewalk at the curb line; thin patch in back placed in 1945. Area in front, not patched, has continued to scale.

Figure 20. Warsaw Street in Toledo, Ohio. Thin resurface placed in 1913. Bond still exists between the base and resurface concretes although the surface exhibits considerable cracking.

Pennsylvania

A bonded resurface was built in 1938 on U.S. 322 in Clearfield County starting 1½ miles northwest of Grampian and extending 3500 feet. The resurface, placed using the vacuum process, was 2 inches thick except on the outside of curves where construction of super elevation required concrete up to 9 inches thick.

The old road, 18 feet wide, probably 6–8–6-inches thickness design, was built a lane at a time without transverse joints. Apparently much of the project was severely cracked. The resurface was built a lane at a time also with transverse joints placed over old construction joints and over a few wide transverse cracks (*14*). Parts of the old surface were cleaned with air hammers and star-drill bits, but most of the project was cleaned with compressed air and hand brooms. The surface then was wetted and a neat cement grout thoroughly broomed in. The vacuum-processed resurfacing concrete, which had a modulus of rupture of 1000 psi, was cured for six days with wet cotton mats.

In 1953, when the project was 15 years old, considerable cracking had occurred and much of the concrete exhibited "D" cracking and showed poor durability. Numerous areas had been patched or were in need of patching. However, there were sections of the roadway, as seen in Figure 21, that were in good condition even though many transverse cracks had occurred. Most of them had developed where

Figure 21. U. S. 322, Clearfield County, Pa. One of the best sections of vacuum processed concrete resurface placed in 1938.

the edges of the vacuum mats joined during construction, and were tightly closed.

Four cores were drilled from the job from the better areas; three of these were tested and had bond strengths of 364, 348, and 500 psi.

Rhode Island

In 1936 a vacuum processed bonded patch approximately 10 feet by 24 feet and 2 inches thick was placed on a 6-inch concrete pavement near a culvert on State Route 44 outside of Providence. No details of construction are available; however, in 1953 the patch was still intact, although it was mostly covered with a thin asphalt surface. Two cores drilled from the patch had bond strengths of 484 and 640 psi.

Wisconsin

In June 1953 the Wisconsin State Highway Commission resurfaced part of the deck of the interstate bridge where it spans Lake St. Croix between Minnesota and Prescott, Wisconsin. The entire deck had been reconstructed in the fall of 1952, and at that time an area 100 feet by 20 feet in the center span was damaged by freezing. In the spring of 1953, some of the damaged concrete developed a thin surface disintegration and the Highway Commission decided to resurface the affected area.

To avoid closing the bridge, one lane of the 20-foot deck was resurfaced at a time. To divide the work, a longitudinal saw cut was made at the center line. A Tennant machine (*10*) was used to remove the old concrete to a depth of ¾ to 1½ inches. In some areas, especially along the deck edges, deeper cuts were made with jack hammers. Final cleaning was with water under pressure and with compressed air.

The slab was maintained in a damp condition and grouted by brooming in a neat cement slurry. Mix proportions of the resurfacing concrete were 1:1½:1½, maximum aggregate size was ½ inch, cement factor was approximately 10 sk/cu yd, and slump was 4 to 5 inches. A quantity of a powdered iron material was added to the mix also. The concrete was dumped into place, struck off with a wood screed, and compacted by hand-finishing with wood floats.

The concrete was cured overnight with wet burlap, and on the following day a coat of Ironite was broomed over the surface. Then the slab was covered again with wet burlap to complete four days curing; it was then opened to traffic, and resurfacing operations were started on the other lane. Figure 22 shows the westbound lane ready for concrete, the eastbound lane having already been resurfaced.

At an age of two years, in 1955, the resurface was 100 percent bonded to the base and was in excellent condition, although several very fine cracks had developed in the resurface over floor beams.

SUMMARY OF FINDINGS

Data have been accumulated in three areas: in the laboratory, in the field on experimental pilot construction projects, and in the field on resurfaced projects in service. Principal findings from these studies are summarized below.

