Field Performance and Evaluation of Thin Bonded Overlays

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Bonded concrete overlays of jointed concrete pavements currently are not used widely for pavement rehabilitation. As part of a major FHWA research project, between 1987 and 1988 an extensive performance evaluation of 16 different bonded overlay designs at 10 locations in 6 states was carried out. The projects were located in three different environmental zones and involved a variety of low- to high-volume pavements. The overlays ranged in age from 3 to 11 years at the time of the surveys. The field performance surveys consisted of the following elements: a comprehensive field survey to identify, measure, and map pavement surface distresses; a debonding survey; the measurement of roughness and a panel present serviceability rating; deflection testing with a falling weight deflectometer; and a materials testing and sampling program. Historical traffic data were collected to estimate the accumulated 18-kip equivalent single axle loads (ESALs) on the pavement before and after the overlay was placed. Environmental data were also collected to describe the nature of the environmental forces to which the various sections were subjected. Previous research projects or state reports were reviewed to characterize the construction conditions and the preoverlay condition of the pavements. The results of the field survey are presented for each pavement section based on all of the major measured parameters. Overall, it was found that bonded concrete overlays showed mixed success. Some of the projects appeared to be nearing failure, based on the accumulation of surficial distresses and the apparent widespread debonding that was observed. In general, it was found that debonding was a cause for concern on many of the projects.

Portland cement concrete (PCC) pavements constitute a large percentage of pavements that are designed to carry high volumes of heavy traffic. When designed, constructed, and maintained properly, PCC pavements can be expected to provide a long service life. Many factors, however, contribute to the accelerated deterioration of pavements, including construction deficiencies, design loadings in excess of those forecasted, materials problems, and unanticipated changes in traffic patterns. It is not surprising, therefore, that there exists a good deal of interest in the rehabilitation of PCC pavements. Of the major rehabilitation approaches—resurfacing, recycling, restoration, and reconstruction—resurfacing (or overlays) is one of the most commonly performed methods of restoring rideability and improving structural capacity.

The most frequently constructed type of overlay is made of asphalt concrete (AC). An AC overlay can be placed fairly rapidly, at a very competitive cost, and with little shutdown time of the facility. However, there are two major problems associated with AC overlays: reflection cracking and rutting. These problems contribute to a shorter service life than is desired in many cases for a rehabilitation strategy on high-volume, heavily loaded pavements. Also, a fairly thick AC overlay is required to improve the structural capacity of the pavement.

An intriguing alternative to the construction of an AC overlay is the use of PCC as an overlay material. A bonded PCC overlay holds the promise of an extended service life, increased structural capacity, and lower life cycle costs, compared with other overlay techniques. Although the initial cost of a bonded PCC overlay may be higher than those of an AC overlay, the benefit of longer life and reduced maintenance costs suggest that bonded overlays can be a viable resurfacing alternative.

The research presented in this report was performed as part of the second phase of a two-phase study for the FHWA, entitled Performance/Rehabilitation of Rigid Pavements. Phase I of this project is devoted to a performance evaluation of selected PCC pavements, with the goal of improving the inputs to new pavement design. The second phase of the project examines the rehabilitation of jointed concrete pavements. One of the goals of Phase II is to evaluate the performance of selected projects, including previously reviewed projects, perform additional testing and/or analysis to verify and/or improve recommended design and construction procedures, and to develop improved design and construction procedures for this technique. The evaluation and performance of the bonded overlay projects selected for this study are presented in this paper.

Bonded overlays currently are not widely used for pavement rehabilitation, except in Iowa, so there are not many candidate sections available for study. A total of 16 different bonded overlay designs at 10 locations in 6 states (covering 3 climatic zones) were evaluated for this project during surveys conducted between 1987 and 1988. All of the overlay projects were constructed since 1976; the age of the original pavement varied considerably. An attempt was made to include sections on interstates or pavements subjected to heavy traffic. Most of the sections that are discussed here are also included in an earlier rehabilitation study performed for the FHWA and in other summary evaluations performed by the FHWA (*1,2*). The data from the 1985–1986 FHWA surveys, where available, are presented for comparison with the more recent data. Table 1 presents the pavement sections that were included in this study.

DATA COLLECTION

Field surveys were conducted by using procedures similar to those in use for the Strategic Highway Research Program (SHRP) Long-Term Pavement Performance (LTPP) project.

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TABLE 1 BONDED OVERLAY SECTIONS INCLUDED IN STUDY

Project	Route	Location	Original Construction Date	Overlay Construction Date
NY 6	I-81	Syracuse, NY	1957	1981
IA 1	I-80	Grinnell, IA	1964	1984
IA 2	I-80	Avoca, IA	1966	1979
IA 3	C 17	Clayton County, IA	1968	1977
IA 4	SR 12	Sioux City, IA	1954	1978
IA 5	US 20	Waterloo, IA	1958	1976
CA 13	I-80	Truckee, CA	1964	1984
SD 1	SR 38A	Sioux Falls, SD	1950	1985
WY 1	I-25	Douglas, WY	1969	1983
LA 1	US 61	Baton Rouge, LA	1959	1981

A detailed distress survey was performed using LTPP guidelines. Debonding, a failure mode of major concern with this rehabilitation method, was estimated using a combination of "sounding" the pavement and limited coring. For the sounding, the survey crew consisted of two people, one to tap the pavement using a 4-lb hammer, and the other to record whether the sound represented a bonded or debonded layer. A debonded area was said to be present if the pavement gave off a hollow sound, or one of "low frequency." When a debonded area was located, its extent was identified by pounding with the hammer and establishing a contour of the debonded area on the pavement surface. It must be stressed that the debonding estimated for these sections is the result of limited testing using a partially subjective technique. To accurately characterize the extent of debonding it would be necessary to survey a larger area of the project with a laboratory-tested method.

