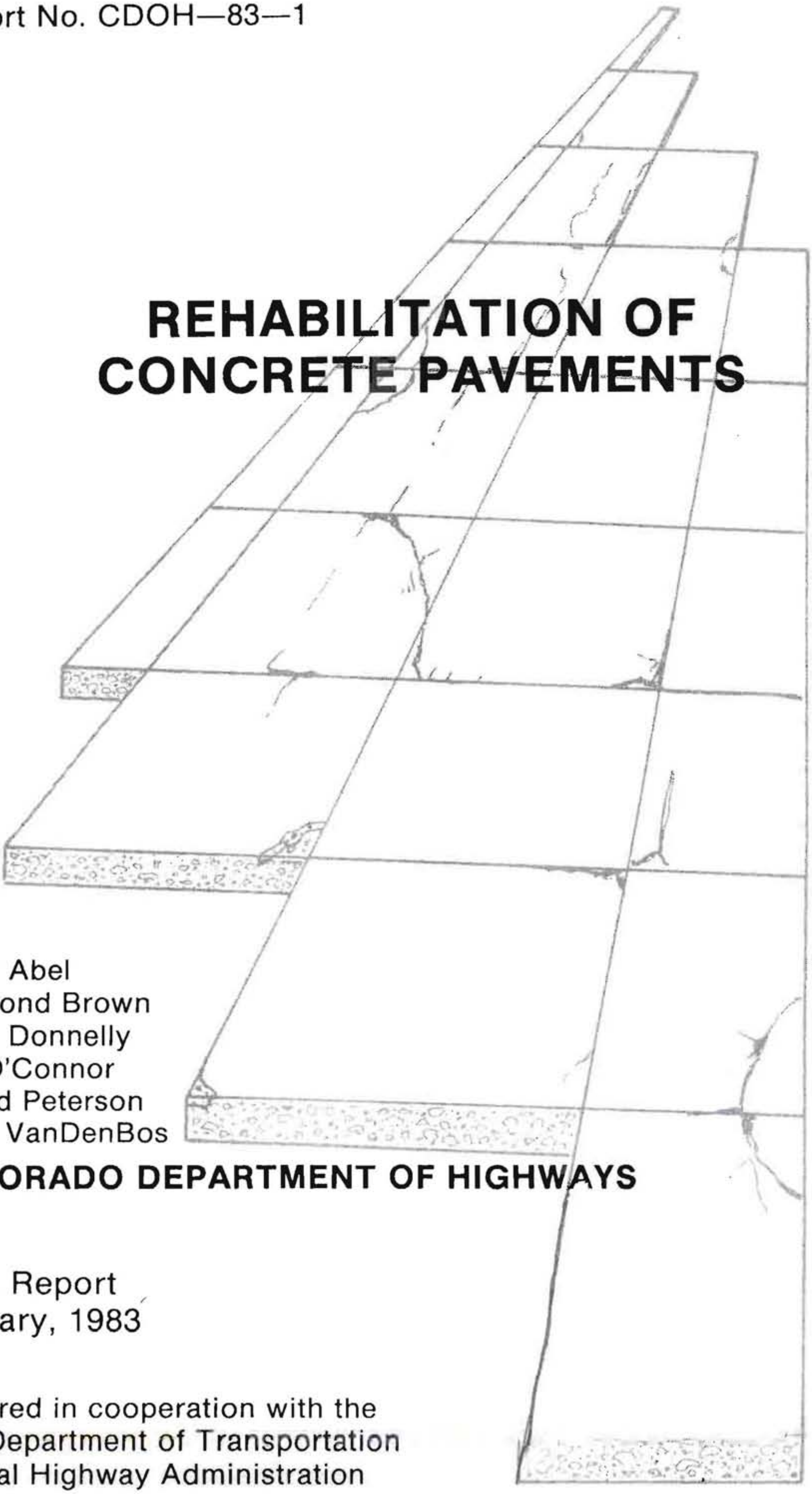
Report No. CDOH—83—1



REHABILITATION OF CONCRETE PAVEMENTS

Frank Abel
Raymond Brown
Denis Donnelly
Leo O'Connor
Gerald Peterson
Merle VanDenBos

COLORADO DEPARTMENT OF HIGHWAYS

Final Report
January, 1983

Prepared in cooperation with the
U.S. Department of Transportation
Federal Highway Administration

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
CDOH-R-83-1		

4. Title and Subtitle	5. Report Date
Rehabilitation of Concrete Pavements	
	6. Performing Organization Code
7. Author(s) Abel, Brown, Donnelly, O'Connor, Peterson, VanDenBos	8. Performing Organization Report No. CDOH-R-83-1
9. Performing Organization Name and Address Colorado Department of Highways 4201 E. Arkansas Avenue Denver, CO 80222	10. Work Unit No. (TRAIS)
	11. Contract or Grant No.
12. Sponsoring Agency Name and Address Colorado Department of Highways 4201 East Arkansas Avenue Denver, CO 80222	13. Type of Report and Period Covered Final Report - 1 year
	14. Sponsoring Agency Code

15. Supplementary Notes

Prepared in cooperation with the U.S. Department of Transportation, Federal Highway Administration

16. Abstract

A project panel was established to provide guidelines for the rehabilitation of concrete pavements in Colorado. Techniques used by other state highway agencies were compared to the type and severity of concrete pavement distress observed in-state. Representatives from the concrete and asphalt pavement paving organizations were also invited to provide input to the study.

Suggested methods are provided to renew the design life of deteriorated concrete pavements. Alternative methods of construction from which to choose are included along with examples for comparing life cycle costs.

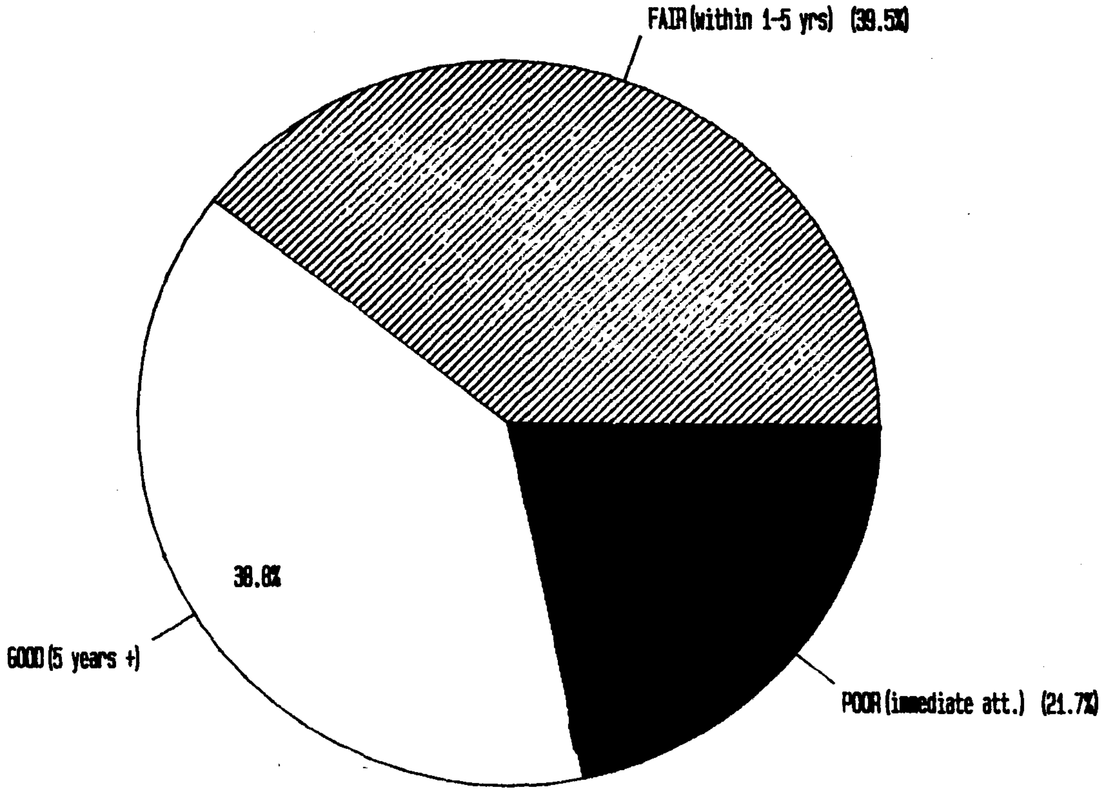
17. Key Words	18. Distribution Statement
Rehabilitation, pavement, concrete, distress	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	73	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Table of Contents

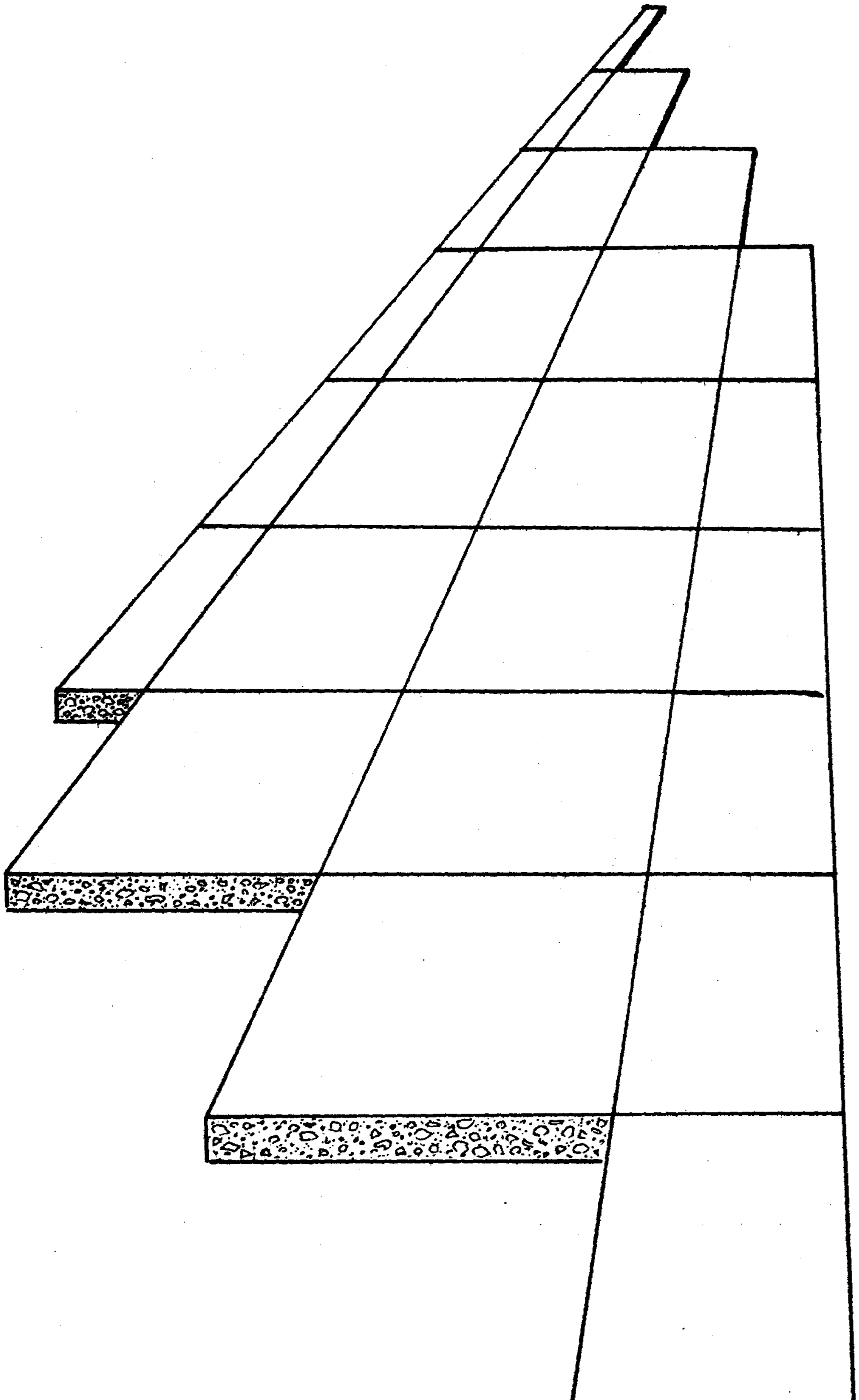
EXECUTIVE SUMMARY



Long-term rehabilitation solutions were investigated for interstate concrete pavements in Colorado. The condition of these pavements, not previously overlayed is illustrated on the above pie chart. Approximately 39 percent of these pavements are considered to be in good condition and should perform adequately for five or more years. Another 39 percent are rated fair and will need some attention within the next one to five years. The remaining 22 percent are in poor condition and need immediate attention.

Nine types of distress were identified on the concrete pavements observed. Reactive aggregates were found to be the most devastating in terms of cost and effective corrective methods.

State of the art rehabilitation methods were investigated and evaluated. Six of these were deemed appropriate for Colorado conditions. The implementation portion of this report contains specific recommendations as to which of these six methods are best suited for each portion of our concrete pavements. These specific recommendations are listed by milepost, highway number, and engineering district.



INTRODUCTION

CHAPTER ONE

INTRODUCTION

Historically, the Colorado Department of Highway has maintained an active program of new highway construction. Approximately 500 miles of concrete pavement were constructed as part of the interstate highway system from the late 1950's to the present. Of this figure 385 miles remain as concrete surface pavements and not overlayed with asphalt. Many of these concrete pavements are nearing, or have already exceeded their design life and are now in need of rehabilitation. The rehabilitation of these pavements in a cost effective manner is a challenge to the department especially in an era of limited resources, the amount of pavements needing attention, and the limited in house experience in this activity.

In order to forestall a series of redundant investigations for the rehabilitation of each concrete pavement project, a coordinated effort to establish a set of standardized guidelines and rehabilitation procedures is needed.

STUDY OBJECTIVES

The objective of this study is to provide concrete pavement rehabilitation techniques for department personnel using the latest state of the art. The conditions existing in Colorado will be observed and recommendations made for appropriate rehabilitation and/or reconstruction on a network wide basis.

It is not the study objective to develop new rehabilitation techniques; however, slight modifications or revisions to existing methods may be made in order to convert to local conditions. Use of existing design procedures will be recommended whenever they are available. In addition, this study was designed to upgrade pavements to their original condition as much as practical with a renewed design life. It was therefore expected that major rehabilitation techniques would be addressed and not routine maintenance activities.

Since most of Colorado's concrete pavements are on the interstate system, this study was intended for implementation by the expected increase in funding as part of the 4R program.

RESEARCH APPROACH

A primary concern of this study was to address the needs of those dealing with concrete pavements throughout the department. Therefore, a six member panel was formed to actively participate in the study. The panel was composed of Frank Abel, Asst. Staff Materials Engineer; Raymond Q. Brown, District Pre-Construction Engineer - Pueblo; Denis E. Donnelly, Research & Development Engineer, Leo N. O'Connor, Jr., District Materials Engineer - Greeley (Chairman); Gerald A. Peterson, District Materials Engineer - Aurora; and Merle E. Van Den Bos, Supervising Roadway Design Engineer. The study activities are as follows:

- A Highway Research Information Service (HRIS) file search was made to determine the state of the art and what was available in the literature. Reports were requested from agencies dealing with the subject as pertinent.

- Representatives of the American Concrete Pavement Association and the Asphalt Institute were contacted and asked to provide input to the study. They met with the panel to discuss Colorado's problems and to provide suggestions for rehabilitation techniques.

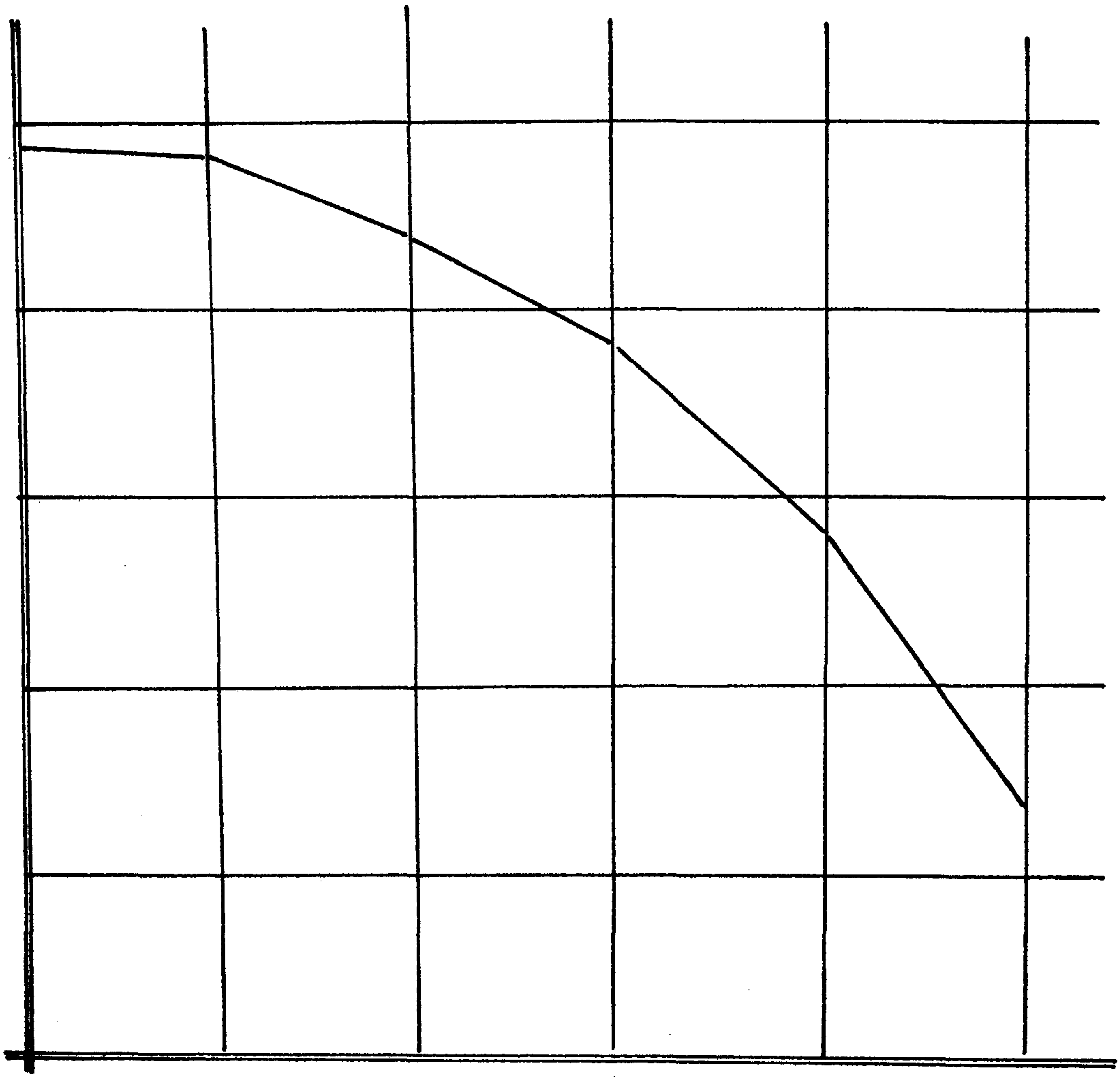
- Staff maintenance and the district maintenance superintendents from each district with concrete pavement were also consulted. The ease of maintainability of concrete vs. asphalt pavements were discussed as well as suggestions for rehabilitation.

