Concrete Overlays for Concrete and Asphalt Pavements

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INTRODUCTION

The subject of pavement resurfacing with concrete is certainly not a stranger to the state of Indiana. In our first technical publication on the subject, "Pavement Resurfacing with Concrete," published in March of 1930, the table of projects shows a total of 42 projects in 21 states. Two of these were in Indiana, both city street projects in Terre Haute built in 1918 and 1923. We published an update of that publication in 1955. The table of examples showed 52 projects in 25 states. Athough Indiana showed only 3 typical projects in the table, the worksheet for the tabulation showed 55 projects in the state, the earliest in 1929. Forty-two of these were built in the 1930s and most were on city streets carrying heavy traffic. Nearly all of these early resurfacings were 5" thick and quite heavy, and only two were 4" thick.

So we see that concrete resurfacings have been around for more than a half century. After the mid-1950s and the beginning of the Interstate System, there was less emphasis on resurfacing and more on new construction. Now with the Interstate nearing completion, the emphasis has shifted back to rehabilitation and we are seeing a resurgence of interest in concrete resurfacing. Resurfacing of all kinds will perhaps be of greater importance than new construction on Interstate and primary highways during the next decade. The interest in concrete for this use has been heightened by two additional developments—the uncertain future supply of asphalt, and the decreasing service life of asphalt overlays on heavily trafficked pavements.

This paper will look at the design aspects and performance of each of the major types of concrete resurfacings that have been used over both concrete and asphalt pavements, including plain and conventionally reinforced concrete; continuously reinforced concrete; bonded concrete; and fiber-reinforced concrete.

OVERLAY DESIGN CONSIDERATIONS

a.) Bonding Requirements

There are three basic variations in degree of bonding that affect the specific design to be used when placing new concrete over old:

Bonded: With fully-bonded resurfacing, measures are taken to ensure a complete bond to the existing pavement so the overlay becomes an integral part of the slab. Bond is generally obtained through the use of a sand-cement bonding grout applied to the base pavement after it has been scarified or roughened to ensure a good bond. The bonded overlays are generally much thinner than either unbonded or partially bonded resurfacing, and for this reason joints must be accurately matched to prevent reflection cracks. Intermediate cracking, if it exists in the base pavement, will also generally reflect through the bonded resurfacing. This type of resurfacing is most appropriate where the base slab is in good structural condition and where a new surface is needed to restore riding qualities, skid resistance, or to add a couple of inches to the structural thickness for heavier loads.

Partially-Bonded: No special steps are taken either to promote or inhibit bond with the existing surface. Direct overlays of concrete over concrete will require that joints in the resurfacing match joint locations in the base pavements to prevent reflection cracks from occurring over these joints. The existing slab cannot have extensive surface distress and must be structurally adequate. Rocking slabs, differential vertical movements at joints, and shattered or broken concrete preclude this bonding technique.

Unbonded: With this type, a separation course is used to prevent the overlay from bonding to the existing pavement. This prevents bond and reflection cracks. Separation courses as thin as a layer of plastic polyethylene film and as thick as perhaps two or three inches of bituminous concrete have been used. In the case of very badly shattered or broken pavement, the use of a separation course may also serve as a leveling course to minimize overrun on the concrete resurfacing. This design has also proved to be quite useful in overlaying pavements with severe joint deterioration due to D-cracking or alkali aggregate reaction.

b) Resurfacing Layer

Type: Within the general restrictions of bonding as discussed above, there are also different designs of the concrete resurfacing layer. These may be for unbonded or partially bonded overlays: plain concrete without dowels; plain concrete with dowels; mesh reinforced concrete with dowels; and continuously reinforced concrete.

Where a bonded resurfacing is specified, it can be either plain concrete or fiber-reinforced concrete.

Thickness: The design of concrete overlays on concrete is not an exact science and not subject to a simple equation or nomograph at this time. The type of overlay and the thickness will depend, to a large degree, on the type and condition of the existing pavement to be resurfaced and the causes of existing distress. Such distress may have occurred in the subgrade, subbase or slab, or may be due to unanticipated traffic, inadequate drainage or soil movements. In some cases, overlays are required to correct geometrics during a widening rather than to alleviate distress or poor rideability. Design equations for this type of resurfacing over concrete were originally developed for airport pavements by the U.S. Army Corps of Engineers and have been published by ACI and PCA. While there has not been much experience with these formulas for highway work, it appears that thickness usually derived from the equations are less than those considered practical to build. Most unreinforced or conventionally reinforced overlays of old concrete have been about six inches thick on roads and streets. On some projects, thicker designs should be used.

Jointing: A bonded resurfacing will reflect most cracks and all working joints below it. Where the base pavement is jointed, new joints placed in the bonded layer must match those in the base pavement exactly. On an unjointed pavement with cracks, the new crack pattern in the resurfacing will resemble the old. This is not critical since the base pavement under a bonded overlay is normally structurally sound.

Thicker unbonded resurfacings of plain or reinforced design should be jointed to match the underlying pavement where a partially bonded overlay is used. Where an interlayer is used to break bond, this requirement may be waived and the resurfacing layer jointed independently without regard for the base pavement jointing pattern.

c) Interlayer

Where the unbonded concrete layer is being placed over old concrete, the interlayer is an important element of the design. Its presence is required where the condition of the base slab is such that it might induce cracking in the concrete placed directly upon it, or if the design used for the resurfacing is different than the one used in the original pavement. Where the base pavement is rough or in poor vertical alignment, the interlayer also serves as a leveling course to provide a uniform interface with the concrete and a uniform overlay thickness. Minor irregularities can be taken up with the resurfacing concrete.