Laboratory Bond Tests

The laboratory tests showed that two factors are critical in governing bond between new and old concretes, provided that sound concrete technology is followed throughout. They are (1) the strength and integrity of the old surface, and (2) the cleanness of the old surface. When a weak layer of concrete (scale, laitance, or otherwise poor material) existed on the surface, or when the old surface was dirty from exposure, poor bond was obtained. When the surface condition was favorable, good bond was obtained, although the magnitude of the bond strength varied depending upon other factors.

Additional findings include:

1. Good bond was obtained when the base concrete was either in a dry or damp condition, but generally, with plastic resurfacing concrete, a dry base developed stronger bond.
2. Good bond was obtained with and without a grout bonding layer. Generally, however, a grout layer increased bond. Neat cement grout, sand-cement grout, cement dust grout brushed on, or grout placed by spraying under pressure were equally beneficial.
3. Cleaning of sound base concrete with hydrochloric acid was very effective and economical, but mechanical cleaning was found to be essential if a weak or deteriorated surface layer existed on the old concrete. No great benefit was derived from intensive mechanical roughening of the old surface provided it was clean and sound.
4. Resurfacing concrete placed in a 2-inch layer compacted by surface vibration, by internal vibration, by vacuum processing, and by mechanical compactor float developed good bond. So did concrete placed by the shotcrete process.
5. The bond strength was not significantly influenced by the cement content of the resurfacing concrete in the range of 6 to 11 sk/cu yd.

Experimental Pilot Field Projects

The field work is in agreement with laboratory tests which indicate that the soundness and cleanness of the old concrete are important factors influencing bond. Cleaning of sound concrete surfaces with hydrochloric acid was found to be effective and economical, and appears to be practical on a field construction basis. The Tennant machine was found effective in scarifying and removing the upper surface of old concrete, including bituminous materials and oil films, to provide a clean, slightly roughened surface. A grout appeared to be helpful in increasing bond strength and was a necessity when dry-mix concrete was placed upon a dry base. When the cement content of the resurfacing mix ranged from 5.5 to 9 sk/cu yd, it had no appreciable effect on bond, nor did the method of concrete placement—provided that the concrete was plastic and well compacted. Bond strengths of cores from the various projects ranged from approximately 200 to 600 psi and were lowest when the surface of the old concrete was of relatively poor quality.

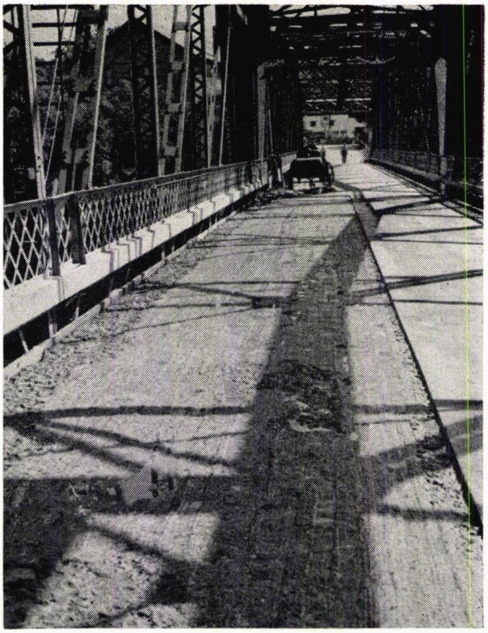

Figure 22. Prescott Bridge, Wisconsin, westbound lane prepared for resurfacing. Eastbound lane has been resurfaced.

Most of the resurfacing concrete in these projects was placed the same day that the old concrete had been given a final cleaning with water. Grouting and resurfacing followed when the concrete had become surface-dry. However, in a few test areas the old concrete was maintained either in a moist or a dry condition for several days before concreting. Based upon the performance of all the work, the moisture condition of the old slab did not appear to influence the results greatly.

Practically all the cracks in the old slabs reflected through the thin bonded resurfaces.