- A series of field trips were made to interstate concrete pavement projects located throughout Colorado.

- As part of the condition survey construction plans were retrieved from the files and information concerning soil classification, base type and thickness, concrete strength, and age of the pavement were all noted. The sections rated, therefore, coincided with the original construction projects.

- A close visual inspection was made on each project with a series of photographs and measurements taken. A consensus was reached among the panel members as to the types and severity of distress observed and percentage of occurance throughout the project. The "Highway Pavement Distress Identification Manual" published by the Federal Highway Administration was used as a guide to determine distress type and severity.

- The panel reviewed the field distress observations and determined the best suited alternative rehabilitation techniques. The data was summarized and the final report written.



CONDITION SURVEY

CHAPTER TWO

CONDITION SURVEY

The six member panel visited each of the interstate projects in Colorado which had concrete pavement as a wearing surface. (Distress on those concrete pavements with an asphalt overlay can be evaluated only after the overlay is removed at which time findings in this report may be implemented.) Figure 1 contains the location of the projects observed in the field. The Concrete Pavement Rehabilitation Survey Form (see Appendix A) along with the FHWA "Highway Pavement Distress Identification Manual" were used to evaluate each project. Rating of the project was performed by riding the entire project with intermittent stops for close-up inspection. Measurements were made of each distress type observed and photographs were taken for documentation. Overall distress severity and amounts for each were determined by consensus among panel members.

The nine types of distress identified on the survey form were those thought to be most frequently observed in Colorado. Condition of the adjacent shoulder was also noted for general information.

Figures 2 thru 10 illustrates the nine concrete pavement distress types evaluated in this study. A written description along with photographs providing visual examples of each distress type are provided. Table 1 lists the concrete pavement distress severity levels as defined by the FHWA manual and used in this study. The pie chart included in the Report Executive Summary page illustrates the severity levels of distress on an overall statewide basis.

Rutting was found to be most prominent in the urban areas where studded tire traffic volume is higher. Pumping was observed only in areas with relatively poor drainage and untreated granular base materials. In these areas the first stage of distress was found to be pumping followed by corner breaks, faulting, and ultimately slab block cracking.

Reactive aggregate was found to be a frequently occurring and severe type of distress observed. This distress was observed shortly after construction of several concrete projects on I76 in northeastern Colorado. The alligator-type cracking results from the alkali reaction between the cement and silica or corbanate aggregates. This type of distress was not found too often in the literature since it most frequently occurs along the eastern slopes of the Rocky Mountains. Cracks begin to occur not only at the pavement surface but also from within as determined from concrete pavement cores. When exposed to air and moisture the reaction/cracking progresses to a point where the pavement particles begin to erode and pop out. Longitudinal and transverse cracking frequently occur in areas of reactive aggregate and heavy truck loads.

Spalling at the joints was observed under two types of conditions. It frequently occurred in areas where the transverse or longitudinal joints were preformed with a plastic ribbon installed by the concrete paving machine. When joints were sawed, spalling seldom occurred. Spalling was also frequently observed in areas where the joint filler material has not been replaced. The void between unfilled joints apparently is filled by sand or other incompressibles and causes spalling as the concrete slab expands in hot weather. This condition was observed most often in urban areas.

Faulting distress most often occurred in areas with poor subgrade support. In some cases, such as that on I25 south of Walsenberg, pumping was also present. In all cases a void was believed to exist beneath the leave slab, (adjacent to the joint) with slab rocking or movement taking place. The transfer of traffic wheel loads from the approach to the leave slab resulted in a joint fault. Fines were also believed to be ejected from under the leave to underneath and raising the approach slab. In an area of I70 near Deartrail where traffic had once been reversed, faulting was observed in the opposite direction. Consequently, the orientation of faulted joints is believed to be directly related to traffic.

The bar graph on Figure 11 lists the nine types of distress and the accumulated miles of each on a state wide basis. Since many of the projects contained more than one type of distress the sum of the data listed exceeds the observed mileage. The most frequently occurring distress type is shown to be rutting however, the severity is relatively low in most cases. Reactive aggregates and faulting are most frequently occurring in the high severity category documenting Colorado's most serious distress type. Medium severity longitudinal cracking was observed quite frequently however, it was often observed in conjunction with reactive aggregate or other types of distress.

The pavements surveyed in this study ranged in age from 4 to 24 years with the average age being 18 years. It should be noted, therefore, that the pavement distress or deterioration referred to should not be inferred to mean that these pavements have performed unsatisfactorily. On the contrary, they have, in general, provided excellent riding surfaces in accordance with their design lives. Many of them will also provide more years of good service before requiring other than routine maintenance.

Concrete pavements with asphalt overlay have not been included in this study. As these projects are selected for rehabilitation it is recommended that their distress condition prior to overlay, if available, be reviewed. Maintenance forces are often a good source of this information. Reflection cracking and other surface conditions may reveal what lies underneath. The asphalt overlay, or portions of it, may be removed to reveal the condition of the original concrete pavement.

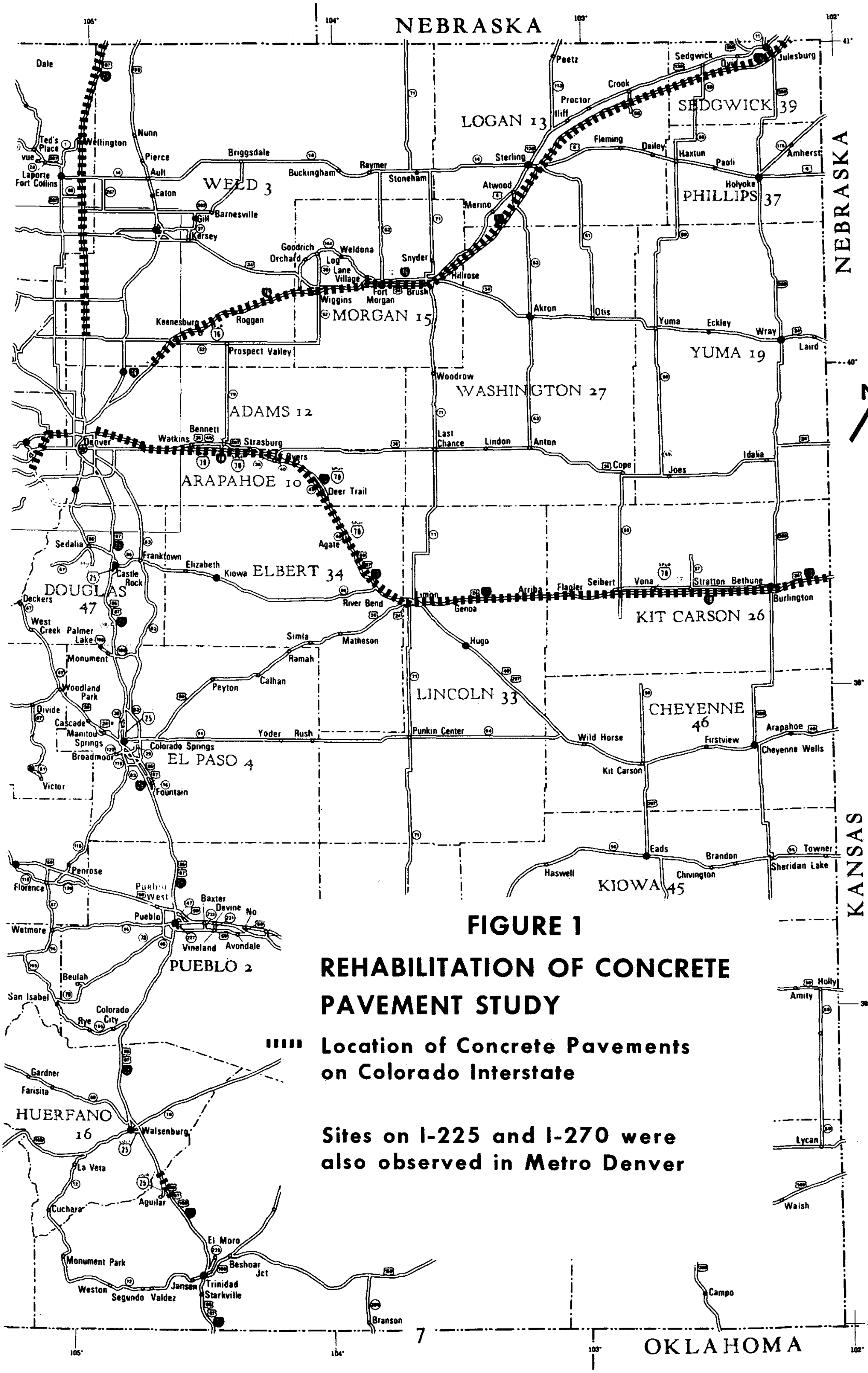


FIGURE 1

REHABILITATION OF CONCRETE PAVEMENT STUDY

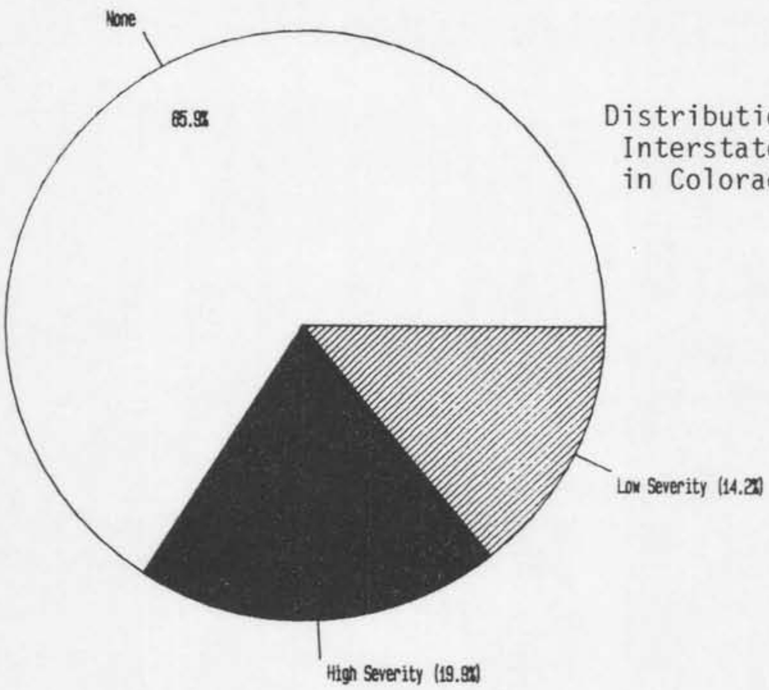
IIIII Location of Concrete Pavements on Colorado Interstate

Sites on I-225 and I-270 were also observed in Metro Denver

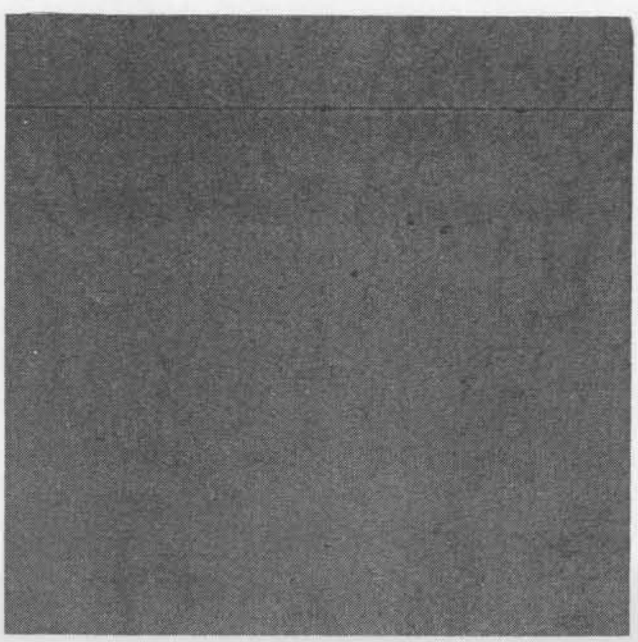
Figure 2

REACTIVE AGGREGATE DISTRESS

Reactive aggregates either expand in alkaline environments or develop prominent siliceous reaction rims in concrete. It may be an alkali-silica reaction or an alkali-carbonate reaction. As expansion occurs, the cement matrix is disrupted and cracks. It appears as a map cracked area; however, the cracks may go deeper into the concrete than in normal map cracking. It may affect most of the slab or it may first appear at joints and cracks.



Distribution of Distress on Interstate Concrete Pavements in Colorado



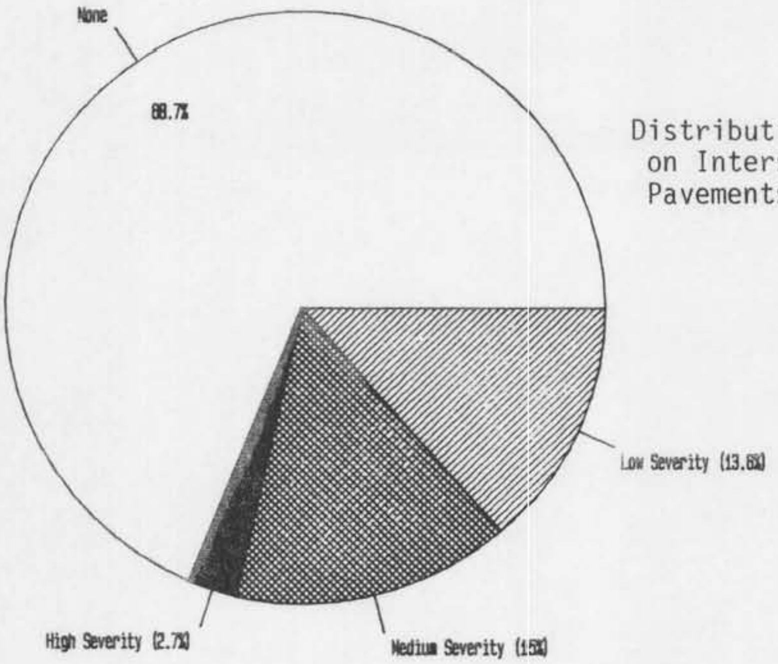
Low Severity

High Severity

Figure 3

LONGITUDINAL CRACKING DISTRESS

Longitudinal cracks occur generally parallel to the centerline of the pavement. They are often caused by improper construction of longitudinal joints, or by a combination of heavy load repetition, loss of foundation support, internal vibrator failure, and thermal and moisture gradient stresses.



Distribution of Distress on Interstate Concrete Pavements in Colorado.

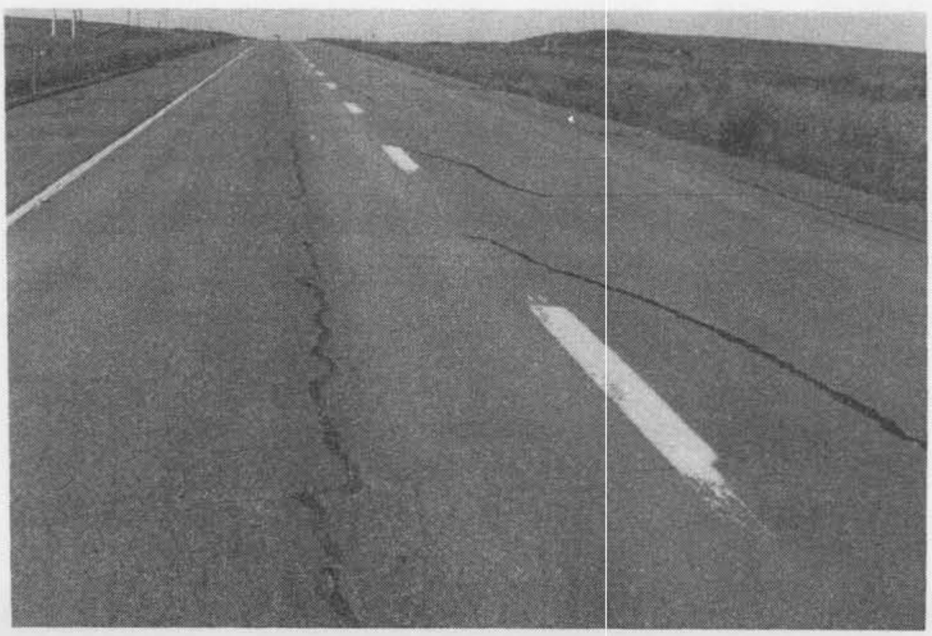
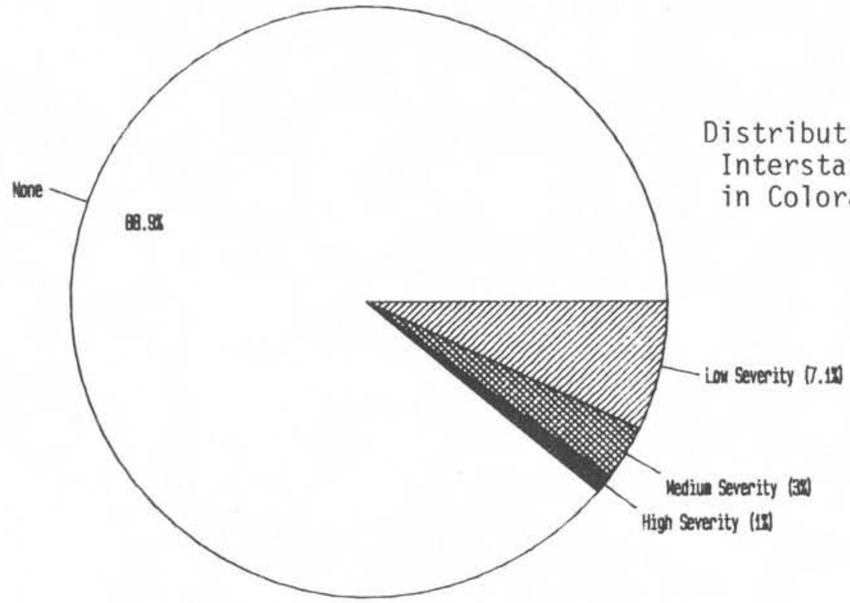


Figure 4

TRANSVERSE CRACKING DISTRESS

These cracks are usually caused by a combination of heavy load repetition, thermal and moisture gradient stresses, and drying shrinkage stresses. Medium or high severity cracks are working cracks and are considered major structural distresses.