Where existing joints or cracks in the base payment can be conve-

Table 1

CONCRETE RESURFACING PROJECTS IN SERVICE

State	Project No.	Route	Age (yr)	Thickness (In.)	Joint Spacing	Reinforced	Dowels	Interlayer	Base Pavement	Integral Widening	Traffic		Serviceability Rating
											ADT	ADTT	
Plain Undoweled Design													
California	CA-3	I-8	9	6	*	None	None	.5-4 in AC	PCC	None	9,900	495	Very Good
	CA-5	I-5	4	8.5	*	None	None	None	0.45 AC on grade	None	10,800	1,300	Good
	CA-4	I-5	9	6	*	None	None		AC on CTB	None	15,000	1,760	Very Good
	CA-2	163	7	6 and 8	*	None	None	2-course AC	PCC	None	80,000	4,800	Very Good
	CA-12	US 101	11	7	*	None	None	AC leveling	AC	None	90,000	5,850	Very Good
	CA-13A	US 99	13	7	15 ft	None	None	None	AC	None	28,000	4,160	Very Good
	CA-15	US 99	6	7 min	*	None	None	None	PCC and AC	None	24,000	4,800	Very Good
	CA-13	US 99	18	8	15 ft	None	None	None	PCC with AC overlay	None	26,000	3,120	Very Good
	CA-14	US 99	21	8	15 ft	None	None	None	PCC with AC overlay	None	26,000	4,160	Very Good
	CA-6	I-80	9	8	*	None	None	Various experimental	PCC	None	55,000		
	CA-8	I-5	11	8	*	None	None	1 in. AC	PCC	None	26,000	5,170	Good
	CA-11	US 91	11	8	*	None	None	AC leveling	AC	None	136,000	13,870	Very Good
	CA-16	US 99	18	9	*	None	None	4 in. CTB	7 in. and 9 in PCC	None	26,000	4,160	Very Good
Georgia	GA-1	SR21	30	5	20 ft-25 ft	None	None	None	6 in. by 16 ft PCC	3 ft		600-1,000	Good
Michigan	MI-2	Dye Rd.	24	8	20 ft	None	None	Sand leveling	Old asphalt road	None			
Indiana	IN-1	Delaware St.	26	6	20 ft	None	None	None	6 in. PCC	None			
	IN-2	Morris St.	27	8	40 ft	None	None	None	8 in. PCC	None			

*13-19-18-12 skewed

Reinforced Short Panel Design

Iowa	IA-1	US 6	25	6	16 ft-4 in.	6x6—5/5	None	None	10-7-10 PCC	3 ft	2,330	160	Fair
	IA-3	US 61	23	6	16 ft-4 in.	6x6—5/5	None	None	10-7-10 PCC	3 ft	7,400	910	Good
	IA-4	US 34	23	6	16 ft-4 in.	6x6—5/5	None	None	10-7-10 PCC	3 ft	3,960	495	Good
Nebraska	NB-2	US 6	28	5 and 6	15 ft-4 in.	6x6—6/6	None	1½ in. AC with 5 in.	9-6-9 PCC	2 ft		350	Very Good
	NB-1	US 6	26	5 and 6	15 ft-4 in.	6x6—6/6	None	1½ in. AC with 5 in.	9-6-9 PCC	2 ft		350	Very Good
N. Carolina	NC-3	US 29	25	7	30 ft	6x12—2/5	None	None	PCC	1 ft		4,500	Fair

Reinforced Long Panel Design

Michigan	MI-1	US 127	24	6	43 ft-99 ft	Yes	None	Bit. and sand	9-7-9 by 20 ft PCC	2 ft (one side)			Fair
	MI-5	M-97	25	5 min	75 ft-100 ft	Yes	Yes	Bit, and sand		1 ft each side	21,000		Fair
	MI-21	M-19	29	5 min	100 ft	Yes	None	Bit.	6 in. by 22 ft PCC	1 ft each side	8,200		Fair
	MI-24	Elizabeth Lake Rd.	27	5 min		6x12—00/4		Bit. and sand	7 in. by 18 ft PCC	3 ft each side	20,000		Fair
Michigan	MI-26	M-29	23	6	40ft-100ft	Yes		Bit. and Sand	18 ft PCC	1ft each side	14,000		Good
	MI-27	I-69 (temp)	20	6 min.	99 ft	Yes		Bit.				2,100	
	MI-3	US 131-M-60	24	6-8	99 ft	Yes		Bit. and sand	18 ft. PCC	2 ft		1,200	
	MI-7	US 31	27	5	99 ft	Yes		Bit.	16 ft PCC	3ft		480	

Reinforced Doweled Design

Missouri	MO-1	SR82	29	4	30 ft	Yes	Yes	2 in. chat	6 in. PCC	None	8,700		Good
	MO-2	US 71	35	5	Various	Yes	Yes	¾ in. chat	PCC	2 ft			Fair
Nebraska	NB-3	US 6-34	13	5	46.5 ft	Yes	Yes	1½ in. sand	PCC	None		360-50	Good
Michigan	MI-4	M-21	25	5	99 ft	Yes	Yes	Bit. and sand	18 ft PCC	2 ft	5,000		Fair
	MI-14	Packard test track	31	6	50 ft. 37.5 ft.	Yes	Yes	Bit. spray	6 in. PCC	None	Test traffic		Good

Miscellaneous Unclassified Design

Iowa	IA-2	Ashworth Rd.	14	5 min	20 ft				10-7-10 PCC	Added lane			Very Good
N. Carolina	NC-2	US 70	23	5	Matched to base	Yes					21,000	2,700	Fair
Texas	TX-2	US 82	31	6 min									

niently matched in the resurfacing, or if some reflection or random cracking would be acceptable, the interlayer may be omitted.

