Performance Review of Concrete Pavement Restoration

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Concrete pavement restoration (CPR) is a pavement rehabilitation strategy for portland cement concrete (PCC) pavements. The method consists of a number of individual techniques, including slab stabilization (subsealing), full-depth patching, partial-depth patching, load transfer restoration, subdrainage, shoulder restoration, diamond grinding, and joint resealing. These practices are designed to provide additional service life to the existing pavement. The FHWA noted growing concerns that both this entire rehabilitation strategy and the individual techniques were performing below expected levels or were not appropriate for actual project conditions. A plan was developed to conduct detailed reviews of completed CPR rehabilitation projects. In all, 26 CPR projects in 8 states were reviewed. It was found that proper preliminary engineering and timing of the individual techniques are critical to project performance. The reviewers found that when projects are properly designed and constructed, CPR will generally reduce pavement deterioration, thereby prolonging pavement life. Continued maintenance will be required, however, throughout the project design life. In addition, it was noted that pavements that have an accelerated rate of slab cracking will continue to have a high rate of slab deterioration immediately after completion of a CPR project.

One of the pavement rehabilitation strategies for portland cement concrete (PCC) pavements is concrete pavement restoration (CPR). Individual techniques within a CPR project include slab stabilization (subsealing), full-depth patching, partial-depth patching, load transfer restoration, subdrainage, shoulder restoration, diamond grinding, and joint resealing. In the past, these techniques had been used on a limited basis as a maintenance strategy. Very few reliable performance data were available for the CPR techniques.

To assess the effectiveness of the CPR strategies that were being undertaken by state highway agencies, the FHWA conducted a review of selected CPR projects. The review focused on three aspects of CPR work that had been completed on jointed plain and jointed reinforced concrete pavements:

- Expected service life, based on observed performance;
- Variables that significantly affect the performance of individual CPR techniques; and
- Conditions under which each strategy has been used in a cost-effective manner.

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Field reviews were conducted jointly by the FHWA's Pavement Division and Demonstration Projects Division between May and October 1986. Teams composed of an engineer from each division conducted in-depth reviews of 26 CPR projects in eight states. These teams were assisted by engineers from the appropriate FHWA regional and division offices and by state engineers familiar with the design, construction, and maintenance of each project. The states also provided historical and inventory data for each project.

The CPR review provides interim technical guidance. The findings represent the consensus of the FHWA engineers who conducted the reviews, based on their experience, data gathered, field observations, and discussions with field practitioners.

In all, 26 CPR projects were reviewed in 8 states. The projects reviewed and techniques evaluated are listed in Table 1. Pertinent information on each of the pavements rehabilitated is summarized in Table 2.

All the projects evaluated were jointed concrete pavements. Half (13) of the projects were plain concrete pavements with undowelled joints. The remaining 13 projects were reinforced concrete pavements with dowelled joints. The average age of the pavements at the time of rehabilitation was 18 years, with a range of 10 to 38 years.

Very few traffic-loading data were available for most of the projects. However, an attempt was made to classify the current truck loadings on the projects into four groups. The groups are based on daily volume of "five-axle or greater" trucks. This grouping was selected because these trucks generally provide 85 percent or more of the 18-kip equivalent single-axle loadings on rural highways. The following groups were selected:

Loading Class	*Daily Truck Volume (5-Axle or Greater)*
1	>1,500
2	1,001–1,500
3	501–1,000
4	<501

For each major rehabilitation project reviewed, a subjective evaluation of the performance was made. All projects were expected to provide 6 to 10 years' service life. Therefore, if the project required early rehabilitation or major maintenance, it was considered to have been a poor overall candidate for rehabilitation.

In addition, the performance of the individual techniques was evaluated. These techniques included full-depth patching,

TABLE 1 PROJECTS AND REHABILITATION TECHNIQUES REVIEWED

				Rehabilitation Techniques						
Route	Project Limits	Year Rehabilitated	Pavement Age[a] (yr)	Subseal	Edge Drains	Pressure Relief	Full Depth	Partial Depth	Diamond Grinding	Joint Sealing
California										
I-5	Shasta Co., MP 3.8–14.0	1983	17	Y	Y		Y			Y
I-80	Placer Co., MP 4–11.4	1984	25	Y	Y		Y	Y		
I-5	Yolo Co., MP 23–27.1	1984	18	Y	Y		Y		Y	
Georgia										
I-75	MP 226–232	1981	12	Y					Y	Y
I-475	MP 0–15	1980	13	Y			Y	Y	Y	Y
I-75	MP 64–72	1978	17	Y			Y	Y		Y
I-75	MP 22–59	1978	17	Y			Y	Y		Y
South Carolina										
I-85	MP 21–34	1979	15	Y			Y		Y	Y
I-20	MP 0–6	1984	17	Y			Y	Y	Y	Y
Virginia										
I-81	MP 147.2–161.8 NB	1984	19	Y	Y		Y	Y	Y	Y
I-64	MP 238.4–254	1982	19				Y			Y
I-64	MP 278.7–283.3	1983	16			Y	Y			Y
Minnesota										
I-694	MP 37–46	1981	20				Y	Y		Y
US-10	MP 204–211.6	1981	35						Y	
US-71	MP 124.9–129.2	1983	14						Y	
I-94	MP 81–103	1981	14					Y		Y
Wisconsin										
WI-29	Chippewa Falls to Thorp	1983	16				Y	Y		Y
US-61	Fennimore to Boscobel Rd.	1982	30				Y	Y	Y	
US-151	Columbus–Beaver Dam Rd.	1982	28				Y		Y	
I-90	MP 138–142	1981	21				Y		Y	Y
Michigan										
I-75	MP 64–80	1983					Y			
M-47	Saginaw Co. State Rd to Div.	1983	16					Y		Y
South Dakota										
I-29	MP 27–62	1972	10					Y		Y
I-29	MP 0–15	1980	19			Y	Y	Y		Y
I-90	MP 395.5–412	1985	24			Y	Y	Y		Y
I-90	MP 265–292.2	1982	17					Y		Y

[a] Average Age: 18.76 (Min: 10.00, Max: 35.00).

partial-depth patching, grinding, joint resealing, and subsealing. Very few projects reviewed included pressure relief joints, subdrains, retrofit load transfer devices, and shoulder restoration techniques, so detailed comments on these techniques are not provided. The reviewers also concluded that it is not possible to evaluate subsurface drainage without performing in-depth testing. A separate project has been initiated to evaluate subsurface drainage on a variety of in-service installations. A detailed discussion of the CPR techniques is presented in the following sections.

OVERALL CPR STRATEGY

On many of the projects reviewed, there was very little information available on the condition of the pavement before the rehabilitation project. This lack of data made it difficult to make before and after evaluations of the effectiveness of the CPR techniques. The absence of information on the rate of pavement deterioration before CPR made it difficult to determine whether CPR slowed the rate of deterioration.