TABLE 5
SUMMARY OF BOND STRENGTHS OF CORES REMOVED FROM PROJECTS IN SERVICE*

Project Name	Resurfacing: Date built	Resurfacing: Nominal thickness	Bond Strengths
		inches	psi
Ilene St., Detroit, Mich.	1950	½	256
Tennant Co., Minneapolis, Minn.	1952	1	316, 424, 596
Themis St., Cape Girardeau, Missouri	1922	5	0, 291
Market St., Savannah, Mo.	1914	3	0, 86, 208
First St., Hastings, Neb.	1948	4	0, 308, 348
Seventh St., Hastings, Neb.	1948	4	0, 186
South St., Hastings, Neb.	1949	4	0, 168
Bus Stop, Rochester, N. Y.	1942	4	444, 480
Meadowbrook Rd., Rochester, N. Y.	1942	1½	0, 120, 396, 520
Suffolk Co., U. S. 27, N. Y.	1947	6	500, 504, 524
Dublin Bridge, Ohio	1945	1	448
Stratford Bridge, Ohio	1949	3	210, 356, 416
Warsaw St., Toledo, Ohio	1913	1½	188, 320, 484
Clearfield Co., U. S. 322, Pa.	1938	2	348, 364, 500
Providence, Rt. 44, R. I.	1936	2	484, 640

* Cores were drilled during summer and fall of 1953.

Bond failures occasionally started in the vicinity of the cracks, but there is evidence that the deterioration of bond progresses slowly.

Projects in Service

A major purpose in coring resurfaced projects in service was to obtain information on the strength and durability of bond in full-scale field construction. Much of the data obtained on the cores, summarized in Table 5, indicates that the bond between new and old concrete can be made long-lasting. Street jobs approximately 40 years old in Savannah, Missouri, and in Toledo, Ohio, are still in service. Bond strengths of cores from these jobs cover a wide range: 0 to 208 psi on the Savannah job and 188 to 484 psi on the Toledo job. Other jobs built in the 1930's and 1940's in Missouri, Nebraska, New York, Ohio, Pennsylvania, and Rhode Island show good performance although the bond strength varied widely, ranging from zero in local areas to 640 psi, with most values in the range 200 to 500 psi. These data indicate that satisfactory performance has sometimes been shown even though bond strengths are low as compared to values obtained in the laboratory and on experimental pilot field jobs, and even though localized areas show little or no bond strength.

Visual observation of the street and highway projects shows that many of the cracks and structural defects that apparently were in the old pavement reflect through a bonded resurface. There does not appear to be a simple economical method for preventing the occurrence of sympathy cracking in a bonded resurface. Some benefit might be obtained by filling wide cracks in the base slab with cement paste or mortar. Such a process would not eliminate the possibility of the cracks reflecting through the resurface, but it would reduce the width of the cracks.

RECOMMENDATIONS FOR BONDING NEW AND OLD CONCRETES

The following fundamental factors must be observed closely when placing bonded concrete: (1) proper preparation of the old base concrete, (2) use of high-quality grout and concrete, (3) good compaction, (4) proper jointing, and (5) proper curing. The need for first-class workmanship and high-quality materials cannot be overemphasized. Wire mesh reinforcement may be desirable at times.

Preparation of the Old Concrete

For best appearance, areas to be patched or resurfaced should be marked with straight lines parallel to nearby joints. A concrete saw or other mechanical equipment should be used to provide vertical edges for a minimum depth of ½ inch. If part of the area extends to a joint, the filler material should be completely removed or leveled with the surrounding concrete to avoid strike-off and edging difficulties later.

To provide bond, the old surface must be cleaned and unsound material removed. When the old concrete is sound and durable, brooming and washing with water followed by hydrochloric acid has been found very effective for this purpose. This is neither difficult nor expensive. Concentrated commercial hydrochloric acid, in rubber drums of 13 gallons each, costs about $0.35 per gallon. The acid may be diluted with equal parts of water, or it may be applied full strength to the concrete slab which has been wetted to facilitate spreading. One application of acid at the rate of 1 gal. to 6 to 10 sq. yd. may be sufficient to clean the surface, but two such applications may be required. The acid must be handled with care. It should be spread uniformly over the wetted slab and lightly brushed to insure complete coverage. After the bubbling action has ceased, the surface should be thoroughly flushed and vigorously brushed to remove partly loosened sand and other residue, as bond is inhibited by its presence. Evidence indicates that even in some *new* two-course floor construction, cleaning of the base surface with hydrochloric acid to remove laitance and dirt appears to be warranted in order to obtain strong bond.