Pavement surface roughness was collected for all of the sections with the aid of a Mays Ride Meter. The survey crew also gave a subjective rating of the rideability of each pavement section, in the form of an average present serviceability rating (PSR). The roughness and PSR data that are presented here represent a very small sample size, and no clear relationship exists between the two values. Deflection testing was performed with the use of a Dynatest Model 8002 falling weight deflectometer (FWD).

Coring and boring were performed at each project location. The retrieved cores were subjected to a visual inspection and a verification of thickness. The bond between the overlay and the existing pavement was tested by applying a shearing force on the monolithic core using a specially constructed apparatus and a compression testing device. Data compiled by the states and submitted to FHWA on truck types and axle load distributions (W-4 tables) were used to calculate truck factors by state and to calculate the number of 18-kip equivalent single axle loads (ESALs) applied to each section. This information was used to estimate the number of ESALs carried by the pavement before the overlay construction and the number of ESALs that had been applied since placement of the overlay.

INTERSTATE 81—SYRACUSE, N.Y. (NY 6)

The first project location was on I-81, near Syracuse, N.Y. The original pavement was constructed in 1957 as a 9-in. doweled, jointed reinforced concrete pavement (JRCP) with 43-ft joint spacing, placed on a 12-in. aggregate base. The original JRCP pavement displayed extensive longitudinal and transverse crack deterioration. This deterioration most likely was a result of the use in the original concrete of coarse aggregate susceptible to freeze-thaw deterioration. Freeze-thaw cycling caused pop-outs in the pavement surface and disintegration beneath the surface similar to D-cracking. The areas that showed the most deterioration were those surface areas exposed to water and areas in which water could be held and trapped, such as the pavement edges and joint faces. Many of the deteriorated areas had been repaired with asphalt patches.

Pavement blowups had occurred during the life of this pavement. In 1972, doweled, full-depth repairs were placed at as many transverse joints as funding permitted. In 1980, many of these repairs were showing deterioration also. Slab cracking was also present on this section, particularly over existing culverts. Before placement of the bonded overlay in 1981, it is estimated that the outer lane of this pavement had sustained 3,350,000 18-kip ESAL applications, the middle lane, 1,260,000 ESAL applications, and the inner lane, 350,000 ESAL applications.

Overlay

In 1981, a 3-in. bonded PCC overlay was constructed following extensive surface preparation. The deteriorated concrete (at almost all of the transverse joints) was milled to a depth of 3 in. The milling generally extended about 2 ft on either side of the joint. About 90 percent of the length of the longitudinal joints required the same milling. These depressed areas were paved over at the same time as the overlay was placed. Pressure relief joints were placed at blowup locations and at either end of northbound and southbound mainline structures over NY-31. Wire mesh was placed over areas of existing cracking where it was felt that the existing mesh was no longer functioning. The surface of the rest of the pavement was milled to a depth between 0.25 and 0.50 in. The pavement was then sandblasted to remove any remaining loose material or contaminants. A cement-sand grout spread by hand and broomed onto the pavement was placed shortly ahead of the paver. Temperatures at the time of placement ranged from about 50°F to nearly 90°F.

TABLE 2 INTERSTATE 81 (SYRACUSE, N.Y.) PERFORMANCE DATA

	1985 FHWA SURVEY	FIELD SURVEY 1987		
	OUTER LANE	OUTER LANE	LANE # 2	LANE # 3
Average PSR	N/A	3.2	N/A	N/A
Mays Roughness, IN/MI	N/A	135	N/A	N/A
Transverse Faulting, IN	0.05	0.07	N/A	0.11
Transverse Cracks/MI L	231	152	300	76
M	5	20	5	0
H	0	0	0	0
Long. Crk., LIN FT/MI L	0	20	0	0
M	0	0	0	0
H	0	0	0	0
% Joints Spalled	0	0	0	0
ESAL's on Overlay (millions)	1.10	2.36	1.01	0.26

% Joint Corners Debonded	95
% Area of Wheelpath Debonded	0
% Total Area Debonded	3

Immediately after paving, the plastic concrete was scored with a straight edge and an edging tool directly over the transverse joints, using previously marked guide locations. Within 5 to 6 hours after placement of the concrete overlay, the transverse joints were sawed to a depth of 5 in. This depth compensated for the additional thickness of the overlay at the transverse joints from the additional milling performed there. The longitudinal joint between lanes was sawed to a depth of 2 in. The transverse joints were sealed with a preformed compression sealant.

Performance of the Overlay

Since construction of the overlay in 1981, this pavement has experienced 2,360,000 ESALs in the outer lane—over 70 percent of the total estimated traffic carried on the original pavement from 1957 through 1981. As an examination of Table 2 shows, there is some cracking and faulting present. There is more transverse cracking in the second lane. The ride is fairly rough, indicating that some problems are developing. Almost all of the corners tested showed debonding. The average size of the debonded area at each corner was about 2 ft^2.

A center slab core showed that the PCC overlay appeared to be completely bonded to the existing slab. A core was also retrieved from a slab corner. Good bond existed between the overlay and the original slab, but the core was not recovered in one piece, having disintegrated from the level of the original slab reinforcement and below.

The overall performance of this section, surveyed 6 years after construction, is not very good. It is very likely that there was too much deterioration present on the original pavement to warrant the construction of a bonded overlay.

INTERSTATE 80—GRINNELL, IOWA (IA 1)

The next project location was on I-80 in central Iowa, near Grinnell. The original pavement was constructed in 1964 as a 10-in. doweled JRCP on a 4-in. aggregate base. The transverse joint spacing was 76.5 ft. Before construction of the overlay, it is estimated that the outer lane had sustained 11,800,000 ESALs and the inner lane, 2,230,000 ESALs.

