man and Jim Daves of the Demonstration Projects Division, Federal Highway Administration, provided technical coordination. Their cooperation and suggestions are gratefully acknowledged. Also, the cooperation and the assistance provided by the personnel from FHWA's district office in Boise, Idaho, and the Idaho Department of Transportation are gratefully acknowledged.

The opinions and findings expressed or implied in this paper are those of the authors, and are not necessarily those of the Federal Highway Administration.

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

# Montana's Experience with and Strategies for Concrete Pavement Rehabilitation

JOHN C. ULBERG

**The first concrete pavement rehabilitation project in Montana presented a unique challenge for all those involved. Outlined in this paper are the background, planning, and design processes involved in the project and the recommendations made. Although concrete pavement rehabilitation may not be the salvation for all concrete pavement, it does provide solutions and repair strategies for some, when appropriate procedures are followed. Even though concrete pavement rehabilitation was not ultimately selected as the treatment of choice for this project, the process of analyzing the project and sustaining the final decision was valuable and will provide a useful basis for future concrete pavement evaluations. Future projects will be selected and designed based on cost-effective analyses and proven performance of the many techniques now being used, and those yet to be discovered.**

In Montana, portions of the Interstate highway system were constructed of portland cement concrete pavement in the 1960s. Montana has 477 lane mi of concrete Interstate and 22 lane mi of concrete primary highway, which have served the state well. However, through the years this pavement has deteriorated to varying degrees owing to increased traffic loading and age, and it has become evident that work will have to be done on "the pavement that should last forever."

Location and Road Design Section, Montana Department of Highways, Helena, Mont.

In the spring of 1983, it was apparent that Montana had to begin assessing it rigid pavement needs and proceeding with rehabilitation programs. It was decided to select an Interstate project in and adjacent to Butte as a pilot project. The concrete pavement in this area appeared to be in the worst condition of all concrete pavements in the state. Based on what was learned there, other projects in the state could be developed.

On June 1, 1983, the Federal Highway Administration (FHWA) approved a preliminary engineering program to study this pavement and determine what rehabilitation work would be required to restore the pavement to a condition that would adequately serve the traveling public (see Figure 1 for location).

## DESCRIPTION OF PROJECT

The project [Project IR 15-2(49)124, Butte—West and South] begins west of Butte and extends southeasterly to 1.7 mi south of the Continental Drive Interchange. The work involved is on about 5.3 mi of I-15 and 3.1 mi of I-90 concrete pavement.

Also included are the asphalt plant mix surfacing of 2.5 mi of frontage roads and portions of Iron Street, the I-115 spur, grade separations, ramps, and miscellaneous work (see Figure 2).