DESIGNS AND PERFORMANCE—U.S. PROJECTS

In 1977, PCA and the American Concrete Paving Association joined in conducting a survey of plain and conventionally reinforced concrete overlays. This survey included all concrete resurfacings that could be located on state highway systems in the U.S. Thirty-nine projects were found that are still in service. They are listed in Table 1.

Project ages varied between 4 and 36 years. The majority had service lives in excess of 20 years. Some of these projects involve plain concrete with no dowels or reinforcing. Others used conventional mesh reinforcing and thicknesses of as little as five inches, with no dowels at the joints. A few projects were mesh reinforced pavements with dowels, and some were found in which it was difficult to obtain specific information on the resurfacing design. Many of these projects, such as the five inch plain concrete project in Georgia on State Route 21, are in excellent condition.

In addition to the nearly 40 projects which were found where the concrete resurfacing was still exposed and carrying traffic, another 43 projects were located that had been overlaid with asphalt. These projects had service lives averaging over 20 years before the asphalt overlay was placed.

Because most concrete resurfacing projects presently in service were built prior to the Interstate System and therefore are about 25 or more years old, Table 1 includes a wide variety of designs that represent the level of expertise and experience that had been gained up to that time. Design requirements may not be the same today as they were then. For instance, since most pavements being resurfaced at that time were not more than 16 or 18 feet wide, resurfacing designs included integral widening of the old pavement. The widening, usually eight to ten inches thick, was cast with the five or six inch resurfacing slab to form a monolithic cap covering the top and sides of the old pavement. Present resurfacing requirements do not usually involve widening because most two-lane pavements are 24 feet wide. This should simplify today's design construction and improve performance.

Designs varied in the requirements for an interlayer or separation course between old slab and resurfacing. Where used, various materials included layers of sand, granular foundation course or mine tailings, asphalt emulsion coatings with or without a sand blotter course, and machine-laid hot-mix asphalt.

Plain Undoweled Design: This design has been used extensively in southern California to update freeway pavements to modern structural standards in conjunction with adding adjacent full-depth lanes to increase capacity. As with their full-depth pavements, the California design uses skewed joints in these plain concrete resurfacings, with spacing at 13-19-18-12 feet intervals, although the three older projects in the survey used an earlier design with 15 feet right-angle joints. Resurfacing thickness ranged from six to nine inches.

Plain concrete resurfacings without dowels or reinforcement have given excellent service in California. They have been used to bring old four-lane pavements up to Interstate structural standards, and increase freeway capacity by matching new resurfacing to new full-depth lane additions. As a result, many projects are more than six inches thick and performance has been enhanced because resurfacing is on the inside lighter-traffic lanes of multiple-lane freeways. Even where such favorable circumstances do not prevail, performance has been excellent under substantial volumes of heavy traffic. None of the projects exhibit major distress manifestations at this time. Maintenance requirements have been minor, and serviceability ratings have remained high.

The plain designs used on projects in three other states in the survey also showed similar good performance with ages of 24 to 30 years. One project in Georgia with the plain design, still in service after 30 years, is five inches thick with contraction joints at 20 to 25 feet and expansion joints at 300 feet.

Plain concrete designs are particularly applicable where the pavement to be resurfaced is in sound condition with no structural breaks or extensive cracking. Where a direct overlay is used, the short joint spacing allows the freedom to match joints in place and to place intermediate joints between them as required to control cracking. Most survey projects of this design included an interlayer where the base pavement was concrete. With the use of an interlayer, matching of joints in old and new concrete is not critical. Dowels at joints should be included in the design where volume of truck traffic warrants additional load transfer.

Reinforced Short Panel Design: This design evolved from 23 years of concrete resurfacing experience in Iowa with concurrent developments in Nebraska. During the period between 1949 and 1954, Iowa built 16 projects of this design, totaling about 90 two-lane miles of concrete resurfacing. Three of these projects, totaling 20 miles, are still in service. Of the other 13 that have been overlaid with asphalt, such overlays occurred at ages of 13 to 15 years on five projects and 19 to 24 years on eight projects, with an average age of 19 years. The design included a 6 inch resurfacing thickness and a 3-foot integral widening 10 inch thick on each side, cast with the resurfacing and tied to it with substantial steel (No. 4 bars 4 feet long at 14½ inch spacing). The fullwidth, welded-wire fabric (style 6x6-5/5) was supplemented with a No. 4 bar placed longitudinally 9 inches from the outer edge of the widening and just below the mesh. Sawed contraction joints 1½ inches deep were at 16 feet 4 inches spacing, with every fifth joint a pre-molded bituminous strip 1/8x2-½ inch placed during construction for crack control. No dowels were used at joints, and no interlayer was employed between old and new concrete.