Overlay

In 1984, a 4-in.-thick, bonded concrete overlay was constructed on this pavement. By then, the original pavement exhibited extensive distress: there were 110 broken interior corners noted in the construction plans. Before construction of the overlay, however, extensive full-depth repairs were placed; 458 areas were noted as being already in place and the construction of an additional 260 patches was required, again according to the plans. Epoxy-coated tie bars were placed on chairs above full-depth concrete repair joints that did not constitute a pavement joint before placement of the overlay. Longitudinal subdrains with transverse outlets were added to the project. At areas of broken interior corners, a depressed area of 4 in. was to be created by milling.

The initial surface preparation consisted of milling to a depth of 0.25 in., except at the locations where 4 in. was specified. The final preparation of the surface consisted of sandblasting. A cement-water grout was sprayed on the cleaned surface just before the application of the overlay. The transverse joints were sawed the full depth of the overlay and sealed with joint sealant material and backer rope. Joints at full depth patches were not sawed. The longitudinal joint was sawed to a depth of 1.5 in.

TABLE 3 INTERSTATE 80 (GRINNELL, IOWA) PERFORMANCE DATA

	1985 FHWA SURVEY	FIELD SURVEY 1988	
	OUTER LANE	OUTER LANE	LANE # 2
Average PSR	N/A	4.2	4.2
Mays Roughness, IN/MI	N/A	69	44
Transverse Faulting, IN	0.05	0.02	N/A
Transverse Cracks/MI L	222	210	225
M	11	0*	0
H	0	0	0
Long. Crk., LIN FT/MI L	21	0	0
M	0	0	0
H	0	0	0
% Joints Spalled	0	4.8	6.7
ESAL's on Overlay (millions)	1.87	6.31	1.41

* Several cracks were sealed and counted as low severity

% Joint Corners Debonded	22.2
% Debonded Crack Corners	27.1
% Area of Wheelpath Debonded	0
% Total Area Debonded	5.8

Performance of the Pavement Section

The results of the field survey from this section are found in Table 3. Table 3 shows that after 4 years of service and 6,310,000 ESALs, the pavement was still performing satisfactorily. The amount of traffic carried by the overlay in 4 years was over 50 percent of the total traffic carried by the original pavement in 20 years. Bonding survey results are also summarized. Debonding was occurring at both joints and cracks, although none was noted in the wheelpaths.

Cores were retrieved from the pavement at a center slab and corner location. The center slab core was in excellent condition, with no distresses noted. The core from the corner, however, was not recovered intact. Extensive horizontal cracking passed through the aggregate and the mortar, starting about 3 in. below the surface of the original slab. Several inches of the bottom of the core were disintegrated. The bond shear strength between the concrete layers, as measured at the corner, was 714 psi. A value of 200 psi is considered the minimum necessary for good performance.

After 3 years of heavy traffic, the only distresses noted were transverse cracking and some joint spalling. A comparison between the results of a 1985 survey and those of the 1988 survey showed no indication of progressive deterioration. However, many of the transverse cracks were of medium severity when surveyed in 1985. These cracks were routed and sealed in 1986, thereby reducing further deterioration of the cracks. The estimated amount of debonding suggests that further deterioration of this section may occur.

INTERSTATE 80—AVOCA, IOWA (IA 2)

The next project was located in west central Iowa, on I-80 near Avoca. The original pavement, constructed in 1966, consisted of a short section of 10-in. doweled JRCP on a 4-in. aggregate subbase, with 76.5 ft transverse joint spacing. It exhibited D-cracking at the transverse and longitudinal joints before construction of the overlay. This probably consisted of low to medium severity D-cracking at most of the joints. Before construction of the overlay, it is estimated that the pavement had sustained 5,410,000 ESALs in the outer lane and 810,000 ESALs in the inner lane.

Overlay

In 1979 a 3-in. bonded overlay was constructed on this pavement. Approximately 400 yd² of partial depth repairs and 153 yd² of full-depth repairs were specified for severely deteriorated areas before placement of the overlay. The continuity of the steel was not maintained in these patches. Pressure relief joints were constructed on an average of every 800 ft. These joints were sawed in the overlay approximately 4 in. wide within 24 hours and sealed with a preformed urethane foam.

The pavement was milled to a depth of 0.25 in. before resurfacing. In areas where there was deteriorated D-cracked pavement the milling extended to a depth of 1 in. Final surface preparation consisted of sandblasting and airblasting. Before placement of the overlay, longitudinal edge drains were installed. Transverse outlets were placed at 1,000-ft intervals. The grout used to bond the overlay consisted of a cement and sand mixture. No longitudinal joint was sawed, but the transverse joint was sawed the full depth of the overlay.

Performance of the Pavement Section

Results of the distress survey are found in Table 4. The table shows some deterioration, with 0.1 in. of faulting and dete-

TABLE 4 INTERSTATE 80 (AVOCA, IOWA) PERFORMANCE DATA

	1985 FHWA SURVEY	FIELD SURVEY 1988	
	OUTER LANE	OUTER LANE	LANE # 2
Average PSR	N/A	N/A	3.7
Mays Roughness, IN/MI	N/A	N/A	173
Transverse Faulting, IN	0.06	0.1	N/A
Transverse Cracks/MI L	164	211	162
M	26	6*	0
H	0	0	0
Long. Crk., LIN FT/MI L	53	0	0
M	0	5280**	0
H	0	0	0
% Joints Spalled	0	25	23.1
ESAL's on Overlay (millions)	4.82	7.93	1.39

* Centerline joint not sawed.

** Sealing may have changed M. sev. cracks to L. sev.

% Joint Corners Debonded	30
% Debonded Crack Corners	11.4
% Area of Wheelpath Debonded	0
% Total Area Debonded	1.7

riorated transverse cracks in the outer lane. There was also a large amount of transverse joint spalling present. Apparent debonding was present at both joint and crack corners, although it was more prevalent at joint corners. At the time of the survey, the overlay had carried approximately 7.9 million ESALs in the outer lane and 1.4 million ESALs in the inner lane, which is approximately 50 percent more than the original pavement had carried.