Hydrochloric acid will not remove asphalt and tar which may be removed best with mechanical equipment or by sandblasting. Oil drippings are partially removed by the acid, but if they are extensive, they should be partially removed with a strong detergent before acid treatment.

If the old concrete surface is not sound and durable, the cleaning operation becomes more complicated and expensive. Obviously, it is not good practice to place a thin bonded concrete patch or a resurface on concrete which has been patched with black top or which is exhibiting either active or incipient scaling. (See Figures 23 and 24.) This requires mechanical treatment with air hammers (*13*) or other equipment such as the Tennant machine (*10*). Cutting should continue until sound, durable concrete is exposed over the entire area. Old surfaces that may have scaled to expose sound, durable concrete need not be mechanically cleaned, but may be treated with hydrochloric acid as described previously.

Final cleaning of an area where mechanical scarifying has been employed is an important construction step. Compressed air followed by washing and brushing are used for this purpose. If possible, the area should be kept dry until all the dust has been blown off. If the dust becomes wet, it packs into hollows and crevices and can then be removed only by repeated washing and brushing followed by compressed air. Final cleaning with water under high pressure should be done sufficiently ahead of concrete placement to permit the surface to become practically dry. A well prepared and cleaned area ready for patching is seen in Figure 25.

If, for any reason, resurfacing does not follow immediately after cleaning, the area should be carefully protected during the interim. If possible, the area should be kept dry, so that a final cleaning before resurfacing may be accomplished with compressed air followed by water under pressure.

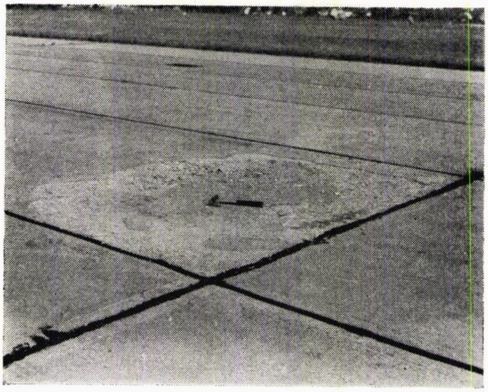

Figure 23. A scaled area requiring thin patching. The unsound surface concrete must be removed before placing new concrete.

Figure 24. City street requiring resurfacing. Cracks in old pavement and questionable quality of the concrete indicate that steel mesh should be used in concrete resurface.

High-Quality Grout and Concrete

Tests and experience have indicated that good bond may be obtained without the use of a grout layer. However, the chances of obtaining stronger bond are increased with a grout. Either a 1:1 sand-cement grout or a neat cement grout may be used; a sand-cement grout is easier to mix and is more economical to use. The grout must be scrubbed thoroughly into the surface to wet it uniformly, to displace air films, and to incorporate any loose particles still on the surface. Figure 25 shows

Figure 25. Grout being thoroughly broomed into surface-dry base concrete prior to placing thin concrete patch.

grout being brushed on an area just ahead of placing patching concrete. A hand brush is used to insure proper grout coverage around the boundaries of the patch. Placement of grout pneumatically (shotcrete or spray-crete process) has proved effective when sand rebound is properly controlled; in fact when steel mesh is used, pneumatic placement of grout may be advantageous.

