Construction of a Thin-Bonded Portland Cement Concrete Overlay in South Dakota

DANIEL JOHNSTON

In the early summer of 1985, a thin-bonded concrete overlay was placed on a badly deteriorated stretch of SD-38A near Sioux Falls, South Dakota. The 1.74-mi-long project [Project M 1186(2)] consisted of two experimental sections 3 and 4 in. thick. In addition, a 500-ft test section was included where no bonding grout was used before overlaying, as well as another 500-ft test section where a 6-in.-wide tape was placed over the old transverse joint instead of inserting backer rod into the joint. Four different methods of reinforcement stabilization of severe cracks were tried on the project, ranging from bars inserted in sawed slots in the old pavement to bars placed on chairs. The project exhibited over 5,800 ft of random centerline cracking immediately after construction due to a combination of factors. Very little random cracking has occurred at transverse joints and the degree of reflection cracking exhibited by the project after one year of service is minimal. Although the unit cost of $25.14/yd^2$ is somewhat excessive, the excellent performance of the project since construction, as well as the dramatic decrease in pavement deflection and roughness and increase in skid resistance, show this method of rehabilitation to be a viable alternative to asphalt overlays or complete reconstruction.

In recent years the high cost of new highway construction has led to an increased emphasis on rehabilitation of existing pavements. As many portland cement concrete roads have exceeded their original design life, normal rehabilitation techniques such as patching, joint repairs, mudjacking, and grinding are neither adequate nor cost effective. The South Dakota Department of Transportation decided to try a technique that has been used with satisfactory results for more than 20 years and was first tried before World War II—a thin-bonded portland cement concrete overlay.

The project selected for this experimental construction [Project M 1186(2)] was a 1.74-mi section of South Dakota Highway 38A in Minnehaha County, just north of the Sioux Falls airport. The existing unreinforced portland cement concrete pavement, placed in 1950, is 8 in. thick with a 6-in. untreated gravel subbase, and is 24 ft wide. Transverse joint spacing is 15 ft with no provision for load transfer beyond aggregate interlock. The centerline is made up of 0.25-in. formed dummy longitudinal joints with 1/2-in.-diameter deformed tie bars 30 in. long, spaced at 29-in. intervals. The pavement was integrally poured.

The cement factor for the original concrete was five bags/yd^3 with a maximum water to cement ratio of 0.53. The concrete was not air entrained. The coarse aggregate used for the original concrete was an extremely hard pink quartzite obtained from a local quarry, graded from 1/2 to 2 1/2 in.

Research Program, South Dakota Department of Transportation, 700 Broadway Avenue East, Pierre, S. Dak. 57501.

EXISTING PAVEMENT CONDITIONS

In early May 1985 a comprehensive pavement condition survey was conducted that included mapping of existing pavement deterioration, core sampling, and deflection, as well as roughness testing. The pavement was found to be badly deteriorated in many areas, with more than 4 percent of the pavement area in need of full-depth patching. The original concrete pavement was poured on a narrow gravel roadbed that was salvaged for earth shoulder material. No provisions were made at the time of construction to ensure a uniform subgrade density, and at the time of the survey the project exhibited a total of 1,100 linear ft of longitudinal cracking, possibly due to differential settlement of the subgrade.

Table 1 is a list of the types of pavement deterioration and their extent. The most prevalent form of deterioration on the project was spalling at transverse joints, with roughly 60 percent of all joints exhibiting spalling, usually near the slab edge or at the centerline. Most spalled areas had a zone of delamination surrounding the spall that required the removal of a much greater amount of concrete than had been originally estimated. The spalling was probably due to incompressible materials in the joints and deicing chemicals, as well as subsidence near the slab edges where corner breaks had occurred.

The east end of the project runs through low, swampy ground, and the entire pavement subsided through this section. Asphalt leveling patches had been placed on either side of a railroad crossing and a bridge. The asphalt concrete was removed and the concrete pavement underneath was severely scaled and had 85 percent delamination. The delamination was mostly near the surface and was associated with a loosely bonded laitance which was the result of freeze-thaw cycling of the non–air-entrained concrete. These sections were of major concern because it was not known whether a good bond could be made between the overlay and this badly deteriorated concrete surface. In addition, several blowups had occurred on the project and these were patched with asphalt or portland cement concrete. One blowup, occurring after the removal of the asphalt concrete patching material, resulted in a full-width 3-ft-long piece of slab sticking out of the pavement at a 45-degree angle. Four full-width concrete patches were located on the project and were probably necessary because the quartzite aggregate used in the concrete is associated with an extremely high incidence of blowups.

At the west end of the project, 120 ft of concrete had to be completely removed as the pavement was badly broken up and had numerous longitudinal cracks with secondary transverse cracks running to the shoulders. This section lay in the only road cut along the project length, but the cause of the breakup is not clear.

Cores were taken along the entire length of the project but

TABLE 1 PRECONSTRUCTION CONDITION SURVEY

Condition	Extent	Percent of Total	Severity
Slab breakage	9,380 ft^2	4.3	High
Asphalt overlay	30,200 ft^2	13.7	–
Asphalt patching	384 ft^2	0.2	–
Concrete patching	2,881 ft^2	1.3	–
Delamination	1,767 ft^2	0.8	High
Scaling	772 ft^2	0.4	Medium
	2,860 ft^2	1.3	High
Spalling (joint)	229 joints	37.4	Low
	121 joints	19.8	Medium
Spalling (corner)	90 joints	14.7	Low
	41 joints	6.7	Medium
	19 joints	3.1	High
Corner breaks	14 joints	2.3	Low
	12 joints	2.0	Medium
	5 joints	0.8	High
Diagonal cracking	4 linear feet		Low
	27 linear feet		Mediun
	28 linear feet		High
Longitudinal cracking	578 linear feet		Low
	127 linear feet		Medium
	392 linear feet		High
Transverse cracking	173 linear feet		Low
	100 linear feet		Medium
	48 linear feet		High

only from areas of sound concrete. Tests were run on compressive strength, chloride permeability, chloride content, and sodium sulfate soundness. The concrete was of adequate quality, with an average compressive strength of 4,770 psi, an average chloride permeability of 3,245 coulombs, and a sodium sulfate soundness of 110+ cycles. Chloride ion determinations yielded an average chloride content in the top 2 inches of 8.5 lb/yd^3, which prompted the specifications of epoxy-coated dowels and tie bars for the overlay.