This undoweled reinforced short panel design resulted in considerable distress on projects in Iowa with high truck counts. In most cases, the thicker integral widening rested on a subgrade-subbase combination that was placed to a higher density during construction than was present in the material in place under the base pavement. Where this difference in subgrade density was substantial, it was theorized that the widening was subjected to greater expansion and frost heave. The upward heave lifted the resurfacing slab off the base pavement, and soil and sand were pumped between the two slabs from the base under the widening and shoulder. This waterborne material was deposited under the approach slab at the joint, and extensive major faulting resulted.

The Nebraska design was substantially the same as that used in Iowa, with minor changes in mesh weight and joint spacing. Nebraska's projects with this design are in excellent condition after 26 and 28 years.

Short reinforced panel design was used in early resurfacing designs to overcome the effects of cracks and structural breaks in the old pavement that could cause reflective cracking in the resurfacing. The increased steel quantity was specified to allow omitting an interlayer, and perhaps to more nearly balance the interior slab design with the thicker 10 inch monolithic widened section. With today's wider pavements that are generally in good condition structurally, It is not anticipated that this design would be widely used. The need for mesh reinforcement in this amount, or indeed in any amount, might be questionable where panels of 15 to 20 feet are specified.

Reinforced Long Panel Design: Projects using long joint spacings (43 to 100 feet) and mesh reinforcement without dowels at the joints, were found only in the state of Michigan. Most projects were five inches thick and used a relatively thin bituminous emulsion separation course between slabs. Nearly all included integral widening of one to three feet on each side and most had joint spacing of about 100 feet. Only one project is known to have had dowels at the joints for load transfer.

The eight Michigan projects with reinforced long panel design are still wholly or partially in service with ages from 23 to 29 years. Records of 14 other projects that were subsequently overlaid with asphalt show an age range of 12 to 38 years at time of overlay, with an average age of 21 years. Most of the projects in service show some distress—cracks, spalls at joints, or patched areas. In spite of these shortcomings, the relatively thin, undoweled long panel design, which might be considered inadequate by today's standards, has an excellent longevity record.

Conventional Mesh-Dowel Design: Resurfacing designs using both mesh and dowels were employed in miswestern states. Five projects with this design were surveyed. Thickness varied from four to six inches, and joint spacings from 30 to 99 feet. Information on mesh weights and dowel sizes used were usually not available.

The conventional mesh-dowel design was used in some of the oldest projects inspected in the 1977 survey. Traffic was not heavy on the two projects surveyed in Missouri, but the 4 and 5 inch thickness showed remarkable longevity of 29 and 36 years. Projects in Michigan used five and six inch slabs and bituminous interlayers and had ages of 25 and 31 years. All projects surveyed were in fair to very good condition.

Projects in Missouri used chat mine tailings as an interlayer between slabs, while Michigan specified a bituminous coating with sand blotter. A single urban project in Nebraska used a five inch thickness of concrete over a pit-run sand interlayer.

In the reinforced doweled (RD) design, where both mesh and doweled joints are used, resurfacing panels should not be over 40 feet. Where a direct overlay without interlayer is specified, joints in the resurfacing need to be matched with the joints in the base pavement, and intermediate joints used to be added to stay within the maximum spacing limitation. Where an interlayer is used to completely separate the two slabs, the need to match joints can be waived. The RD design would appear to be particularly applicable where subgrade movement, frost action, or similar problems have caused erratic cracking in the underlying pavement.

Current Projects: In our 1977 resurfacing survey, we also tabulated all concrete resurfacing projects of plain and reinforced designs constructed in recent years that have no significant performance history to date. These are shown in Table 2.

Some excellent recent examples of concrete overlays are included in Table 2. The Georgia Department of Transportation built a test section in 1975 which included six inches plain concrete over an existing pavement with thirty feet transverse contraction joint spacings. Since many of the joints on this project were faulted, dowels were used over all transverse joints in the base pavement, and intermediate undowelled joints were cut at 15 feet intervals to prevent intermediate cracking in the six inch layer. This pavement is now four years old and is in excellent condition. The six inch pavement was placed on a double application of curing membrane as a bond breaker. It was slipformed, tie