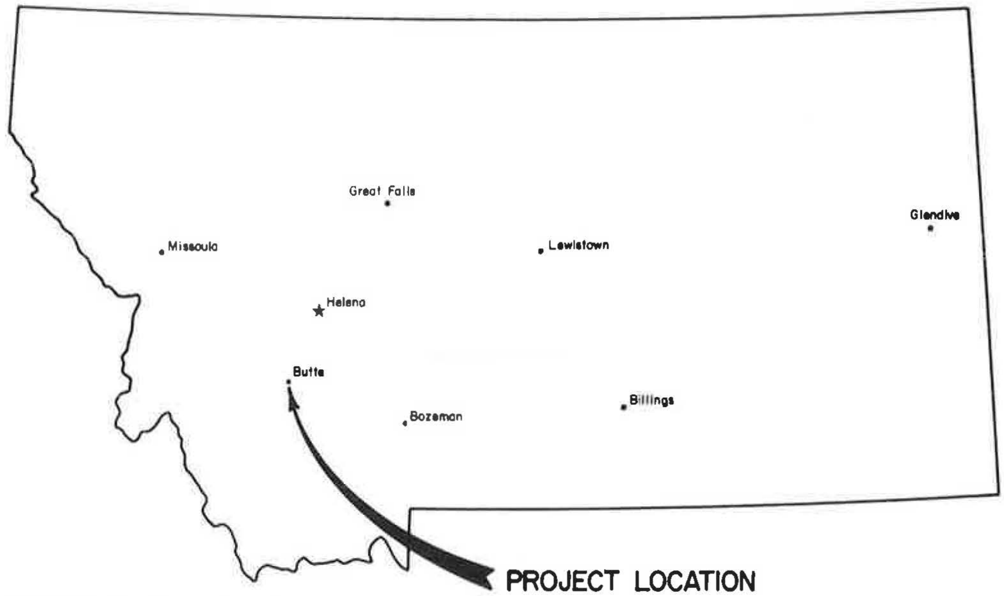



**FIGURE 1 Project location.**

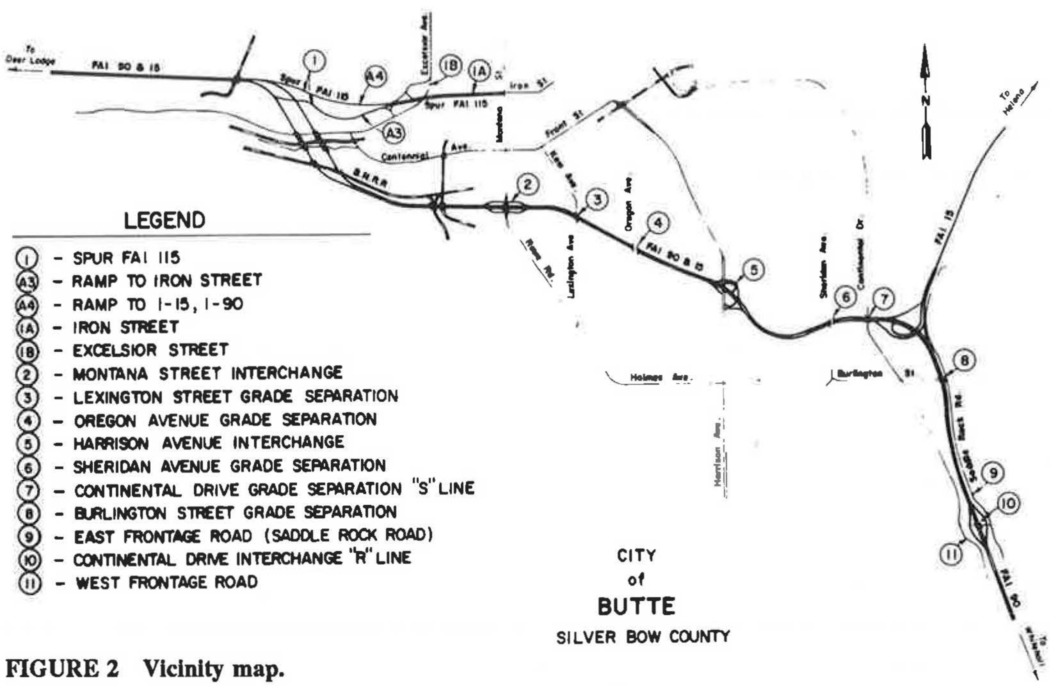



**FIGURE 2 Vicinity map.**

## OVERVIEW

The concrete pavement on this project was constructed in the early 1960s. By 1983, increased traffic loading, the general level of distress, and low pavement serviceability indices (PSIs) indicated the need to rehabilitate the pavement.

The existing plain, jointed portland cement concrete pavement (PCCP) had 15-ft joint spacing. Portions were constructed on cement-treated base (CTB) and portions on a gravel base. Load transfer was accomplished through aggregate interlock at the sawed joints.

The typical section consisted of twin 38-ft-wide roadways, each with two 12-ft-wide concrete driving lanes, one 10-ft-wide asphalt shoulder, and one 4-ft-wide asphalt shoulder (see Figure 3).

The traffic data were as follows:

West Butte Interchange to East Butte Interchange

| | | |
|---|---|---|
| ADT 1983 | = | 6,270 |
| ADT 2003 | = | 9,300 |
| DHV | = | 1,040 |
| D | = | 55–45 |
| T | = | 17 percent |
| V | = | 55 mph |
| All trucks | = | 40 percent |

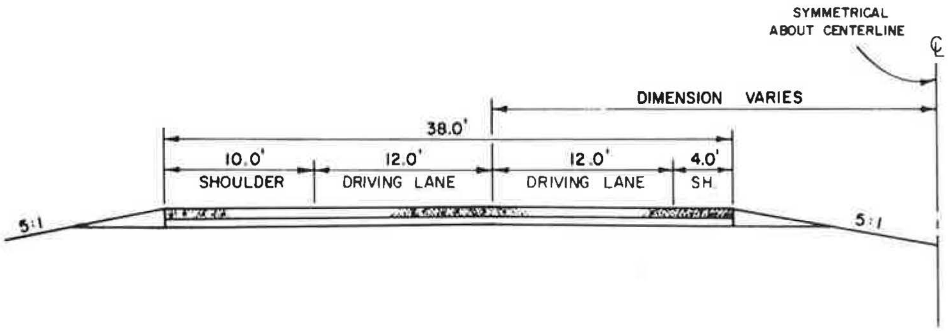



**FIGURE 3 Typical section.**

East Butte Interchange to East of Continental Drive Interchange

| | | |
|---|---|---|
| ADT 1983 | = | 4,400 |
| ADT 2003 | = | 7,150 |
| DHV | = | 930 |
| D | = | 55–45 |
| T | = | 23 percent |
| V | = | 55 mph |
| All trucks | = | 49 percent |

NOTE: ADT = average daily traffic; DHV = design hour volume; D = directional split, typically 55 percent in one direction, 45 percent in the other; T = percent trucks that are two-axle, single tire; V = design speed; and all trucks = T plus pickups and all other two-axle, single tire trucks.

The most southerly 2.2 mi was constructed by placement of the 8-in.-thick PCC pavement over 6 in. of cement-stabilized base, which was placed directly on the subgrade. The next 2.7 mi were constructed with the 8-in.-thick PCC pavement placed over a subgrade constructed with 2 ft of borrow at the upper limits, plus 6 in. of compacted foundation course. The next project north was 0.8 mi in length. The 8-in. concrete pavement was placed over subgrade and base materials comparable to the most southerly 2.2-mi section. The three projects to this point were constructed as I-15 mileage. The last 2.6 mi of the study section were constructed as I-90 mileage. PCC pavement on this project was placed over 4.8 in. of cement-stabilized base overlying 6 in. of compacted crushed base surfacing (see Figure 4).

## PRELIMINARY WORK

Before determining how to proceed with rehabilitating the concrete using concrete pavement rehabilitation (CPR) techniques, considerable data had to be gathered and analyzed.