Sufficient grout for brushing can be mixed to provide material for about an hour. It should be covered to reduce evaporation of water, and remixed as it is being used. A water-cement ratio of 5.5 to 6 gal/sk will produce a grout of proper consistency for use indoors or for use outdoors in cool, cloudy weather. However, on hot, sunny days grout of such consistency placed on dry concrete may not brush out well. Under such conditions the water content may be increased slightly to permit brushing, or the old surface may be lightly sprayed with water to permit uniform spreading of grout. Wetting of the surface should be done carefully and free water should not be permitted to collect in hollows and depressions; when it does it should be removed with compressed air or mopped up.

In cloudy, cool weather the grout may be spread a considerable distance ahead of concrete placement, but in hot, dry weather the two operations will have to follow rather closely in order that the grout does not dry out excessively. Grout that has lost its water sheen is in proper condition for the concreting operation.

Concrete used for patching or resurfacing must be of high quality and resistant to freezing and thawing, particularly where it will be subjected to salt applications. Thus, for outdoor work in the north, air-entrained concrete must be used. In certain types of work where the cement content is relatively high and the water-cement ratio is low, say below 4 gal/sk, and a nonplastic mix is used, air-entrainment is less significant. However, as mixes of this type are difficult to use outdoors, particularly during warm weather, it is usually better practice to use a plastic mix with air-entrainment to insure durability and with a reasonably low water-cement ratio to insure high strength and low drying shrinkage.

The mix design of patching or resurfacing concrete will vary depending upon the depth of concrete to be placed. Generally, the maximum aggregate size should be about half the depth of the layer for thicknesses up to 3 inches. Water-cement ratio may range from 5 to 6 gal/sk. Trial mixes, all having a w/c ratio of 5 gal/sk, are listed below for various thicknesses of resurfacing. Weights are for dry aggregates. Generally, air-entrained concrete with a slump of 2 to 4 inches will work nicely. On hot days, a slump of 4 inches may be desirable, and on cloudy, cool days a slump of 1 to 2 inches may be preferable. Depth of patch, absorptive properties of the old concrete, temperature, and placement equipment will govern concrete consistency on each job.

For a patch or resurface 3 inches or more thick the following trial mix is suggested using an aggregate of 1½- inch maximum size:

94 lb. cement
180 lb. fine aggregate
305 lb. coarse aggregate
42 lb. water
Air content 4 to 6 percent
Approximate cement factor 6.4 sk/cu yd

For a patch 2 inches deep the following mix is suggested, using aggregate of 1-inch maximum size:

94 lb. cement
180 lb. fine aggregate
260 lb. coarse aggregate
42 lb. water
Air content 5 to 7 percent
Approximate cement factor 6.8 sk/cu yd

For a patch 1 inch deep the following mix is suggested, using aggregate of ½-inch maximum size:

94 lb. cement
170 lb. fine aggregate
175 lb. coarse aggregate
42 lb. water
Air content 6 to 8 percent
Approximate cement factor 7.8 sk/cu yd

For patches about ½ inch deep the following mix is suggested, using aggregate passing the No. 4 sieve (concrete sand):

94 lb. cement
280 lb. fine aggregate
42 lb. water
Air content 9 to 11 percent
Approximate cement factor 8.6 sk/cu yd

Compaction

To obtain secure bond, thorough compaction of the fresh concrete is essential. This is not difficult to attain if a plastic concrete is used having a slump of about 2 to 4 inches. Surface vibratory screeds as shown in Figure 26 do a very satisfactory job and are desirable for most work. For placing concrete more than about 3 inches deep, a small internal vibrator is helpful for obtaining good compaction along the edges. On small jobs, where vibratory equipment is not available, satisfactory consolidation may be obtained by puddling the concrete along the edge of the patch, and by compacting the surface with a 2- by 4- or 3- by 6-inch wood screed. This is done by first screeding the fresh concrete a little high. Then one end of the screed is held stationary while the other end is lifted and dropped on the concrete at close intervals, advancing forward slightly with each stroke. For small patch jobs a surface vibratory screed may be improvised by attaching a spud vibrator to a light steel angle or channel. Final finishing may be done with long-handled darbies, or with small hand floats, followed by light brooming for most paving jobs.