Dynaflect deflection data were obtained on the project immediately before construction started. The average deflection for the project was 1.49 mils with the lowest deflection obtained 9.78 mils and the highest 3.33 mils. Deflection measurements were also made on either side of several of the most severe longitudinal cracks and they indicated that, although the pavement nearest the shoulder was weaker, the broken sections of slab were adequately seated on the subgrade.

A determination of preconstruction roughness, using a profilometer, produced a fair to poor rating of 2.47 out of a possible 5.0.

TRAFFIC HISTORY

A listing of the traffic history for this stretch of Highway 38A is given in Table 2. The current average daily traffic (ADT) of approximately 5,500 is a 14-fold increase in traffic since the pavement was first built. The sharp decrease in ADT and percentage of trucks between 1955 and 1966 is due to the construction of I-29. The highway traffic remains fairly uniform throughout the day except for the morning and evening rush hour passenger car traffic. The highway serves as the major access between I-29 and several large corporations just east of the thin-bonded overlay project.

DESIGN

The project had been originally programmed for asphalt resurfacing in 1984, as the pavement condition warranted some type of rehabilitation in the near future. The selection of the project for a thin-bonded overlay alternative was justifiable on the

TABLE 2 TRAFFIC HISTORY: SD-38A

Year	ADT	Percent Trucks	ADL (18 kip)
1951	393	33.3	101.5
1955	1995	20.2	333.8
1966	1457	12.1	96.7
1970	1216	12.1	77.9
1975	2225	12.1	170.3
1980	1755	10.8	145.2
1985	5509	12.28	523.1

NOTE: ADL = average daily load. Total 18-kip loads at time of overlay = 2.4 million.

basis of an assumed service life of more than double that of the proposed asphalt resurfacing.

The thickness chosen for the thin-bonded overlay was 3 in. for most of the project, with an additional experimental section 4 in. thick to be placed on a 1/3-mi section in the middle of the project to be used to monitor long-term performance. Plans called for the scarification of the old concrete pavement at the west end of the project to allow for a 1.5-in. minimum thickness of the overlay through an approximate 25-ft transition. The actual thickness of the overlay could vary from 1 1/2 to 4 in. depending on location and gradeline. Figure 1 shows a typical pavement section.

A total of 25 full-depth patch areas were identified in the plans, ranging in size from 8 ft^2 to 2,160 ft^2. By the time construction began, the total number of full-depth patches needed had risen to 51. The full-depth patches were installed by cutting out the deteriorated concrete and drilling holes on 30-in. centers along the vertical face of the cut section. Deformed tie bars (1 1/4 in. × 13 in.) were epoxied into the drill holes to tie the patch into the original slab. Where the patches were full roadway width, deformed tie bars on 48-in. centers were placed along the centerline and transverse joints sawcut in the patch.

In the case of one-lane-width patches, the existing tie bars along the centerline were retained and the transverse joints in the patch were matched to the transverse joints in the adjacent lane. Where the patch width was variable, a bond breaker was used along transverse and longitudinal joints coinciding with the edge of the patch. All full-depth patching was specified to be done before the actual thin-bonded overlay.

Partial-depth patches were also planned, to be prepared by removing spalled or deteriorated concrete to sound concrete. A bond breaker was to be placed through any transverse or longitudinal joints adjacent to a partial-depth patch and the patches filled with new concrete as an integral part of the PCC overlay.

The high incidence of severe longitudinal cracking on the project presented a particular problem because normal full-depth patching, if applied to all the longitudinal cracks, would not be economically feasible. Three different methods of attaching the broken sections onto the original slab were to be tried. These included *(a)* tie bars on chairs, *(b)* bent tie bars in drilled holes, and *(c)* tie bars in sawed slots. The tie bars were to be installed perpendicular to the crack along a longitudinal or transverse crack and were to be 3/4 in. by 3 ft. Details of the proposed stabilization techniques are shown in Figure 2. A fourth method, using 5/8-in. reinforcing steel rails running parallel along either side of a crack to which the tie bars were attached, was added at the time of construction.

The original transverse joints on the project were formed using redwood inserts and were, unfortunately, extremely crooked. The original design called for the placement of 4- to 6-in.-wide masking tape over these joints before overlay placement to prevent bonding of the overlay at the old joint and to minimize any reflective cracking due to misalignment of the old joint with the new transverse sawcut, which was to be cut through the full depth of the overlay. This design was abandoned, except for a 500-ft experimental section, and was replaced with backer rod inserts and single-lane, instead of full-width, sawcuts oriented on steel pins placed on the shoulders.

In order to prepare the existing concrete for the overlay, the plans called for scarification to a depth of 1/4 in. and a thorough cleaning of all dirt and oil just before overlay placement. Shotblasting was allowed as an alternative.

A grout was required as a bonding medium, consisting of one part portland cement and one part mortar sand mixed with sufficient water to form a stiff slurry. An alternate grout mixture of portland cement and water (7 gal/bag) was also acceptable. It was also planned to use a 500-ft experimental section without grout to compare bond strength with and without the use of grout.