Distribution of Distress on Interstate Concrete Pavements in Colorado.

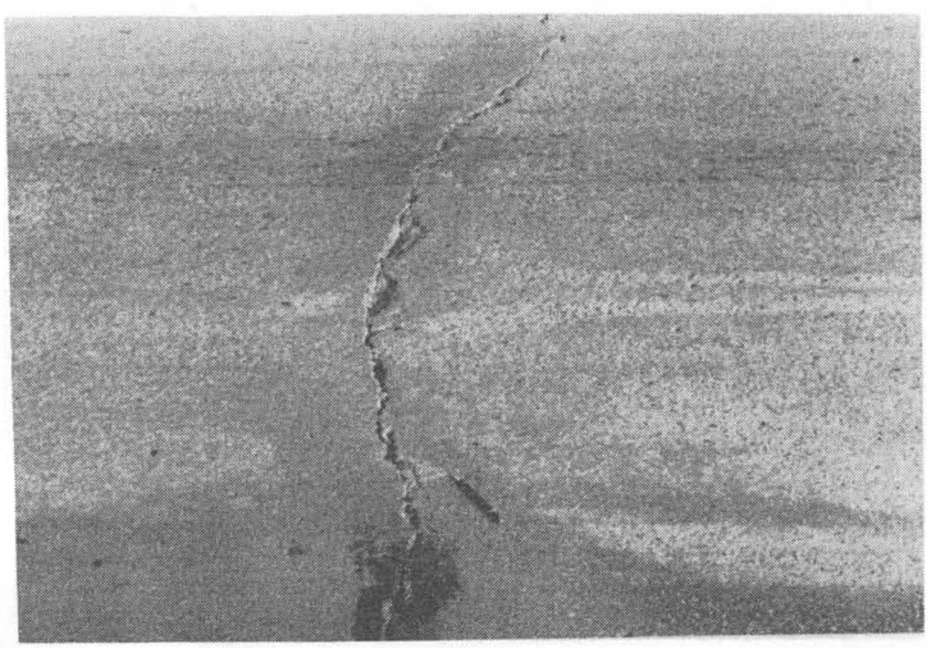
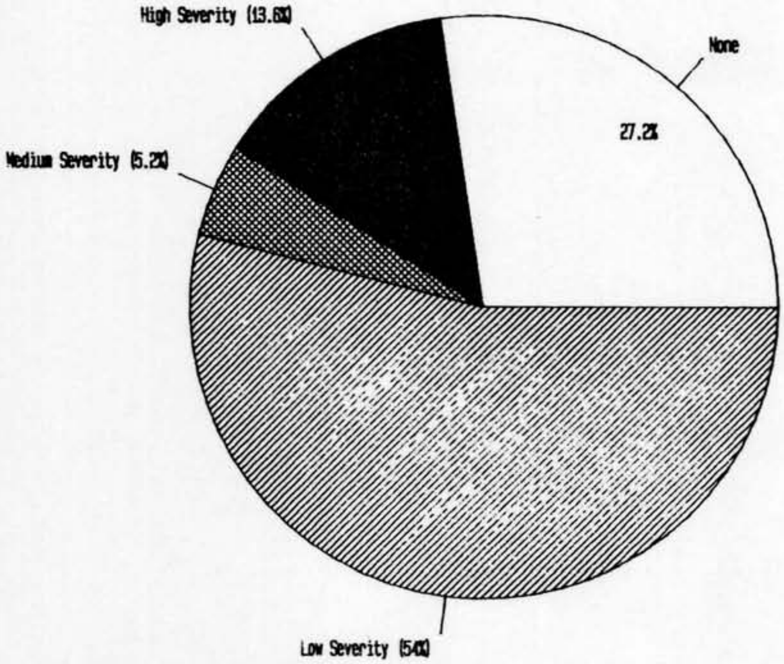


Figure 5

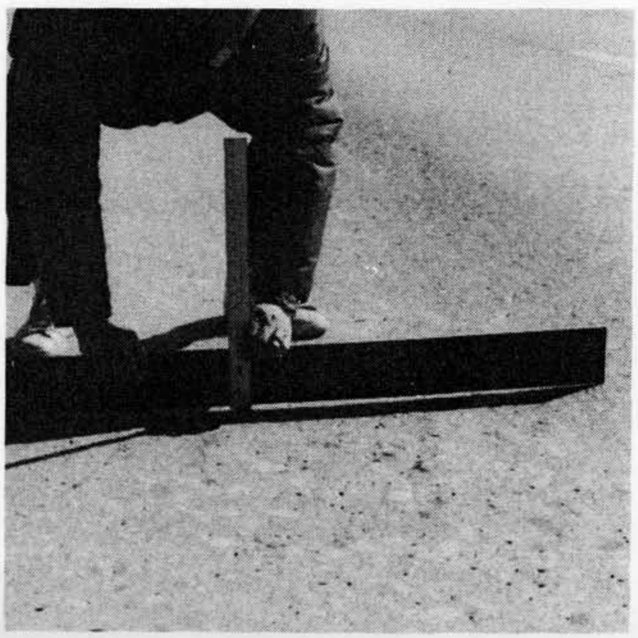
RUTTING DISTRESS

A rut is a surface depression in the wheel paths. In many instances ruts are noticeable only after a rainfall, when the wheel paths are filled with water. Significant rutting can lead to major structural failure of the pavement and hydroplaning potential. Rutting stems from wearing of the surface in the wheel paths from studded tires.



Distribution of Distress on Interstate Concrete Pavements in Colorado.

Medium Severity

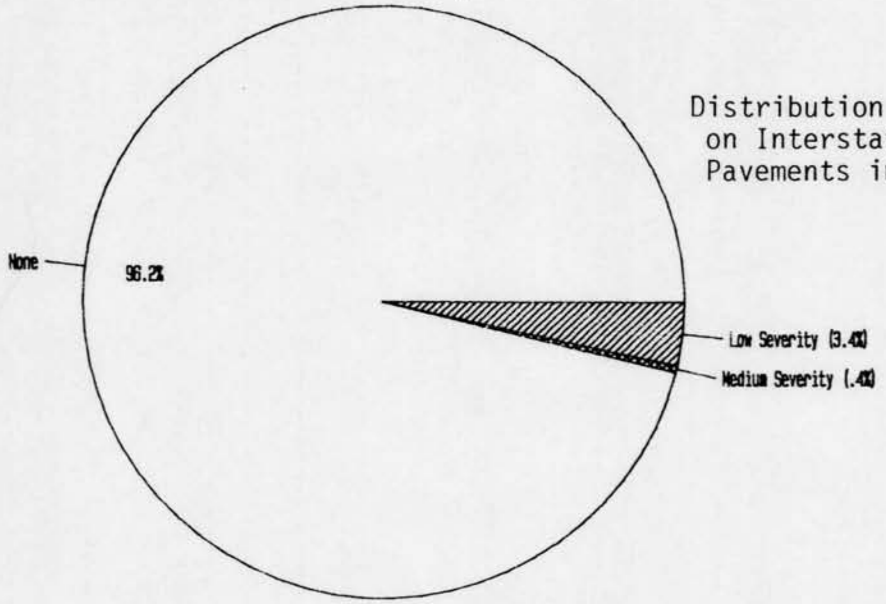


High Severity

Figure 6

DEPRESSION DISTRESS

Depressions in concrete pavements are surface areas having elevations lower than those of the surrounding pavement. There is generally significant slab cracking in these areas due to uneven settlement. In many instances, light depressions are not noticeable until after a rain when ponding water creates "bird-bath" areas. The depressions may also be located without rain by stains caused by oil droppings from vehicles. Depressions can be caused by settlement or consolidation of the foundation soil or can be "built in" during construction. They are frequently found above culverts. This is usually caused by poor compaction of soil around the culvert during construction. Depressions cause slab cracking, roughness, and hydroplaning when filled with water of sufficient depth.

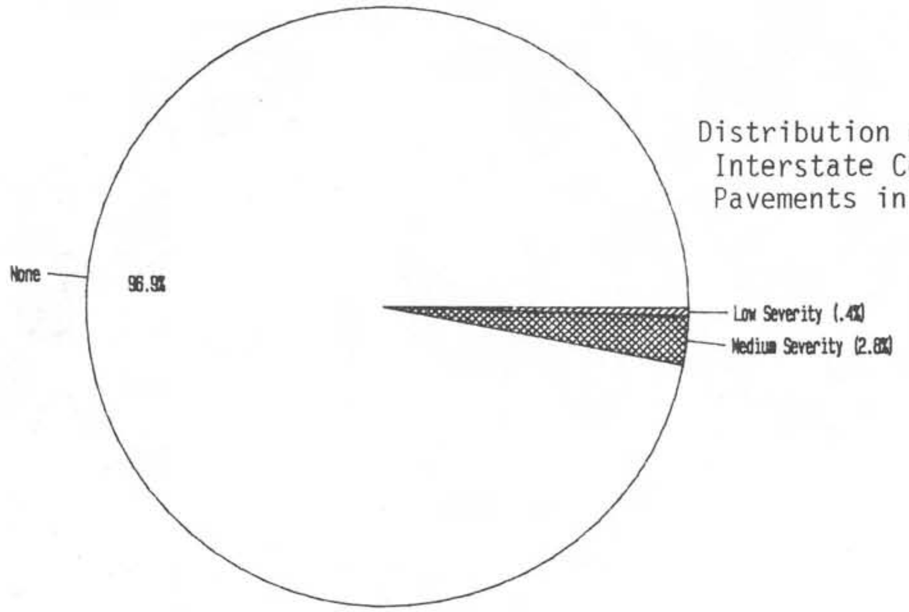


Distribution of Distress on Interstate Concrete Pavements in Colorado.

Figure 7

PUMPING DISTRESS

Pumping is the ejection of material by water through joints or cracks, caused by deflection of the slab under moving loads. As the water is ejected, it carries particles of gravel, sand clay, or silt, resulting in a progressive loss of pavement support. Surface staining or accumulation of base or subgrade material on the pavement surface close to joints or cracks is evidence of pumping. Pumping can occur without such evidence, particularly when stabilized bases are used. The observation of water being ejected by heavy traffic loads after a rain storm can also be used to identify pumping. Water bleeding occurs when water seeps out of joints or cracks.



Distribution of Distress on Interstate Concrete Pavements in Colorado.

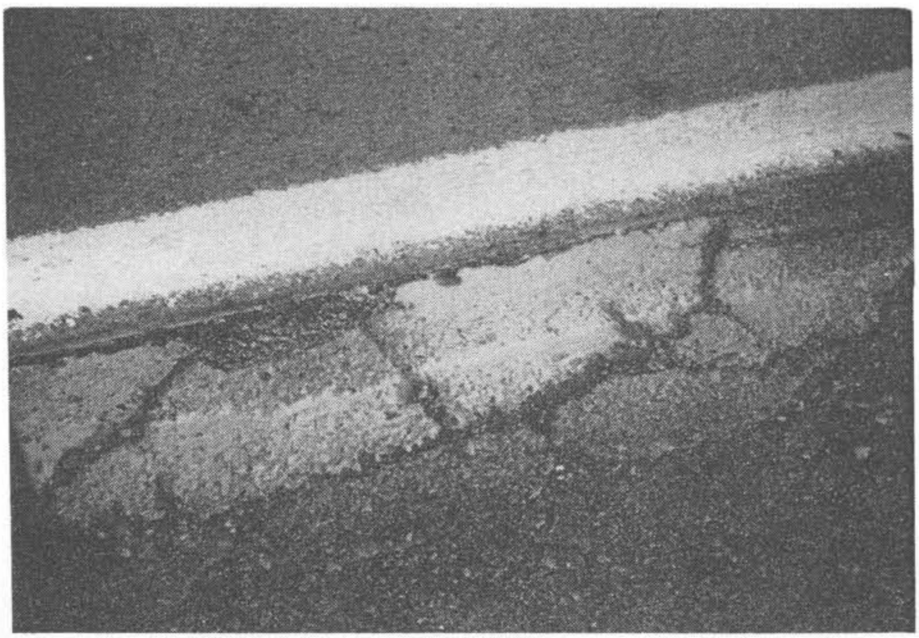
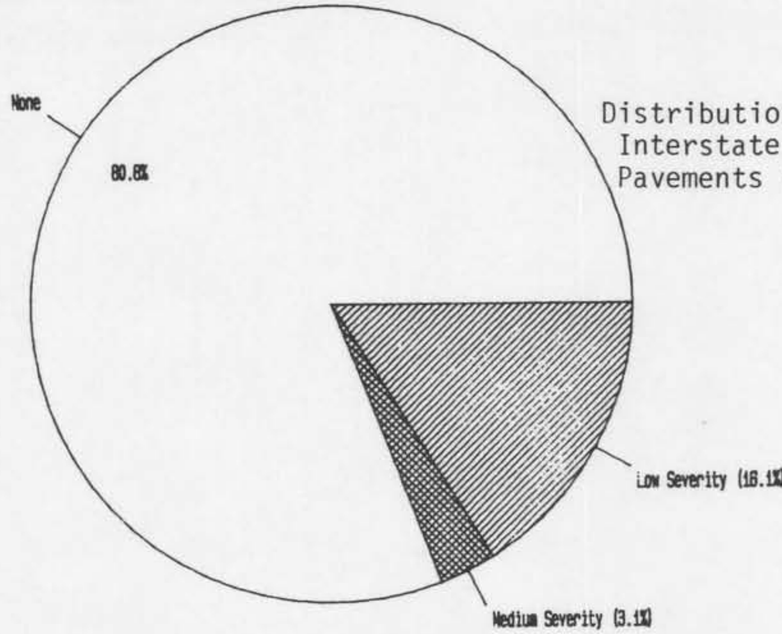


Figure 8

SPALLING DISTRESS

Spalling of cracks and joints is the cracking, breaking or chipping of the slab edges within 2 ft. of the joint. A joint spall usually does not extend vertically through the whole slab thickness, but extends to intersect the joint at an angle. Spalling usually results from (1) excessive stresses at the joint or crack caused by infiltration of incompressible materials and subsequent expansion or traffic loading, (2) disintegration of the concrete, (3) weak concrete at the joint (caused by over-working) combined with traffic loads, or (4) poorly designed or constructed load transfer device.



Distribution of Distress on Interstate Concrete Pavements in Colorado.