Another complication, in addition to the lack of detailed information on the extent and causes of distress, was that the pavement condition on most projects was not formally checked during the latter stages of project development. As a result, several projects experienced overruns that exceeded 500 percent for full- and partial-depth patching quantities. On one project, the quantity of partial-depth patching increased from 11,511 ft^2 to 89,893 ft^2 for an overrun of $470,292. At least one project was terminated before all CPR work was completed because overruns in quantities exceeded available funds. These findings emphasize the need for detailed monitoring of conditions throughout the preliminary engineering phase of candidate CPR projects.

In retrospect, 4 of the 26 projects reviewed were probably poor candidates for CPR. This judgment was based on the condition of the pavements 5 yr or less after rehabilitation. Three of these projects were in need of major maintenance or

TABLE 2 DESCRIPTION OF THE ORIGINAL PAVEMENT ON EACH PROJECT REVIEWED

Route	Project Limits	Year Opened	Load Class[a]	Pavement Type[b]	Pavement Depth (in.)	Joint Spacing (ft)	Skew ('/12)	Dowels	Climate Zone	Avg. Monthly Temperature Min.	Avg. Monthly Temperature Max.	Freeze Index	Base Material	Subgrade	Year Rehabilitated	Pavement Age[c] (yr)
California																
I-5	Shasta Co., MP 3.8–14.0	1966	2	JPCP	8	12–19	2	N	IIC	37	97	0	CTB	CLY-GR	1983	17
I-80	Placer Co., MP 4–11.4	1959	1	JPCP	8	15	0	N	IIC	39	95	0	CTB	SD-ST	1984	25
I-5	Yolo Co., MP 23–27.1	1966	2	JPCP	8	12–19	2	N	IIC	38	96	0	CTB	ST-CLY	1984	18
Georgia																
I-75	MP 226–232	1969	1	JPCP	10	30	0	N	IC	35	88	0	CTB	ST-CLY	1981	12
I-475	MP 0–15	1967	2	JPCP	9	30	0	N	IC	38	93	0	ATB	Select	1980	13
I-75	MP 64–72	1961	1	JPCP	9	30	0	N	IC	38	93	0	ATB	Select	1978	17
I-75	MP 22–59	1961	1	JPCP	9	30	0	N	IC	38	93	0	ATB	Select	1978	17
South Carolina																
I-85	MP 21–34	1964	1	JPCP	9	25	0	N	IC	35	92	0	Earth	A-7-5 & 6	1979	15
I-20	MP 0–6	1967	2	JPCP	9	25	0	N	IC	35	91	0	Earth	A-2-4	1984	17
Virginia																
I-81	MP 147.2–161.8 NB	1965	3	JRCP	9	61.5	0	Y	IB	29	88	0	Crushed aggregate	A-6 & A-7	1984	19
I-64	MP 238.4–254	1963	2	JRCP	9	61.5	0	Y	IC	32	88	0	Aggregate	A-6 & A-7	1982	19
I-64	MP 278.7–283.3	1967	1	JRCP	9	61.5	0	Y	IC	32	88	0	CTB	A-3 & A-2	1983	16
Minnesota																
I-694	MP 37–46	1961	1	JRCP	10	40	0	Y	IA	1	81	1567	Gravel	A-6	1981	20
US-10	MP 204–211.6	1946	4	JPCP	9–7–9	15	0	N	IA	−2	81	1987	None	A-1-B	1981	35
US-71	MP 124.9–129.2	1969	4	JPCP	8.5	20	2	N	IIA	−1	84	1597	Aggregate	A-4	1983	14
I-94	MP 81–103	1967	3	JRCP	9	39.3	0	Y	IIA	−4	81	2262	Gravel	A-6	1981	14
Wisconsin																
WI-29	Chippewa Falls to Thorp	1967	3	JRCP	9	90	0	Y	IA	3	82	1750	Crushed aggregate	Granular	1983	16
US-61	Fennimore to Boscobel Rd.	1952	4	JPCP	8	20	0	N	IA	9	84	1000	Crushed aggregate	GI = 14	1982	30
US-151	Columbus–Beaver Dam Rd.	1954	4	JPCP	9	80	0	N	IA	8	81	1000	Gravel	A-4	1982	28
I-90	MP 138–142	1960	1	JRCP	9	80	0	Y	IA	8	81	1000	Gravel	N/A	1981	21
Michigan																
I-75	MP 64–80	N/A	1	JRCP	9	99	0	Y	IA	19	83	750	N/A	N/A	1983	–
MI-47	Saginaw Co. State Rd to Div.	1967	4	JRCP	9	71	0	Y	IA	15	81	750	N/A	N/A	1983	16
South Dakota																
I-29	MP 27–62	1962	N/A	JRCP	9	61.5	0	Y	IIA	5	86	N/A	Aggregate	A-7-6-12	1972	10
I-29	MP 0–15	1961	N/A	JRCP	10	61.5	0	Y	IIA	5	86	N/A	Aggregate	A-7-6-12	1980	19
I-90	MP 395.5–412	1961	N/A	JRCP	9	61.5	0	Y	IIA	5	86	N/A	Granular	A-7-6-12	1985	24
I-90	MP 265–292.2	1965	N/A	JRCP	9	46.5	0	Y	IIA	5	86	N/A	Lime/aggregate	A-7-6-12	1982	17

[a] JPCP=jointed plain concrete pavements. JRCP=jointed reinforced concrete pavements.
[b] Load classes are based on the following one-way volumes of five-axle or greater trucks: >1,500=1, 1,001–1,500=2, 501–1,000=3, <501=4.
[c] Average age: 18.76 (Min: 10.00, Max: 35.00)

complete reconstruction. The other project is displaying significant distress less than 2 yr after rehabilitation. The principal type of distress on these projects was the structural failure of the slabs. When these projects were rehabilitated, ~4.7 to 16.3 percent of the pavement in the right lane was replaced by full-depth patching. Generally, additional patching was required, but contract overruns were limited by fiscal constraints. In most cases, full-depth patches were constructed to replace slabs that were breaking up.

Of the remaining 22 projects reviewed, 3 had a significant amount of full-depth patching to correct joint distress. In general, the slabs were in good structural condition other than at the joints. The remaining 19 projects were considered proper candidates for CPR and exhibited satisfactory performance as long as 8 yr. The maximum quantity of full-depth patching on these 19 projects amounted to 2.6 percent of the surface area of the right lane.

The following discoveries on the use and performance of CPR were made:

- Properly designed and constructed CPR techniques can be expected to provide 6 to 10 yr of service life; however, continued maintenance throughout the project's design life will be required.
- The level of performance of each individual CPR technique was highly dependent on the adequacy of design, quality of construction, and the appropriateness of the technique selected to address the cause of distress. Even with high-quality controls, a few early failures of the repairs occurred, and maintenance within 1 yr after completion of CPR is generally required.
- Lack of detailed condition data during project development resulted in major overruns.
- Pavements that have an accelerated rate of slab cracking before rehabilitation had a high rate of slab deterioration immediately after completion of a CPR project. It was found that the percent of the right lane requiring full-depth replacement of cracked slabs appeared to be a good indicator of a project's suitability for CPR. The criteria listed below are based on field observations of the 26 projects:

  - When 5 percent or more of the right lane required full-depth replacement, the project was probably not a suitable CPR candidate.
  - When 2 percent or less of the right lane required full-depth replacement and other forms of distress were within reasonable limits, the project was a suitable CPR candidate.
  - Projects that require between 2 and 5 percent full-depth replacement of the right lane are marginal CPR candidates and require careful monitoring to establish the current rate of pavement deterioration.