Table 2

RECENT CONCRETE RESURFACING PROJECTS

State	Route	Location	Year Built	Design*	Thickness (in.)	Joint Spacing	Interlayer	Base Pavement	Traffic ADT	Remarks
California	163	San Diego	1977	PC	9	13-19-18-12	AC leveling	AC pavement	65,000 ADT 10% trucks	
Georgia	I-85	Gwinnett Co.	1975	PC and PD	6	15 ft and 30 ft	Curing compound	PC 30 ft joints 1965	10,000 ADT 33% trucks	Includes concrete shoulders
Illinois	Manteno Rd.	Kankakee Co.	1971	PC	6	15ft	None	PC-6 in. by 9ft AC—7 in. by 10 ft.	1,600	
	Plank Rd.	LaSalle Co.	1974	PC	5 min.	20 ft.	None	2 in. AC on 6 in. agg. base	2,200	
Indiana	Columbus	Anderson	1976	PC and RD	3, 4	15 ft.	None or polyethylene	8 in. RD 1944	17,000	
Iowa	US 30	Green Co.	1973	PC and RD	5 PC 4 RD	20 ft PC 30 ft RD	None	Built 1922		
	US 20	Blackhawk Co.	1976	PB	2	—	—	10 in. conc. Built 1958 22 ft. wide		
		Dallas Co.	1977	PC	5 min.	20 ft	None	Asphalt		
		Washington Co.	1977	PC	5 min	Various	None	Asphalt		
		Boone Co.	1977	PC	5 min	Various	None	Asphalt		
	County C-17	Clayton Co.	1977	PB	2	—	—	6 in. PC		Short sections of 3 in., 4 in. and 5 in. reinforced
Kansas	US 24	Shawnee Co.	See remarks	PC	6	15 ft	1 in. AC	PC 30 ft joints Built 1956		Scheduled to be built in 1978
Minnesota	TH 71	Kandiyohi-Renville Co.	1977	5½	Random	1 in. AC skewed	9-7-9	22 ft wide		
Utah	I-80N	Snowville	1976	PC	9	Random skewed	1 in. AC	AC pavement Built 1966		Includes concrete shoulders

*PC—plain concrete; PD—plain w/doweled joints; PB—plain bonded; RD—reinforced doweled bars were added in the slab edge and six inch concrete shoulders were added on both sides—ten feet wide on the outside and four feet on the inside.

This project is typical of the kinds of experimental work being done by several states. They are an indication of the interest on the part of highway agencies to determine the best and most economical methods and materials for extending pavement life.

Concrete Overlays on Asphalt: Table 2 shows a noticeable trend toward the use of concrete resurfacing to restore worn bituminous pavements. Six of the 15 projects listed used plain concrete designs for this purpose. One project was on the Interstate System and one was on a heavily traveled freeway in San Diego.

In 1976 and 1977, the Utah DOT placed almost seven miles of concrete overlay on an existing asphalt pavement on Interstate 80. The bituminous pavement on this Interstate highway had been in service approximately 10 years, but was suffering considerable distress. As their first major 3R project, Utah slipformed an eight inch concrete overlay directly over the existing asphalt. Ten-foot wide shoulders on the outside and four foot wide shoulders on the inside were placed at the same time with a 38-foot wide slipform paver. The new concrete pavement had a skewed randomized arrangement of transverse contraction joints. Utah is planning additional concrete overlays of asphalt on their Interstate System.

In Iowa, many counties have slipformed six inch concrete pavements on the state secondary system. The excellent performance of six inch pavement on little or no subbase encouraged county engineers to try slipforming concrete directly on existing bituminous pavements in order to have a more durable pavement with a longer service life. In 1977, four counties constructed concrete overlays of existing asphalt pavements. Most of these were built to a minimum five inch thickness and a maximum of seven inches. The amount of surface preparation of existing pavements varied depending on conditions. If it is badly distorted or has an excessive amount of crowns, some trimming can be accomplished with a fine grader to create a more uniform cross-section for the new concrete pavement. The concrete is slipformed directly over the existing asphalt, using a stringline for surface control. It is usually necessary to do a certain amount of checking before stringlines are set to prevent excessive pavement thickness. The new pavement is usually 22 feet wide and transverse joints are sawed at 20 feet intervals, just as in their new pavements placed on grade. This type of construction has become quite popular, with additional counties building concrete overlays of asphalt during 1978.

a) Continuously Reinforced Concrete Resurfacing

CRC overlays depend on continuous longitudinal steel to hold tightly together the closely-spaced cracks that form in the slab. Ideally the crack spacing should be six to ten feet so that sufficient continuity in the form of shear transfer is obtained across the cracks.

The first CRC resurfacing in the U.S. was in Texas in 1959. To date, more than 340 two-lane miles of CRC overlays have been built throughout the U.S.

To check on the performance of CRC resurfacing, a survey was made in 1975 of 23 projects in 11 states. These projects are listed in Table 3. Traffic on these projects ranges from a low of 1,500 vehicles per day on a Iowa county road to 42,000 on a rehabilitation project. The service lives of the projects surveyed ranged from 1 to 16 years and about half of the total sections shown were built six inches thick. Only two projects, both of them experimental, used thicknesses less than six inches.

The percentage of longitudinal steel in the projects surveyed ranged from 0.45 to 1.0. Most of the sections contained 0.6%, which is commonly used in most new full-depth CRC pavements.

Transverse bars were omitted on two projects. Neither has longitudinal cracking in the resurfacing and both were rated as excellent.

The average typical transverse crack spacing is 6 feet. The average typical minimum spacing is about two feet, and the average maximum spacing is 10 feet. Cracks closer than 20 inches occurred regularly on 35% of the projects for which this information was reported. Five of these projects with the regular close crack spacing were rated as excellent, one as good, and one as good-to-fair, indicating that the regularity of closely spaced cracks has not affected performance.

Results of the survey showed the 94% of the total miles were rated excellent to good, and 6% of the mileage was rated poor. Poor ratings were attributed to one or more of the following factors:

- —Nonuniform thickness of the overlay where a leveling course was omitted and the base slab was irregular or settled;
- —Poorly consolidated concrete resulting from improper vibration of concrete under closely spaced steel;
- —Inadequate subgrade drainage; high water table with no provision for adequate edge drains; and
- —Nonuniform base pavement support and failure to stabilize original pavement in known problem areas.