The center slab core was in good condition with no distresses noted. The core retrieved from the slab corner showed good bonding, but the original slab was totally deteriorated, with extensive cracking and disintegration. The slab appeared to have had a bituminous subsealing, because asphaltic material had infiltrated cracks at the bottom of the slab. The shear test performed on the center slab core showed a bond of 756 psi.

This bonded overlay has performed fairly well in light of the loads it has carried. It was placed over a pavement that probably showed distress at every transverse joint. Although the overlay does not exhibit D-cracking at the joints, there were a large number of spalled joints and transverse cracks. Deteriorated cracks and transverse joints are showing signs of debonding.

COUNTY ROUTE C-17—CLAYTON COUNTY, IOWA (IA 3)

Another experimental project was located in east central Iowa, near the Mississippi River. The original pavement, constructed in 1968, was a two-lane, 22-ft-wide and 6-in.-thick JPCP, with 40-ft joint spacing. It was constructed on a granular surfaced, secondary roadway that had been shaped to the required cross-section. The existing pavement had experienced 350,000 ESALs in the eastbound direction and 150,000 ESALs in the westbound direction before placement of the overlay.

Overlay

The original pavement was badly cracked, and numerous patches were placed before construction of the overlay. Also, the sections that were thicker and reinforced were constructed over areas of the pavement that were more severely deteriorated, thus skewing the performance results somewhat. A total of seven different sections, designated IA 3-1 through 3-7, were evaluated. These included variations in the following: overlay thickness; surface preparation; concrete water reducing admixtures; reinforcement; and sawing of joints. The full range of variables in this 1.3-mi-long project is described in previously published reports (*1,3*).

The grout used was a mix of cement and sand and was spread using brooms and squeegees. The overlay was reinforced with No. 4 reinforcing bars placed on 30-in. centers in 3-, 4-, and 5-in.-thick sections. Transverse joints were marked with nails and resawed following paving. These were cut to a depth of 1.5 in., with the exception of the 2-in.-thick slab, which had a 1-in. sawcut. A longitudinal joint was sawed only on 300 ft of the project, as an experimental feature.

Performance of the Pavement Sections

The field survey results are presented in Table 5. This 10-year-old project displayed significant distress over most of its length. It is estimated that at the time of the field survey, the eastbound lane had experienced 1.0 million ESALs and the westbound lane had experienced 0.4 million ESALs. The results of the bonding survey are also shown in Table 5. Debonding appeared to be widespread on all of the sections, especially at cracks, but also at most of the transverse joints. The section with the least overall debonding was the 2-in. overlay. The 3-in. and 5-in. overlays had the most debonding.

Pavement cores were retrieved from five sections. All of these cores showed the pavement to be in good condition,

TABLE 5 COUNTY ROAD 17 (CLAYTON COUNTY, IOWA) PERFORMANCE DATA

	3 - 1		3 - 2		3 - 3		3 - 4		3 - 5		3 - 6		3 - 7	
	3 in OL Sandblast		3 in OL Sandblast Reinforced		5 in OL Milled		5 in OL Milled Reinforced		4 in OL Sandblast		4 in OL Milled Reinforced		2 in OL Sandblast	
	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB	EB	WB
Transverse Faulting, IN	0.07	N/A	0.08	N/A	0.16	N/A	0.11	N/A	0.17	N/A	0.11	N/A	0.06	N/A
Transverse Cracks/MI L	14	14	0	0	132	0	0	66	0	0	0	0	16	4
M	284	185	264	106	330	132	330	132	236	177	462	396	20	24
H	14	28	0	0	0	0	66	66	15	0	264	0	0	0
Long. Crk., LIN FT/MI L	0	0	634	0	0	0	0	0	0	0	0	0	63	0
M	5834	0	4963	0	10098	5280	9834	2574	7065	1755	7920	4554	246	214
H	114	0	0	0	462	0	0	0	15	15	660	0	0	0
% Joints Spalled	66.7	22.2	0	0	0	33.3	0	33.3	54.6	27.3	33.3	0	44.5	27.8
ESAL's on Overlay (millions)	1.03	0.44	1.03	0.44	1.03	0.44	1.03	0.44	1.03	0.44	1.03	0.44	1.03	0.44
% Joint Corners Debonded	100		50		100		N/A		77.8		N/A		92.9	
% Crack Corners Debonded	100		100		100		N/A		100		N/A		91.7	
% Area of Wheelpath Debonded	0		0		0		N/A		0		N/A		0	
% Total Area Debonded	69.6		72.3		77.9		N/A		46.5		N/A		26.2	

with no visible deterioration. The average shear strengths obtained from tests run on corner cores ranged from 310 psi to 586 psi.

This is the only project that allows for a comparison between some of the various design variables that influence the performance of a bonded overlay. For example, Table 5 shows that a comparison of sections 3-1 and 3-2 should show the effects of reinforcement, as should a comparison of sections 3-3 and 3-4. Section 3-1, 3-5, and 3-7 can be used to examine the effects of the overlay thickness on performance. However, these apparent effects are confounded by other variables, particularly cracking of the original pavement before the overlay was constructed. Also, it should be noted that sections 3-2, 3-3, 3-4, and 3-6 were short and that the presentation of the observed distresses on a per mile basis has most likely skewed the results; sections 3-1 and 3-7 were much longer. Finally, this pavement receives much more heavy truck traffic in the eastbound lane than in the westbound lane. In general, the distresses were considerably less severe in the westbound lane.

STATE ROUTE 12—SIOUX CITY, IOWA (IA 4)

A bonded overlay project was constructed in the western part of Iowa, on State Route 12 (SR-12) in Sioux City. The original pavement, constructed in 1954, consisted of a 9-in. nondoweled JPCP, with a 20-ft transverse joint spacing. The pavement had sustained approximately 1,660,000 ESALs in the outer lane and 180,000 ESALs in the inner lane before placement of the overlay.