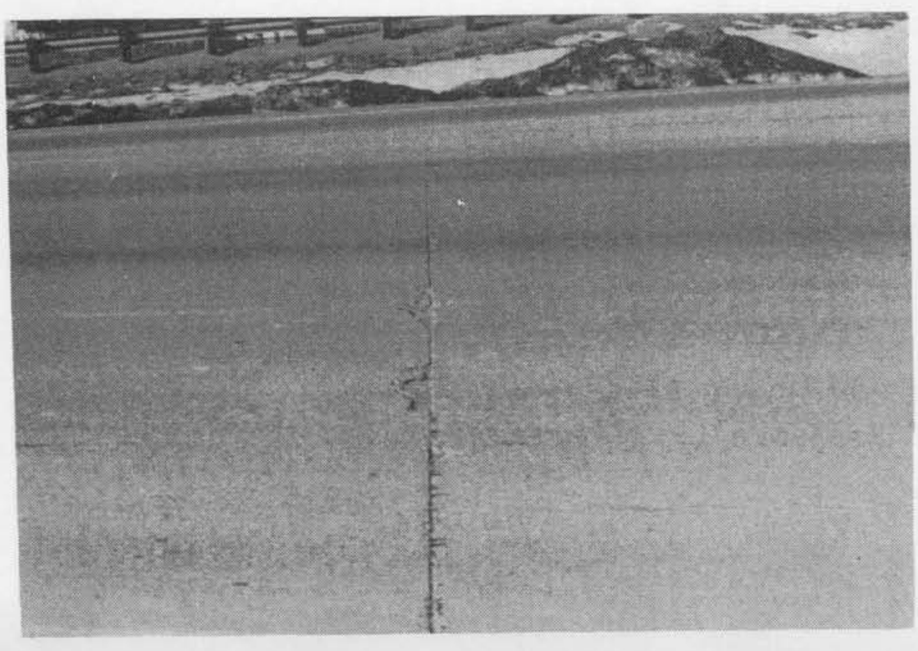
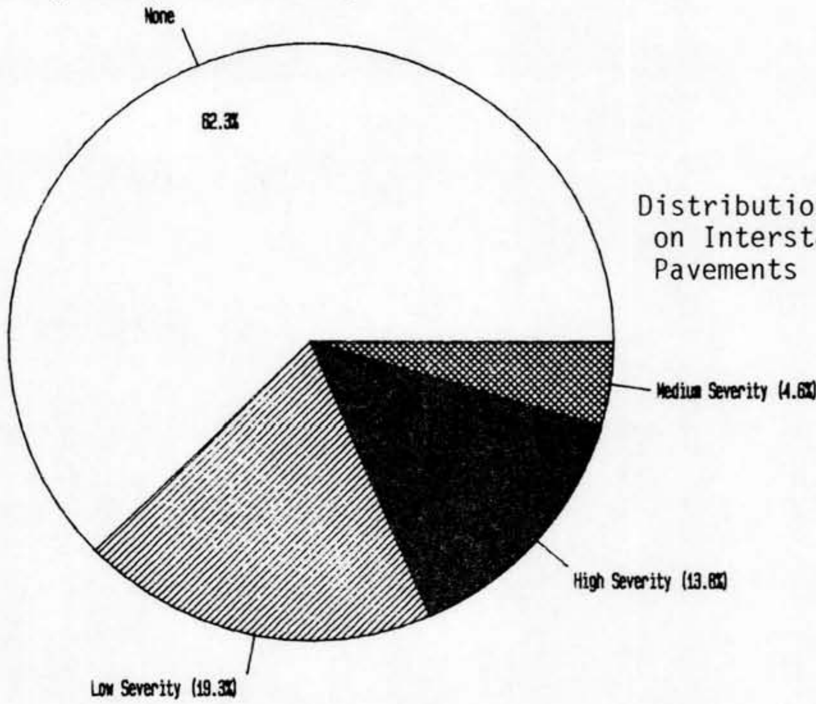


Figure 9

FAULTING DISTRESS

Faulting is the difference of elevation across a joint or crack. Faulting is caused part by a buildup of loose materials under the approach slab near the joint or crack as well as depression of the leave slab. The buildup of eroded or infiltrated materials is caused by pumping (free moisture under pressure) due to heavy loadings. The warp and/or curl upward of the slab near the joint or crack due to moisture and/or temperature gradient contributes to the pumping condition. Lack of load transfer contributes greatly to faulting.

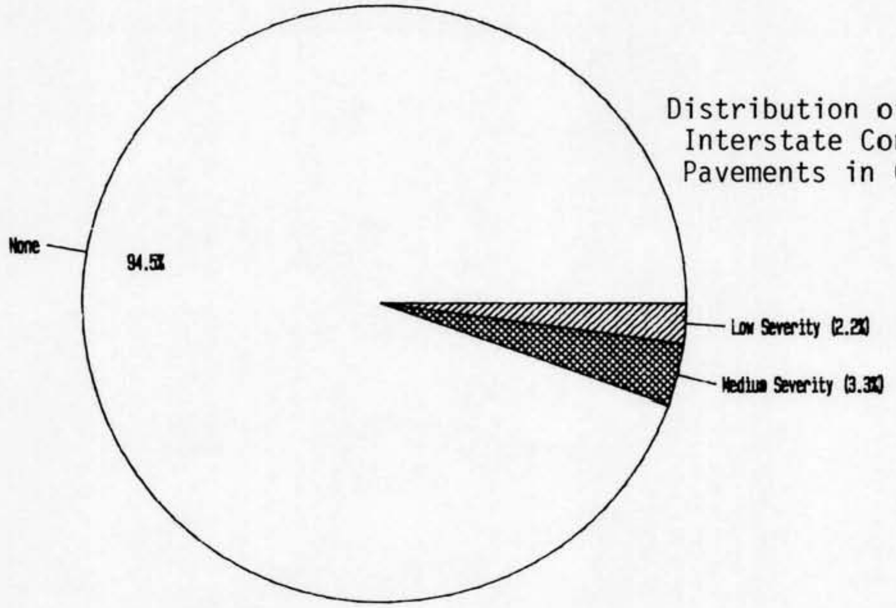


Distribution of Distress on Interstate Concrete Pavements in Colorado.

Figure 10

CORNER BREAKS DISTRESS

A corner break is a crack that intersects the joints at a distance less than 6 ft on either side measured from the corner of the slab. A corner break differs from a corner spall in that the crack extends vertically through the entire slab thickness, while a corner spall intersects the joint at an angle. Load repetition combined with loss of support, poor load transfer across joint, and thermal curling and moisture warping stresses usually cause corner breaks.



Distribution of Distress On Interstate Concrete Pavements in Colorado.

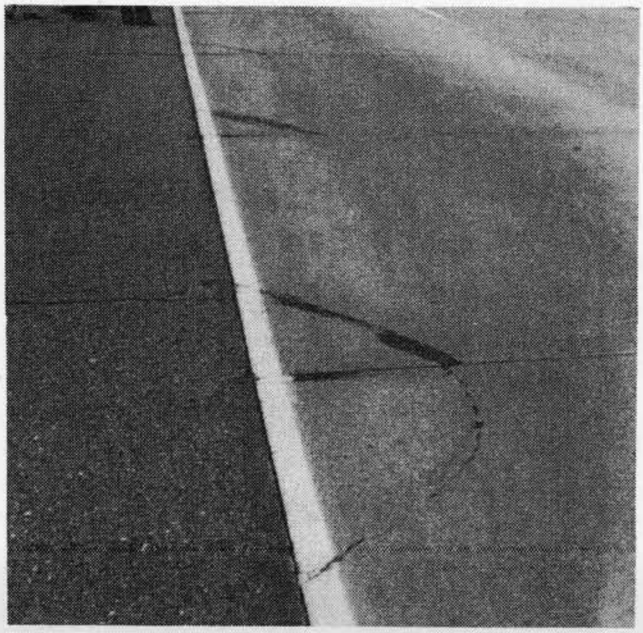


Table 1

Concrete Pavement Distress

Severity Levels

Reactive Aggregate Distress

- Only two levels of distress have been defined.

Low - Fine alligator-type cracks exist but no matrix exists between cracks to act as an integral structure.

High - Cracks have opened to the point where individual particles are not interlocked. Particles may be rocking or removed by traffic.

Longitudinal Cracking Distress

Low - Hairline (tight) crack with no spalling.

Medium - Working crack with moderate or less severity level of spalling and/or faulting less than ½ inch.

High - A crack with width greater than 1 inch; a crack with a high severity level of spalling; or, a crack faulted ½ inch or more.

Transverse Cracking Distress

Same as Longitudinal Cracking Distress.

Rutting Distress

Low - ¼ to ½ inch rut depth.

Medium - >½ to 1 inch rut depth.

High - >1 inch rut depth.

Depression Distress

Low - Depression causes some bounce of the vehicle which creates no discomfort.

Medium - Depression causes significant bounce of the vehicle which creates some discomfort.

High - Depression causes excessive bounce of the vehicle which creates substantial discomfort, and/or a safety hazard, and/or vehicle damage requiring a reduction in speed for safety.

Table 1

Pumping Distress

Low - Water is forced out of a joint or crack when trucks pass over the joints or cracks, water is forced out of the lane/shoulder joint when trucks pass along the joint, or water bleeding exists. No fines can be seen on the surface of the traffic lanes or shoulder.

Medium - A small amount of pumped material can be observed near some of the joints or shoulder.

High - A significant amount of pumped material exists on the pavement surface of the traffic lane or shoulder along the joints or cracks.

Spalling Distress

Low - A spall less than two feet long; if spall is broken into pieces and fragmented, it must not extend more than three inches from the joint or crack. A spall more than two feet long with spall held tightly in place; if spall is cracked, it cannot be broken into more than three pieces. The joint is lightly frayed with fray extending no more than three inches from the edge of the joint or crack.

Medium - A spall is broken into pieces or fragmented and spall extends more than three inches from joint or crack. Some pieces may be loose and/or missing, but the spalled area does not present a tire damage or safety hazard. The joint or crack is moderately frayed with fray extending more than three inches from the edge of the joint or crack, but not causing a tire damage or safety hazard. Temporary patching has been placed because of spalling.

High - The joint is severely spalled or frayed to the extent that a tire damage or safety hazard exists.

Faulting Distress

Low - Average faulting is equal to or less than 1/16 inch.

Medium - Average faulting is more than 1/16 inch but less than 1/5 inch.

High - Average faulting is equal to or more than 1/5 inch.

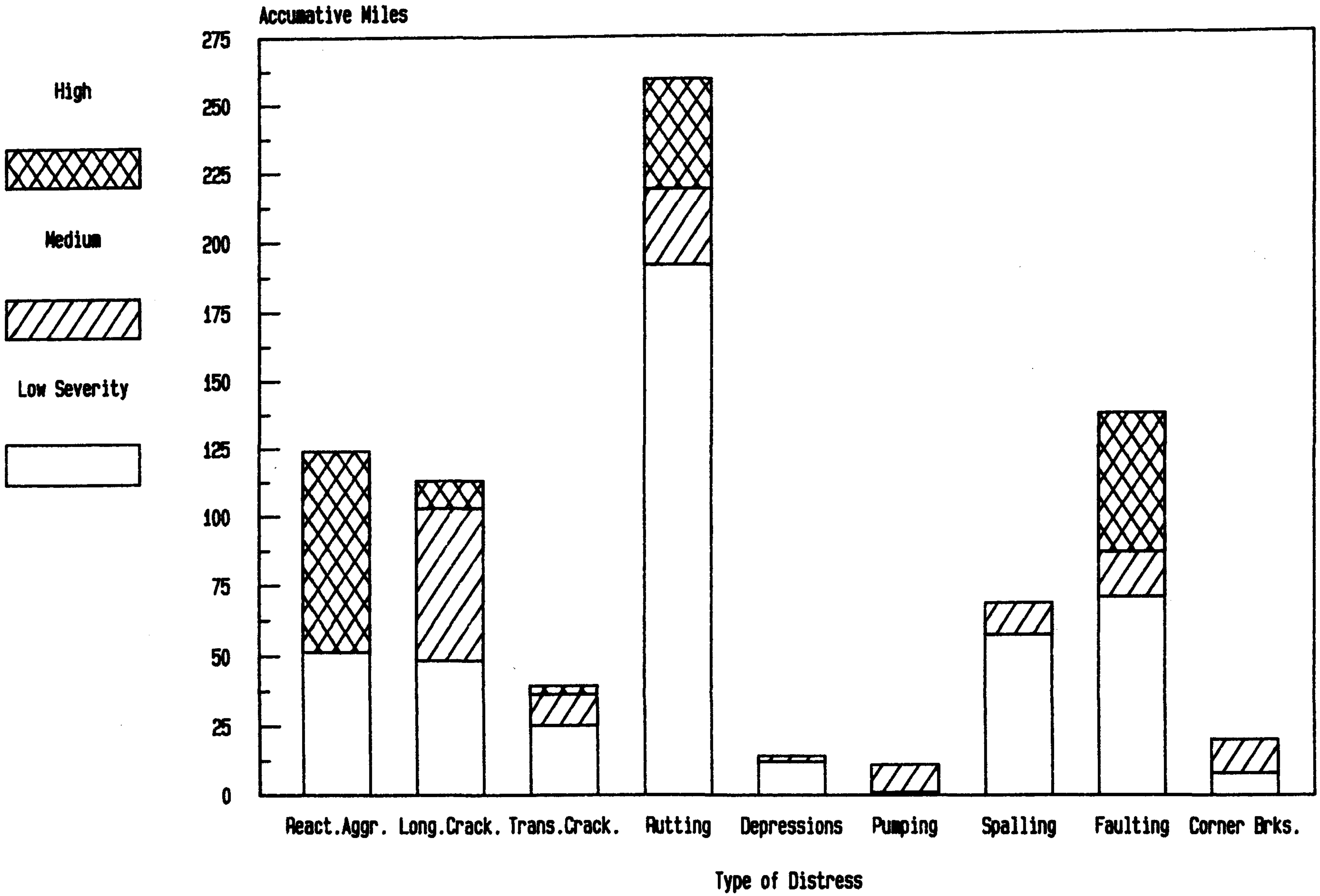
Table 1

Corner Breaks Distress

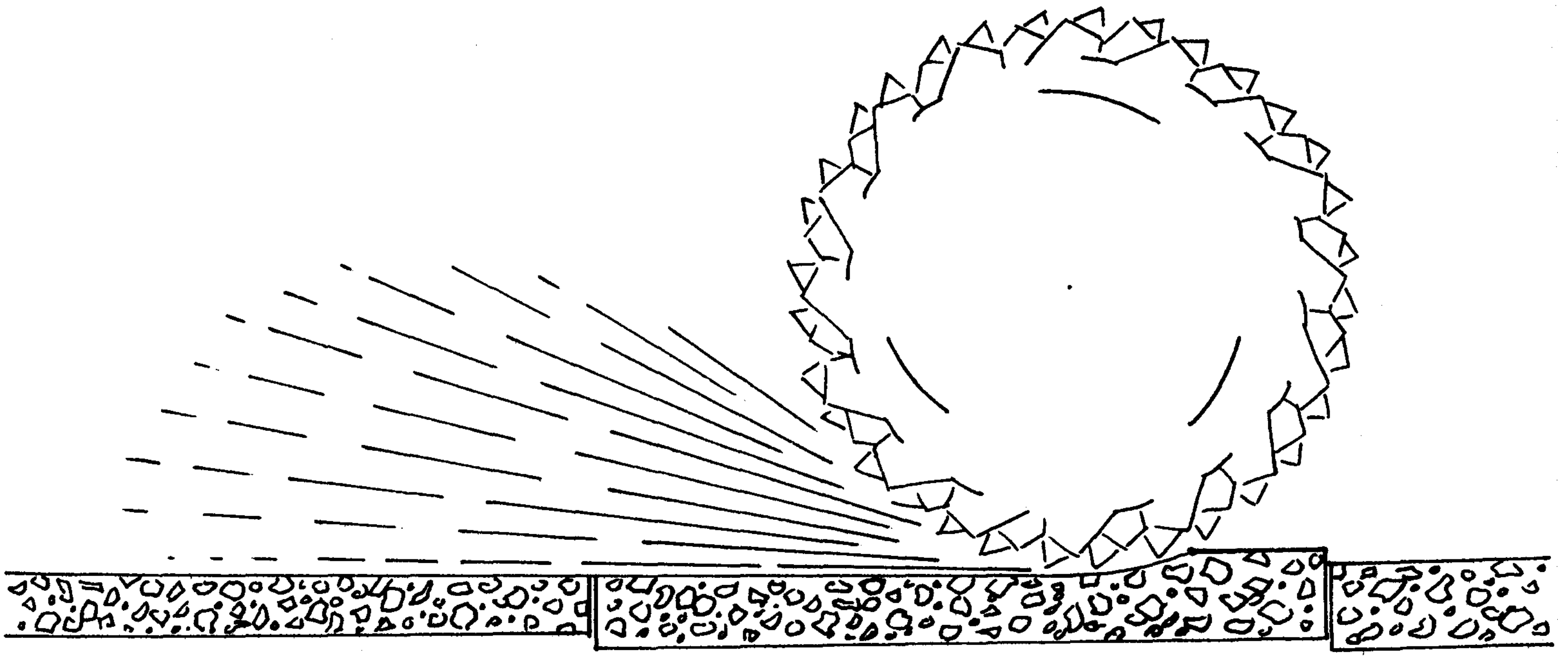
Low	-	Crack is tight (hairline). Well sealed cracks will be considered tight. No faulting or break-up at broken corner exists. Crack is not spalled.
Medium	-	Crack is working and spalled at low or medium severity. Break-up of broken corner has not occurred. Faulting of crack or joint must be less than ½ inch. Temporary patching may have been placed because of corner break.
High	-	Crack is spalled at high severity or the corner piece has broken into two or more pieces. If faulting of crack or joint is more than ½ inch, it will be considered high severity.

FIGURE 11

MILES OF DISTRESS BY SEVERITY



REHABILITATION



METHODS

CHAPTER THREE

REHABILITATION

Each individual state has its own peculiar and sometimes unique type of concrete pavement distress. The reason for this diversiveness is largely due to pavement design, material characteristics and environmental conditions. Also, each type of distress has associated rehabilitation methods that are best suited and have the highest probability of success. Based on the types of distress found in Colorado, one or more of the following general rehabilitation methods will be recommended for each section of concrete pavement:

- Thin Asphalt Overlay
- Thick Asphalt Overlay
- Thick Concrete Overlay
- Thin Bonded Concrete Overlay
- Rehabilitation Without Overlay (Surface Correction)
- Reconstruction

Definitions

In order to provide a base of understanding, terms common to pavement rehabilitation need to be defined. General rehabilitation methods in Colorado will use one or more of the following specific procedures listed below. In depth details regarding the identification and use of these procedures may be found in the publication, "Techniques for Pavement Rehabilitation, A Training Course", by ERES, Inc.

Partial Depth Patch

Involves repair of partial depth spalls, usually occurring at either the transverse or longitudinal joints. These spalls are caused by incompressible materials being trapped in the joint.

Full Depth Patch

This method involves full depth replacement of a portion of a slab, usually full lane width, by a minimum of 4 to 6 feet in length.

Slab Replacement

The limits of replacement are one lane width, between sawn joints. These slabs are usually long enough (15 feet) that no load transfer devices are necessary. Slab replacements may be considered in conjunction with an AC or PCC overlay project.

Surface Grinding/Milling

Grinding is accomplished with diamond saw blades. This restoration technique has proven to be an effective method to correct the pavement profile and to restore ride quality of old PCCP; especially, to remove faults from concrete pavement, restore surface texture and remove rutting.

Milling is accomplished with carbide tipped cutters mounted on a rotary drum to produce a chipping action on the concrete. This method produces spalling at the joints which is undesirable unless some type of overlay is going to be placed.