FULL-DEPTH PATCHING

Full-depth concrete pavement repairs were reviewed on 19 CPR projects in 8 states. The age of the oldest patches observed was 8 yr, with an average age of 4 yr. The projects reviewed are summarized in Table 3.

Three methods of providing load transfer at the transverse boundary between the patch and the existing concrete were observed. Dowels were used on eight projects, and undercutting (inverted tee) was used on four projects. Load transfer by aggregate interlock only was used for patches on six projects. In addition, all three methods were tried on one project in Wisconsin.

Full-depth patches with dowels used for load transfer provide the best overall performance. Where undercutting was used, a majority of the patches observed exhibited settlement of the patch, faulting at the joint, or both. In many cases, both sides of the patch would be lower than the adjacent slabs. Patches with aggregate interlock had severe faulting, which generally appeared to be greater than the faulting on the original pavement.

Patch cracking was not a major source of distress, although a number of states permitted early opening (48 hr) after concrete placement. Typical concrete mix designs required 3,000 lb/in^2 compressive strength in 24 hr. Reviewers in Georgia noted that patches there were opened to truck traffic after 6 hr at concrete compressive strengths of 1,200 to 1,500 lb/in^2, with no resulting problems.

Of the 19 CPR projects that incorporated full-depth patching, 14 had a minimum patching dimension of one lane width in the transverse direction. The length varied from 2 ft to a full slab length. It was noted that many of the patches that were less than 4 ft long developed longitudinal cracking in the middle third of the patch. Most of the states that were reviewed specify a minimum patch size of a full lane wide by 6 ft long.

The review confirms that full-depth concrete repairs can be constructed to provide satisfactory long-term performance. The additional expense of the dowel bars appears to be very cost-effective in reducing the recurrence of faulting. Patching is a major cost item on most CPR projects, so the rate of continued deterioration of the pavement joints and slabs not repaired must be given careful consideration in the economic (life-cycle cost) analysis of rehabilitation alternatives.

The following findings on full-depth patching were made:

- Dowelled, jointed full-depth concrete patches provide satisfactory long-term performance (as long as 8 yr observed).
- Patches should have a minimum dimension of one lane width in the transverse direction and 6 ft in the longitudinal direction.
- Satisfactory performance was achieved from patches opened to traffic in as little as 4 hr. In these cases, higher cement factors, Type III cement, and as much as 2 percent calcium chloride (by weight of cement) were used to accelerate the strength gain.

PARTIAL-DEPTH PATCHING

Partial-depth patching was performed on 13 CPR projects. Nine of the projects were jointed reinforced pavements with dowelled joints. The remaining four projects were plain pavements with undowelled joints. On all projects reviewed, the partial-depth patches were generally used to correct spalling at transverse contraction joints.

No problems occurred with partial-depth saw cuts and concrete removal. The Georgia reviewers noted excellent results with their procedures. They specify a series of parallel partial-depth saw cuts within patch boundaries to facilitate concrete

TABLE 3 SUMMARY OF FULL DEPTH PATCHING PROJECTS

Route	Project Limits	Year Rehabilitated	Pavement Age (yr)	Patch Age (yr)	Saw Depth (in.)	Minimum size (ft)	Removal Method	Load Transfer	Concrete Mix Strength	Opening Time (hr)
California										
I-5	Shasta Co., MP 3.8–14.0	1983	17	3	3	3 × 3	Break	None	7 bag/2% CaCl	4
I-80	Placer Co., MP 4–11.4	1984	25	2	3	N/A	Break	None	7 bag/2% CaCl	4
I-5	Yolo Co., MP 23–27.1	1984	18	2	3	6 × 6	Break	None	7 bag/2% CaCl	4
Georgia										
I-475	MP 0–15	1980	13	6	Full	Lane width × 15	Lift	Dowels	7.5 bag/Type III/3000 psi/24 hr	6
I-75	MP 64–72	1978	17	6–8	Full	Lane width × 15	Lift	Dowels	7.5 bag/Type III/3000 psi/24 hr	6
I-75	MP 22–59	1978	17	8	Full	Lane width × 15	Lift	Dowels	7.5 bag/Type III/3000 psi/24 hr	6
South Carolina										
I-85	MP 21–34	1979	15	7	Full	Lane width × 6	Break	Undercut 1 side	8 bag/Type III/2% CaCl	N/A
I-20	MP 0–6	1984	17	2	Full	Lane width × 12	Break	Dowels	6.5 bag/Type I	N/A
Virginia										
I-81	MP 147.2–161.8 NB	1984	19	2	Full	Lane width × 2	Lift	Undercut both sides	8.5 bag/Type III/3000 psi/24 hr	48
I-64	MP 238.4–254	1982	19	4	Full	Lane width × 2	Break	Undercut	8.5 bag/Type III/3000 psi/24 hr	6
I-64	MP 278.7–283.3	1983	16	3	Full	Lane width × 2	Lift	None	8.5 bag/Type III/3000 psi/24 hr	N/A
Minnesota										
I-694	MP 37–46	1981	20	5	Full	None specified		Dowels	8.5 bag/Type I/5600 psi/28 days	7
Wisconsin										
WI-29	Chippewa Falls to Thorp	1983	16	3	Full	Lane width × 6	Lift	Dowels	9 bag/Type I/2–4% CaCl	8
US-61	Fennimore–Boscobel Rd.	1982	30	4	Full	Lane width × no min.	Lift	Undercut	9 bag/Type I	8
US-151	Columbus–Beaver Dam Rd.	1982	28	4	Full	Lane width × no min.	Lift	Dowels	9 bag/Type I/2–4% CaCl	8
I-90	MP 138–142	1981	21	5	Full	4 × 4	Lift	Varied	6 bag/Type 1A	N/A
Michigan										
I-75	MP 64–80	1983	N/A	3	Full	Lane width × 6	Lift	Dowels (no grout)	2% CaCl/300 psi/8 hr	8
South Dakota										
I-29	MP 0–15	1980	19	6	8	Lane width × 10	Break	None	N/A	96
I-90	MP 395.5–412	1985	24	1	8	Lane width × no min.	Break	None	N/A	96

removal with lightweight chipping hammers (30-lb maximum size).

The patching materials included "Set 45" on one project in Michigan and high-aluminum cement on one project in California. The remaining projects were patched with PCC, using either Type I or Type III cement. In some of the projects, as much as 2 percent calcium chloride (by weight of cement) was used as an accelerator.

The cement content for the PCC patches ranged from 6.5 to 8.5 bags. Air contents were between 5.5 and 7 percent. A bonding agent was used on all the PCC patches. The most commonly used material was a sand-cement slurry applied to either a dry or damp surface. On several projects, epoxy resin was applied to a dry surface.