Overlay

In 1978, a 3-in. bonded concrete overlay was constructed on this pavement. The surface preparation consisted of removal of an old AC overlay, followed by milling. Partial depth repairs were also carried out before placement of the overlay. These consisted of milling the pavement at deteriorated areas until sound concrete was reached. A cement-sand grout in a 1:1 ratio was used to bond the overlay to the existing pavement. The joints were sawed directly over existing joints. The transverse joints were sawed through the overlay, and the longitudinal joints were sawed to a depth of 1 in. Because the existing joints were not well aligned, it was sometimes difficult to follow the underlying joint pattern.

Performance of the Pavement Section

The distresses noted during the field survey are shown in Table 6. These distresses are representative of a pavement in fairly good condition, although there is a large amount of longitudinal cracking. The distresses in the inner lane are higher than those in the outer lane. It was estimated that at the time of the survey the outer lane had sustained 1.3 million ESALs and the inner lane had sustained 0.2 million ESALs. This is about the same amount of traffic carried by the original pavement before construction of the overlay. Results from the debonding survey are also presented. Debonding had begun to develop along cracks and joints, and 5.5 percent of the total slab area showed signs of debonding, which may be cause for future concern. These data indicate a progressive deterioration of the overlay, especially in the amount of medium to high severity cracks and faulting.

Cores were retrieved from both center slab and slab corner locations. These cores both were in excellent condition, with no noticeable deterioration. Shear tests performed on the corner core indicated a bond of 537 psi.

This 10-year-old overlay project is performing well. The excessive longitudinal cracking may be caused by the insufficient depth of cut of the longitudinal joint.

US-20—WATERLOO, IOWA (IA 5)

Another bonded concrete overlay section is located in east central Iowa on US-20. The original pavement was constructed in 1958. The pavement consisted of 10 in. of nondoweled JPCP on an aggregate base with a transverse joint spacing of 20 ft. The original 10-in. slab exhibited extensive D-cracking. There was considerable spalling of the transverse joints, especially near the intersection with the longitudinal joints. Some of these areas had been repaired with bituminous patches. Approximately 1,190,000 ESALs had been applied to the outer lane and 95,000 ESALs had been applied to the inner lane before construction of the overlay.

Overlay

In 1976, a 3-in.-thick bonded overlay was placed on this pavement. However, extensive work was completed on the pavement before that construction. Partial depth repairs at the joints consisted of additional milling of approximately 2 in. of the deteriorated pavement, sandblasting, grouting, and fill-

TABLE 6 STATE ROAD 12 (SIOUX CITY, IOWA) PERFORMANCE DATA

	1985 FHWA SURVEY	FIELD SURVEY 1988	
	OUTER LANE	OUTER LANE	LANE # 2
Average PSR	N/A	N/A	2.4
Mays Roughness, IN/MI	N/A	N/A	163
Transverse Faulting, IN	0.04	0.07	N/A
Transverse Cracks/MI L	4	10	5
M	13	55	50
H	0	5	15
Long. Crk., LIN FT/MI L	40	0	0
M	84	100	5260
H	0	0	0
% Joints Spalled	10	4.4	29.6
ESAL's on Overlay (millions)	0.87	1.34	0.15

% Joint Corners Debonded	3.3
% Debonded Crack Corners	8.3
% Area of Wheelpath Debonded	0
% Total Area Debonded	5.5

ing of the patched area with new concrete. This work was performed at 30 joints for the full width of the pavement, and at 5 joints for one-half the width. Also, full depth repairs were constructed at four locations. Finally, 4-in. pressure relief joints were sawed at either end of the project before the placement of the overlay and also were constructed in the overlay.

In preparation for placement of the overlay, the entire top 0.25 in. of the pavement was milled off. This was followed by sandblasting. Just before placement of the overlay, the surface of the pavement was cleaned by airblasting. The grout used was a 1:1 mix of cement and sand, with enough water added to produce a creamy consistency. Existing transverse joints were marked with nails on the shoulder. The resurfacing was then sawed a minimum of 1 in. deep over approximately 20 percent of the existing transverse joints. Of the 38 joints where no partial depth patching was done, 7 were sawed after resurfacing. No centerline joint was sawcut in the pavement overlay. After 2 or 3 months, most of the transverse joints had reflected through the resurfacing.

Performance of the Pavement Section

The results from the field survey are summarized in Table 7 and show that this 12-year-old overlay is in very poor condition. This overlay exhibits extensive cracking and joint spalling and has noticeable transverse joint faulting. The condition of the inner lane is similar to that of the outer lane; it also had signs of D-cracking in the overlay. There were approximately 1.3 million ESALs applied on the overlay in the outer lane and 0.1 million applied in the inner lane. This is about 110 percent of the traffic applied on the original pavement before rehabilitation.

TABLE 7 US-20 (WATERLOO, IOWA) PERFORMANCE DATA

	1985 FHWA SURVEY	FIELD SURVEY 1988	
	OUTER LANE	OUTER LANE	LANE # 2
Average PSR	N/A	2.4	2.6
Mays Roughness, IN/MI	N/A	174	201
Transverse Faulting, IN	0.07	0.12	N/A
Transverse Cracks/MI L	40	198	168
M	216	228	228
H	0	18	6
Long. Crk., LIN FT/MI L	216	601*	222
M	0	5334*	0
H	0	0	0
% Joints Spalled	0	40	50
ESAL's on Overlay (millions)	1.07	1.32	0.11

* Centerline joint not sawed.

% Joint Corners Debonded	83.3
% Debonded Crack Corners	76.9
% Area of Wheelpath Debonded	0
% Total Area Debonded	45.7

The bonding survey results suggest that there is a serious loss of bond developing between the overlay and the original pavement. The debonding is primarily associated with distresses occurring at the joints and cracks, and not in the wheelpath.