The report describing this condition survey is available. Since that time, additional projects have been constructed in Texas, Arkansas, and Connecticut. Projects in Pennsylvania shown in Table 3 were constructed in 1975-77. Early in their life under very heavy truck traffic some spalls and punchouts occurred over joint locations in the underlying pavement. These areas were carefully repaired and now appear to have stabilized and distress is minimal. The Pennsylvania experience emphasizes the importance of the need to stabilize and immobilize the underlying pavement so that no movement can occur.

c) Bonded Concrete Resurfacing

As discussed earlier, this method of resurfacing involves measures taken to insure a complete bond to the existing pavement so the overlay becomes an integral part of the slab. Bonding is necessary for thin overlays, but has also been used for layers as thick as 8 inches on airports. The existing concrete must be in sound structural condition, but can have some surface distress such as shrinkage cracks, spalling, and scaling. Existing joints must be matched and surface preparation is extremely critical. Surfaces must be scarified to remove unsound concrete, exposed reinforcing steel must be thoroughly cleaned, and a bonding grout or epoxy must be applied. Until recently the extent of this operation was considered prohibitive for long stretches of highway. Thus, its use was confined primarily to bridge decks where the extra expenditure could be justified. Also, preparation could be controlled better on a small area where the production necessary on a highway is not required.

Recently, the milling, planing, and grinding of pavements has taken on a renewed importance, with new machines developed to advance this technology. Consequently, removal of surface concrete is changing from a time-consuming and costly operation to a routine one. In view of this, the concept of thin-bonded overlays is becoming more attractive for highways.

The state of Iowa has been the most active innovator in the area of bonded resurfacings. (See Table 4) Their successful "Iowa Method" of constructing bonded bridge deck resurfacings had demonstrated that bond could be obtained with a scarified, clean, dry surface of old concrete using a grout coat of cement, sand and water. Whether these techniques could be adapted to larger paving projects with higher production rates was the question that prompted experimental projects in 1976, 1977, and again in early 1978. A fourth project, a full-scale, non-experimental resurfacing of a five-mile section of I-80 in western Iowa this year, will place a three-inch bonded resurfacing over a CRC pavement.

A description of the methods and equipment used in this process is necessary to a full understanding of bonded resurfacing. The first step in bonded resurfacing is scarification of the surface of the existing con-

Table 3

CRCP Highway Overlay Projects

			Overlay					Base Pavement		
State	Route	Location	Area, (sq. yd.) Length, (mi.)	Year Built	Thickness, (in.)	Interlayer	Condition 1975	Type	Year Built	1 Design
Ark.	I-55	W. Memphis	24,000 1.7	1972	6	Bitum. leveling course	Excellent	PCC	1951	9 in. reinf.
Conn.*	I-86	Near Mass. line	152,000	1975 1976	6	Bitum.-leveling course		PCC		
Ga.	I-75	N. of Macon, Monroe Co.	191,000 13.5	1971	7, 8	None—partially bonded	Excellent	PCC	1954	8 in. plain
Ga.*	I-85	N. of Hamilton, Mill Road, SB	10,000 0.7	1975	3, 4.5, 6	Curing compound		PCC		9 in. plain
La.	Greene Co. E-53	E. of Jefferson	4,600 0.3	1973	3, 4	Curing compound	Excellent	PCC	1921- 1922	8½ in. reinf., 4 in. widening 1973
Ill.	I-70	W. of Pocahontas, WB	54,000 3.8	1967	6, 7, 8	Bitum, leveling course	Excellent	PCC	1939	10-8-10 in. reinf.
Ind.	I-69	N. of Indianapolis	13,000 1	1970	6	None—partially bonded	Poor	PCC	1955	9 in. reinf.
Ind.	I-69	N. of Indianapolis	52,000 4	1971	6	Polyethylene	Poor	PCC	1955	9 in. reinf.
Md.	I-70	3 projects W. of Baltimore	366,000 13.5	1972- 1974	6	Bitum, leveling course	Good	PCC		Reinf.
Md.	I-83	S. of Penn. border	43,000 3.1	1973	6	Bitum, leveling course	Good to Fair	PCC		Reinf.
Miss.	I-20	Vicksburg	30,000 2.1	1971	6	Bitum, leveling course	Excellent	PCC	1955	9 in. reinf.

N.D.	I-29	Near Manvel, SB	59,000 4.2	1972
N.D.	I-29	Near Grafton, NB & SB	101,000 4.7	1974-1975
Ore.	I-5	4 projects S. of Portland	1,247,000 28.3	1969-1975
Ore.	I-205	E. of Portland	34,000 2.4	1973
Ore.*	I-80	Near Ladd	66,000 2	1971
Pa.*	I-90	Erie Co., Sec. B-10	558,000 19	1975-1976
Pa.*	I-90	Erie Thruway, Sec. B-20	12	New 1975
Tex.	I-35	N. of Eddy	15,000 0.9	1959
Tex.	I-35	Near Schertz, SB only	30,000 2.1	1965
Tex.	I-35W	S. of Burleson, SB	102,000 6.6	1965
Tex.	I-40	W. of Bushland	68,000 7.2	1972
Wis.	US-16	Heartland-Pewaukee	16,000 1.2	1973

*Not included in 1975 survey.