Undersealing

Consists of drilling several holes in each slab or at the joint and pumping a cementitious grout or hot asphalt into the voids under the slabs to stabilize movement. Care must be taken not to lift the slab as new voids will be created. The material most commonly used is made up of one part of cement to three parts of fly ash, pozzolan, or other compatible cementitious material. Undersealing should proceed profile correction by grinding where there are rocking slabs or slabs that do not have uniform support.

Joint Restoration/Resealing

Rehabilitation of this type is done to prevent surface water from entering the pavement structure and to prevent incompressibles from entering the joints. Resealing requires removal of any existing joint material restoring the joint to the proper shape factor, (depth to width ratio) and replacement with new sealant material, and possibly, addition of a backer rod prior to sealing.

Thin Asphalt Concrete Overlay (Thickness = 3 inches)

Thin asphalt concrete overlays are generally not the answer to concrete pavement distress. However, for rutting and/or surface texture improvement this method might prove to be cost effective. A leveling course may be required for severe rutting.

Thick Asphalt Concrete Overlay (Thickness = 4 inches, min.)

Utilization of this type of rehabilitation usually requires a design to reduce reflective cracking. A typical overlay would require adjustment for vertical clearances as well as other roadside items (guardrail, exit and entrance ramps, etc.).

Thin Bonded Concrete Overlay (Thickness = 1 to 5 inches)

Thickness of this type of overlay ranges from 1 to 5 inches. Due to its thinness, it must be completely bonded to the existing pavement. This is not recommended for heavily cracked pavements.

Thick Unbonded Concrete Overlay (Thickness = 6 inches, min.)

This type of overlay is 6 inches thick or greater. A bond breaker must be placed on the existing PCC pavement to prevent adhesion. This method is acceptable for distressed areas.

Crack Relief Layer

A layer of material between the existing cracked PCC pavement and the overlay designed to prevent reflective cracking. This could be a coarse, open graded asphalt mix or a crack reduction fabric.

Rehabilitation Methods

Thin Asphalt Overlay

Because this study deals with pavement rehabilitation and not maintenance, a minimum thickness for an asphalt overlay is considered to be 3 inches. This treatment is primarily used to correct surface distress such as rutting, reactive aggregate, etc. In some cases, a leveling course may be required. An attractive feature of this method is that the clearance and roadside improvements associated with thick overlays are not necessary. However, if severe rutting continues, the life cycle benefits may be altered by the need to redo the thin asphalt overlay.

Thick Asphalt Overlay

This method involves the use of a minimum of 4" asphalt overlay to provide additional structural capacity for the existing pavement.

Since the principal causes of cracking in an overlay are thermal contractions and expansions, and vertical differential deflections of the underlying slabs, some effort must be made to mitigate these stresses. Differential deflections at cracks or joints are considered to be more critical due to the quicker loading rate. If excessive, this vertical deflection can be reduced by undersealing or replacement of slabs. If the vertical deflections are not excessive a crack relief layer, stress absorbing interlay membrane, or a fabric membrane interlayer could be utilized. Additional design and cost considerations such as impairment of vertical clearance under structures, disruption of and need for alteration of existing drainage patterns, and the need to increase the height of railings and barriers should be considered.

Thick Concrete Overlay

A thick concrete overlay is a minimum of 6" thick, which provides additional structural capacity to the roadway.

A bond breaker is placed between the old pavement and the new overlay to prevent reflective cracking. Slabs that are rocking, pumping or faulted should be stabilized by undersealing prior to overlaying. Since there will be a considerable vertical height increase, additional design and cost considerations similar to the thick asphalt overlay must be addressed. Concrete shoulders should also be considered at this time.

Thin Bonded Concrete Overlay

A thin bonded concrete overlay has a minimum thickness of 1 inch. This type of overlay must be bonded to the existing PCC pavement. To ensure an adequate bond, the existing surface should be cleaned of all surface contaminants including oil, paint, and unsound concrete. This can be accomplished by cold milling, sand blasting, water blasting or a combination of the above. A grout made from sand and cement or neat cement should be placed on the cleaned surface just in front of the paver and broomed in. The grout should not be allowed to dry before the overlay is placed. Since all cracks in the old surface will reflect through the overlay, all joints in the original pavement must be reproduced in the overlay. For this reason, thin concrete overlays are restricted to pavements which are not heavily cracked. Thin concrete overlays should be used only when the existing concrete is in good condition and surface corrections are necessary.

Rehabilitation Without Overlay

PCC pavements which are rutted and/or faulted with little or no additional distress can be corrected by grinding with diamond saws. In the case of rutting, the surface is retextured and transverse drainage is restored. Thus, the problem of the ruts filling with water and resulting hydroplaning are eliminated. This problem is prevalent in metro areas where heavy traffic and studded tires combine to create deep rutting. The joints should then be resawn to the proper shape factor (depth to width ratio) for the sealant used and resealed. A shallow, wider seal is more effective than the deep, narrow shape of Colorado's sawn joints. If grinding is excessive, the thickness of the pavement may need to be increased to handle existing or future traffic loads.

Faulted pavement should first be checked for excessive deflection and this problem corrected before grinding. The entire surface can then be ground or the height of the fault can be feathered back into the slab. After grinding, the joints should be restored using the same technique as for rutting. Grinding has the advantage that it can be done only where needed, the traveled lane for example. Also, there is less traffic disruption since only one lane of the highway is closed, and there is no loss of vertical clearance.

Reconstruction

Reconstruction involves removal of the existing pavement, reconditioning the base, and replacement with new or recycled material.

Concrete has been recycled into new concrete on many projects throughout the U.S. While the techniques may vary from project to project, basic similarities remain. The existing pavement is sized, usually to 3/4 to 1½ inches, and is used as the coarse aggregate component of the new concrete mixture. The fines created by the sizing are wasted or used as subbase material. Fly ash is usually used as a partial cement replacement and as a deterrent to reactive aggregate distress. The remainder of the operation of mixing and placement is identical to new construction. If the existing pavement is overlaid with asphalt, it should be milled off before removing the concrete. If it is to be recycled into an asphalt mix, the asphalt overlay can be crushed with the concrete. The existing pavement could also be recycled into a granular base material for a new pavement structure.

If the concrete is not recycled, it must be removed and taken to a disposal site. A cost analysis should consider the use of reclaimed materials to determine feasibility of the different alternates on a project by project basis.

A summary of the rehabilitation methods listed above may be found in Table 2.

Rehabilitation Method Selection By Live-Cycle Costs

An important factor to be considered when selecting rehabilitation methods is life-cycle costs. The procedure given in 602.2 of CDOH Design Manual should be followed when making life-cycle cost comparisons. This procedure addresses the comparison of concrete pavement to asphalt pavement. There are several other comparisons that could be made when selecting rehabilitation methods for concrete pavements. The guidelines found in Table 3 should be used in addition to those listed in the Design Manual.

Two examples of life cycle costs have been included to illustrate a method for selecting rehabilitation alternatives.

1982 Cost Data

Cost data for 1982, as shown in Table 4, were obtained from: American Concrete Paving Association, Asphalt Institute, Colorado Division of Highways Cost Estimating Section, and several large paving contractors.

These cost data have been used in the life-cycle cost examples listed in this report.

LIFE-CYCLE COST EXAMPLE #1

THICK ASPHALT OVERLAY vs. THICK CONCRETE OVERLAY

Thick Asphalt Overlay

Hot Asphalt Pavement	(ton)	=	$24.00
Crack Relief Layer	(ton)	=	$30.00
Tack Coat - Emulsified Asphalt	(gal)	=	$ 0.80
Maintenance Cost	(Lane mile/yr)	=	$ 1500

Analysis for one typical two-lane mile

Crack Relief Layer - using 100#/yd²/in.

3½" thick and 39' wide

$$\frac{\frac{5280 \times 39}{9} \times 350}{2000} \times 30 = \$120{,}120$$

Tack Coat - using two applications and .10 gal/yd²

$$\frac{5280 \times 38}{9} \times .10 \times .80 = \$1{,}784$$

Hot Asphalt Pavement - using 4" thickness and 110#yd²/in.

$$\frac{\frac{5280 \times 38}{9} \times 440}{2000} \times 24 = \$117{,}709$$

Hot Asphalt Pavement Overlay - as per DOH Design Manual - 15 years 2", 25 years 2", and 35 years 1"

For 2" overlay - (117,709/4)2 = $58,885

For 1" overlay - (117,709/4)1 = $29,427

Tack coat/application - 1784/2 = $892

CI = Initial Cost	= $239,613
R_1 = Resurfacing 15th year (2" overlay)	= $ 59,747
R_2 = Resurfacing 25th year (2" overlay)	= $ 59,747
R_3 = Resurfacing 35th year (1" overlay)	= $ 30,319
MA = Annual Maintenance Cost	= $ 3,000
PW = Present Worth 239,613 + 59,747 (.5552) + 49,747 (.3751) + 30,319 (.2534) + 3,000 (19.7927)	= $362,257

AC = Annual Cost
362,257 (.0505)

Thick Concrete Overlay

Concrete Pavement (7 inch)(yd^2)	= $11.50
Bond Breaker (yd^2)	= $ 1.50
Maintenance Cost (Lane mile/yr)	= $ 500

Analysis for one typical two-lane mile

Bond Breaker - one inch thick and 38' wide

$$\frac{5280 \times 38}{9} \times 1.50 = \$33,440$$

Concrete Pavement - using 7" thickness and 38' width

$$\frac{5280 \times 38}{9} \times 11.50 = \$256,373$$

Hot Asphalt Pavement Overlay - 20 years 2" and 30 years 1"

For 2" overlay = $58,855
Tack Coat = 892
For 1" overlay = 29,427

CI = Initial Cost	= $289,813
R_1 = Resurfacing 20th year (2" overlay)	= $ 59,747
R_2 = Resurfacing 30th year (1" overlay)	= $ 30,319
MA = Annual Maintenance Cost	= $ 1,000
PW = Present Worth 289,813 + 59,747 (.4564) + 30,319 (.3083) + 1,000 (19.7927)	= $346,222
AC = Annual Cost 346,222 (.0505)	= $ 17,484

This life-cycle cost comparison does not include items such as structure, considerations, guardrail height adjustments, slope flattening, curbs, drainage, etc., because the cost will be the same for either pavement type.

SUMMARY

	Initial Cost	Present Worth	Annual Cost
Asphalt	$239,613	$362,257	$18,294
Concrete	$289,810	$346,222	$17,484

LIFE-CYCLE COST EXAMPLE #2

DIAMOND GRINDING vs. THIN BONDED CONCRETE vs. THIN ASPHALT OVERLAY

Diamond Grinding

Grinding	(sq yd)	= $ 3.10
Reseal Joints	(lin ft)	= $ 0.50
Slab Replacement	(sq yd)	= $ 55.00
Maintenance Costs	(Lane-mile/yr)	= $500.00
Remove Asphalt Shoulders	(sq yd)	= $ 1.00
Recondition Base	(sq yd)	= $ 0.20
Pave Asphalt Shoulder	(ton)	= $ 24.00

Analysis for one typical two-lane mile

Grinding - 24' wide and 1" depth

$$\frac{5280 \times 24}{9} \times 3.10 = \$45{,}648$$

Reseal Joints

$$(5280 + 24(265)) \times .50 = \$5{,}820$$

Slab Replacement - Assume 2%

$$\frac{5280 \times 24}{9} \times .02 \times 55 = \$15{,}488$$

3" Asphalt Overlay @ 20 years = $90,066

2" Asphalt Overlay @ 30 years = $59,747

Remove and Replace Asphalt Shoulders

Remove - $\frac{5280 \times 14}{9} \times 1 = \$8{,}213$

Recondition Base - $\frac{5280 \times 14}{9} \times .20 = \$1{,}643$

Replace - $\frac{\frac{5280 \times 14}{9} \times 330}{2000} \times 24 = \$32{,}524$

CI = Initial Cost	= $107,336
R_1 = Resurfacing 20th year	= $ 90,066
R_2 = Resurfacing 30th year	= $ 59,747
MA = Annual Maintenance Cost	= $ 1,000

PW = Present Worth = $186,655
107,336 + 90,066 (.4564) +
59,747 (.3083) + 1,000 (19.7927)

AC = Annual Cost
186,655 (.0505) = $ 9,426

Thin Bonded Concrete Overlay

Bonded Concrete Overlay - 2½" thick	(sq yd)	= $ 5.00
Slab Replacement	(sq rd)	= $ 55.00
Asphalt Shoulder Overlay - 2½" thick	(ton)	= $ 24.00
Reset Guardrail (Type 3)	(lin ft)	= $ 5.00
Slope Flattening	(lin ft)	= $ 0.50
Maintenance Cost	(lane mile/yr)	= $500.00

Bonded Concrete Overlay

$$\frac{5280 \times 24}{9} \times 5 = \$70,400$$

Slab Replacement - Assume 2% = $15,488

Asphalt Shoulder Overlay

$$\frac{\frac{5280 \times 14}{9} \times 275}{2000} \times 24 = \$27,104$$

Reset Guardrail

1000 x 5 = $5,000

Slope Flattening

5280 x 2 x .50 = $5,280

CI - Initial Cost = $123,272

R_1 = Resurfacing 20th year (2" overlay) = $ 59,747

R_2 = Resurfacing 30th year (2" overlay) = $ 59,747

MA = Annual Maintenance Cost = $ 1,000

PW = Present Worth
123,272 + 59,747 (.4564) +
59,747 (.3083) + 1,000 (19.7927) = $188,753

AC = Annual Cost
188,753 (.0505) = $ 9,532

Thin Asphalt Overlay

Hot Asphalt Pavement - 3" thick	(ton)	= $ 24.00
Tack Coat	(gal)	= $ 0.80
Slab Replacement	(sq yd)	= $ 55.00
Reset Guardrail (Type 3)	(lin ft)	= $ 5.00
Slope Flattening	(lin ft)	= $ 0.50
Maintenance Cost	(lane mile/yr)	= $1,500.00

Asphalt Overlay - 3" thick

$$\frac{\frac{5280 \times 38}{9} \times 330}{2000} \times 24 = \$88,281$$

Tack Coat (CSS-1)

$$\frac{5280 \times 38}{9} \times 0.10 \times 0.80 = \$1,784$$

Slab Replacement - Assume 2% = $15,488

Reset Guardrail

1000 x 5 = $5,000

Slope Flattening

5280 x 2 x .50 = $5,280

CI = Initial Cost = $115,833

R_1 = Resurfacing 15th year (2" Overlay) = $ 59,747

R_2 = Resurfacing 25th year (2" Overlay) = $ 59,747

R_3 = Resurfacing 35th year (1" Overlay) = $ 30,319

MA = Annual maintenance Cost = $ 3,000

PW = Present Worth
115,833 + 59,747 (.5552) +
59,747 (.3751) + 30,319 (.2534) +
3,000 (19,7927) = $238,477

AC = Annual Cost
238,477 (.0505) = $ 12,043

SUMMARY

	Initial Cost	Present Worth	Annual Cost
Diamond Grinding	$107,336	$186,655	$ 9,426
Thin Bonded Concrete	$123,272	$188,753	$ 9,532
Thin Asphalt Overlay	$115,833	$238,477	$12,043

Table 2

SUMMARY OF REHABILITATION METHODS

Distress Type	Recommended Corrective Method(s)
Corner Break	Full Depth Patch
Reactive Aggregate (high)	Thick AC Overlay, Thick Concrete Overlay or Reconstruction
Reactive Aggregate (low)	Thin AC Overlay
Faulting	Underseal, Grind and Reseal Joints
Longitudinal Cracks	Full Depth Patch
Transverse & Diagonal Cracks	Full Depth Patch
Pumping and Water Bleeding	Underseal, Reseal Joints, Drainage Correction
Spalling	Partial Depth Patch, Full Depth Patch, Reseal Joints
Rutting	Grind, Thin AC Overlay, Thin Concrete Overlay
Depressions	Grind, Slab Jacking

Table 3

THICK ASPHALT PAVEMENT OVERLAY VS. THICK PORTLAND CEMENT OVERLAY

A. Thick Asphalt Overlay - Consider as new pavement and follow 602.2 of Design manual for life-cycle cost calculations.

B. Thick PCC Overlay - Two inch overlay at 20 years and one inch overlay at 30 years.*

* Design Manual calls for 2" overlay at 30 years. Thick concrete over old concrete is considered to be better than new concrete construction - reduce 30 year overlay to 1" thickness.

Diamond Grinding vs. Thin-Bonded Concrete Overlay vs. Thin Asphalt Overlay

A. Diamond Grinding -

(1) Grinding <1" - Consider as new pavement

(2) Grinding >1" - 3" overlay @ 20 years
2" overlay @ 30 years

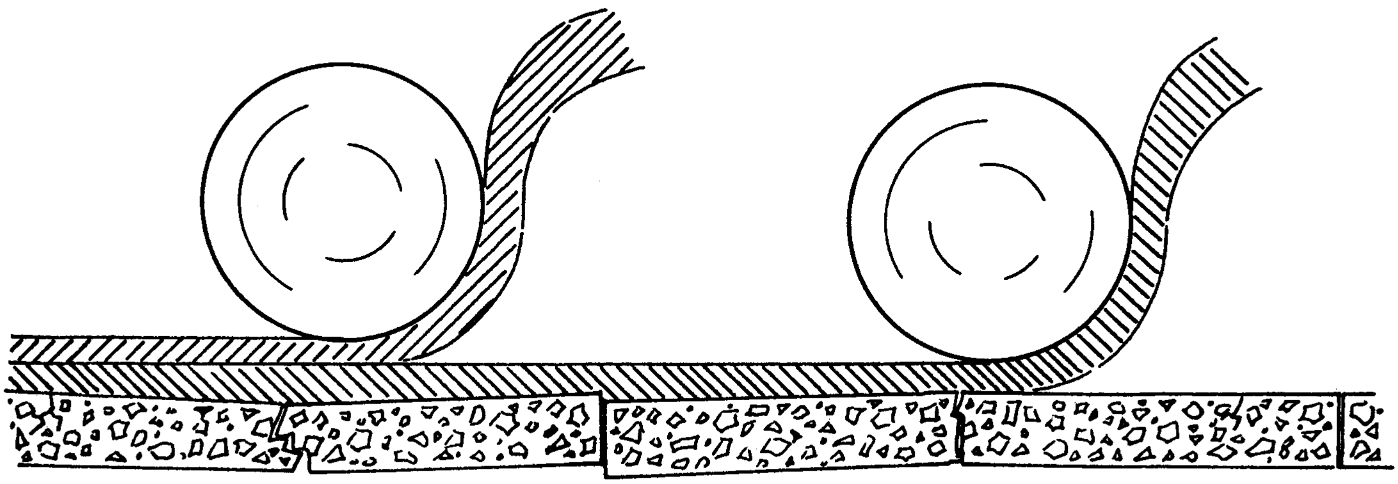
B. Thin Asphalt Overlay - use 3" minimum thickness and consider as new pavement.