Sample cores were obtained from representative slab corner and center slab locations. The center slab core was in good condition, with no noted distresses. The corner core, however, was in poor condition. It had primarily horizontal cracking throughout the aggregate and mortar, extending to within 0.25 in. of the original surface. A shear test performed on the center slab core showed a bond of 706 psi; the shear strength from the corner core was only 160 psi.

As is noted previously, the original pavement was severely distressed by D-cracking at the time of the overlay construction. D-cracking and spalling had evolved into severe joint deterioration, necessitating widespread repair both before placement of the overlay and as preoverlay repair. This pavement is now approaching a failed condition. The original pavement was most likely not a good candidate for the selection of a bonded overlay as the appropriate rehabilitation strategy because of the extensive D-cracking.

INTERSTATE 80—TRUCKEE, CALIF. (CA 13)

The I-80 thin bonded concrete overlay project is located in a mountainous region of central California. The original pavement was constructed in 1964 and consisted of 8 in. of nondoweled JPCP on a 4-in. cement-treated base (CTB) and a 12-in. aggregate subbase. The transverse joint spacing was a random pattern of 12-13-19-18 ft.

The original pavement was exhibiting some random cracking when the overlay was constructed. Also, much of I-80 in this mountainous region had experienced a severe loss of wearing surface in the wheelpaths because of the use of chains on tires during periods of inclement weather. Before the placement of the overlay in 1984, the outer lane of the pavement had experienced approximately 5,900,000 ESALs. The inner lane had experienced approximately 860,000 ESALs.

Overlay

A bonded concrete overlay was constructed on this section in 1984. It was 2 in. thick for a distance of 750 ft and 4 in. thick for 300 ft. Before placement of the overlay, the sealant material in the random cracks was removed by impact hammers. Contraction joints were also cleaned out. The initial surface preparation for the existing concrete pavement consisted of cleaning by shot blasting. The final surface preparation was by airblasting. An epoxy was used as the bonding agent. It was applied to the existing pavement just before the overlay, which was placed within 36 hours of shot blasting. Placement temperatures ranged from 46°F to 86°F. Reinforcement was placed in the overlay in the inner, or second, lane. This reinforcement consisted of both No. 4 rebar and welded wire. There was no reinforcement used in the outer lane.

The transverse joints were sawed directly over the joints in the existing pavement to the full depth of the overlay and sealed with silicone. The two lanes were paved separately, so

no special provisions were made for a longitudinal joint. The specifications required sawing of the transverse joints within 12 hours of paving.

Performance of the Pavement Section

The distresses measured on the pavement section are summarized in Table 8. These indicate a pavement that is performing well, although there are transverse and longitudinal cracks present. It is not known how many of these are reflected cracks. The bonding survey results show that an extraordinarily large area of this pavement appears to be debonded. This debonding does not appear to be restricted to joints or the wheelpath area but covers substantial portions of the entire slab area. An informal survey of this project by Caltrans in 1986 revealed minimal debonding. It is estimated that the overlay had sustained 3.1 million ESALs in the outer lane and 0.5 million ESALs in the inner lane at the time of the survey. This figure is slightly more than 50 percent of the traffic carried by the original pavement until construction of the overlay.

This pavement has good serviceability and no faulting. However, there is a fairly large amount of low-severity transverse and longitudinal cracking that has not yet deteriorated. Given the extent of the debonding, some type of further deterioration is likely. The cause of the apparent debonding may be related to the performance of the epoxy grout or environmental conditions at the time of paving. An earlier bonded overlay (1981) in the same area failed to develop bond, although in that instance a cement grout was used and the debonding occurred almost immediately.

SR-38A—SIOUX FALLS, S.D. (SD 1)

The SR-38A project is located in the extreme southeastern portion of South Dakota, on State Route 38A. The original pavement, constructed in 1950, consisted of 8 in. (203 mm) of nondoweled JPCP on a 6-in. aggregate base. The transverse joint spacing was 15 ft. A survey conducted before construction of the overlay showed that 4 percent of the pavement area required full-depth patching. There were 1,100 linear ft of longitudinal cracking recorded, and 60 percent of the transverse joints were spalled. Corner breaks were also noted, as were transverse cracking, delamination, and large areas of asphalt overlay and patching already in place. Several blowups had occurred on the pavement; these had been repaired either with AC patches or full-depth concrete repairs. The pavement had sustained approximately 1,130,000 ESALs in each direction by the time the overlay was constructed.

TABLE 8 INTERSTATE 80 (TRUCKEE, CALIF.) PERFORMANCE DATA

	FIELD SURVEY 1987	
	OUTER LANE	LANE # 2
Average PSR	4.2	N/A
Mays Roughness, IN/MI	134	N/A
Transverse Faulting, IN	0	N/A
Transverse Cracks/MI L	245	136
M	0	0
H	0	0
Long. Crk., LIN FT/MI L	1002	543
M	0	0
H	0	0
% Joints Spalled	3	1.5
ESAL's on Overlay (millions)	3.09	0.53

% Joint Corners Debonded	75
% Area of Wheelpath Debonded	19
% Total Area Debonded	56.8

Overlay

The 3-in.- and 4-in.-thick, bonded concrete overlay was constructed in 1985. Only the 3-in. section was evaluated for this project. Extensive repairs were performed before placement of the overlay, including 51 full-depth patches and additional partial-depth patching. The partial-depth patches were prepared and then filled as part of the overlay paving operation. Four different methods of reinforcing the longitudinal cracks were tried, including placing tie bars on chairs, placing bent tie bars in predrilled holes on either side of the crack, tying tie bars to reinforcing steel rails running parallel along either side of a crack, and placing the tie bars in sawed slots.