The concrete used for full-depth patching was a standard Class A mix with a maximum coarse aggregate size of 1 1/2 in., a cement factor of 6.38 bags/yd^3, a specified air content of 4.5 to 7.5 percent, and a slump between 1 and 3 in. The original mix design for the concrete to be used in the actual overlay was a modified Class A with a maximum aggregate size of 3/4 in. The aggregate for use in this mix was the same quartzite used in the original construction, but the material available did not yield adequate strength or workability with the nominal mix quantities. The final mix design used was a standard Class A mix. No additives, aside from an air-entraining agent, were employed.

Low-modulus silicone sealant was specified for the transverse joints and a hot-pour elastic sealant was to be used on the centerline. Transverse joints were to be sawcut the full depth of

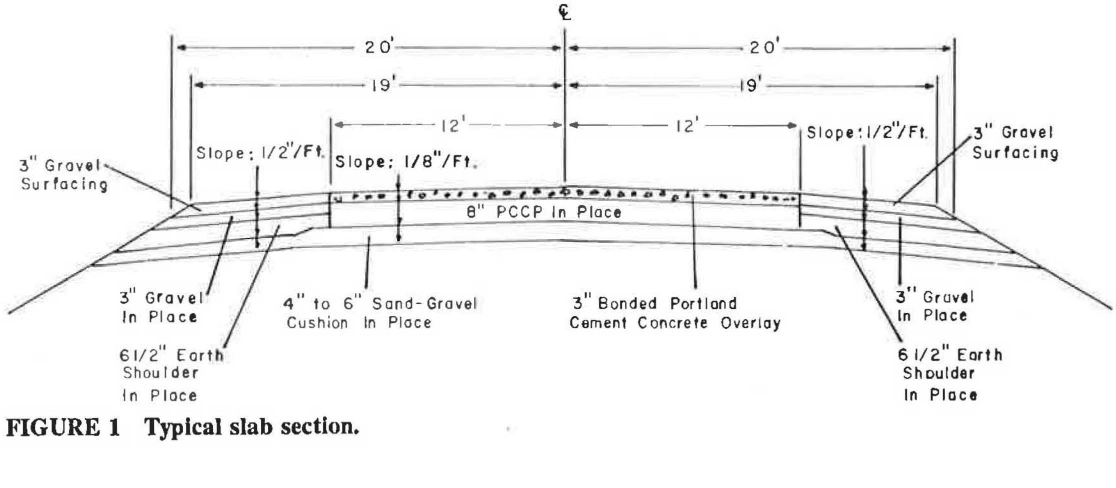

FIGURE 1 Typical slab section.

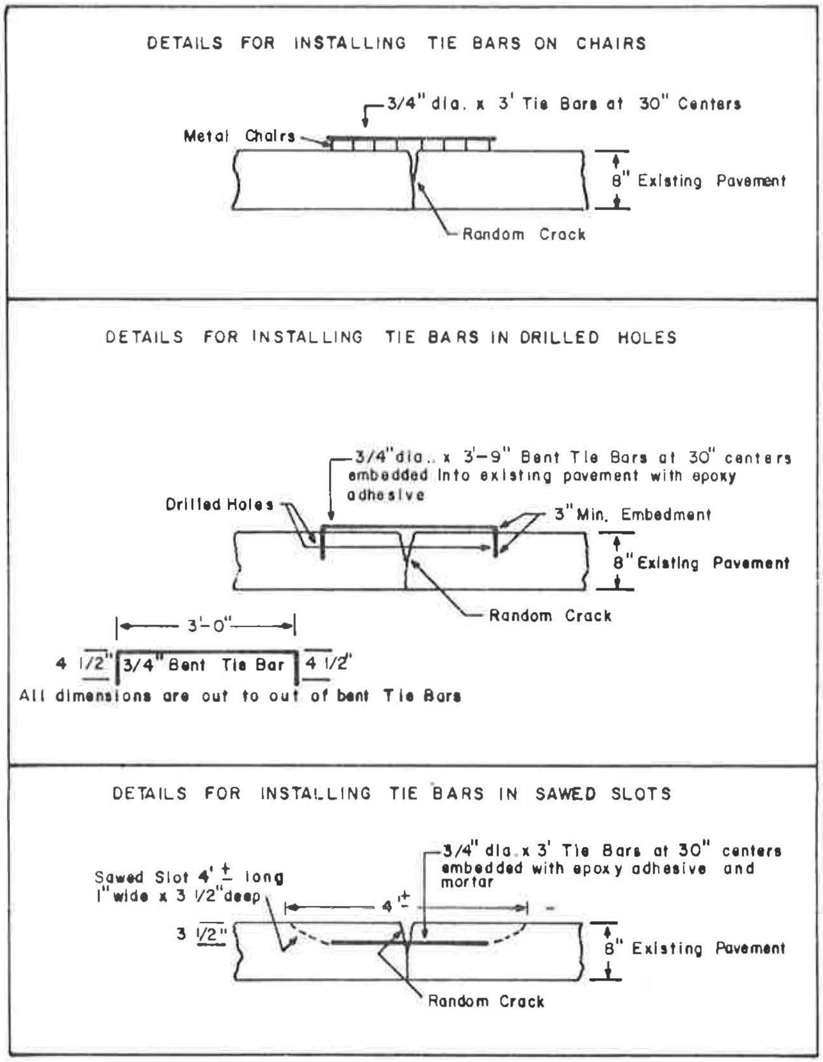

FIGURE 2 Crack reinforcement treatments.

the overlay as soon as possible and longitudinal joints were to be cut within 48 hr. Seven 4-in.-wide full pavement width growth joints were located at approximately uniform intervals. Traffic was to be maintained at the west end of the project throughout the construction period to allow access to the entrance of a truck sales and service firm located about 500 ft from the end of the project. The existing 8-ft-wide shoulder on the south side of the pavement was widened to 12 ft before any slab repair work was begun on this section. The rest of the project was to be closed to all but local traffic.