First, a literature search was begun. National Cooperative Highway Research Program (NCHRP), FHWA, and industry reports and handbooks were reviewed. Reports and sample sets of plans were secured from other states, and discussions were held on their experiences, both successful and unsuccessful.

Arrangements were made for in-house training for design and construction personnel, including FHWA courses, seminars, and workshops and presentations by industry representatives. Design and construction personnel attended conferences and made field trips to construction sites in other states. The Montana Department of Highways (MDOH) Pavement Management System's *Rigid Pavement Condition Inventory* was consulted (see Figure 5). The present serviceability indices ranged from 1.4 to 2.3 on the westerly 3 mi, and 2.5 to 3.2 on the remainder. Every 2 years this inventory is updated, rating surface conditions and ride quality. It is proving to be a valuable guide, indicating areas needing attention and triggering studies of these areas.

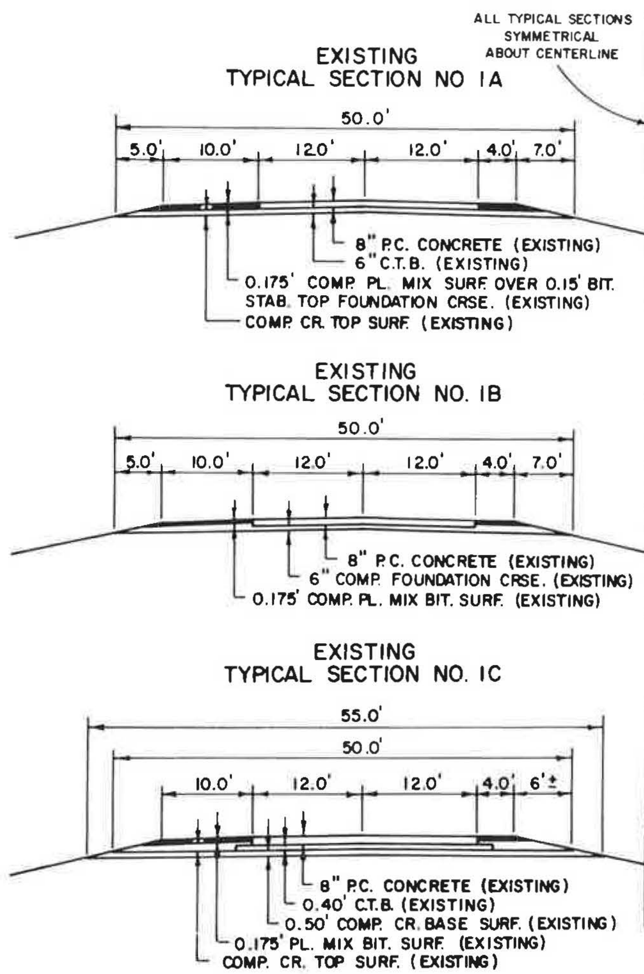



**FIGURE 4 Existing typical sections.**

PAVEMENT MANAGEMENT SYSTEM
RIGID PAVEMENT CONDITION INVENTORY
BASED ON 85/86 SURVEY

DISTRICT: 02 ROUTE: 0151 COUNTY: SB

PM 124.0 TO PM 125.0 300 FT BRIDGE, 400 FT BRIDGE, 200 FT BRIDGE

| | | | |
|---|---|---|---|
| LOG LENGTH: | 1.0 | ADT | : 8820 |
| TOTAL LANES: | 4 | % TRUCKS | : 19 |
| SECTION CREW: | 2101 | FUNCTIONAL CLASS: | INTERSTATE |
| SURVEY DATE: | 04-85 | FEDERAL AID | : INTERSTATE |
| INCHES RAIN: | | RIDE DATE | : 05-02-85 |
| SURFACE WDTH: | 76 | ROADWAY WDTH | : 76 |

| | DIR & LANE | ROADTYPE | RIDE SPEED | RIDE SCORE | D+R SUF | PSI | SLAB BREAKUP 1ST/2ND STAGE | SLAB BREAKUP 3RD STAGE | 3RD STAGE & SPALL | PATCHES AREA | PATCHES COND | FAULTING | PAVE/SHOULD JOINT SEP | PAVE/SHOULD JOINT DISPL | RT SHLD COND |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L 1 | MULTILANE DIVIDED | 50 | 153 | 20+01 | 2.1 | 11% | 3% | MOD | | | SEV | | | |
| EXCESSIVE ROUGHNESS | L 2 | | 50 | 174 | 01+00 | 1.6 | 26% | 28% | SEV | | | LGT | YES | DOWN | GOOD |
| EXCESSIVE ROUGHNESS | R 1 | | 50 | 184 | 17+00 | 1.4 | 12% | 2% | SEV | 10% | GOOD | SEV | | | |
| EXCESSIVE ROUGHNESS | R2 | | 50 | 187 | 02+00 | 1.4 | 38% | 33% | SEV | 10% | GOOD | SEV | YES | | FAIR |