For nonplastic concrete (such as may be specified for the wearing surface in two-course floor construction) a special mechanical compactor float is required to insure proper compaction of the concrete. A compactor float will also prove very useful where plastic concrete has been placed but has stiffened for some reason before final hand-finishing has been accomplished.

Jointing

Wherever a bonded patch or a resurface extends over a joint, or butts against an expansion joint in the old pavement, a joint will be necessary in the new concrete. Contraction joints should be placed over contraction joints, and expansion joints over expansion joints. Guide marks must be set carefully to insure that the joints placed in the topping are directly over those in the base slab. Joints may be tooled in the plastic concrete, or cut with a concrete saw (see Figure 27). Time of sawing will be governed by the rate of hardening of the concrete, but sawing generally must be done within several hours after placement before cooling shrinkage has taken place. Blade penetration will vary depending upon the depth of resurface and the type of joint in the old pavement. Cuts over tight longitudinal joints may extend about ¼ to ⅓ the depth of resurface, but a cut in thin bonded resurface over an expansion joint or a wide open contraction joint must extend through the new concrete into the old filler. In some cases, two cuts will be required over expansion joints to provide sufficient expansion space. For relatively thick patches and resurfaces, where full depth sawing is not practical, special attention must be given to the jointing in each individual case. Where practical, wood headers, which may be removed later and replaced with joint filler, may be installed over expansion joints in the old pavement.

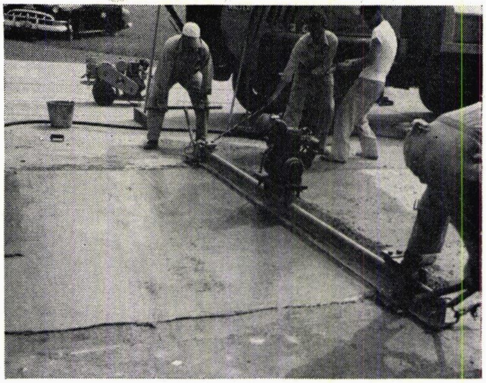

Figure 26. Vibratory screed compacting plastic concrete for thin patch.

Curing

Curing of the patch or resurface serves two purposes. It tends to reduce temperature changes during the early life of the concrete when resulting volume changes may be detrimental to bond, and it prevents early drying,

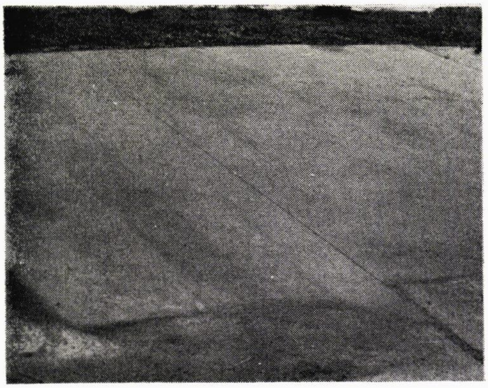

Figure 27. A longitudinal contraction joint, cut with a concrete saw in a thin concrete patch.

thus aiding in proper hydration of the cement at the time rapid strength gain is important. Curing with wet burlap covered with a light-colored vaporproof paper will be most effective. Burlap that is definitely maintained wet, or light-colored paper without the under layer of wet burlap, are second choices. If paper is used, the concrete should be flushed with water immediately before covering. The paper or the burlap should be placed as soon as possible without marring the surface. On windy days when ambient relative humidity is low, particularly in combination with hot weather, special precautions may be required to prevent rapid drying before placement of curing materials. The application of a light spray of water at this time will be helpful. Curing should continue for at least three days and preferably about a week. If it is necessary to remove the burlap and paper before seven days, a light-colored membrane coating should be applied to prevent rapid drying.

Steel Mesh in Bonded Resurfaces

The usefulness of steel mesh reinforcing in a bonded resurface will depend upon several factors. For instance, if there are cracks in the base slab which ultimately would reflect through the resurface, a fairly heavyweight mesh having sufficient strength to hold the composite pavement together at the cracks would be useful.