CONSTRUCTION

Construction of the thin-bonded concrete overlay was begun on May 8, 1985. The contractor removed all the asphalt patch and approach material first so that slab condition could be determined, elevations taken, and final gradeline established. The thickness of the asphalt overlay approaches to a railroad crossing and bridge approach slabs exceeded 6 in. The concrete slabs under the asphalt were badly scaled and delaminated, with one 500-ft section 85 percent delaminated.

The full-depth patch areas were next removed and replaced, with the contractor proceeding from the west to the east ends of the project. The engineer's estimate for full-depth patching was 93 yd^3 and the actual amount required was 259 yd^3. The total area of full-depth patching on the project was 1,040 yd^2 versus an original estimate of 416 yd^2. Several of the larger full-depth patches could not be placed until enough of the subbase material was removed and replaced with a more select material to obtain a stable working platform for the concrete pour. All full-depth patch areas were sawcut before removal.

Partial-depth patch areas were jackhammered to a depth sufficient to remove all spalled and deteriorated concrete. A total of 94 yd^2 of spalled concrete was removed. The numerous slab corner breaks on the project presented a special problem where the break was severe and the small triangular corner piece had subsided below the existing pavement surface. Although the original plans did not specify any particular method for dealing with these corner breaks, it was decided to treat them as full-depth patches at the pavement edge phasing into a partial-depth patch. Slots 4 in. deep and 1 in. wide were cut on 18-in. centers, and 3/4-in. epoxy-coated tie bars 30 in. long were embedded in the slots with nonshrinkable mortar before the corner patch was filled with concrete. The slots were oriented toward the centerline, and as many slots were cut as the patch could accommodate.

Tie bars were also installed across selected longitudinal and transverse cracks in drilled holes and sawcut slots. The tie bars on chairs and tie bars on bars were not placed on the slab until immediately before the paving operation reached that portion of the project to allow machinery access to the slab. Several of the more severe longitudinal cracks had perpendicular transverse cracks running to the pavement edge. These were treated with reinforcing steel in a way similar to that of the major crack. Table 3 is a list of crack locations, types, and treatments.

After full- and partial-depth removal and patching were completed, the first 25 ft at the west end of the project was scarified to a depth of $1^1/_2$ in., then tapered out another 50 ft because of the difficulty in meeting gradeline in such a short distance without creating a bump. A rotomill was used and it took more than 8 hr to complete the scarification. A small section of asphalt concrete just off the east end of the project was also scarified to eliminate the need for feathering the asphalt concrete onto the slab after construction of the overlay.

Spalled concrete and asphalt patch material was cleaned off all medium-to-severe cracks in the pavement by using concrete chippers just before the final sweeping of the pavement with a rotary broom. The contractor decided to use a shotblaster instead of a milling machine for the final slab preparation. The shotblaster used cleaned a 7-ft-wide section of pavement at each pass and had a variable production rate of 20 to 80 ft/min, depending on the condition of the pavement. A minimum of two passes were made with the preliminary cleaning run operating at a nominal speed of 50 ft/min and the final shotblasting, which was done immediately ahead of the paving train, at speeds ranging from 20 to 80 ft/min.

The shotblaster did an excellent job of cleaning sound concrete and even lightly scaled concrete surfaces presented no problem (see Figures 3 and 4). The sections of the project that

TABLE 3 CRACK REINFORCEMENT TREATMENT

Station				Crack		Reinforcement Treatment				
From	To	Lane	Type of Crack	Length (ft)	Severity	Bar on Bar[a]	Chairs[a]	Drilled[a]	Sawed[a]	Epoxy
1025+27	1025+37	Left	Longitudinal	10	Medium	4				
1025+32	1025+37	Right	Diagonal	8	High			3		
1026+90	1027+20	Left	Longitudinal	30	High		12			
1031+45	1031+75	Left	Longitudinal	30	High		12			
1031+49		Left	Transverse	3	Medium		2			
1031+77	1032+00	Right	Longitudinal	29	High		10			
1033+40	1033+85	Right	Longitudinal	45	High				17	
1041+41	1041+73	Right	Longitudinal	32	High		12			
1041+46		Right	Transverse	5	Low		2			
1041+53		Right	Transverse	5	Low		2			
1043+12	1043+42	Left	Longitudinal	30	High				12	
+18		Left	Transverse	5	Low				3	
+24		Left	Transverse	4	Low				2	
+28		Left	Transverse	4	Low				2	
+34		Left	Transverse	4	Low				2	
1044+10	1044+92	Left	Longitudinal	72	High			29		
1044+21		Left	Transverse	3	Low			2		
+29		Left	Transverse	2	Low			1		
+37		Left	Transverse	3	Low			2		
+53		Left	Transverse	3	Low			2		
+65		Left	Transverse	3	Low			2		
1045+52	1045+66	Left	Longitudinal	14	High	6				
1050+40	1050+50	Left	Longitudinal	12	Medium	5				
1051+35	1051+50	Left	Longitudinal	15	Medium					X
1066+60	1066+73	Left	Diagonal	19	High		5			
1068+60		Full	Transverse	24	Medium	10				
1070+54		Full	Transverse	24	Light			9		
1070+72			Transverse	20	Low	10				
1070+96			Transverse	12	Low				4	
1072+84			Transverse	24	Low	10				
1072+95			Transverse	20	Low			6		
1080+15	1080+27	Right	Longitudinal	15	High	6				
1080+40			Transverse	24	Medium			10		
1080+72	1081+02	Right	Longitudinal	30	High	9				
1081+32	1081+47	Right	Longitudinal	15	Medium				6	
1081+77	1081+92	Left	Longitudinal	16	Medium	6				
1082+90	1083+15	Left	Longitudinal	30	High				13	
1084+53			Transverse	14	High					X
1092+37	1092+52	Right	Longitudinal	15	High	8				
1106+73	1106+85	Right	Longitudinal	13	High	5				

[a]Number of bars.