PM 125.0 TO PM 126.0 0.1 BRIDGE

| | | | |
|---|---|---|---|
| LOG LENGTH: | 1.0 | ADT | : 6220 |
| TOTAL LANES: | 4 | % TRUCKS | : 19 |
| SECTION CREW: | 2101 | FUNCTIONAL CLASS: | INTERSTATE |
| SURVEY DATE: | 04-85 | FEDERAL AID | : INTERSTATE |
| INCHES RAIN: | | RIDE DATE | : 05-02-85 |
| SURFACE WDTH: | 76 | ROADWAY WDTH | : 76 |

| | DIR & LANE | ROADTYPE | RIDE SPEED | RIDE SCORE | D+R SUF | PSI | SLAB BREAKUP 1ST/2ND STAGE | SLAB BREAKUP 3RD STAGE | 3RD STAGE & SPALL | PATCHES AREA | PATCHES COND | FAULTING | PAVE/SHOULD JOINT SEP | PAVE/SHOULD JOINT DISPL | RT SHLD COND |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | L 1 | MULTILANE DIVIDED | 50 | 175 | 20+01 | 1.6 | 11% | 3% | MOD | | | SEV | | | |
| EXCESSIVE ROUGHNESS | L 2 | | 50 | 185 | 04+00 | 1.4 | 23% | 33% | SEV | | | LGT | YES | DOWN | GOOD |
| EXCESSIVE ROUGHNESS | R 1 | | 50 | 146 | 17+03 | 2.2 | 19% | 4% | MOD | 10% | FAIR | LGT | | | |
| EXCESSIVE ROUGHNESS | R2 | | 50 | 157 | 01+00 | 2.0 | 35% | 31% | SEV | 10% | FAIR | SEV | YES | | GOOD |

SOURCE: Montana Department of Highways, Rigid Pavement Condition Inventory, (Helena, Montana, October, 1984), p. 1.

**FIGURE 5 Inventory sheet.**

An on-site review of the project by state and federal personnel was conducted on November 18, 1983. In the field many distress types were evident, including corner breaks, faulting (average = $^3/_8$ in.), longitudinal and transverse cracking, slab breakup, severe spalling, pavement and shoulder joint separation and displacement, seal damage, pumping, popouts, and minor rutting. It was apparent at this time that any solution would be costly.

In addition, the following activities were conducted. As-built construction plans were studied and traffic counts were analyzed. Deflection testing was performed to determine voids. The data, secured by use of a Road Rater, proved to be inconclusive. Future void detection will be accomplished through use of a falling weight deflectometer or other device with a sufficient weight. The subgrade soils were also reviewed. Consisting mainly of weathered, silty, clayey, granite sand, the materials still had good support properties.

Core samples were taken of the pavement and subgrade. PCCP and CTB strengths were determined. The PCCP core average compressive strength was 6,898 psi, whereas the CTB average compressive strength was 4,060 psi. Aggregate characteristics were determined. The average degradation factor was 32 and the average percentage of wear was 69.25. Accident statistics were reviewed. No trends or correlations were found that related to the pavement distress. A review was also undertaken of the project's drainage. In two locations where the drainage was poor, slabs had heaved and cracked. Maintenance asphalt overlays had restored a temporarily usable surface.

Maintenance personnel were interviewed. Although detailed written documentation was lacking, testimony verified that higher maintenance costs were being experienced on the westerly portion.

As-built stationing was established in the field. This has proved to be more valuable than establishing a new baseline. Stationing was painted on the asphalt shoulders at the outside edge of the eastbound and westbound driving lanes. Two-foot-high numbers at five-station intervals were used except in the interchange areas where a two-station interval was used. Intervening stations were marked with a painted stripe. The stationing was then used throughout the design phase as a ready reference when doing field work. The numbers also show up well on the aerial photographs.

Aerial photography, 1 in. = 50 ft, was obtained. This was useful in locating most of the distress types, but a lane-pass distress survey was still needed to prepare adequate plans. The photography served well as a verification tool. Optimum conditions for disclosure of pavement cracking are in the morning hours following a rain when the cracks are still retaining moisture and the top surface of the pavement is reasonably dry.

A complete distress survey was performed that identified

- All longitudinal and transverse cracks;
- Spalls;
- Amount of faulting;

- Surface deterioraton;
- Corner breaks;
- Lane-shoulder dropoff, heaving, or separation;
- Popouts;
- Scaling, map cracking, or crazing; and
- Joint seal deterioration.

Information was entered on standard forms (see Figure 6).

Construction methods were reviewed. Rigid forming had been used on much of the westerly portion of the project, with slipforming on the rest. Where rigid forming was used, project personnel stated that the pavement was rough immediately after construction. The increased dynamic loading because of the rougher pavement would help explain the greater distress found there, including more severe faulting, slab breakup, and corner breaks.

A California profilograph was purchased and used to determine roughness of the existing pavement. This instrument is now being used throughout the state. Readings are taken after the spring thaw, in the early morning hours before the slabs lock up. The machine was run 3 ft from the outside pavement edge and 1 ft from the center joint for each 12-ft lane. This resulted in four traces for the eastbound lanes and four for the westbound, basically in the wheelpaths. Since this was the first time department personnel had used a profilograph, some difficulty was experienced in producing accurate readings. Readings varied from 26.6 in./mi to 66.45 in./mi.