The projects reviewed, specifications, and comments on performance are outlined in Table 4. The performance of the partial-depth patching projects is summarized as follows:

Failure Rate (Percent of Patches)	*Number of Projects*
<5	8
15	1
75	2
>90	2

TABLE 4 SUMMARY OF PARTIAL DEPTH PATCHING PROJECTS

Project	Depth of Saw Cut	PCC Removal	Preparation	Patch Material	Bond Agent	Surface Condition	Air Temperature (°F)	Joint Form	Remarks
California									
I-80, MP 4–11.4	1.5 in.	Air hammer	Sand blast	High-aluminum cement	Epoxy	Dry	>45	Styrofoam or cardboard	Less than 5% failure
Georgia									
I-475, MP 0–15	Depth of failure, 2 in. beyond spall	Air hammer	Sand blast	8 bags/Type III/3000 psi/24 hr	Unknown	Unknown		None; saw within 24 hr	Most of the original partial-depth patches have been replaced (>90% failure)
South Carolina									
I-20, MP 0–6.0	2 in. depth, 6 in. beyond spalls	Air hammer; min. length 12 in., min. width 12 in., max. depth 5 in.	Sand blast, air	6.5 bags/Type I/2000 psi/min, to open to traffic	Epoxy resin	Dry		Insert 5 in. deep, 6 in. beyond each side patch	Patches looked good; 1 failure in a 0.5 mi sample (<5% failure)
Virginia									
I-81, MP 147.22–161.77	3 in.	Air hammer, 15-lb max.; min. length 12 in., min. width 12 in., min. depth 3 in., max. depth 4 in.	Water and air blast	8.5 bags/Type III/3000 psi/24 hr	Cement slurry	Damp		Bituminous expansion board	Partial-depth patches were performing well (<5% failure)
Minnesota									
I-694, MP 37–MP 46	1 in.	Air hammer, 30-lb max.; min. depth 1 in., max. depth 5 in.	Sand blast and air	8.5 bags/Type I/5600 psi/24 hr/5.5% air	Equal parts sand and cement; water to produce a stiff slurry	Dry		20 mil. plastic	About 15% have failed; common distress was noted as spalling at edges
I-94, MP 81–MP 103	1 in.	Air hammer, 30-lb max; min. depth 1 in., max. depth 5 in.	Sand blast and air	8.5 bags/Type I/5600 psi/24 hr/5.5% air	Equal parts cement; water to produce stiff slurry	Dry		Compressible materials	Less than 5% showed any distress; none observed had failed completely
Wisconsin									
WI-29, Chippewa Falls–Thorp	2 in.	Air hammer; min. depth 2 in., max. not spec.	Brooming and water pressure	Portland cement concrete Type I	Acryl 60	Dry		Premolded filler strip or sawing	About 75% of patches have failed
U.S.H. 61 Fennimore to Boscobel Rd.	2.5 in.	Air hammer; min. depth 2.5 in., max. depth bottom of slab	Water blasting	7 bags/Type IA	Acryl 60	Dry		None; tooled surface	Most were loose (>90% have failed)
Michigan									
MI-47, Saginaw Co. N58 to US-10	1.75 in.	Air hammer, 15-lb spec. (30-lb actual for some)	Compressed air	Set 45	None	Damp		Polyurethene foam	About 2% of the patches have failed
South Dakota									
I-90 MP265–292.22	1 in.	Light jackhammer	Sand blast	7 bags/Type III		Dry		Joints formed to	0% failure

TABLE 4 *continued*

Project	Depth of Saw Cut	PCC Removal	Prepara-tion	Patch Material	Bond Agent	Surface Condi-tion	Air Tempera-ture (°F)	Joint Form	Remarks
								top of dowels only	
I-29 MP 27–66	–	–	–	7 bags/Type III/ air 7 ± 2	Cement: 1 part sand, 1 part cement, ½ part water	Dry		See above	Bottom of patches were at the dowels or below (75% failure)
I-29 MP 0–15	1 in.	Air hammer, 30-lb max.	–	7 bags/Type III	Cement grout	Dry		See above	less than 5% failure
I-90 MP 395.5–412	1 in.	Air hammer, 30-lb max.	Sand blast	7 bags/Type III		Dry		See above	less than 5% failure

The only consistent difference between the projects with a low failure rate and those with a rate greater than 5 percent was the use of compressible material in the joints. One of the projects with a 75 percent failure rate required a compressible material in the joints, but the depth of many of the patches was reported to be below the depth of the dowel bars. The specifications on the project required the compressible material to be placed to the top of the dowels. A bond breaker was to be used below the dowels.

Problems were observed on several projects where partial-depth patches extended into the dowel bars. It is very difficult to place the compressible material in the joint adjacent to the dowels. Also, the dowel-to-patch contact may result in excessive stresses in the patch and at the interface of the patch and existing concrete. These stresses develop during joint movement or during curling and warping of the slab.

The following findings were made on partial-depth patching:

- A compressible material must be placed in all working joints and cracks within or adjacent to the patch. The compressible material should extend 1 in. below and 3 in. laterally beyond patch boundaries.
- Partial-depth patches should be limited to the top third of the slab and should not extend to a depth that allows the dowel bars to bear directly on the patching material.
- Standard and high–early strength PCC mixes provided satisfactory long-term performance (as long as 6 yr observed).

GRINDING

Of the projects reviewed, 13 included diamond grinding. Of these projects, 11 were on plain undowelled pavements. Grinding was used to improve poor ride quality caused by faulting.

Before and after data on ride or joint faulting were limited. On the basis of the data available and comments by personnel familiar with the projects, grinding appears to provide a significant long-term improvement in ride quality. Continuous grinding of the entire lane achieved uniform ride, friction, and appearance. It was noted that grinding in the either direction—with or against traffic flow—met ride specifications. Several states prefer to grind in the direction of traffic as a safety precaution.

Pavement texture was also discussed. Three of the six states that used grinding require the contractor to adjust the blade spacing to achieve a specified texture. Wisconsin specifies that 95 percent of any 3 × 100–ft section that is ground must meet the texture (depth and spacing) requirements.

A ride or profile equal to or better than new concrete pavement can be obtained through grinding. It appears that specifications for a grinding project could reasonably include profile requirements at least as stringent as those for new PCC pavements. Data on the projects with grinding are summarized in Table 5. Performance to date indicates that 5 to 10 yr of service life can be expected before faulting returns to the condition that existed before grinding. However, grinding is only appropriate if the project meets criteria for CPR, as previously outlined.

On projects where friction data were available, grinding did not provide a long-term increase in pavement friction. On one project in California, the pavement 3 years before grinding had an average skid number at 40 mph (SN 40) of 38, as compared with an average of 35 a year after grinding. Friction data for several projects in Georgia indicated that there is a significant increase in friction number immediately after grinding; however, the friction numbers returned to their pregrinding levels within ~2 yr. Proper blade spacing appears to be a critical factor in maintaining long-term improvements in pavement friction after grinding, particularly if soft coarse aggregates were used in the concrete.

The following findings were made on grinding:

- A significant long-term improvement in ride quality can be obtained on CPR projects by grinding. Performance to date indicates a service life of 5 to 10 yr can be expected before faulting returns to the pregrinding condition.
- Ride specifications were met when grinding was performed in either direction (with respect to the flow of traffic).