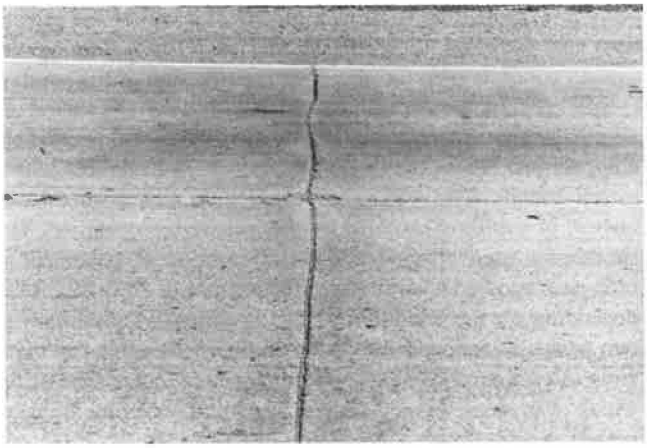

FIGURE 3 Typical crooked transverse joint.

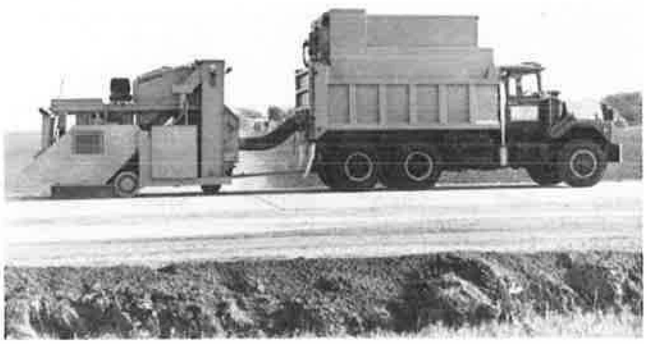

FIGURE 4 Shotblaster in operation.

had been overlaid with asphalt were an exception requiring numerous passes at low speed, as the residual asphalt caused the shot to bounce off the pavement surface without removing much of the asphalt. The badly delaminated and scaled pavement between the railroad crossing and bridge at the east end of the project was shotblasted repeatedly, but the shotblaster was incapable of removing all the surface delamination although it did clean the asphalt residue. This section was originally slated to have a 3-in. overlay but the thickness was increased to 4 in. to try to offset the potential negative effect of poor bonding.

Pavement cross sections were taken at 25-ft intervals and hubs were placed at 50-ft spacings to establish grade and alignment for paving using a taut stringline. After the stringline was in place, work on the concrete paving began. The shotblaster made its final cleaning run first and then a cement-water grout was sprayed onto the clean slab surface. The grout was mixed in an upright tank mounted on a flatbed truck and pumped to the applicator. The rate of application depended on the speed of the slipform paver in order to prevent the grout from drying out before concrete placement.

A Rex slipform paver was used for the overlay placement. No mechanical breakdown occurred during paving operations. The vibrators were set at the beginning of paving and left at that setting throughout. The finishing crew working behind the paver were required to do very little handwork. They straightedged the pavement and took out any bumps or tears in the concrete surface. Waste material on the pavement edge was somewhat excessive.

Considerable difficulty was experienced when paving over crack sections that had either bar-on-chairs or bar-on-bar reinforcing steel. The paving operation tended to shove the bars out of position as the paver moved forward. Attempts to hold the steel in place by standing on it until the paver reached the bar area were not entirely successful. The bars on chairs could not be held in position at all, whereas the bar-on-bar steel, if covered with concrete before the concrete being pushed ahead by the paver reached it, could be maintained relatively close to its original position. The use of bar on chairs for future crack stabilization is not recommended.

After the bleed water was off the concrete surface but while the concrete still remained plastic, the pavement was dragged with Astroturf. A 3/16-in.-deep randomized-tine transverse texture was then cut into the surface using a motor-driven tine rake. An 8-in. gap of untextured surface was left across each joint.

The tining rake was followed immediately by a cure wagon that made two applications of 1 gal/150 ft^2 of white pigmented curing compound. The first application was allowed to dry a little before the second was applied in order to minimize loss. The pump for the curing compound sprayer broke down and about 50 ft of pavement was treated with a hand-held sprayer for the first application. The paver slowed down during this period. After a new pump was installed, normal operation resumed.

The concrete was supplied by a nearby readi-mix plant in nine 7-yd trucks. The plant was not automatic and each load of concrete was batched into a truck. The trucks used the old slab for delivery to the paver as the shoulders were not wide enough to accommodate them. The trucks were diapered in order to prevent the introduction of oil or grease onto the clean pavement.

No mechanical or physical problems were encountered during concrete production and all concrete test specimens met specifications. The average slump produced was slightly over 1 3/4 in. and the average air content was 6.25 percent. A penalty of 40 lb of cement/yd^3 was added to the concrete mix because the concrete plant was not automated. An extra gallon of water was added during the first day of production but the water was cut back to the original design mix quantity thereafter. The actual water to cement ratio of the concrete was 0.41.

Temperatures during the entire construction period remained moderate, ranging from a low of 57°F to a high of 80°F during actual paving operations. A severe thunderstorm with cold rain and hail caused three uncontrolled transverse cracks just behind a header. The hail cooled the pavement so rapidly that it cracked before it could be sawcut.