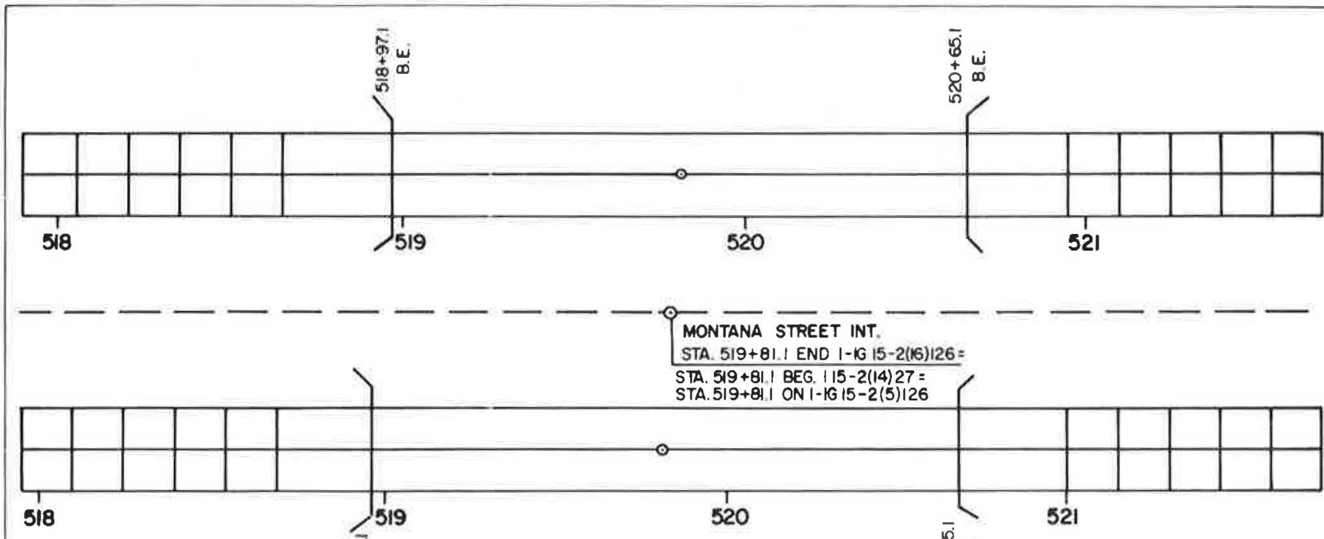
## ANALYZING THE DATA

By overlaying the available information, certain patterns began to emerge. Right-hand lane breakup was normally greater than passing-lane breakup in all cases. On steep uphill grades, however, where heavy units could not readily pass, the right-hand lanes exhibited even greater distress. On lesser and minus grades providing relatively easy passing opportunities, distress types were more evenly distributed between the right-hand lane and the passing lane. Poor drainage was directly related to slab breakup in two areas.

Alternatives were reviewed. A decision tree analysis was used to select the strategy to be used for each location of distress. This was a critical point in the process, requiring a complete review of all data and preliminary decisions.

## THE PLANS

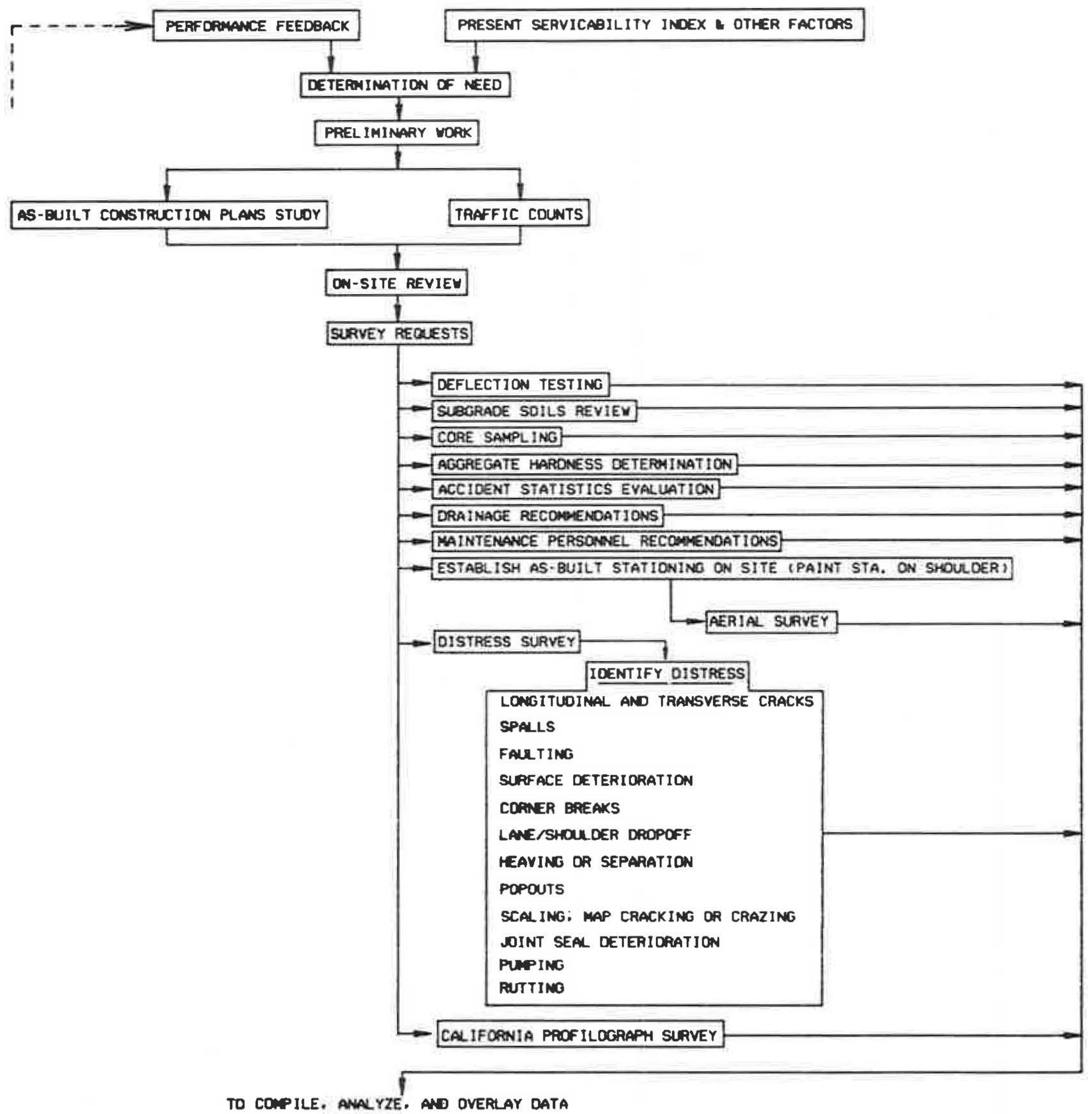
The plan format consisted of sheets showing every slab and the selected strategy for that slab indicated by a letter. Work to be performed included full- and partial-depth patching, slab jacking, undersealing, joint sealing, diamond grinding, slab removal and replacement, milling and replacing the asphalt shoulders, cut-off drains, and 2.3 mi of total replacement or recycling. Eighty-three separate special provisions were written and keyed to each selected strategy. Details, a vicinity map,