6	Bitum, leveling course	Good	PCC	1959	8 in. plain
6	Bitum, leveling course	Excellent	PCC	1958	8 in. plain
7-9 var.	Bitum. leveling course	Excellent	Flex.	Prior 1959	
7-9 var.	Bitum, leveling course	Excellent	Flex.	Prior 1959	
7-9 var.	Bitum. leveling course		Flex.	Prior 1959	
7	Bitum, leveling course		PCC	1960	10 in. reinf.
7	Bitum, leveling course		PCC	1960-1962	10 in. reinf.
7	3½ in. AC overlay	Fair to Poor	PCC	1934	9-6-9 in. reinf.
6	1½ in. AC (1934) ¾ in. leveling	Excellent	PCC	1934	9-6-9 in. reinf.
6	2 in. AC (1947) 1in.leveling (1967)	Excellent	PCC	1936	9-6-9 in. reinf.
8	Bitum, leveling course	Excellent	Flex.	1953	16 in. base & AC surface
7 avg.	Polyethylene	Excellent	PCC	Earty 1950s	9 in. plain

Table 4 Bonded Concrete Resurfacing Projects - Iowa

Year	Location	Thickness (in.)	Base Pavement
1954	U.S. 34, W. Burlington	1-3	7-8-7 PCC
1972	Cedar Rapids	Various (fiber)	PCC St. & AP
1973	Green Co. - U.S. 30	2-3	Old Conc. Pvt.
1976	Waterloo - U.S. 20	2	Concrete
1977	Clayton Co. - U.S. 20	3-4-5	6-in. concrete
1978	Sioux City - U.S. 20	3	3-in. AC on PCC
1979	I-80, Western Iowa	3	8-in. CRCP

crete approximately ¼-inch in depth to remove road oils, linseed oil, tire rubber, and any other contaminants which might prevent bond. The CMI Roto-Mill has been used for this purpose. The Roto-Mill consists of a helical or spiral rotary cutter with 228 tungsten carbide teeth. The cutting head is nine feet wide. The machine is quite dust-free, quiet and operates at speeds up to 40 feet per minute. It is equipped with a hydrostatic loading belt for picking up and loading all cuttings. The machine can be equipped with a ski to sense the level of the existing pavement and establish grades for the new ground surface.

After grinding, all surfaces are sandblasted to remove any fractured concrete left by the grinding operation. An automatic one-man sandblasting machine using two 600-CFM pneumatic compressors, two five-ton canned sand units, and a hydraulic driving system for oscillation and forward movement, has been developed for this use. Four #7 nozzles on an oscillating metal frame, sandblast widths up to 16 feet at speeds up to 14 feet per minute under 110 pounds of pressure. Some test sections which eliminated this operation have been established to determine if it is necessary for bond.

Other surface preparation methods have been tried, including "water-blasting." The water-blaster used is similar to the type used to clean airport runways of excess rubber. A five-foot spray bar shoots water at 7,000 psi onto the surface of the existing pavement. The surface of the pavement is extremely well cleaned by the water-blast operation. Some difficulty has been encountered in removing etched-painted lines. Tests conducted by the Iowa DOT have shown no difference in bonding between the sandblast or the water-blast, and the ground sections. Both the water-blaster and the sandblasting machine provide high production rates. Consideration is being given to the possibility of combining the sand and water-blast procedures on future projects to produce an effective surface preparation method which is environmentally acceptable.

After the surface has been scarified and sandblasted, concrete fragments and dust are picked up by a street-sweeper. Just prior to grout application, the existing slab is cleaned with an air blast to remove all foreign material from the surface.

Grout is normally mixed in a central-mix concrete plant and transported to the job in agitator trucks. It is a 50% sand-50% cement mix with enough water added to create a consistency of thick cream. The grout is spread by rubber floats and brooms over the dry surface just prior to the placement of the new concrete. A uniform thickness of grout not more than 1/8 inch thick on the dry surface is desirable.

Iowa's research has shown that grout should not be used if it has been mixed for a period in excess of two hours and that agitation of the grout must be continued at all times so that cement and sand do not settle to the bottom. The placement of this grout on a dry pavement surface is credited with the success of bonding in Iowa. The resurfacing concrete should be placed over the grout before it dries.

Resurfacing concrete is normally placed with a slipform paver. The normal paving mix has been used, with experiments also conducted on mixes containing super water reducers and higher cement contents. Most bonded resufacing has been two inches thick, in which case the maximum coarse aggregate size specified is one inch. Normal slump is quite low and vibration is required to achieve maximum density. It is desirable to use a heavy slipform paver to minimize the possibility of the paver riding up on the stiff concrete and causing a rough-riding pavement surface.

Most specifications call for transverse grooving of the overlay surface to provide superior skid-resistance. This is sometimes preceded by a burlap or astrograss drag to impact a micro-texture to the concrete surface.

Curing of early highway overlay projects in Iowa and all bridge deck resurfacings in the state was done by wet burlap, moistened for 72 hours. The experimental overlay projects have evaluated white pigmented liquid cure against this standard. Present specifications call for a double application of liquid cure, each separate application at the rate of 1 gallon per 15 square yards (total .13 gallon per square yard.).

Transverse joints are cut through the full depth of the overlay directly over the joints in the base slab as soon as possible after paving. Iowa engineers believe the full-depth contraction joint through the overlay is necessary to prevent severe stress concentrations from being generated in any portion of the overlay through which the joint would not extend. Locations of joints in old slab are previously marked by nails at joint ends. No special cleaning, sealing, or other preparation is done to the old joints before resurfacing. Sawed joints in the resurfacing are sealed in accordance with normal paving specifications.