As soon as the concrete had hardened sufficiently to support the sawcutting machinery transverse sawcutting began. An initial sawcut was made using steel pins as references to locate the original transverse joints. Two sets of steel pins were color coded to identify each lane. Sawcuts were made separately in each lane along a line representing the least deviation of the new sawcut from the old, generally crooked, transverse joint. As a result, the transverse sawcuts were seldom straight across (see Figures 5 and 6). A total of 20 random cracks on transverse joints appeared soon after sawing was complete. The average length of the cracks was 3 1/2 ft and ranged from 6 in. to 12 ft in length. All random transverse cracks were routed with a 3/8-in. router and filled with epoxy.

FIGURE 5 Clean concrete after one shotblaster pass.

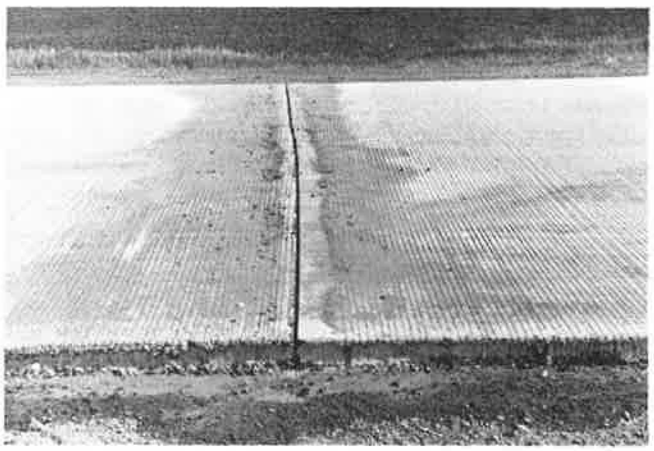

FIGURE 6 Transverse joint sawed half-lane.

During the first day of construction, the first 720 ft of overlay suffered a random centerline crack before longitudinal sawcutting could be carried out. The original plans called for a $^1/_4$-in.-wide by 1-in.-deep joint to be sawcut within 48 hr. The contractor sawed the longitudinal joint on the rest of the project at the same time as adjacent transverse joints were sawcut, usually as soon as the concrete was strong enough to support the sawing without raveling. Unfortunately, the overlay exhibited another 5,100 linear ft of random centerline cracking, which wandered in and out of the centerline throughout the length of the project (see Figure 7).

The random cracking along the centerline was routed $^3/_8$ in. wide wherever the crack was more than $^1/_2$ in. away from the centerline sawcut and filled with hot-pour sealant. The centerline in these areas was filled with epoxy. If the random crack was $^1/_2$ in. or less from the centerline, the concrete between the sawcut and the crack was chipped out to the depth of the centerline sawcut and sealed with hot pour.

Class D asphalt concrete was placed on 75 ft of the shoulders at the west end of the project at a business entrance and intersecting road, and at the east end of the project as a transition onto existing asphalt concrete. The 6.5-ft gravel shoulders on either side of the pavement were built up to the level of the concrete overlay and the experimental section opened to traffic.

FIGURE 7 Typical random centerline cracking.

POSTCONSTRUCTION EVALUATION

Four-inch cores were taken throughout the project length. The average depth of the overlay was adequate in both the 3- and 4-in. sections. Cores taken of the random centerline cracking showed several possible contributing factors that could have led to the cracking (see Figure 8). They include

1. Inadequate depth of sawcut: A 1-in. centerline sawcut was specified and proved to be too shallow to direct proper crack propagation.
2. Coarse mix: The use of a 1.5-in. maximum-size aggregate instead of the $^3/_4$-in. originally specified could have contributed to the cracking in conjunction with the shallow sawcut.
3. Inadequate debonding of centerline: No provisions were made to assure debonding of the centerline as it was believed the hot-pour sealant would act as a bebonding agent. The grout, as well as the spalling of the centerline that subsequently filled

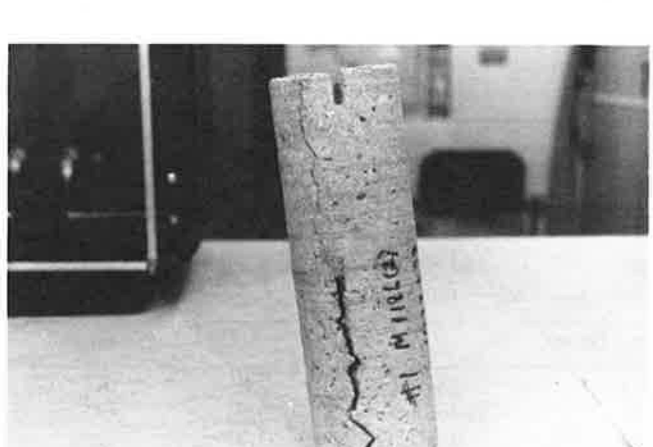

FIGURE 8 Core taken along centerline.

with grout, could have interfered with proper cracking. Interestingly, the 500-ft test section where no grout was used did not suffer from random centerline cracking.

4. Improper orientation of the new centerline cut over old: The machine used for sawcutting the centerline aligned itself with the pavement edge. Considerable difficulty was experienced in cutting a uniformly straight centerline for any distance and the resulting lack of proper alignment along the old centerline was undoubtedly a contributing factor to the cracking.

A core was also taken of a transverse joint in the taped experimental section. The tape effectively prevented bonding of the overlay with at least 2 in. of concrete on either side of the joint totally debonded from the original slab. No damage to the joints in this section was noted but the impact of traffic here will be closely monitored.