C. Thin Bonded Concrete Overlay - Consider as new pavement.

Table 4

1982 COST DATA

Hot Asphalt Pavement	\$24.00 per ton
Crack Relief Layer (Arkansas Method)	\$30.00 per ton
Thick Concrete Overlay (5" to 8")	\$ 1.64 per yd^2/in
Bond Breaker (For Concrete Overlay)	\$ 1.50 per yd^2
Thin Concrete Overlay (2" to 3")	\$ 2.00 per yd^2/in
Joint Reseal	\$ 0.50 per lin. ft.
Full Depth Slab Replacement	\$55.00 per yd^2
Undersealing	\$ 1.80 per yd^2
Diamond Grinding	\$ 3.10 per yd^2
Remove Asphalt Shoulders	\$ 1.00 per yd^2



IMPLEMENTATION

CHAPTER FOUR

IMPLEMENTATION

Thus far, this report has dealt with distress found in Colorado and the associated rehabilitation on a general basis. The implementation section of this report is designed to provide specific suggestions, as made by the project panel, as to the type of rehabilitation recommended for given sections of concrete pavements.

Tables 5 thru 18 list strip charts illustrating the distress observed on each of the inventoried concrete pavements. The tables are divided into each of the districts and interstate routes observed. Since only a cursory review was made of each project with a panel concensus listed the recommendations should be used as appropriate. An in-depth pavement condition survey should be performed on each individual project as they are being considered for rehabilitation.

The top portion of the strip maps illustrated on Tables 1-14 list the projects by milepost. The data listed indicate the nine distress types, the percentage of that distress observed on each project, and the severity of each distress type.

Generic distress types are listed below along with one or more recommended rehabilitation methods. Combinations of these distress types and rehabilitation methods formed the basis for the panel's recommendations which are listed at the bottom of Tables 5 through 18.

Reactive Aggregate

Low - Thin Asphalt Overlay
Dense Graded - 3" Thickness
High - a) Thick Asphalt Overlay
b) Thick Concrete Overlay
c) Remove and Replace

Cracking - Longitudinal, Transverse and Corner Breaks

Isolated Cracks - a) Stabilize slabs and rout and reseal
b) Slab Replacement

Extensive Cracks - a) If associated with reactive aggregates, see Reactive Aggregate above.
b) Stabilize slabs and place thick overlay

Rutting

a) Diamond Grinding, rout and reseal joints
b) Thin Bonded Concrete Overlay
c) Thin Asphalt Overlay - dense graded - 3" thickness plus leveling

Depressions

a) Slab Replacement
b) Diamond Grinding
c) Milling (with overlay)
d) Leveling course (with overlay)

Pumping

Underseal and reseal joints and cracks. May require drainage correction.

Spalling

a) Full depth patch with load transfer device
b) Partial depth patching

Faulting

a) Underseal, diamond grind and reseal joints and cracks
b) Diamond grind and reseal joints and cracks

Shoulder Rehabilitation

If driving lanes are to be overlayed, then overlay shoulders also.

If driving lanes are to be rehabilitated without overlay, then remove and replace asphalt shoulders. The replaced shoulders can be either asphalt or concrete doweled into driving lane.

TABLE 5

CONCRETE PAVEMENT LOG

PERCENTAGE OF PAVEMENT DISTRESS - I25/DIST 2

MILEPOST	27.5 — 41.1
DISTRESS TYPE	
REACTIVE AGG.	
LONG.CRACKING	
TRANS.CRACKING	
RUTTING	<--100%L -->
DEPRESSIONS	<-- 10%M -->
PUMPING	<-- 70%M -->
SPALLING	<-- 10%L -->
FAULTING	<--100%H -->
CORNER BREAKS	
REHABILITATION ALTERNATIVES:	
THICK AC OVERLAY	<----------->
THICK PCC OVERLAY	<----------->
THIN AC OVERLAY	
THIN PCC OVERLAY	
SURFACE CORRECT.	<----------->
RECONSTRUCTION	

NOTE; H-HIGH, M-MEDIUM, L-LOW SEVERITY

TABLE 6

CONCRETE PAVEMENT LOG

PERCENTAGE OF PAVEMENT DISTRESS - I25 N

MILEPOST	235.4 – 243.7	243.7 – 250.7	250.7 – 256.8	256.8 – 268.2
DISTRESS TYPE				
REACTIVE AGG.				100%H
LONG.CRACKING	90%M	75%M	75%M	90%M
TRANS.CRACKING	20%M	25%M	25%M	30%M
RUTTING	100%H	100%H	100%H	100%H
DEPRESSIONS	2%L	5%L	5%L	5%L
PUMPING				
SPALLING	50%L	50%L	5%L	5%L
FAULTING			25%L	
CORNER BREAKS	5%L	10%L	10%L	
REHABILITATION ALTERNATIVES				
THICK AC OVERLAY	<----------->	<----------->	<----------->	<----------->
THICK PC OVERLAY	<----------->	<----------->	<----------->	<----------->
THIN AC OVERLAY				
THIN PCC OVERLAY				
SURFACE CORRECT.				
RECONSTRUCTION				

NOTE; H-HIGH, M-MEDIUM, L-LOW SEVERITY

TABLE 7

CONCRETE PAVEMENT LOG

PERCENTAGE OF PAVEMENT DISTRESS - I25 N

MILEPOST	268.2 – 271.5	271.5 – 282.0	282.0 – 298.9
DISTRESS TYPE			
REACTIVE AGG.		50%L	100%H
LONG.CRACKING	10%L	5%L	20%L
TRANS.CRACKING	2%L	2%L	10%L
RUTTING	100%H	100%L	100%L
DEPRESSIONS			
PUMPING			
SPALLING			
FAULTING	50%L	30%L	
CORNER BREAKS			
REHABILITATION ALTERNATIVES:			
THICK AC OVERLAY			<----------->
THICK PC OVERLAY			<----------->
THIN AC OVERLAY	<----------->	<----------->	
THIN PCC OVERLAY			
SURFACE CORRECT.	<----------->	<----------->	
RECONSTRUCTION			

NOTE; H-HIGH, M-MEDIUM, L-LOW SEVERITY

TABLE 8

CONCRETE PAVEMENT LOG

PERCENTAGE OF PAVEMENT DISTRESS - I70/DIST 6

MILEPOST	259.2 – 262.5	262.5 – 265.9	265.9 – 269.6	269.6 – 274.0
DISTRESS TYPE				
REACTIVE AGG.				
LONG.CRACKING	5%L	10%L	10%L	10%L
TRANS.CRACKING	5%L	5%L	5%L	
RUTTING	100%H	100%M	100%H	100%H
DEPRESSIONS				
PUMPING			5%L	
SPALLING		2%L	5%L	5%L
FAULTING	100%H		100%H	100%H
CORNER BREAKS	5%L	1%L	5%L	
REHABILITATION ALTERNATIVES:				
THICK AC OVERLAY	<---------->		<---------->	<---------->
THICK PC OVERLAY	<---------->		<---------->	<---------->
THIN AC OVERLAY		<---------->		
THIN PCC OVERLAY		<---------->		
SURFACE CORRECT.	<---------->	<---------->	<---------->	<---------->
RECONSTRUCTION				

NOTE; H-HIGH, M-MEDIUM, L-LOW SEVERITY

TABLE 9

CONCRETE PAVEMENT LOG

PERCENTAGE OF PAVEMENT DISTRESS - I70/DIST 6

MILEPOST	277.1 – 277.4	277.4 – 279.3	279.3 – 283.3	283.3 – 286.6
DISTRESS TYPE				
REACTIVE AGG.			100%L	100%L
LONG.CRACKING	10%H	50%L	40%L	85%M
TRANS.CRACKING		10%L	20%L	20%M
RUTTING	100%H	100%H	100%M	100%M
DEPRESSIONS				
PUMPING				
SPALLING	5%L	5%L	10%L	5%L
FAULTING				100%M
CORNER BREAKS		2%L	2%L	25%M
REHABILITATION ALTERNATIVES:				
THICK AC OVERLAY		<---------->	<---------->	<---------->
THICK PC OVERLAY		<---------->	<---------->	<---------->
THIN AC OVERLAY	<---------->			
THIN PCC OVERLAY	<---------->			
SURFACE CORRECT.	<---------->			
RECONSTRUCTION				

NOTE; H-HIGH, M-MEDIUM, L-LOW SEVERITY

TABLE 10

CONCRETE PAVEMENT LOG

PERCENTAGE OF PAVEMENT DISTRESS - I70/DIST I

MILEPOST	293.8 – 306.4	306.4 – 318.4	318.4 – 323.0	323.0 – 330.8
DISTRESS TYPE				
REACTIVE AGG.		<-- 10%L -->		
LONG.CRACKING	<-- 30%H -->	<-- 50%H -->	<-- 5%L -->	<-- 30%L -->
TRANS.CRACKING	<-- 15%M -->	<-- 30%H -->	<-- 5%L -->	
RUTTING	<--100%L -->	<--100%L -->	<--100%L -->	<--100%L -->
DEPRESSIONS	<-- 30%L -->	<-- 50%L -->		
PUMPING				
SPALLING	<-- 80%L -->	<-- 20%L -->	<-- 80%L -->	<-- 40%L -->
FAULTING	<-- 5%L -->	<-- 80%H -->	<--100%H -->	<-- 80%M -->
CORNER BREAKS	<-- 1%L -->	<-- 5%M -->	<-- 1%M -->	<-- 80%M -->
REHABILITATION ALTERNATIVES:				
THICK AC OVERLAY	<---------->	<---------->	<---------->	<---------->
THICK PC OVERLAY	<---------->	<---------->	<---------->	<---------->
THIN AC OVERLAY				
THIN PCC OVERLAY				
SURFACE CORRECT.			<---------->	
RECONSTRUCTION				

NOTE; H-HIGH, M-MEDIUM, L-LOW SEVERITY

TABLE 11

CONCRETE PAVEMENT LOG

PERCENTAGE OF PAVEMENT DISTRESS - I70

MILEPOST	330.8 – 337.9	337.9 – 358.4 Eastbound	358.4 – 337.9 XXXXXXXX	337.9 – 340.6 Westbound
DISTRESS TYPE				
REACTIVE AGG.		<-- 20%L -->		
LONG.CRACKING	<-- 65%L -->	<-- 15%M -->		<-- 50%M -->
TRANS.CRACKING	<-- 5%L -->	<-- 40%L -->		<-- 50%M -->
RUTTING	<--100%L -->	<--100%L -->		<--100%L -->
DEPRESSIONS		<-- 80%H -->		
PUMPING	<-- 20%L -->			
SPALLING	<-- 80%M -->	<-- 10%L -->		<-- 70%M -->
FAULTING	<-- 90%H -->	<--100%M -->		<--100%H -->
CORNER BREAKS	<--60%M -->	<-- 5%L -->		<-- 15%M -->
REHABILITATION ALTERNATIVES:				
THICK AC OVERLAY	<---------->	<---------->		<---------->
THICK PC OVERLAY	<---------->	<---------->		<---------->
THIN AC OVERLAY				
THIN PCC OVERLAY				
SURFACE CORRECT.				
RECONSTRUCTION				

NOTE; H-HIGH, M-MEDIUM, L-LOW SEVERITY

TABLE 12

CONCRETE PAVEMENT LOG

PERCENTAGE OF PAVEMENT DISTRESS - I70

MILEPOST	402.9 – 428.2	428.2 – 402.9	402.9 – 428.2	428.2 – 437.5
	Eastbound	XXXXXXXXX	Westbound	
DISTRESS TYPE				
REACTIVE AGG.	<--100%H -->			<--100%H -->
LONG.CRACKING	<-- 5%L -->		<-- 1%L -->	<-- 90%L -->
TRANS.CRACKING	<-- 20%L -->		<-- 1%L -->	<-- 5%L -->
RUTTING	<--100%L -->		<--100%L -->	<--100%L -->
DEPRESSIONS	<-- 5%L -->			
PUMPING				
SPALLING	<-- 5%L -->			<-- 50%L -->
FAULTING				
CORNER BREAKS				
REHABILITATION ALTERNATIVES:				
THICK AC OVERLAY	<----------->			<----------->
THICK PC OVERLAY	<----------->			<----------->
THIN AC OVERLAY			<----------->	
THIN PCC OVERLAY			<----------->	
SURFACE CORRECT.			<----------->	
RECONSTRUCTION				<----------->

NOTE: H-HIGH, M-MEDIUM, L-LOW SEVERITY

TABLE 13

CONCRETE PAVEMENT LOG

PERCENTAGE OF PAVEMENT DISTRESS - I76

MILEPOST	6.8 – 9.8	9.8 – 12.5	12.5 – 31.4	31.4 – 45.0
			XXXXXXXXX	
DISTRESS TYPE				
REACTIVE AGG.				
LONG.CRACKING				<-- 5%L -->
TRANS.CRACKING				<-- 2%L -->
RUTTING	<--100%M -->	<--100%L -->		<-- 100%L-->
DEPRESSIONS				<-- 5%L-->
PUMPING				
SPALLING	<-- 80%L -->	<-- 90%M -->		<-- 30%L-->
FAULTING				
CORNER BREAKS				
REHABILITATION ALTERNATIVES:				
THICK AC OVERLAY				
THICK PC OVERLAY				
THIN AC OVERLAY	<---------->	<---------->		<---------->
THIN PCC OVERLAY				
SURFACE CORRECT.	<---------->	<---------->		<---------->
RECONSTRUCTION				

NOTE; H-HIGH, M-MEDIUM, L-LOW SEVERITY

TABLE 14

CONCRETE PAVEMENT LOG

PERCENTAGE OF PAVEMENT DISTRESS - I76

MILEPOST	45.0 – 50.1	50.1 – 56.8	56.8 – 63.1	63.1 – 67.0
DISTRESS TYPE				
REACTIVE AGG.	<--100%L -->	<--100%L -->	<--100%L -->	<--100%L -->
LONG.CRACKING	<-- 5%L -->	<--100%L -->	<--100%L -->	<--100%L -->
TRANS.CRACKING	<-- 2%L -->	<-- 1%L -->		<-- 1%L -->
RUTTING	<--100%L -->	<--100%L -->	<--100%L -->	<--100%L -->
DEPRESSIONS				
PUMPING				
SPALLING	<-- 40%L -->			<-- 10%L -->
FAULTING			<-- 50%L-->	
CORNER BREAKS				
REHABILITATION ALTERNATIVES:				
THICK AC OVERLAY		<----------->	<----------->	<----------->
THICK PC OVERLAY		<----------->	<----------->	<----------->
THIN AC OVERLAY	<----------->			
THIN PCC OVERLAY				
SURFACE CORRECT.				
RECONSTRUCTION				

NOTE; H-HIGH, M-MEDIUM, L-LOW SEVERITY

TABLE 15

CONCRETE PAVEMENT LOG

PERCENTAGE OF PAVEMENT DISTRESS - I76

MILEPOST	67.0 – 74.2	74.2 – 91.5	91.5 – 115.2	115.2 – 125.2
DISTRESS TYPE				
REACTIVE AGG.				<--100%L -->
LONG.CRACKING		<-- 2%L -->	<-- 10%L -->	<-- 30%L -->
TRANS.CRACKING		<-- 5%L -->		
RUTTING				
DEPRESSIONS				
PUMPING				
SPALLING	<-- 10%L -->	<-- 5%M -->		<-- 5%L -->
FAULTING			<-- 50%L -->	
CORNER BREAKS				
REHABILITATION ALTERNATIVES:				
THICK AC OVERLAY				
THICK PC OVERLAY				
THIN AC OVERLAY				<---------->
THIN PCC OVERLAY				
SURFACE CORRECT.	<---------->	<---------->	<---------->	
RECONSTRUCTION				

NOTE; H-HIGH, M-MEDIUM, L-LOW SEVERITY

TABLE 16

CONCRETE PAVEMENT LOG

PERCENTAGE OF PAVEMENT DISTRESS - I76

MILEPOST	125.2 – 149.0	149.0 – 165.0	165.0 – 180.3	180.3 – 184.1
DISTRESS TYPE				
REACTIVE AGG.	<--100%H -->			<--100%L -->
LONG.CRACKING	<--100%M -->		<-- 2%L -->	
TRANS.CRACKING	<-- 10%L -->	<-- 2%L -->	<-- 50%L -->	<-- 50%L -->
RUTTING	<--100%L -->			
DEPRESSIONS				
PUMPING				
SPALLING	<-- 5%L -->	<-- 5%L -->	<-- 5%L -->	<-- 10%L -->
FAULTING	<-- 50%L -->	<--100%L -->	<--100%L -->	<-- 30%L -->
CORNER BREAKS	<-- 20%L -->	<-- 2%L -->		
REHABILITATION ALTERNATIVES:				
THICK AC OVERLAY	<---------->		<---------->	<---------->
THICK PC OVERLAY	<---------->		<---------->	<---------->
THIN AC OVERLAY				
THIN PCC OVERLAY				
SURFACE CORRECT.		<---------->	<---------->	
RECONSTRUCTION				