JOINT RESEALING

Of the CPR projects examined, 14 included joint resealing. It should be noted that the review concentrated primarily on

TABLE 5 SUMMARY OF GRINDING PROJECTS

	Extent	Friction Before	Friction After	Ride Before	Ride After	Specifications Profile	Specifications Equipment	Comments
California								
I-5, MP 23–27.1	All lanes; entire project	3 yr, 38	1 yr, 35	3 yr: PCA-29, PSI = 2.6	1 yr: PCA-12, PSI = 3.8	California Profileograph, 15 in./mi	None	
Georgia								
I-75, MP 227–232	Outer lane (by maint.)	2 yr, 36	1 yr, 41; 2 yr, 38; 3 yr, 33	1 yr: 10[a]	4 yr, 4[a]	PCA roughness 300 max.; if >300, must meet Rainhart of <7 in./mile		
I-475, MP 0–15	All lanes for entire project by state forces	3 yr, 44; 1 yr, 40	2 yr, 45; 4 yr, 44	0 years[a] (just before), 22	5 yr, 13[a]			Work performed by maintenance
I-75, MP 64–72	Outside lane					PCA <300; Areas not meeting PCA to meet Rainhart 7 in./mi. Diff. at joints shall not exceed 1/6 in.; Cross slope, 1/4 in. in 12′	Self propelled machine; peaks 1/32 higher than bottom 60 grooves/ft 60 grooves/ft	
I-75, MP 22–59	Outside lane				good	As for MP 64–72	As for MP 64–72	
South Carolina								
I-85, MP 21–34	All lanes		N/A		N/A	1/8 in. in 10 ft	Machines using diamond blades	Average faulting 1/16–1/8 in. with areas of 1/4 in.
I-20, MP 0–6.0	All lanes		N/A		N/A	Mayes Meter, <55 in./mi	As for I-20	Diamond grinding saw blade spacing appeared to have been wide, resulting in high fines
Virginia								
I-81, MP 147–160	All lanes	35	N/A			1/8 in. in 10 ft	Power driver, self-propelled; Min wt. 15,000 lbs., Min. HP 200	
Minnesota								
US-10, MP 204–211	All lanes					3/16 in. in 10 ft, parallel to centerline	–	Grooves between 0.097 and 0.128 in. wide, spaced 0.062–0.115 in. apart; Depth = 0.31–0.115 ft.
US-71, MP 124–129	All lanes					1/8 in. in 3 ft at right angle to centerline; 1/16 in. at joints		As for US-10
US-61, Fennimore–Boscobel	All lanes							95 percent of any section 1/16 in. from top to bottom; 50 grooves/ft. min.
US-151, Columbus–Beaver Dam	All lanes					1/8 in. in 10 ft or 0.3 in. in 25 ft	–	As for US-61
I-90, MP 138–142	All lanes					Transverse 1/8 in. in 3	–	As for US-61

NOTE: N/A = not available.
[a] Faulting indices.

resealing of the transverse joints. As such, the following observations and subsequent findings are applicable to transverse joints, unless indicated otherwise.

The projects reviewed are summarized in Table 6. In 11 of the projects, a single type of sealant material was used exclusively. The sealant used was silicone in six projects, hot-poured sealant in four, and neoprene in one. The remaining three projects used two sealant materials.

On the projects that were inspected, the hot-poured joint seals experienced adhesion failures, generally within 2 years after construction. Preformed neoprene seals appear to be better suited to new construction. Because minor joint spalling is generally present in rehabilitation projects, the full bearing required for preformed seals to remained compressed and in place may not be achieved.

A majority of projects that had joints resealed with silicone material are providing good performance. Periodic maintenance is required, however, to cut out and repair isolated failures. In those cases for which field personnel had mentioned that the manufacturer's guidance for installation was not followed explicitly, significant failures (as much as 75 percent) were observed. Procedures such as refacing the joint to allow for the proper shape of the joint sealant material, providing a clean and dry bonding surface, and inspecting the application and tooling of this sealant closely are critical to performance.

Several projects included sealing of the longitudinal PCC pavement/asphalt concrete (AC) shoulder joint with hot-poured sealants. This material appears to be effective for about 2 yr before maintenance is required.

The following findings were made on joint resealing:

- Preformed neoprene joint seals are generally not suitable for rehabilitation projects because even a small amount of spalling in the existing joint can result in failure of the seal.
- The hot-poured sealants were observed to experience significant adhesion failure, generally within 2 yr.
- Silicone, when properly installed, provided good performance. In all cases, however, maintenance was required after 1 to 2 yr to correct construction deficiencies.
- Hot-poured sealants used in the longitudinal PCC pavement/AC shoulder joint requires maintenance on a ~2-yr cycle.

SLAB STABILIZATION (SUBSEALING)

Subsealing as a rehabilitation technique was reviewed in eight projects, located in four states. Criteria for subsealing ranged from blanket subsealing of all faulted slabs to subsealing only those slabs that exceeded a minimum specified deflection under loading. The projects reviewed are summarized in Table 7.

It was difficult to evaluate the effectiveness of the technique visually, but an attempt was made to determine whether the subsealing appeared to have any detrimental effects. Slabs were closely observed for cracks that passed through or radiated from the subsealing holes. No distress of this type was observed. One project had a high level of slab breakup after a CPR project that included subsealing. A review of the project records and discussion with project personnel, however, revealed that there was a high rate of deterioration before the CPR project.

The review of subsealing indicated that although the benefits of subsealing could not be readily observed, there appeared to be no adverse effect to pavement performance on the projects inspected. Further research in this area appears warranted.

COST DATA

The available cost data for the rehabilitation techniques used on each project are listed in Table 8. The planned and final quantities are also presented. The data are presented by project to give the reader a "feel" for the total scope of each project.

SUMMARY

In all, 26 completed CPR projects in 8 states were reviewed. The reviewers found that proper preliminary engineering and timing of the individual techniques are critical to project performance. It was found that if CPR projects are properly designed and constructed, they will generally reduce pavement deterioration, thereby prolonging pavement life. Properly designed and constructed CPR techniques can be expected to provide 6 to 10 yr of service life, but continued maintenance throughout the project design life will be required. On most projects, a follow-up maintenance effort was needed within 1 yr of project completion.

Like that of any other pavement rehabilitation strategy, the overall effectiveness of CPR techniques is highly dependent on design adequacy, construction quality, and maintenance practices. The available preliminary engineering data developed for each CPR project were reviewed. On many projects, very little detailed information on the causes and extent of distress had been assembled. Some projects experienced large overruns in quantities, and at least one project was terminated because of cost overruns before all the CPR work could be completed. The lack of timely, detailed condition data probably contributed to the major overruns.

The individual CPR techniques that were reviewed included subsealing, full-depth patching, partial-depth patching, grinding, and joint resealing. Very few of the projects reviewed included pressure relief joints, subdrains, retrofit load transfer devices, and shoulder restoration techniques. It was concluded that proper evaluation of subdrainage is not possible without performing in-depth testing. A separate project has been initiated to evaluate subsurface drainage on a variety of in-service installations.