Several cores were taken in the area where severe delamination was noted before the overlay was applied. Only one of the cores exhibited a poor bond with the overlay. Chain dragging of the area did not yield any perceptible delaminations even though the area had been rated as 85 percent delaminated before placement of the 4-in. overlay. In fact, no delamination or overlay debonding was detectable throughout the project immediately after construction.

Shear strength tests were run on cores taken throughout the project where grout was applied and in the test section where no grout was used. The results of these tests are shown in Table 4. The cores were taken 1 week after construction was completed and allowed to cure for 3 weeks in a moist room before testing. There is no significant difference between the grouted and ungrouted shear strengths.

Aside from the random centerline and transverse edge cracking mentioned previously, the project exhibited only three cracks that were reflections of cracks in the old slab. Two of these cracks occurred on the same section of slab. One crack had been treated with drilled-in reinforcing steel and the other with bar on bar, yet the reflection cracks were almost immediately apparent. The two cracks lay directly adjacent to a growth joint that was previously cut in the old slab and filled with styrofoam at the time of the application of the overlay. The resulting lack of movement restriction undoubtedly led to the rapid appearance of the cracks at the surface of the overlay. The selection of growth joint locations in an overlay should avoid any proximity to serious slab cracking.

The third reflection crack on the project was a 30-ft longitudinal crack, which occurred over what had previously been a low-severity crack about 3 ft long. As the crack appeared to be tight, it was decided that no repair or maintenance would be done unless it became necessary.

A thorough deflection survey was done on the project both before and after the overlay. A summary of the project averages and some typical deflections across longitudinal cracks are shown in Table 5.

The addition of the 3 to 4 in. of PCC overlay has produced excellent results in increasing the strength of the pavement, especially considering the fact that the majority of the Dynaflect readings were taken on either side of severe longitudinal or transverse cracks. The load-transfer capability of the overlay will not be determined until the experimental section has been subjected to traffic for one year.

A determination of the postconstruction roughness using the profilometer gave an overall project rating of 3.80, which compares favorably with the preconstruction value of 2.47.

The average skid number before construction was 44; after construction it was 57. A K. J. Law skid tester operated at 40 mph was used to obtain the test results.

TABLE 4 SHEAR STRENGTH OF CORES

Core Number	Location	Overlay Thickness (in.)	Shear Thickness (psi)
Grout			
13	Station 1035+	3.75	673
14	Station 1047+	3.50	738
15	Station 1074+	4.25	637
16	Station 1099+	4.25	458
Average = 626.5 ± 120 psi			
No Grout			
17	Station 1112	3.25	661
18	Station 1113	3.50	541
19	Station 1114	3.00	685
Average = 629 ± 77 psi			

COST OF CONSTRUCTION

The gross-sum bid accepted for the thin-bonded overlay was $538,304.53 compared to an engineer's estimate of $519,-010.45. The actual construction cost was somewhat greater than the original bid due to underestimation of material and repair quantities. The amount of the final cost of the thin-bonded overlay is not yet available.

CONCLUSIONS AND RECOMMENDATIONS

The thin-bonded overlay concept appears to be a viable rehabilitation alternative for concrete pavements. The overall improvements in rideability and strength realized immediately after the construction of the overlay were impressive, but a full 5-yr evaluation period will be required before any final conclusions can be drawn.

Although the slab preparation work before overlay required more time and materials than originally estimated, the actual paving operations went smoothly with few problems and little delay. The random centerline cracking, although somewhat unsightly, is not expected to have a marked effect on the performance of the overlay. Reflection cracks from crooked transverse joints and existing longitudinal and transverse slab cracking have not presented any problem to date, but the stresses induced by traffic and cold temperatures are expected to increase the incidence of reflective cracking.

The use of a cement-water grout for overlay bonding does not appear to be necessary as shear strength tests indicate no difference in bond strength between the grouted and ungrouted overlay sections. The use of a shotblaster running just ahead of the paving train to clean dust or other foreign materials from the old slab surface is recommended if no bonding grout is to be used.

TABLE 5 SLAB DEFLECTION DATA

Location	Deflection Before	Deflection After	Remarks
Project average	1.49	0.86	All deflections seasonally corrected
Lane 1 average	1.52	0.82	
Lane 2 average	1.44	0.90	
Station 1027+04	2.22	1.96	10 ft left centerline severe longitudinal crack
Station 1027+04	2.00	1.31	7 ft left centerline severe longitudinal crack
Station 1044+41	2.55	1.05	10 ft left centerline severe longitudinal crack
Station 1044+41	1.78	0.85	7 ft left centerline severe longitudinal crack
Station 1070+53	1.00	0.65	5 ft left centerline transverse crack
Station 1070+56	1.00	0.65	5 ft left centerline transverse crack
Station 1107+08	3.88	0.65	4 ft right centerline culvert
Station 1107+08	3.33	0.79	7 ft right centerline culvert

NOTE: All deflection data seasonally corrected to reflect weakest condition.

It is also recommended that the initial sawcuts for both transverse and longitudinal joints be done as soon as feasible because there is a critical need to relieve drying shrinkage stresses in the overlay. In addition, the longitudinal joint sawcut depth should be at least one-half of the overlay thickness, and provision should be made to ensure proper alignment of the new sawcut over the old joint.

FIRST ANNUAL REPORT ON PERFORMANCE

The project was visually inspected in early January and again in late May 1986, and its overall condition appears to be excellent at the present time.

The only major problem encountered since construction was the development of an extremely rough (2.5 in.) bump during December 1985, at the railroad crossing near the east end of the project. The cause of the bump was originally ascribed to settlement of the railroad grade because of the passage of two unit trains along the track in one night. A preliminary survey of pavement height indicated that the pavement on either side of the crossing was at the same height. A 10-mph speed limit was imposed at the crossing and bump signs were installed on either side.