CATEGORIZATION OF JOINTED CONCRETE PAVEMENT DISTRESS

1. BLOW UP
2. CORNER BREAK
3. DEPRESSION
4. DURABILITY "D" CRACKING
5. FAULTING OF TRANS. JTS.
6. JT. LOAD TRANSFER SYSTEM ASSOC. DET.
7. JT. SEAL DAMAGE OF TRANS. JTS.
8. LANE/SHOULDER DROPOFF OR HEAVE
9. LANE/SHOULDER JT. SEPARATION
10. LONGITUDINAL CRACKS
11. LONGITUDINAL JT. FAULTING
12. PATCH DETERIORATION
13. PATCH ADJACENT SLAB DET.
14. POPOUTS
15. PUMPING & WATER BLEEDING
16. REACTIVE AGG. DUR. DIST.
17. SCALING, MAP CRACKING & CRAZING
18. SPALLING (TRANS. & LONG. JTS.)
19. SPALLING (CORNER)
20. SWELL
21. TRANS. & DIAGONAL CRACKS

**FIGURE 6** Distress survey form.



PERFORMANCE FEEDBACK
PRESENT SERVICABILITY INDEX & OTHER FACTORS
DETERMINATION OF NEED
PRELIMINARY WORK
AS-BUILT CONSTRUCTION PLANS STUDY
TRAFFIC COUNTS
ON-SITE REVIEW
SURVEY REQUESTS
DEFLECTION TESTING
SUBGRADE SOILS REVIEW
CORE SAMPLING
AGGREGATE HARDNESS DETERMINATION
ACCIDENT STATISTICS EVALUATION
DRAINAGE RECOMMENDATIONS
MAINTENANCE PERSONNEL RECOMMENDATIONS
ESTABLISH AS-BUILT STATIONING ON SITE (PAINT STA. ON SHOULDER)
AERIAL SURVEY
DISTRESS SURVEY
IDENTIFY DISTRESS
LONGITUDINAL AND TRANSVERSE CRACKS
SPALLS
FAULTING
SURFACE DETERIORATION
CORNER BREAKS
LANE/SHOULDER DROPOFF
HEAVING OR SEPARATION
POPOUTS
SCALING; MAP CRACKING OR CRAZING
JOINT SEAL DETERIORATION
PUMPING
RUTTING
CALIFORNIA PROFILOGRAPH SURVEY
TO COMPILE, ANALYZE, AND OVERLAY DATA