The use of mesh is desirable also when the quality of the concrete in the base slab is questionable. In such cases, bond may not be uniformly strong throughout the whole area, and if local bond failures should occur, the mesh will hold the resurface together over these areas.

The placement of mesh in a thin resurface, say only 3 inches thick, requires special precautions to insure that it is held at the proper level of 1½ to 2 inches below the surface. To accomplish this, it may be necessary to use ties such as powder-driven plugs to hold and space the mesh properly.

Mesh does not appear warranted where bonded patches or resurfaces are placed on base pavements that are practically free of cracks, and in which the concrete is sound, clean, and of good quality. By omitting mesh in such cases the resurface may be held to a minimum thickness of about ½ inch.

ACKNOWLEDGMENTS

Fred C. Curtis and Robert C. Richert, formerly employed with the Research and Development Division of the Portland Cement Association, conducted most of the laboratory tests discussed in this report and were in charge of the construction of the pilot field projects in Wauwatosa, Wisconsin, and Minneapolis, Minnesota. Curtis was in charge of the Rhode Island Airport patching project, coring of the many jobs in service, and other miscellaneous studies. P. J. Tatman was in charge of the experimental project built in Skokie, Illinois. Assistance on all of the work was given by J. R. Schnell.

The paper was critically reviewed by Douglas McHenry, Director of Development, and his suggestions were of great value to the author.

Credit is given also to administrative engineering personnel in Wauwatosa, Minneapolis, Skokie, and at the Rhode Island State Airport, for their cooperation in making the pilot field studies possible; and to city and state officials who gave their permission to remove cores from their streets, highways, and bridges.

REFERENCES

1. Withey, M. O., "Bond of Vibrated Concrete," Proceedings Highway Research Board, 16, 1936, 193–206.
2. Thornton, J. C., "Relation Between Bond and the Surface Physics of Ma-

sonry Units—An Abstract," ASTM Bulletin, May 1953.

3. WATERS, T., "A Study of the Tensile Strength of Concrete across Construction Joints," *Magazine of Concrete Research*, England, Vol. 6, December 1954, pp. 151–153, Highway Research Abstracts, April 1955.
4. "Bonding New Cement Mortar and Concrete to Old Concrete," Concrete Products, Vol. 17, October 1919, pp. 19–20.
5. DAVIS, R. E., AND DAVIS, H. E., "Bonding New Concrete to Old at Horizontal Construction Joints," Proceedings American Concrete Institute, Vol. 30, May-June 1934, pp. 422–436.
6. CLEMMER, H. F., "Patching Spalled Areas with Cement Mortar," Roads and Streets, Vol. 84, March 1941, p. 46.
7. UNGER, A. K., AND BARENTZEN, W., "Concrete Roads Repaired by Application of a New Surface Course," Cement (Amsterdam), No. 5-6, 1951, 98–100. Reviewed in Proceedings American Concrete Institute, Vol. 48, December 1951, p. 361.
8. CARLSON, C. C., "Investigation of the Dry Cement Method of Bonding New and Old Concrete," Unpublished Report, Development Department, Portland Cement Association, January 1943.
9. BLANKS, R. F., AND TUTHILL, L. H., "Horizontal Construction Joints," Technical Memorandum No. 622, Bureau of Reclamation, Department of the Interior, October 28, 1941.
10. "Chipping Machine Cuts Concrete Removal Time," Construction Methods and Equipment, Vol. 35, November 1953, pp. 58–59.
11. FLEMING, E. M., "Resurfacing with Portland Cement Concrete," Proceedings Highway Research Board, Vol. 12, 1932, pp. 206–222.
12. LEWIS, D. W., "The Performance of Concrete Resurfacing in Indiana," Proceedings Highway Research Board, Vol. 30, 1950, pp. 81–91.
13. HUGHES, H. W., "Thin Concrete Topping Restores Old Pavement," Proceedings American Concrete Institute, Vol. 22, April 1951, pp. 653–659.
14. JOHNSON, G., "New Top Pressed on Concrete Road," Engineering News-Record, Vol. 121, October 27, 1938, pp. 531–532.