On the basis of the review of these 26 projects, the following conclusions were drawn:

- When 5 percent or more of the right lane required full-depth replacement, the project was probably not a suitable CPR candidate.
- When 2 percent or less of the right lane required full-depth replacement, and other forms of pavement distress were within reasonable limits, the project was a suitable CPR candidate.
- Projects that required between 2 and 5 percent full-depth replacement of the right lane were marginal CPR candidates. In these cases, pavement deterioration should be more closely monitored and evaluated. This analysis will assist in determining whether to undertake CPR.

TABLE 6 SUMMARY OF JOINT RESEALING PROJECTS

Route	Project Limits	Year Rehabilitated	Pavement Age (yr)	Type of Joint	Sealant Material	Sealant Reservoir Shape: Width (in.)	Sealant Reservoir Shape: Depth (in.)	Sealant Reservoir Shape: Top Below Surface	Backer Rod	Comments
California										
I-5	Shasta Co. MP 3.8–14.0	1983	17	Transverse	Rubber-asphalt	½	1¼	N/A	Not required	
				Longitudinal	Rubber-asphalt	½	1¼	N/A	Not required	
Georgia										
I-75	MP 226–232	1981	12	Transverse	Low-mod. silicone (Dow)	⅜–⅝	1½	½	Polyethylene	Minor failures at 25–50% of joints
				Longitudinal	Low-mod. silicone (Dow)	⅜–⅝	1½	½	Polyethylene	Minor failures at 25–50% of joints
I-475	MP 0–15	1980	13	Transverse	Low-mod. silicone (Dow)	⅜–⅝	1½	½	Polyethylene	Joints regularly maintained; most in good condition
				Longitudinal	Low-mod. silicone (Dow)	⅜–⅝	1½	½	Polyethylene	Joints regularly maintained; most in good condition
I-75	MP 64–72	1978	17							Construction data not available
I-75	MP 22–59	1978	17							Construction data not available
South Carolina										
I-85	MP 21–34	1979	15	Transverse	Hot-poured ASTM D3405	⅜–⅓	1¼–1½	N/A	Upholstery chord	
				Long. (ctrline)	Not sealed					
				Shoulder	Hot-poured ASTM D3405	¾	¾			Sealants failed in adhesion
I-20	MP 0–6	1984	17	Transverse	Low-mod. silicone (Dow)	–[a]	–[a]	–[a]	Polyethylene	
				Longitudinal	Low-mod. silicone (Dow)	–[a]	–[a]	–[a]	Polyethylene	
				Shoulder (Long.)	Low-mod. silicone (Dow)	¼	¼	½		
				Shoulder (Trans.)	Low-mod. silicone (Dow)	⅜–½	2½	Flush		25% of sealant failed due to construction issues
Virginia										
I-81	MP 147.2–161.8 NB	1984	19	Trans. <1–⅛ in.	Low-mod. silicone (Dow)	Varied	Varied	¼	Polyethylene	Numerous adhesion failures, possibly due to aggregate incompatibility
				Trans. >1–⅛ in.	Pref. compression seal					Seals looked to be in good conditon

				Long. <1–⅛ in.	Low-mod. silicone (Dow)	Varied	Varied	¼	Polyethylene	
				Long. >1–⅛ in.	Pref. compression seal					
I-64	MP 238.4–254	1982	19	Transverse	Hot-poured elastomeric	½	½	Flush		All failed in adhesion
				Longitudinal	Hot-poured elastomeric	½	½	Flush		All failed in adhesion
I-64	MP 278.7–283.3	1983	16	Transverse	Rubber-asphalt	¾	¾	Flush		Adhesion failures were noted
				Longitudinal	Rubber-asphalt	¾	¾	Flush		Adhesion failures were noted
Minnesota										
I-694	MP 37–46	1981	20	Transverse	Rubber-asphalt	¾	¾	0–⅛		Sealants failed in adhesion
				Longitudinal	Rubber-asphalt	¾	¾	0–⅛		Sealants failed in adhesion
I-94	MP 81–103	1981	14	Transverse	Rubber-asphalt	¾	¾	0–⅛		Sealants failed in adhesion
				Longitudinal	Rubber-asphalt	¾	¾	0–⅛		Sealants failed in adhesion
Wisconsin										
WI-29	Chippewa Falls to Thorp	1983	16	Transverse	Hot-poured elastomeric	½	½	⅛–¼		All failed in adhesion
				Longitudinal	Hot-poured elastomeric	½	½	⅛–¼		All failed in adhesion
I-90	MP 138–142	1981	21	Transverse	Low mod. silicone (Dow)	⅜	½	⅛	Polyethylene	75% had failed in adhesion
				Longitudinal	Hot-poured ASTM D3405	(Exist.)	¾	¼		
Michigan										
MI-47	Saginaw Co. State Rd. to Div.	1983	16	Transverse	Neoprene	(Exist.)	(Exist.)	¼	N/A	
				Longitudinal	Sof Seal	¼–⅜	1–1¼	⅛	Polyurethane	50% had failed in adhesion
South Dakota										
I-29	MP 27–62	1972	10	Transverse	Neoprene					Construction data not available
I-29	MP 0–15	1980	19	Transverse	Low-mod. silicone (Dow)	⅞	½	¼	Polyethylene	
				Longitudinal	Not sealed					
I-90	MP 395.5–412	1985	24	Transverse	Low-mod. silicone (Dow)	⅞	½	⅛	Polyethylene	
				Longitudinal	Hot rubber-asphalt	⅞	1⅞	⅛		
I-90	MP 265–292.2	1982	17	Transverse	Low-mod. silicone (Dow)	N/A	N/A	N/A	Polyethylene	

[a] Manufacturer's recommendation.

TABLE 7 SUMMARY OF SUBSEALING PROJECTS

Project	Deflection	Grout	Hole Pattern	Pressure	Depth of Hole	Minimum Air Temperature (°F)	Holes Plugged	Lift	Comments
California									
I-5, MP 23–27.1	None available	2.5 parts pozzolan, 1 part cement, time efflux 10–16	3–5 in leave slab	None specified	15 in.	45	Wooden pegs	First movement	No deterioration that could be related to subsealing noted
I-80, MP 4.0–11.4	See remarks	As for I-5	3–4 in leave slab	None specified	15 in.	45	Wooden pegs	First movement	Deflections were taken before and after subsealing. When taking deflections, the difference between the deflection of loaded and unloaded side was measured: before 0.007 in., after 0.008 in.
I-5, MP 3.8–14	Load transfer only	3 parts pozzolan, 1 part cement, time efflux, 11–16 spec., 10–11 actual; comp. strength spec. 750 psi/7 days, actual 1430 psi/7 days	3–4 in leave slab	None specified	15 in. Nozzle not to extend below bottom of slab			First movement but not monitoried in all slabs	
Georgia									
I-75, MP 227–232	Min 0.025 in.								No deflection >0.025 in., so subsealing was deleted.
I-475, MP 0–15	Min 0.005 in.	3 parts limestone, 1 part cement, time efflux 16–22 sec	2 holes 18 in. from leave, 4 additional along outer edge		8 in. below bottom of slab	No	⅛ in.		
South Carloina									
I-85, MP 21–34	Tested under 18-kip axle; if movement visually was observed, pavement was subsealed	3 parts ag. lime, 1 part type III cement; water content to give slurry apearance of thick cream	1 hole on approach side, 4 on leave side	None specified	Bottom of slab	35 and rising, 40 and falling	Wooden pegs	When dial indicates movements, max. ⅛ in.	Slabs retested and regrouted as necessary
I-20, MP 0–6	Min 0.020 in.	3 parts ag. lime, 1 part cement; time efflux 14–22 sec	2 holes on approach, 4 on leave	None specified	8–10 in. below slabs	35 and rising	Wooden pegs	⅛ in.; any slab raised more than ⅛ in. replaced	Slabs retested, and any with movement >0.020 in. were regrouted
Virginia									
I-81, MP 147–161 NB	Not performed; all slabs in rt lane were subsealed.	3 parts pozzolan, 1 part cement; time of efflux 10–16; sec; mean compressive strength: 1 day, 300 psi; 3 days, 620 psi; 7 days, 1,000 psi	7 holes per slab	200 psi max.	Bottom of slab	35	Wooden pegs	0.125 in. per hole; many holes pumped to max.	