After all of the patching was completed and the undesirable deteriorated material was removed, the pavement was shotblasted. A cement-water grout, used to bond the overlay, was sprayed onto the surface immediately before application of the overlay. Ambient temperatures during placement ranged from 57°F to 80°F. Three transverse cracks occurred during rapid cooling of the pavement from a severe thunderstorm that produced a cold rain.

The transverse joints were sawcut the full depth of the overlay as soon as possible after placement of the overlay. The cuts were made across a single lane, guided by two sets of reference pins, in an attempt to compensate for the nonuniformity of the joints. The longitudinal joint was specified to be cut within 48 hours of paving, but was actually sawed at the same time as the transverse joints. In addition, seven 4-in.-wide pressure relief joints were constructed along the project.

Soon after the sawing was completed, 20 random transverse cracks, most very short, developed. These cracks were routed and sealed with epoxy. During the first day of paving, a random centerline crack occurred on 720 ft of overlay before sawing of the longitudinal joint. The sawing time was adjusted, but the overlay still developed another 5,100 ft of random centerline cracking. These cracks were also sealed, with the sealant material determined by the crack's location. No delamination of the overlay was detected on the project after construction.

A survey made a year later indicated a small amount of reflection cracking. The only cracks that weren't reflection cracks were located along the boundary of full-depth repairs in the overlay or the next slab.

Performance of the Pavement Section

A field survey was conducted on this pavement in May 1988, after nearly 3 years of service and 0.71 million ESALs in each lane. This is over 60 percent of the traffic carried by the pavement in the 25 years of service before construction of the overlay. The distresses were nominal, consisting of some longitudinal cracking and slight transverse joint spalling. These results are shown in Table 9. A bonding survey was also performed and showed that very little of the pavement was debonded. The only debonded areas consisted of 9 percent of the slab corners tested.

Cores were taken from the slab center and corner. They were both in excellent condition, with no signs of deterioration or distress. The shear strength between the overlay and the pavement, measured from a corner core, was 675 psi—higher than the shear strength obtained from the slab center core.

This bonded overlay is performing very well after 3 years of service and approximately 710,000 ESALs. This good performance is occurring despite the preexisting distresses and the need for widespread preoverlay repairs. It is not known whether the good performance is a result of some design factor or whether the low number of applied ESALs has helped to minimize the presence of deterioration.

INTERSTATE 25—DOUGLAS, WYO. (WY 1)

The Douglas, Wyo., project is located on I-25, in the southeastern corner of the state. The original pavement, constructed in 1969, was an 8-in.-thick nondoweled JPCP on an aggregate base, with a 20-ft transverse joint spacing. When the overlay was constructed, the original pavement was relatively sound, with some transverse and longitudinal cracking and corner breaks evident in limited areas. Minor pumping and faulting were observed throughout the project. Maintenance operations up to the time of the 1983 overlay construction included sporadic joint resealing and maintenance patching with an AC cold mix. It is estimated that the outer lane of the pavement had sustained 1,970,000 ESALs before construction of the bonded overlay. In 1983, many different repairs were carried out on this section. These included subsealing in the outer lane for the entire length of the project with a cement-pozzolan grout, full and partial depth repairs, and joint and crack resealing.

TABLE 9 STATE ROAD 38A (SIOUX FALLS, S.D.) PERFORMANCE DATA

	1985 FHWA SURVEY	FIELD SURVEY 1988	
	EB LANE	EB LANE	WB LANE
Average PSR	N/A	4.2	4
Mays Roughness, IN/MI	N/A	59	72
Transverse Faulting, IN	0.02	0.03	N/A
Transverse Cracks/MI L	0	0	0
M	0	0	0
H	0	0	0
Long. Crk., LIN FT/MI L	0	63	0
M	0	73	250
H	0	0	0
% Joints Spalled	0	1.3	6.3
ESAL's on Overlay (millions)	0.11	0.71	0.71

* Centerline joint not sawed.

% Joint Corners Debonded	9.2
% Area of Wheelpath Debonded	0
% Total Area Debonded	0.1

Overlay

Before placement of the 3-in. overlay, the pavement was milled to a depth of 0.5 in. and then sandblasted. The final surface preparation consisted of airblasting immediately before the application of the bonding agent. The temperature range during the paving period was between 65°F and 86°F. A cement-water mixture was used as the bonding agent, with a maximum water-cement ratio of 0.62. The transverse joints were sawed full depth above the marked joints of the original pavement, except for at several locations. They were then sealed with a silicone sealant before the pavement was opened to traffic. The longitudinal joint was sawed along the middle of the overlay slab, to an initial depth of 2 in. However, the original longitudinal joint was formed with an insert, which may have made it difficult to locate and follow the longitudinal joint.

Performance of the Pavement Section

The pavement was evaluated several times by the Wyoming State Highway Department. Deflection testing performed shortly after construction showed that one area appeared not to have been successfully undersealed and that there were three slabs that appeared not to be bonded. Cores taken less than 1 year after construction showed shear strengths ranging from 223 to 360 psi. One year after construction, there were a few interior corners that had become debonded and broken out. The extent of this problem was considered minimal. A subsequent survey conducted by the state in the spring of 1986 showed extensive deterioration, consisting of fine transverse cracks spaced 6 in. to 9 in. apart over the entire project. There were many areas of the project that were experiencing more severe cracking and several areas that had broken up.

This pavement was next evaluated by the FHWA in 1986. Debonding was noted at the intersection of reflected transverse and longitudinal cracks. There were also about a dozen instances of small corner breaks with associated debonding. Some transverse cracks occurred in relation to missawed joints. There was minor cracking attributable to reflection of underlying cracks or joints. Some of the cracks had developed minor spalling. According to the Wyoming State Highway Department, this cracking had begun to develop during the winter and spring of 1985–1986.