NOTE; H-HIGH, M-MEDIUM, L-LOW SEVERITY

TABLE 17

CONCRETE PAVEMENT LOG

PERCENTAGE OF PAVEMENT DISTRESS - I225

MILEPOST	3.9 – 7.0	7.0 – 9.1	9.1 – 12.2
DISTRESS TYPE			
REACTIVE AGG.			
LONG.CRACKING		<-- 5%L -->	<-- 5%L -->
TRANS.CRACKING		<-- 1%L -->	
RUTTING	<--100%L -->	<--100%M -->	<--100%M -->
DEPRESSIONS		<-- 5%L -->	
PUMPING			
SPALLING	<-- 50%L -->		<-- 40%M -->
FAULTING			<--100%L -->
CORNER BREAKS			
REHABILITATION ALTERNATIVES:			
THICK AC OVERLAY			
THICK PC OVERLAY			
THIN AC OVERLAY	<----------->	<----------->	
THIN PCC OVERLAY	<----------->	<----------->	
SURFACE CORRECT.	<----------->	<----------->	<----------->
RECONSTRUCTION			

NOTE; H-HIGH, M-MEDIUM, L-LOW SEVERITY

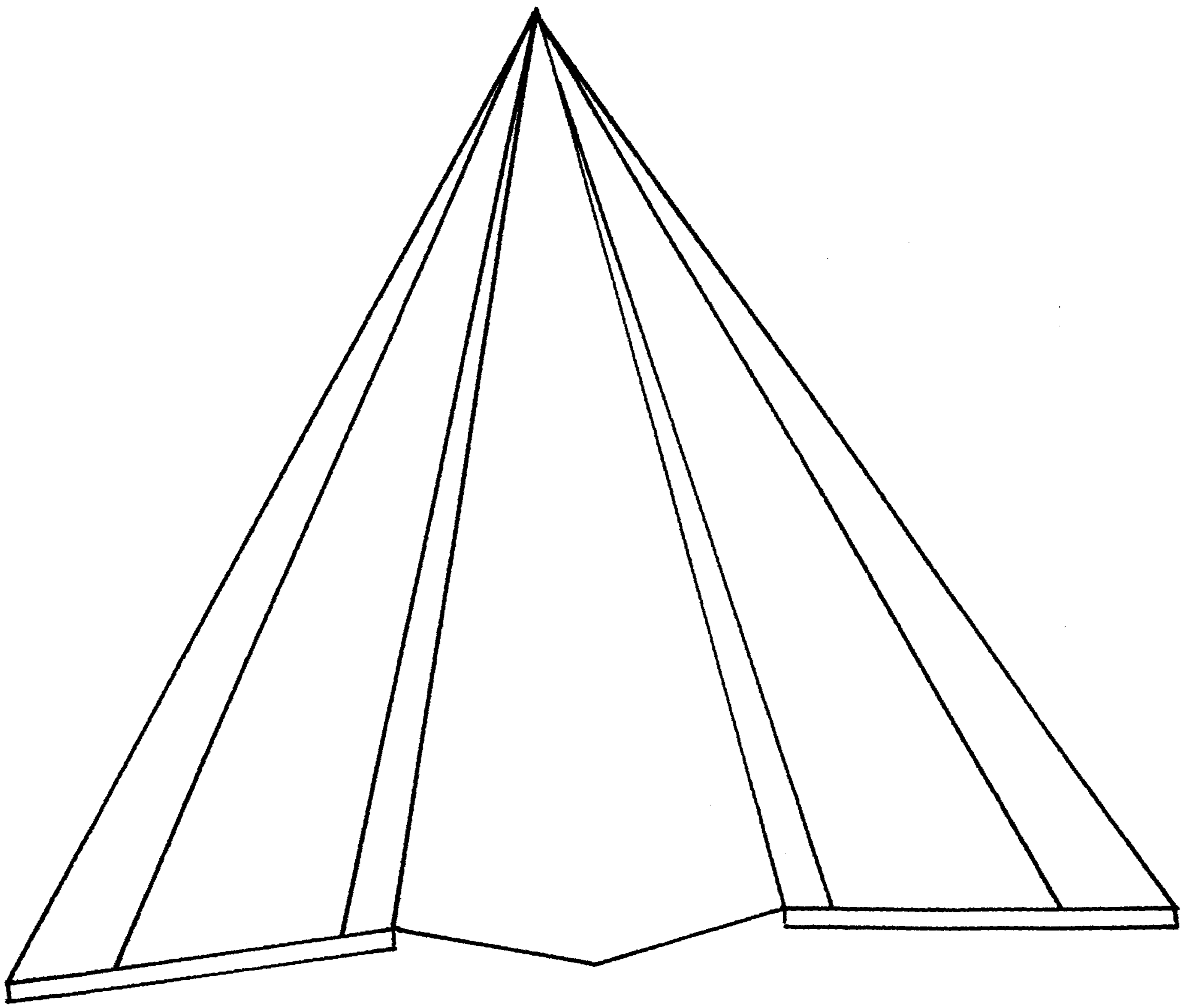
TABLE 18

CONCRETE PAVEMENT LOG

PERCENTAGE OF PAVEMENT DISTRESS - I270

MILEPOST	0.05 – 5.2
DISTRESS TYPE	
REACTIVE AGG.	
LONG.CRACKING	<-- 15%L -->
TRANS.CRACKING	<-- 15%L -->
RUTTING	<--100%M -->
DEPRESSIONS	
PUMPING	
SPALLING	<-- 30%L -->
FAULTING	
CORNER BREAKS	
REHABILITATION ALTERNATIVES:	
THICK AC OVERLAY	
THICK PCC OVERLAY	
THIN AC OVERLAY	<---------->
THIN PCC OVERLAY	
SURFACE CORRECT.	<---------->
RECONSTRUCTION	

NOTE; H-HIGH, M-MEDIUM, L-LOW SEVERITY



CONCLUSION

CHAPTER FIVE

CONCLUSIONS

Plain jointed concrete pavement has provided satisfactory service and we should continue its use. The decision to use it rather than continuously reinforced pavement was a good choice for Colorado. Examination has shown that most concrete pavements in the State have successfully served over their design life. Careful selection of rehabilitation methods will provide substantially longer service lives.

Numerous rehabilitation methods were examined during the course of this study. These methods were described in the available literature and by representatives of various product manufacturers. Not all of the methods studied apply to Colorado, only those which do were selected for inclusion in this report. The recommended rehabilitation methods will provide for long term design life given the distress mechanisms found in Colorado. These methods will not only test the symptoms but also the rudimentary causes of the distress. This will cure and prevent recurrence of the identified problems.

It is the opinion of the panel conducting this study that the significant sources of distress in the State of Colorado are studded tires, heavy loads, moisture and reactive aggregates. Future concrete pavement projects, rehabilitation projects and maintenance can be designed or otherwise programed to overcome all but damage from studded tires. It is recommended that legislation preventing the year round use of studded snow tires be pursued by the Department.

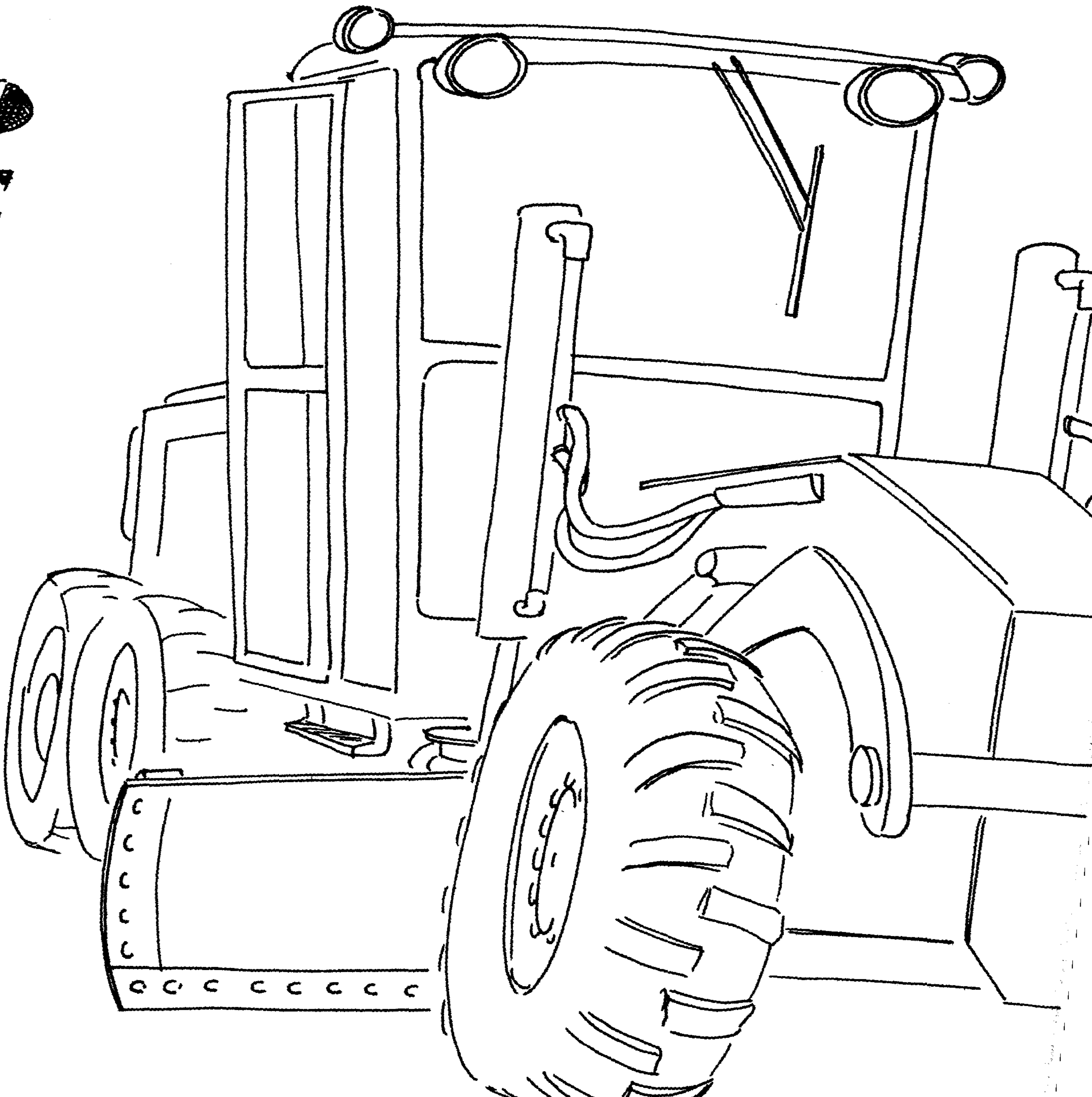
It is also recommended that programs be developed for further study of the following subjects:

- Current and future concrete pavement rehabilitation projects be observed and evaluated.

- The interaction of fly ash with concrete containing reactive aggregates be studied.

- A method of locating and identifying reactive aggregates should be established.

DESIGN AND MAINTENANCE RECOMMENDATIONS



CHAPTER SIX

RECOMMENDATIONS

State-of-the-Art overlay thickness equations for concrete overlays are included in Appendix B. These guideline equations were obtained from the publication, "Techniques for Pavement Rehabilitation-Training Course", Federal Highway Administration, as revised. These guidelines should be used when designing concrete pavement overlays.

The study panel felt that the design of asphalt overlays should incorporate the procedures found in the publication, "Asphalt Overlays for Heavily-Trafficked PCC Pavements", The Asphalt Institute, February, 1981, Information Series Number 177. Appendix C contains the thickness chart listed in that publication.

Guidelines for determining detailed existing conditions for specific projects are listed in Appendix D.

Design Recommendations

Field observations by the project panel have produced the following design recommendations:

> The plastic parting strip now allowed for use in some joints should no longer be used. This strip has not and apparently cannot be placed to form an acceptable joint. The parting strips observed by the panel have curled or bent, causing non-vertical joints and have exhibited a propensity to spall having a rough surface open to water intrusion. Sawing is recommended for all longitudinal and transverse joints.
>
> Future concrete pavement projects should be full width, with concrete shoulders. Asphalt pavement shoulders are maintenance headaches and sources of moisture intrusion under the concrete slabs.

The current practice or random spacing of transverse points between sixteen to eighteen feet should be continued.

Curb and gutter sections placed in conjunction with concrete pavement should be used where feasible. This practice can result in as much as a 30% reduction in required pavement depth.

The current angle and direction of transverse joint skew should be studied. The current design, subjected to heavy traffic, leads to corner curl and subsequent corner breaks. Reversal of the skew should eliminate the curl in rural, low volume areas, but could cause problems for snow plow operations. The possible solution could be in retaining the same skew direction, but reduction of the angle.

The current Colorado Department of Highways design manual (Section 602.2) should be used except where modified by this report.

In areas or conditions where reactive aggregate problems are known to exist, an additive such as fly ash, should be used on a routine basis.

Maintenance Recommendations

An improved maintenance program on existing H.B.P. shoulders should be developed to seal the pavement surface and to seal the longitudinal joint along the edge of the concrete pavement.

Joints and large cracks in concrete pavements should be kept sealed using a high quality joint sealing material.

BIBLIOGRAPHY AND LIST OF REFERENCES

"National Seminar on Portland Cement Concrete Pavement Recycling and Rehabilitation," Transportation Research Board/ Federal Highway Administration, September 27-30, 1981, St. Louis, Missouri.

Smith, R. E., et. al., "Highway Pavement Distress Identification Manual," Federal Highway Administration, March 1979.

Darter, M. I., et. al., "Techniques for Pavement Rehabilitation - Training Course," Federal Highway Administration, as revised.

"Asphalt Overlays for Heavily-Trafficked PCC Pavements," The Asphalt Institute, February 1981, IS 177.

Darter, M.I., et. al., "Evaluation of Joint Repair Methods for Portland Cement Concrete Pavements," Transportation Research Board, February 1981.

Basha, M. A., "Rigid Pavement Repair Techniques," Utah Department of Transportation, July 1979.

"Rehabilitation Demonstration Project - New Mexico," American Concrete Pavement Association, July 1981.

"Wisconsin's Rehabilitation and Evaluation Project," American Concrete Pavement Association, February 1982.

Thornton, J. B. and Gulden, W., "Pavement Restoration Measures to Precede Joint Resealing," Georgia Department of Transportation, January 1980.

Temple, W. H. and Rasoulian, M., "Thin Bonded P.C.C. Resurfacing," Interim and Summary Report, April 1982.

Nan Jim Chen, et. al., "Finite Element Analysis of Arizona's Three-Layer Overlay System of Rigid Pavements to Prevent Reflective Cracking," Arizona Department of Transportation, February 1982.

Pumphrey, N. D., "Relief Layer Reduces Reflective Cracking," Arkansas Highway and Transportation Department, July 1982 "Public Works" magazine.

Gulden, W. and Brown, D., "Treatments for Reduction of Reflective Cracking of Asphalt Overlays over Jointed Concrete Pavements in Georgia," Georgia Department of Transportation, 1983.

A P P E N D I X

APPENDIX A

Concrete Pavement Rehabilitation Survey Form

CONCRETE PAVEMENT REHABILITATION SURVEY FORM

INTERSTATE NO. ______________ LOCATION ______________

DIRECTION ______________ PROJECT NO. ______________

DISTRICT ______________ M.P. ______________ M.P. ______________

DATE CONSTRUCTED ______________ AGE ______________

DESIGN TRAFFIC ______________ TOTAL TRAFFIC ______________

DESIGN INFORMATION

CONCRETE

THICKNESS		
MODULUS OF RUPTURE	PSI	
AGGREGATE TYPE	CRUSHED	
	ROUNDED	
AGGREGATE MAXIMUM SIZE		
CONCRETE CLASS		

BASE

THICKNESS	
TYPE	
STRENGTH (R-R_T-PSI)	
ASPHALT (TYPE & GRADE)	
% ASPHALT (BY TOTAL WEIGHT)	
CEMENT CONTENT (LBS/CUBIC YARD)	
CLASS OR GRADING	

SUB-GRADE

SOIL TYPE (TYPICAL) (AASHTO)	
NARRATIVE	
SWELLING SOIL (YES OR NO)	
SOIL STRENGTH (TYPICAL) ("R")	

DISTRESS EVALUATION

TYPE	SEVERITY	AMOUNT
REACTIVE AGGREGATES		
LONGITUDINAL CRACKING		
TRANSVERSE CRACKING		
RUTTING		
DEPRESSION		
PUMPING & WATER BLEEDING		
SPALLING		
FAULTING		
CORNER BREAKS		
OTHER		

SEVERITY: RATE L - Low Severity Level
M - Medium Severity Level
H - High Severity Level

AMOUNT: RATE APPROXIMATE PERCENTAGE

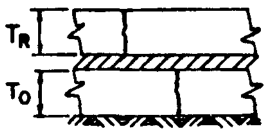
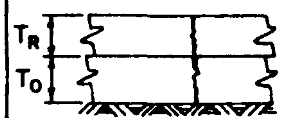
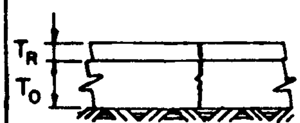
RATER ______________________