TABLE 8 SUMMARY OF QUANTITIES AND BID PRICES

Route	Limits	Year Rehabilitated	Technique	Units	Bid Price($)	Quantities Plan	Final	Comments
California								
I-5	Shasta Co., MP 3.8–14.0	1983	Slab replacment	yd²	36.27	8,970	11,307	No load transfer
			Corner patch	yd²	214.33	45	45	
			Subseal hole	each	4.50	21,600	32,521	
			Grout	cwt.	15.00	11,000	19,562	
I-80	Placer Co., MP 4–11.4	1984	Full-depth patches	yd²	63.95	2,340	2,588	No load transfer
			Partial-depth patches	yd²	250.00	210	191	
			Subseal hole	each	4.50	14,200	13,181	
			Grout	ton	320.00	230	222	
I-5	Yolo Co., MP 23–27.1	1984	Full-depth patches	yd²	73.33	2,073	2,706	No load transfer
			Subseal hole	each	5.50	6,318	5,813	
			Grout	ton	1,600.00	158	52	
			Grinding	yd²	2.99	95,000	N/A	
Georgia								
I-75	MP 227–232	1981	Subseal hole	each	3.00	2,500	0	
			Grout	bags cement	27.50	600	0	
			Subseal pre. test	mi	1,200.00	12	12	
			Subseal stab. test	joint	600.00	800	0	
			Grinding	yd²	4.04	80,800	80,761	Includes traffic control
			Joint seal	linear ft	0.64	167,000	133,826	Low-mod silicone
			Sawing joints	linear ft	0.50	167,000	133,826	
I-475	MP 0–15	1980	Slab replacement	yd³	90.00	240	457	Dowelled load transfer
			Slab removal	yd²	70.00	600	1,259	
			Partial-depth patches	ft²	19.50	4,000	7,869	
			Subseal hole	each	4.42	5,300	4,678	
			Grout	bags cement	19.50	1,100	494	
			Subseal pre. test	mi	1,050.00	28	28	
			Subseal stab. test	joint	556.00	890	820	
			Grinding	yd²				Done by maintenance forces
			Saw and reseal	linear ft	1.61	92,300	80,742	Existing joints were uni-tube; low-mod silicone
			Saw and reseal	linear ft	1.48	154,200	154,309	Other joints and cracks; low-mod silicone
I-75	MP 64–72	1978	Grinding	yd²	3.49	N/A	126,900	
I-75	MP 22–59	1978	Grinding	yd²	3.07	N/A	232,600	
South Carolina								
I-85	MP 21–34	1979	Full-depth patches	yd²	N/A	3,800	N/A	No load transfer
			Subseal hole	each	N/A	2,375	N/A	
			Grout	bags cement	N/A	1,068	N/A	
			Grinding	yd²	N/A	361,891	N/A	Continuous grinding
I-20	MP 0–6	1984	Full-depth patches	yd²	110.80	750	2,155	Dowelled load transfer
			Partial-depth patches	ft²	24.00	1,000	9,555	
			Subseal hole	each	4.00	12,240	12,459	
			Grout	bags cement	22.00	4.080	1,472	
			Grinding	yd²	2.48	217,621	183,551	Continuous grinding
			Joint sealing	linear ft	1.53	170,311	171,136	Existing joints were uni-tube; low-mod silicone
			PCC shoulder 4 ft	yd²	14.75	36,448	34,431	Full-depth retrofit shoulders
			PCC shoulder 6 ft	yd²	14.05	8,548	9,142	Full-depth retrofit shoulders
			PCC shoulder 10 ft	yd²	13.55	70,757	61,984	Full-depth retrofit shoulders
Virginia								
I-81	MP 147.2–161.8 NB	1984	Full-depth slab rep.	yd²	100.00	1,884	3,502	Final quantities represent only half of entire project; other half was readvertised. Inverted tee if patch 2–42 ft, dowelled if longer
			Partial-depth patches	yd²	80.00	0	87	
			Subseal hole	each	2.00	9,885	10,956	
			Grout (cement)	ft³	25.00	2,275	10,809	
			Grinding	yd²	2.00	202,611	108,851	
			Joint sealing	linear ft	1.30	104,985	61,988	Silicone