Table 10 presents the results of the 1988 field survey. Overall, the pavement showed significant deterioration, with a large number of medium severity transverse cracks and extensive longitudinal cracking. The distresses are notably higher in the outer lane than in the inner, less traveled lane. There appears to be a debonding problem at over one-half of the

TABLE 10 INTERSTATE 25 (DOUGLAS, WYO.) PERFORMANCE DATA

	1986 FHWA SURVEY	FIELD SURVEY 1988	
	OUTER LANE	OUTER LANE	LANE # 2
Average PSR	N/A	4.2	4
Mays Roughness, IN/MI	N/A	82	113
Transverse Faulting, IN	0.01	0.04	N/A
Transverse Cracks/MI L	21	158	0
M	0	42	0
H	0	0	0
Long. Crk., LIN FT/MI L	42	232	0
M	0	2165	528
H	0	296	11
% Joints Spalled	8.3	23	3.8
ESAL's on Overlay (millions)	1.12	1.90	0.13

* Centerline joint not sawed.

% Joint Corners Debonded	52.9
% Area of Wheelpath Debonded	1
% Total Area Debonded	3.6

corners and in 1 percent of the wheelpath area. This is a large amount of debonding for a 4-year-old project. The loads applied to the overlay at the time of the survey were 1.9 million ESALs in the outer lane and 0.1 million ESALs in the inner lane—over 95 percent of the traffic carried by the original pavement before construction of the overlay. The amount of longitudinal cracking appears to be the most serious problem, as much of it is deteriorated. The transverse cracking could also further deteriorate and develop into excessive roughness.

A joint core was retrieved from a representative slab corner. There was no bond between the existing pavement and the overlay, as the overlay section was totally separated from the underlying pavement.

This project is in fairly good condition in terms of serviceability, with a high PSR, but the debonding observed suggests that further cracking may occur. The original pavement required extensive rehabilitation before the overlay construction, which may be an indication that a bonded overlay might not have been the most appropriate rehabilitation strategy.

SUMMARY AND CONCLUSIONS

The pavement sections investigated in this study represent the majority of the bonded overlays that have been constructed in the United States. The original pavements ranged in age from 9 years to 35 years before overlay. The overlays ranged in age from 3 years to 11 years. The original pavements and the overlays had carried a wide range of traffic levels. In fact, several of the overlays have carried nearly as much or more traffic than the original pavements.

These overlays were constructed by using various surface preparations and bonding agents. Because of the various design factors involved in the design and construction of each overlay, the effect of many of these factors was confounded. Therefore, no strong conclusions regarding surface preparation or bonding agent could be drawn.

It is believed that curing conditions play a large role in the performance of bonded overlays. The ambient conditions at the time of concrete placement have an effect on the curing and bonding of the overlay. Rapid curing is associated with shrinkage cracking and debonding of the overlay, particularly at the corners. Undesirable climatic conditions may also cause rapid drying of the grout, which will not promote a good bond between the overlay and the original surface. Information regarding the curing conditions in this project was unavailable, however, and these conclusions can not be substantiated by the results presented herein.

Sawing of the transverse as well as longitudinal joints soon after placement of the overlay is critical in controlling the deterioration of the joints. Several of the sections exhibited cracking because of inadequate joint sawing or no joint sawing at all. For example, no longitudinal joint was sawed on IA 2, and only 20 percent of the transverse joints were sawed on IA 5. Not surprisingly, these sections exhibited more cracking at higher severity levels than sections whose joints were sawed.

There was a large degree of difference in the amount of preoverlay repair performed. Many of the sections had extensive preoverlay repairs whereas others had very little. The conclusions regarding preoverlay repair are fairly clear. If the existing slab has working cracks, deteriorated joints, or materials problems, and an overlay is placed on the slab, the chances of the overlays performing well are not good. It is believed that working cracks in the existing slab propagate quickly through the overlay. The sections on IA 3 and IA 5 show this type of propagation.

Deteriorated joints resulting from excessive spalling of materials problems result in problems in the overlay. The IA 5 section showed deterioration of the overlay joints caused by inadequate support from the original slab, which exhibited "D" cracking.

Several of the sections exhibited serviceabilities of 3.2 or less. These pavements have failed in terms of their serviceable lives. Closer examination shows that these sections are in poor structural condition as well, typically exhibiting cracking and faulting.

- NY 6—This section had a serviceability rating of 3.2 and showed transverse cracking, faulting, and a large degree of debonding at the corners.
- IA 3—Although it was not possible to determine the serviceability of these sections because of the geometry of the roadway, observations were made regarding their remaining serviceable life. The extensive deterioration of the slabs and the amount of debonding present indicate that the sections are near failure.
- IA 4—The IA 4 section had a serviceability of 2.4, indicating that the pavement was very rough. The section exhibited a large amount of longitudinal cracking and some medium and high severity transverse cracking, as well as some faulting.
- IA 5—The serviceability rating given to the IA 5 section was 2.4. This rating indicates failure of the section in terms of rideability. The section also exhibited extensive transverse cracking, several shattered slabs, a high level of faulting, and longitudinal cracking. All of these indicate a serious structural failure.

Because of inadequate documentation, the condition of the original pavement after full-depth repairs (if performed) and before overlay is unknown. This information would be useful in determining the amount of deterioration in the overlay that may be attributed to deficiencies in the original slab.

Unfortunately, many of the factors that affect the performance of the bonded overlays cannot be compared in this study because they are confounded by the various designs, climates, curing agents, bonding agents, and so on. Also, bonded overlays are typically constructed to either improve the structural capacity of a pavement or correct a surficial defect (*4*). It was not possible to determine whether any of the overlays evaluated for this study were constructed for either of these reasons. Generally, the bonded overlays that were studied had mixed success. However, it is believed that with proper preoverlay repair, thorough cleaning and preparation of the surface, use of a good bonding agent, careful placement and curing of the concrete, and proper joint sawing techniques, many years of benefit can be attained through the placement and use of bonded overlays. Also, the effect of the selection of proper candidate sections for this rehabilitation technique cannot be understated.

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