DATE ______________________

APPENDIX B

Concrete Overlay Guidelines

CONCRETE OVERLAYS ON CONCRETE PAVEMENT

TYPE OF OVERLAY	UNBONDED OR SEPARATED OVERLAY	PARTIALLY BONDED OR DIRECT OVERLAY	BONDED OR MONOLITHIC OVERLAY
			
PROCEDURE	CLEAN SURFACE DEBRIS AND EXCESS JOINT SEAL PLACE SEPARATION COURSE-PLACE OVERLAY CONCRETE.	CLEAN SURFACE DEBRIS AND EXCESS JOINT SEAL AND REMOVE EXCESSIVE OIL AND RUBBER-PLACE OVERLAY CONCRETE	SCARIFY ALL LOOSE CONCRETE, CLEAN JOINTS, CLEAN AND ACID ETCH SURFACE-PLACE BONDING GROUT AND OVERLAY CONCRETE.
MATCHING OF JOINTS IN OVERLAY & PAVEMENT — LOCATION	NOT NECESSARY	REQUIRED	REQUIRED
MATCHING OF JOINTS IN OVERLAY & PAVEMENT — TYPE	NOT NECESSARY	NOT NECESSARY	REQUIRED
REFLECTION OF UNDERLYING CRACKS TO BE EXPECTED	NOT NORMALLY	USUALLY	YES
REQUIREMENT FOR STEEL REINFORCEMENT	REQUIREMENT IS INDEPENDENT OF THE STEEL IN EXISTING PAVEMENT OR CONDITION OF EXISTING PAVEMENT.	REQUIREMENT IS INDEPENDENT OF THE STEEL IN EXISTING PAVEMENT. STEEL MAY BE USED TO CONTROL CRACKING WHICH MAY BE CAUSED BY LIMITED NON-STRUCTURAL DEFECTS IN PAVEMENT.	NORMALLY NOT USED IN THIN OVERLAYS. IN THICKER OVERLAY STEEL MAY BE USED TO SUPPLEMENT STEEL IN EXISTING PAVEMENT.
FORMULA FOR COMPUTING THICKNESS OF OVERLAY (T_r) NOTE: T IS THE THICKNESS OF MONOLITHIC PAVEMENT REQUIRED FOR THE DESIGN LOAD ON THE EXISTING SUPPORT C IS A STRUCTURAL CONDITION FACTOR T_R SHOULD BE BASED ON THE FLEXURAL STRENGTH OF	$T_r = \sqrt{T^2 - C T_0^2}$ OVERLAY CONCRETE	$T_r = \sqrt[1.4]{T^{1.4} - C T_0^{1.4}}$ OVERLAY CONCRETE	$T_r = T - T_0$ NOTE: THE ABILITY OF THE OVERLAID SLAB TO TRANSFER LOAD AT THE JOINTS SHOULD BE ASSESSED SEPARATELY EXISTING CONCRETE
MINIMUM THICKNESS	6"	5"	1"
APPLICABILITY OF VARIOUS OVERLAY TYPES — STRUCTURAL CONDITION OF EXISTING PAVEMENT — NO STRUCTURAL DEFECTS C = 1.0*	YES	YES	YES
APPLICABILITY OF VARIOUS OVERLAY TYPES — STRUCTURAL CONDITION OF EXISTING PAVEMENT — LIMITED STRUCT. DEFECTS C = 0.75*	YES	ONLY IF DEFECTS CAN BE REPAIRED	ONLY IF DEFECTS CAN BE REPAIRED
APPLICABILITY OF VARIOUS OVERLAY TYPES — STRUCTURAL CONDITION OF EXISTING PAVEMENT — SEVERE STRUCT. DEFECTS C = 0.35*	YES	NO	NO
APPLICABILITY OF VARIOUS OVERLAY TYPES — SURFACE CRACKS, SCALING, SPALLING AND SHRINKAGE CRACKS — NEGLIGIBLE	YES	YES	YES
APPLICABILITY OF VARIOUS OVERLAY TYPES — SURFACE CRACKS, SCALING, SPALLING AND SHRINKAGE CRACKS — LIMITED	YES	YES	YES
APPLICABILITY OF VARIOUS OVERLAY TYPES — SURFACE CRACKS, SCALING, SPALLING AND SHRINKAGE CRACKS — EXTENSIVE	YES	NO	YES

* C VALUES APPLY TO STRUCTURAL CONDITION ONLY, AND SHOULD NOT BE INFLUENCED BY SURFACE DEFECTS.

Summary of concrete overlays on concrete pavement

APPENDIX C

Asphalt Overlay Guidelines

FLOW CHART

DESIGN OF H.B.P. OVERLAY

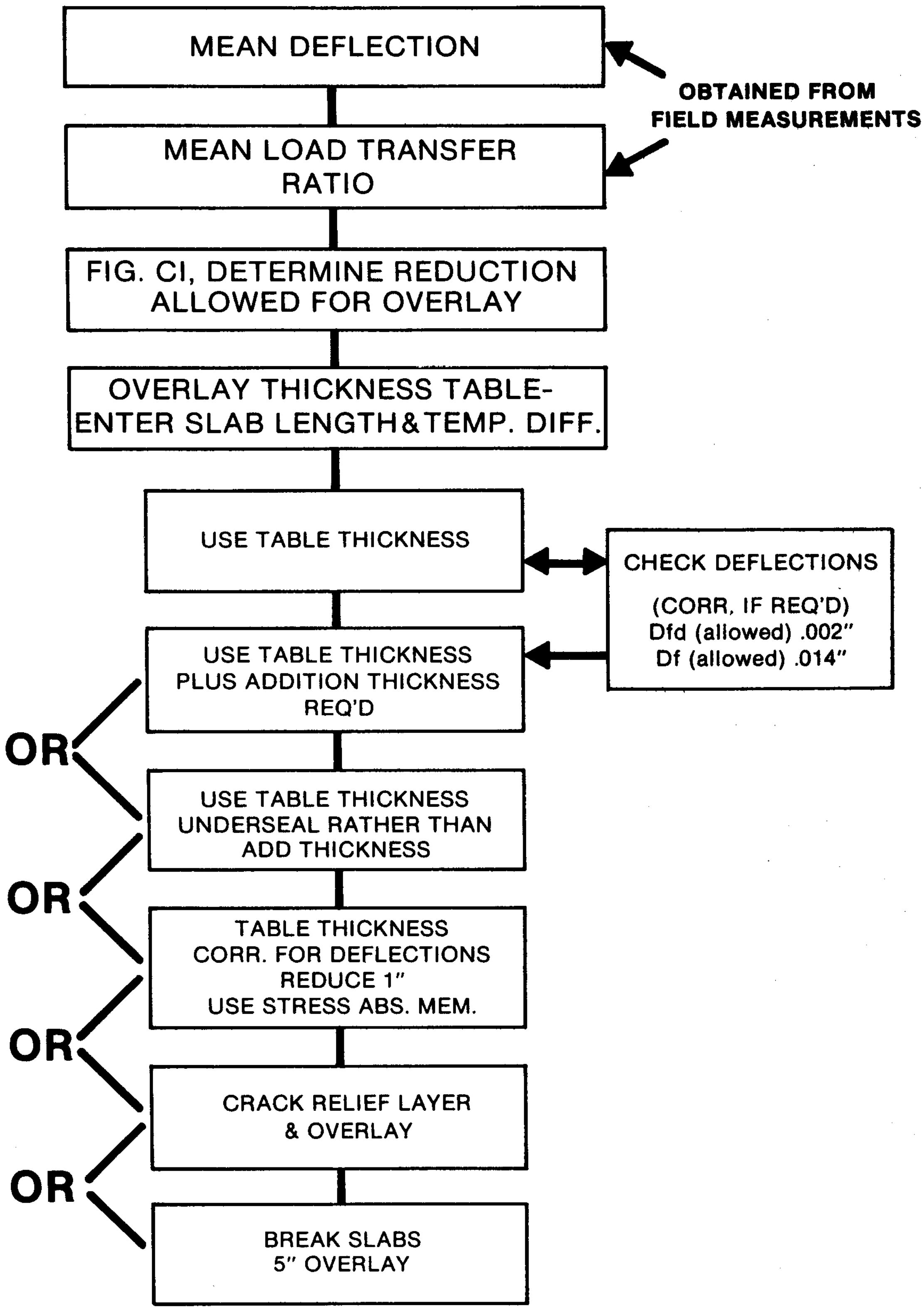
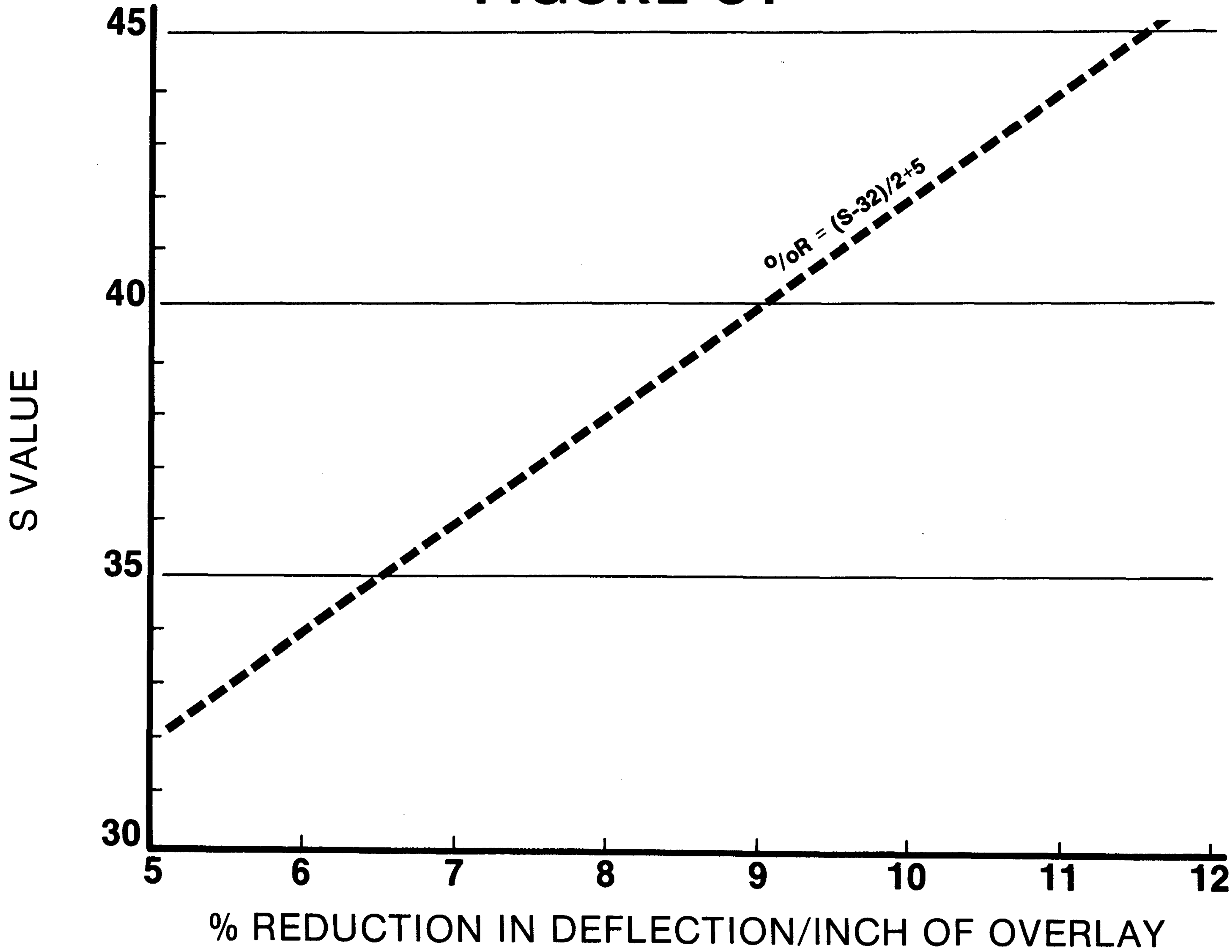


FIGURE C1



DENSE GRADED CRUSHED AGGREGATE

TEMPERATURE DIFFERENTIAL* (°F)

Slab Length (Ft)	30	40	50	60	70	80
10 or Less	10cm (4 in.)	10cm (4 in.)	10cm (4 in.)	10cm (4 in.)	10cm (4 in.)	10cm (4 in.)
15	10cm (4 in.)	10cm (4 in.)	10cm (4 in.)	10cm (4 in.)	10cm (4 in.)	10cm (4 in.)
20	10cm (4 in.)	10cm (4 in.)	10cm (4 in.)	10cm (4 in.)	13cm (5 in.)	14cm (5.5 in.)
25	10cm (4 in.)	10cm (4 in.)	10cm (4 in.)	13cm (5 in.)	15cm (6 in.)	18cm (7 in.)
30	10cm (4 in.)	10cm (4 in.)	13cm (5 in.)	15cm (6 in.)	18cm (7 in.)	20cm (8 in.)
35	10cm (4 in.)	11.5cm (4.5 in.)	15cm (6 in.)	18cm (7 in.)	21.5cm (8.5 in.)	Use Alternative 2 or 3
40	10cm (4 in.)	14cm (5.5 in.)	18cm (7 in.)	20cm (8 in.)	Use Alternative 2 or 3	Use Alternative 2 or 3
45	11.5cm (4.5 in.)	15cm (6 in.)	19cm (7.5 in.)	23cm (9 in.)	Use Alternative 2 or 3	Use Alternative 2 or 3
50	13cm (5 in.)	18cm (7 in.)	21.5cm (8.5 in.)	Use Alternative 2 or 3	Use Alternative 2 or 3	Use Alternative 2 or 3
60	15cm (6 in.)	20cm (8 in.)	Use Alternative 2 or 3	Use Alternative 2 or 3	Use Alternative 2 or 3	Use Alternative 2 or 3

***Temperature differential (Δt) is the difference between the highest normal daily maximum temperature and the lowest normal daily minimum temperature for the hottest and coldest months, based on a 30-year average. See Tables 1 and 2 for maximum and minimum daily temperature at locations throughout the United States.**

Denver has a temperature differential of 71.2°F.

Alternative No. 2 is: Reduce slab length.
Alternative No. 3 is: Use crack relief layer.

APPENDIX D

Concrete Pavement Condition Survey

CONCRETE PAVEMENT CONDITION SURVEY

A detailed concrete pavement condition survey is required before a rehabilitation project can be evaluated and designed. The types of distress in concrete pavements have to be identified and documented prior to the selection of corrective measures. The causes of distress are not always easily identified and may consist of a combination of problems. The following types of distress are common to deteriorating concrete pavements: excessive deflection, differential deflection at joints, moisture related distress at cracks and joints, cracking due to reactive aggregate, longitudinal and transverse cracking, spalling, faulting, pumping, rutting, movement of slabs due to swelling soils. The condition survey should identify and document the types, location, and amount of distress encountered in the project selected for rehabilitation. Photographs are a good way to document many of the distresses mentioned above.

A detailed analysis should include investigation of the following:

RIDEABILITY

Rideability can be measured with equipment such as roughometer or profilometer. The rideability can also be assessed by a person, or group, traveling the pavement in an automobile, and rating the pavement during the ride. The rating can be translated into a Present Serviceability Rating.

DEFLECTION MEASUREMENTS (Structural Evaluation)

Deflection of the existing pavement can be measured with the Dynaflect or the Benkleman Beam. For divided highways, deflections should be measured in the outermost wheel path. Although measurements may be taken at any time of the year, they should reflect the pavement condition in the most severe environmental condition.

The environmental conditions affecting pavements most adversely occur in the spring of the year, therefore, measurements taken in other seasons require adjustments. In analyzing concrete pavements, additional deflection measurements should be made at corners, joints, cracks, and deteriorated pavement areas, to determine load transfer capabilities. This information may indicate the need for undersealing.

CRACKING, FAULTING, SPALLING, PUMPING

Figure D-1 illustrates a typical Pavement Condition Survey Form. A form similar to the example can be used to document the extent of distress such as cracking, faulting, spalling, and pumping.

Typical sections should be isolated and measured in detail. The number and length of these sections will depend on the length and complexity of the project. A sufficient number of sections should be taken to adequately represent the entire project. Measuring approximately five percent of the project in detail may be sufficient to represent the entire project. For example: a 250-foot section, selected at random, per two lane mile of concrete pavement.

CORES, BASE SAMPLES, SUBGRADE SAMPLES

Concrete pavement cores, base samples, and subgrade samples should be taken for analysis if slab pumping, excessive deflection, or serious deterioration is observed. Free water in the pavement structure and/or shoulder should be recorded by station. Such data can be used to determine any required work for drainage or undersealing.

RUTTING

Rutting should be measured at several locations throughout the project. This information can be used to calculate the amount of grinding or the thickness of a leveling course required for the project.

SHOULDERS

The condition, type, width, and thickness of the shoulders should be investigated and recorded.

REACTIVE AGGREGATES

When reactive aggregates are suspected, the severity and extent should be analyzed and documented. The records of the aggregates and cement used on the original project should be reviewed. A visual examination of the pavement and the cores can be used for identifying the severity of the reactive aggregate problem.

MISCELLANEOUS CONSIDERATIONS

In general, all items that will affect the cost of rehabilitation should be included in the survey. Items such as clearance under structures, location and height of guardrail, drainage structures, and other items that may affect the project should be measured and recorded.

It is recommended that photographs of typical conditions be taken during the survey. These will be helpful in communicating pavement conditions to management and the designer.

The survey crew should discuss the pavement distress with local maintenance personnel to evaluate their judgment as to cause and rate of occurrence of the distresses encountered.

The distress data should be summarized so that a clear picture of the existing condition can be obtained by those involved in making design decisions.

Concrete pavements can be overlayed with either hot bituminous pavement or portland cement concrete. There are many approaches for overlay thickness design. It involves both the problems of pavement design as well as problems evaluating the existing pavement. Since both of these problems involve engineering judgment, as well as technology, different engineers can come up with different results. Because of these differences, it is important that design engineers become familiar with the procedure they use and understand the strengths as well as the weakness of the approach used. Detailed procedures may be found in "Techniques For Pavement Rehabilitation - A Training Course" by EKES, Inc., as revised and "Asphalt Overlays for Heavily-Trafficked PCC Pavements", The Asphalt Institute, Information Series Number 177, February, 1981.

CONDITION SURVEY REPORT
CONCRETE PAVEMENT

Project No. ____________

Joint Spacing ____________

Joint Type ____________

Date ____________

Station	Cracking (Lin. ft/Sta.)	Faulting (inches)	Spalling (ft^2/sta.)	Pumping (Lin. ft/Sta.)	Drainage Good-Poor		Grade Cut-Fill		Comments

Figure D-1 Example of a Condition Survey Report Form for Concrete Pavement