In early spring the magnitude of the bump began to decrease and by the middle of May 1986 the height of the bump was down to about 1 in. The railroad added about 1 in. of ballast under the rubber railroad crossing, which eliminated the bump.

The cause of the bump is water-related and involves subsidence of the railroad grade in early winter. The gradual decline in the severity of the bump without any remedial action, however, suggests two possibilities. Either the railroad grade rebounded with the spring thaw, or the adjacent concrete pavement frost-heaved and then subsided, or both. The preliminary survey of pavement height did not indicate whether the concrete pavement heaved, so a benchmark was installed adjacent to the railroad crossing to measure accurately whether frost-heave is involved in case the problem recurs.

Although no cracking has occurred in the concrete pavement on either side of the railroad, the potential for the development of excessive roughness and bumps at such locations should preclude the placing of portland cement concrete directly adjacent to a crossing. Instead, a transition zone of asphalt concrete should be used in the future to allow more flexible and expeditious correction of any problems that might arise.

The reflection cracks manifested during the first winter were not nearly as numerous as expected. Because only 40 percent of the cracking on the project was stabilized with various reinforcing steel treatments, over 1,200 linear ft of longitudinal, transverse, and diagonal cracks were overlaid without any provision to prevent reflective cracking beyond spall removal and cleaning with compressed air. To date, only 200 ft of non-joint-related cracking has occurred on the project and only 120 ft of this is reflective cracking. Cracking status is shown in Table 6.

In July 1986, a 30-ft longitudinal crack reflected through the overlay where an untreated low-severity crack had been. The crack was positioned only one panel away from a stabilized severe longitudinal crack, and the reflective crack appears to represent an extension of this severe crack. The weight of the overlay apparently caused failure.

None of the treated cracks have reflected through the overlay except for one 15-ft longitudinal crack where chairs were used to position the reinforcing steel. The steel was pushed forward by the slipform paver and the final location of the steel along this crack is uncertain. Interestingly, the original crack length was 30 ft but only the first 15 ft came through. The portion of the original crack that reflected through was paved first, and no provision was made by the contractor to maintain the original position of the reinforcing steel. After the contractor became aware of the shoving problem, he tried various means of holding the steel in place, including pooling concrete around each bar in front of the paver and having a man stand on the bar until it was covered with concrete. Two additional cracks, where reinforcing steel on chairs was used, have not reflected through; however, chairs are not recommended.

Untreated longitudinal and transverse control cracks, originally rated as high severity, had reflected through the overlay by May 1986, indicating the importance of stabilizing severe cracks with reinforcing steel. Even though these cracks were widened and deepened after all the spalled concrete was removed along their lengths, the overlay concrete poured into the cracks did not prevent reflection. Both cracks are tight and no repair or maintenance will be done until necessary. A medium-severity diagonal control crack had not reflected through the overlay at the time of the last visual inspection.

One 15-ft longitudinal and two 24-ft transverse cracks found on the project did not correspond to any previous cracking. All three cracks lay, however, either along the boundary of a full-depth patch or in the next slab. The longitudinal crack followed

TABLE 6 CURRENT CRACKING STATUS

Station					
From	To	Lane	Type of Crack	Length (ft)	Comments
1024+45	1116+45	Centerline	Longitudinal	5820	Joint related
1025+27	1025+32	Left	Diagonal	7	Joint related
1025+27	1025+37	Left	Longitudinal	10	Joint related
1025+32	1025+37	Right	Diagonal	8	Joint related
1031+45	1031+60	Left	Longitudinal	15	Reflection crack (chairs)
1032+66	1032+81	Right	Diagonal	18	In full-depth patch
1041+62		Full	Transverse	24	Control-reflection crack
1042+62	1042+77	Right	Longitudinal	15	On edge of full-depth patch
1043+73	1043+88	Left	Longitudinal	15	Control-reflection crack
1045+17	1045+47	Left	Longitudinal	40	Reflection crack
1062+08		Full	Transverse	24	Adjacent to full-depth patch
1079+49		Full	Transverse	24	Adjacent to full-depth patch
1104+45		Left	Transverse	8	Joint related
1107+83		Right	Transverse	12	Joint related
1108+13		Full	Transverse	24	Joint related
1108+27		Left	Transverse	12	Joint related
1108+42		Full	Transverse	24	Joint related
Total Reflection		94			
Total Joint Related		5,925			
Total Other		81			
Total		6,100			

the boundary of an L-shaped full-depth patch that encompassed only part of a slab along the inside head of the L. The two transverse cracks were located near full-depth, full-width patches, where plastic inserts were used to form dummy transverse joints to prevent bonding of the full-depth patch to the original slab. The inserts did not work satisfactorily and the cracking appears to be due to excessive slab length. One of the cracks is badly spalled and appears to be acting as a working joint.

One diagonal crack 18 ft long appeared in the largest full-depth patch on the project. The reason for the crack is not immediately apparent, but it could possibly be related to poor subgrade and traffic, which was allowed on the patch too soon after construction.

Only one significant joint-related crack has occurred on the project since construction—a 12-ft-long transverse crack next to three other wild joint cracks. All four cracks may have been affected by a hailstorm occurring during construction.

COST OF CONSTRUCTION

The original bid for the project was \$538,304.53, which equated to a unit cost of \$21.96/yd^2 of finished overlay. The increase in bid quantities owing to additional partial- and full-depth patching, an increase in overlay thickness in one section of the project, additional gravel for shoulders, and the extensive epoxy repair of the randomly cracked centerline yielded a final cost for the project of \$616,348.10 or \$25.14/yd^2. No further costs have been incurred since construction was completed.

Publication of this paper sponsored by Committees on Pavement Rehabilitation and on Rigid Pavement Construction and Rehabilitation.