Longitudinal joints are not sawed in the resurfacing layer. The thin layer of bonded concrete above the joint forms a very narrow, straight crack that is not considered detrimental to performance. Experience to date appears to substantiate this approach.

The Iowa DOT also specifies four-inch wide full-depth pressure relief joints in the old pavement at ¼-mile, or 1,000-feet, intervals to relieve any compression prior to overlay. The pros and cons of this rather drastic interruption to the continuity of the pavement structure are still being evaluated.

The 1978 project in Iowa was significant in that it involved the removal of an existing asphalt overlay from the old concrete pavement prior to resurfacing with concrete. Removal was done by cold milling in two passes, and a third pass then scarified the upper ¼-inch of underlying pavement to prepare it for the bonded layer of concrete. This method combining removal, stockpiling for recycling, and replacement with a more durable layer of bonded concrete, is a natural for pavement surface restoration. Iowa's Chief Engineer, Robert Given, described its potential as follows:

> "There is a place for thin-bonded, high-density concrete overlays in extending highway pavement service life. The concrete system seems particularly appropriate where overlay thickness must be limited, structural qualities enhanced and surface texture restored. We feel the concrete system has been successfully demonstrated and that it will be used increasingly in the future."

d) Fiber-Reinforced Concrete Resurfacing

Another type of concrete resurfacing is one reinforced with fibers. Most projects to date have used a relatively thin layer, bonded to the base slab. However, at least one project has been built in which a six-inch thick independent layer of fiber-reinforced concrete was placed on an old asphalt runway.

The concept of reinforcing concrete with randomly distributed fibers has received major emphasis only in about the last decade. Field testing has been done on fibers of steel, glass, plastic, and asbestos, with steel the most commonly used in resurfacing applications.

Fibers are generally one to two-one-half inches long, and either round or flat in cross-section. They are introduced into the concrete mix during batching, in rates up to 2-½% of the mix volume.

Fibers have been shown to increase toughness, ductility, and resistance to crack propagation in concrete. These qualities have enhanced its consideration for use as a resurfacing material. However, its performance in overlays has been somehat spotty — some failures have occurred on both highway and airport overlay projects. Some of these performance problems may have been due as much to lack of proper bond with the old concrete as to the fact that fibers were a part of the concrete mix in the resurfacing layer.

A major problem with the mixing of fiber concrete is the difficulty of attaining uniform dispersion of the fibers throughout the mix. Clumping together or balling of the fibers occurs frequently, interfering with normal spreading and finishing operations, producing voids in the hardened concrete if not removed. A number of steps have been taken to prevent this clumping — vibrating the fiber feed belts, varying their direction, reducing length of fibers, changing mixing sequence, etc. Two changes have solved the problem on some jobs — reducing length of fibers to ½ inch or ¾ inch and introducing the fibers with the aggregate instead of independently. Another promising innovation uses a proprietary system of steel fibers glued together in small packets which allows the fibers to disperse after reaching the mix.

One other property of fiber-reinforced concrete that affects handling and finishing is its increased stiffness. Additional consolidation is needed, with external vibration preferable to internal or spud vibration which may leave voids in the mix.

There have been a number of demonstration sections and some full-scale projects in which steel fibers have been used in the concrete resurfacing to develop a more crack-resistant layer which spans cracks in the base pavement minimizing reflection cracks. While the cost of fiber-reinforced concrete has prevented its general acceptance for highway resurfacing, several major airport projects have been built in which fiber-reinforced concrete has been used as a resurfacing of existing pavements for aprons, runway ends, and taxiways. The early projects in which fiber-reinforced concrete was used as a resurfacing have shown the importance of matching the joints in the base pavement. Between the joints the fiber reinforcement seems to minimize reflection cracking, provided a proper mix is used with high enough fiber contents and adequate concrete resurfacing thickness. Table 5 lists resurfacing projects built in recent years using fiber-reinforced concrete.

SUMMARY AND CONCLUSIONS

We believe that concrete resurfacing is a practical means of extending the service life of existing pavements, whether asphalt or concrete, without major reconstruction. Our surveys in recent years have shown that with proper attention to detail, concrete resurfacings with a number of different basic designs can be built to last more than 20 years. Such length of service life, coupled with reasonable first cost and minimum maintenance requirements, should result in life-cycle costs

Table 5 Fiber-Reinforced Concrete Resurfacing Projects

Year	Location	Thickness (in.)	Base Pavement
1971	WES, Vicksburg	4	10-in. concrete
1972	Tampa AP Taxiway	4-6	10-in. concrete
	Detroit Major Arterial	3	Concrete street
1973	Green Co., Iowa - U.S. 30	2-3	Old Conc. Pvt.
1974	Minnestoa - T.H. 51	2-3	Concrete
	Ft. Hood, Texas Tank Parking	4	Asphalt
1975	Reno, Nev. AP Apron	4	11-in. concrete
1976	Las Vegas, Nev. AP Apron	6	Asphalt

lower than those for resurfacings requiring multiple surface renewals over the same time period. These lower costs will be accompanied by the additional advantages of a higher level of serviceability and minimum interruptions to traffic during the life of the concrete resurfacing.