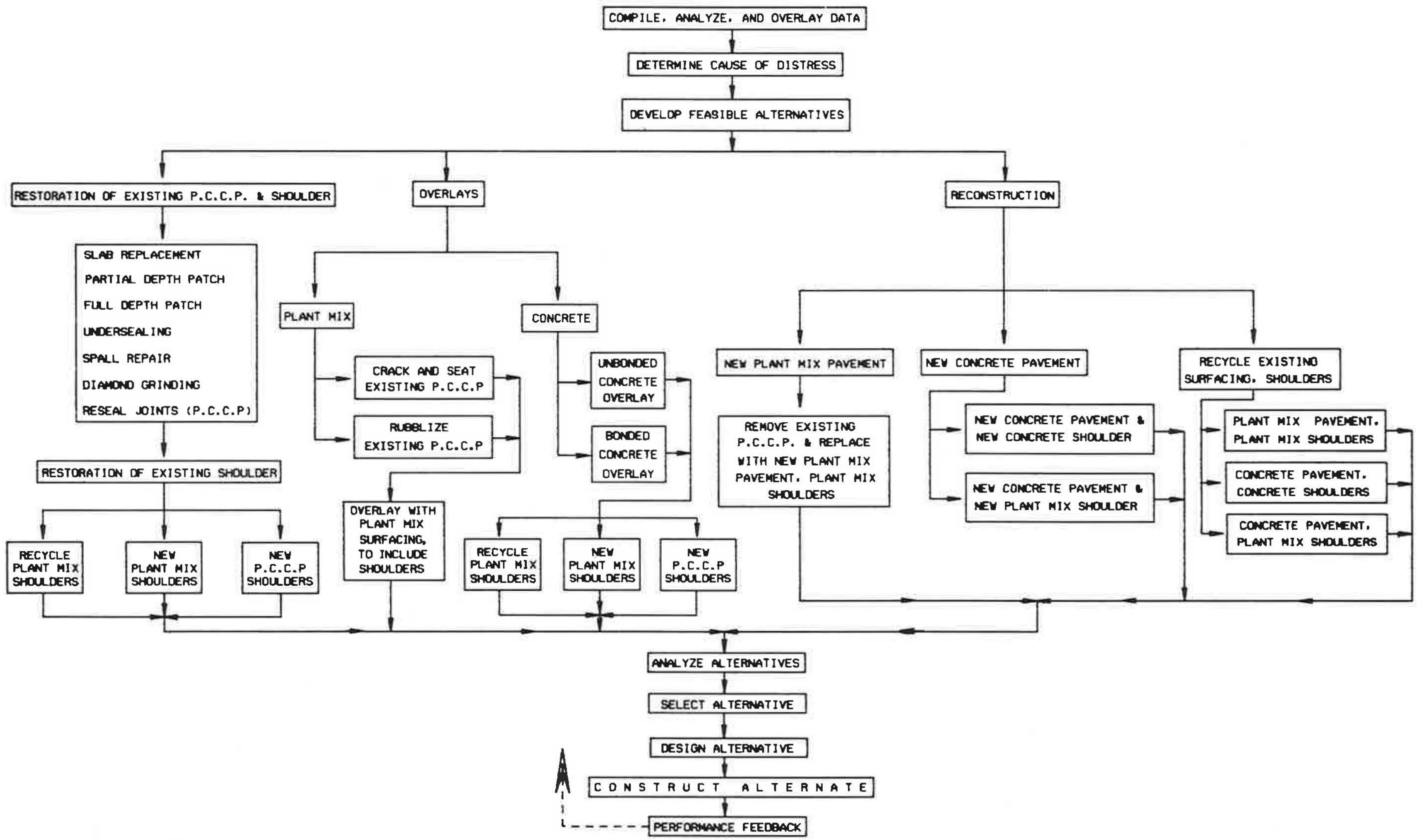



**FIGURE 7 Rehabilitation flow chart.**

summaries, and a traffic control plan to accommodate local and through traffic rounded out the package.

## THE 5 PERCENT RULE

During the final stages of design of this project, some engineers began to question whether some of the CPR techniques were appropriate. Even though performance data were generally lacking, they believed that experiences of other states indicated that anything short of total recycling of the pavement could be the wrong choice. If more than a certain percentage of slabs need to be removed and replaced, it may be more cost effective to recycle the entire set of lanes. This percentage can vary from 5 to 50 percent or more, depending upon project characteristics, traffic control problems, and cost estimates. The westerly 2.3 mi of this project had in excess of 50 percent of the slabs needing replacement, while the easterly 6.1 mi had about 10 percent. Using a 45 percent cutoff, it was decided that the westerly 2.3 mi should be recycled.

After further study of the experiences of other states, including on-site reviews, and additional consultation with the FHWA and private industry representatives, it was decided to proceed with the CPR design of the Butte—West and South project.

In a subsequent meeting with the FHWA, the value of a recycled project compared to a rehabilitated project was again discussed. The relative worth of each method was compared and a life-cycle cost analysis was performed. It was assumed that the CPR project would last 10 years and the recycled project 20 years. At this time other alternatives were also reviewed, including crack and seat, asphalt overlays, and complete reconstruction with asphalt instead of concrete. More cost analyses were performed. The results of the cost analyses plus other factors, such as the need for future overlays with plant mix sections and possible rutting from heavy traffic, made the concrete options appear more attractive.

As a result of this meeting, the decision was made to proceed as follows:

Two plan packages, Package A and Package B, were prepared. Package A provided for recycling the westerly 2.3 mi and rehabilitating the easterly 6.1 mi. The recycled portion would have concrete shoulders and be placed over a lean concrete base. The contractor would be given the option of using the old concrete and CTB as an aggregate source for lean concrete base, PCCP, or plant mix bituminous surfacing or crushed top surfacing. Also included was the plant mix overlay of frontage roads and other miscellaneous work. Package B provided for recycling the entire 8.4 mi plus the associated frontage road and miscellaneous work.

The two packages were available to bidders and were processed as follows:

1. Bidders could bid on A or B, or both A and B.
2. The low bid for A would be compared with the low bid for B.
3. If the difference between the low bid for A and the low bid for B was less than a set value per mile of rehabilitation, and the difference was largely attributable to those items of construction reflected by the different designs, the option to award the contract to the low bidder for Package B would be favored.
4. Conversely, if the difference between the low bid for A and the low bid for B was greater than the set value per mile of rehabilitation, and the difference was largely attributable to those items of construction reflected by the different designs, the option to award the contract to the low bidder for Package A would be favored.
5. The set value per mile of rehabilitation was arbitrarily determined through discussions with the FHWA. It was based on engineering and economic judgment of value and overall life and performance in a heavy truck traffic urban environment.