TABLE 8 *continued*

Route	Limits	Year Rehabilitated	Technique	Units	Bid Price($)	Quantities Plan	Quantities Final	Comments
			Joint sealing (2 in. pref.)	linear ft	12.00	7,001	888	Neoprene compression seal
			Joint sealing (3 in. pref.)	linear ft	20.00	1,046	871	Neoprene compression seal
			Joint sealing (3.5 in. pref.)	linear ft	40.00	38	234	Neoprene compression seal
			Edge drains	linear ft	10.00	16,685	8,835	
I-64	MP 238.4–254	1982	Full-depth patches	yd^2	109.00	2,300	2,721	Final quantities represent only half of entire project; project was terminated. Inverted tee load transfer
			Joint sealing	linear ft	0.55	174,010	79,644	Hot-poured elastomeric
I-64	MP 278.7–283.3	1983	Full-depth patches	yd^2	89.00	9,323	8,221	No load transfer
			Joint sealing	linear ft	0.65	96,222	150,516	Rubber-asphalt joint sealant
			Pressure relief joint	linear ft	25.00	2,300	2,044	
Minnesota								
I-694	MP 37–46	1981	Full-depth patches	N/A				Full- and partial-depth patch quantities were intermixed; partial depth patch boundaries are tapered; dowelled load transfer
			Partial-depth patches	N/A				
US-10	MP 204–211.6	1981	Grinding	yd^2	2.88	59,269	N/A	
US-71	MP 124.9–192.2	1983	Grinding	N/A				Quantities and costs not available
I-94	MP 81–103	1981	Partial-depth patches	ft^3	N/A	580	4,421	Boundaries are tapered
			Joint sealing	linear ft	N/A	271,787	278,508	Hot-poured rubber
			Crack sealing	linear ft	N/A	6,275	2,864	
Wisconsin								
WI-29	Chippewa Falls to Thorp	1983	Full-depth patch 6 × 12 ft	yd^2	47.00	14,136	16,448	Dowelled load transfer
			Full-depth patch 8 × 12 ft	yd^2	42.84	960	1,397	Dowelled load transfer
			Full-depth patch 10 × 12 ft	yd^2	39.37	440	733	Dowelled load transfer
			Full-depth patch 12 × 12 ft	yd^2	37.81	176	416	Dowelled load transfer
			Full-depth patch 16 × 12 ft	yd^2	35.64	427	1,024	Dowelled load transfer
			Full-depth patch 20 × 12 ft	yd^2	34.50	720	347	Dowelled load transfer
			Partial-depth patches	ft^2	9.00	2,000	4,154	
			Longitudinal joint sealing	linear ft	0.85	167,000	152,898	Hot-poured elastic
			Transverse joint sealing	linear ft	0.90	40,000	37,807	Hot-poured elastic
US-61	Fennimore to Boscobel Rd.	1982	Full-depth patches	yd^2	30.60	7,981	7,197	Inverted tee (6 × 6 in.) load transfer
			Partial-depth patch	ft^2	16.00	1,000	1,392	
			Grinding	yd^2	2.50	77,500	77,460	
US-151	Columbus–Beaver Dam Rd.	1982	Full-depth patches	yd^2	68.00	700	1,172	Inverted tee (6 × 6 in.) load transfer
			Grinding	yd^2	2.55	97,350	89,759	
I-90	MP 138–142	1981	Full-depth full-lane patch	yd^2	40.00	4,074	7,866	Dowelled and no load transfer methods used
			Full-depth corner patch	yd^2	42.00	475	800	No load transfer
			Full-depth inverted tee patch	yd^2	50.00	210	416	
			Grinding	yd^2	2.92	41,710	41,674	
			Longitudinal joint sealing	linear ft	0.70	28,785	30,156	Hot-poured elastic meeting ASTM D3405
			Transverse joint sealing	linear ft	1.25	48,722	64,941	Low-mod. silicone (Dow 888)
Michigan								
I-75	MP 64–80	1983	Full-depth patches	yd^2	N/A	23,532	26,481	Dowelled load transfer
			Pressure relief joints	each	N/A	0	864	
MI-47	Saginaw Co. State Rd. to Div.	1983	Joint spall repair	linear ft	16.00	7,750	10,918	
			Patching material	ft^3	42.00	930	1,032	
			Sealing transverse cracks	linear ft	1.75	10,960	16,514	Sealtight Sof-Seal (hot poured)
			Replace neoprene seals	linear ft	3.10	N/A	28,940	
			Exp. joint removal and reseal	linear ft	4.25	N/A	7,512	Sealtight Sof-Seal (hot poured)

TABLE 8 *continued*

Route	Limits	Year Rehabilitated	Technique	Units	Bid Price($)	Quantities Plan	Final	Comments
South Dakota								
I-29	MP 27–62	1972	Partial-depth patch (Type B)	ft^2	17.50	364	568	
			Partial-depth spall repair	ft^2	5.79	24,337	105,336	
			Joint sealing	linear ft	1.01	117,481	118,223	Neoprene
I-29	MP 0–15	1980	Full-depth repair	yd^2	60.00	N/A	800	No load transfer
			Partial-depth patch (Type B)	ft^2	40.00	255	255	
			Partial-depth patches	ft^2	6.40	127,653	109,193	
			Joint sealing	linear ft	2.00	65,424	67,765	Silicone (Dow 888)
			Pressure relief joints	each	800.00	107	106	
I-90	MP 395.5–412	1969	Partial-depth patch (Type A)	ft^2	N/A	8,268	21,381	Type A patch >0.4 ft wide
			Partial-depth patch (Type B)	ft^2	N/A	690	1,890	Type B patch ≤0.4 ft wide
			Remove unitube	linear ft	0.80	62,425	60,304	
			Install neoprene	linear ft	1.10	62,425	60,304	No pavement/shoulder joint sealing setup in contract
			Seal w/hot rubber-asphalt	linear ft	0.30	11,016	8,622	
		1985	Full-depth patches	yd^2	60.00	636	1,581	Dowelled load transfer
			Partial-depth patch (Type A)	ft^2	6.00	11,511	89,893	
			Joint sealing (silicone)	linear ft	1.68	77,712	74,981	No pavement/shoulder joint sealing setup in contract
			Pressure relief joints	each	400.00	32	32	
I-90	MP 265–292.2	1982	Partial-depth patch (Type A)	ft^2	6.87	36,806	32,547	Type A patch >0.4 ft wide
			Partial-depth patch (Type B)	ft^2	N/A	72	181	Type B patch ≤0.4 ft wide
			Joint sealing	linear ft	1.59	6,094	6,094	Silicone sealant
			Pressure reflief joints	each	695.00	45	45	

- The minimum length for a full-depth patch in the longitudinal direction should be 6 ft to prevent longitudinal cracking.
- Full-depth patches with dowelled joints provided satisfactory long-term performance. However, patches placed with the inverted tee method or those that depended on aggregate interlock for load transfer did not provide satisfactory performance.
- High cement factors (seven bags or more), Type III cement, and as much as 2 percent calcium chloride (by weight of cement) were used to accelerate the concrete mix strength in the full-depth patching projects. These projects were opened to traffic in as little as 4 hr and were performing satisfactorily after 8 yr.
- Partial-depth patching was performed on 13 CPR projects. On eight of these projects, less than 5 percent of the total number of patches had failed.
- Field inspections of completed patches and discussions with state engineers demonstrated that a compressible material must be placed in all working joints and cracks within and adjacent to the patch to obtain satisfactory performance from partial-depth patches.
- Field observations also confirmed that partial-depth patches should be limited to the top third of the slab and should not extend to a depth that allows the dowel bars to bear directly on the patching material.
- Satisfactory long-term performance (as long as 6 yr observed) of partial-depth patches was achieved with standard and high–early strength PCC mixes.
- Grinding resulted in a ride or profile equal to or better than that of a new concrete pavement. Specifications for a grinding project should include profile requirements at least as stringent as those for new PCC pavements.
- Of the reviewed CPR projects, 17 included joint resealing. Hot-poured transverse joint sealants were used on seven projects. Those sealants experienced adhesion failure, which generally occurred within 2 yr after construction.
- Silicone sealants provided generally good performance. Minor adhesion failures were noted in ~25 percent of the joints inspected. Many of these failures appeared to be due to improper cleaning of the joints before resealing.
- The benefits of subsealing could not be readily determined. Field reviews on eight projects in four states indicated there was no apparent visual difference in pavement performance between states that had subsealed as part of CPR and those that did not. Where recommended procedures were followed, subsealing did not appear to have any adverse effects on pavement performance. Further research is needed to refine the correct procedures and to define the benefits of subsealing.

The contents and opinions presented in this paper reflect the views of the authors, who are responsible for the facts presented and the accuracy of the data. The contents do not necessarily reflect the views of the FHWA.

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