By following this procedure, it was believed that if the total recycle project could be obtained for the predetermined difference, it would be worth the extra expenditure. However, the cost differences were not absolute criteria, only guidelines for evaluation. The Montana Department of Highways (MDOH) could recommend one alternative over the other to the State Highway Commission for award, even if the differences were outside the guidelines.

When bids were opened March 27, 1986, the low bid for A was $7,935,436.76. The engineers' estimate was $8,695,-599.75. The low bid for B was $9,392,691.10. The engineers' estimate was $11,864,688.60. The difference was small enough so that B was the most cost effective and so the contract was awarded to Acme Concrete Co., Spokane, Washington, the low bidder for B.

The contractor elected to use some of the recycled concrete and CTB in the lean concrete base. The remainder of the project was built with virgin aggregates.

Traffic was maintained through the construction zone. The contractor was allowed to close one set of lanes at a time, maintaining two-way traffic on the remaining two lanes. At interchanges, only one-half of the interchange could be closed at a time, and then for only short periods. Median crossovers provided continuity of traffic flow.

## FUTURE PROJECTS

Future CPR projects must be timely and appropriate to be cost effective. Each project must be judged on its merits. Decisions on how to maximize the use of the existing pavement and extend its service life should be determined through a comprehensive and systematic investigation of accepted procedures for this type of work.

The important point to keep in mind is that a logical process, in accordance with good engineering practice, should be followed to determine the appropriate treatment. This process, endorsed by the FHWA and used for the project described in this paper, is to

1. Establish existing condition,
2. Identify distress,
3. Determine causes of distress,
4. Develop feasible alternatives,
5. Conduct economic and engineering analyses,
6. Select an appropriate alternative,
7. Design the alternative, and
8. Provide feedback on performance. (Letter from R. A. Barnhart, Federal Highway Administrator, to Regional Federal Highway Administrators, November 15, 1983.)

Of these steps, Number 8 could be considered as step number 1 in planning for future projects. Performance should be the ultimate guide.

Of the many possible methods that could have been used to correct the poor pavement in Butte, two were selected. The MDOH has recently reviewed the needs on all of its PCCP and decided to proceed with three more projects. Consideration is being given to crack, seat and overlay, partial CPR, and other techniques. Figure 7 is a flow chart illustrating steps to follow in undertaking pavement rehabilitation.

## RECOMMENDATIONS

The following is a list of guidelines for future undertakings:

1. Review concrete rehabilitation projects on a yearly basis for about 5 years after construction to determine if the method used was successful; problem areas should be remedied immediately.
2. Perform some degree of rehabilitation on all concrete pavement approximately every 3 to 5 years. CPR is a valid approach, but it is most effective if used early. For example, if the 8- to 12-yr life of joints cannot be realized, even through proper maintenance, smaller, less expensive rehabilitation projects would go a long way in stopping joint failure and consequent pumping, subgrade failure, broken slabs, and other expensive distresses before they start.
3. Do not "cookbook" CPR projects. Each project should be viewed separately, with careful attention given to the parameters unique to each. The poor performance of some CPR projects observed in other states appears to stem not so much from the techniques used as from the misapplication of a repair strategy.
4. Resist the tendency, however tempting, to leave out parts of the whole of CPR. The effectiveness of each component of repair often relies on others being accomplished first.
5. Approach projects through a team effort. Input from planners, designers, and construction personnel is necessary to provide a balanced project that satisfactorily meets the needs.
6. Provide up-to-date training for inspection personnel. CPR work is extremely sensitive to the quality of construction. Consider having one crew do the inspection for all rehabilitation projects.
7. Accept the fact that traffic control is a major factor to be addressed in any project. A well-thought-out plan is essential.
8. Be prepared to do some public relations work. It is not enough to be secure in the knowledge that what is being done is correct from an engineering standpoint. The public perception of what is being done must also be dealt with and explanations of the work should be available to the public, legislators, and others.
9. Continue to maintain contact with the FHWA, other states, research personnel, and the industry. This will result in an exchange of information vital to keeping up with the art of CPR.

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

# Field Performance of Bonded Concrete Overlays

GERALD F. VOIGT, MICHAEL I. DARTER, AND SAMUEL H. CARPENTER

**Bonded concrete overlays provide two improvements to an existing pavement: increased structural capacity and a new riding surface. The importance of these benefits and improved construction technology have encouraged several states to construct bonded concrete overlays over the past several years to evaluate this type of rehabilitation. A fair amount of performance data have accumulated so that an initial evaluation of this rehabilitation technique can be conducted. The University of Illinois is currently conducting a study for the Federal Highway Administration (FHWA) entitled *Determination of Rehabilitation Methods for Rigid Pavements.* One objective of this study is to improve design and construction procedures for selected rigid pavement rehabilitation techniques. Field performance data has been collected on more than 150 projects in 24 states for the following rehabilitation techniques: *(a)* full-depth repair, *(b)* partial-depth repair, *(c)* diamond grinding, *(d)* crack and seat and overlay, *(e)* tied concrete shoulders, *(f)* joint load transfer, and *(g)* bonded and unbonded concrete overlays.**

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