This manual describes the evaluation and design procedures for pavement rehabilitation. The evaluation emphasizes a number of variables or conditions that should be considered. This manual does not introduce any new technology. Thickness designs of new pavements require two primary variables: traffic and soil strength. Rehabilitation design requires several additional variables such as: pavement structure, condition and strength. Rehabilitation design can involve more alternatives than new design that deal with materials, equipment, disruption of traffic and work zone safety. This manual has been written as a working reference to help identify and classify the surface distress, explore the various rehabilitation alternatives, select an appropriate alternative and briefly describe the rehabilitation procedure. The manual provides standardized identification of distress types for both flexible and rigid pavements, calculation procedures for Equivalent Axle Loads, and a brief synopsis of the AASHTO thickness design procedure. This manual should be used by cities and counties as a reference in developing rehabilitation strategies.
PAVEMENT REHABILITATION

A GUIDE FOR

MINNESOTA CITIES AND COUNTIES

A LOCAL ROAD RESEARCH BOARD
RESEARCH IMPLEMENTATION PROJECT
INVESTIGATION 645

JULY, 1989
# TABLE OF CONTENTS

**INTRODUCTION** .......................................................... I- 1

**HOW TO USE THIS MANUAL** .............................................. I- 1

**BACKGROUND INFORMATION** ........................................... II- 1

**SOURCES OF INFORMATION** ............................................. II- 3

**CONSTRUCTION HISTORY** ............................................... II- 4
  Embankment Construction .............................................. II- 4
  Use as a Gravel Road: ................................................... II- 4
  Year of First Surfacing: ............................................... II- 5
  Overlay History: ........................................................... II- 5

**MAINTENANCE HISTORY** ................................................ II- 5

**CONDITION HISTORY** ................................................... II- 5

**CURRENT SURFACE CONDITION** ........................................ II- 6
  Recent Seal Coats ....................................................... II- 7
  Patching ........................................................................... II- 7

**USE HISTORY** ............................................................... II- 7

**TRAFFIC** ........................................................................ II- 8
  Volume ............................................................................. II- 8
  Loadings ........................................................................... II- 8

**STRUCTURAL EVALUATION (Strength)** ................................. II-10
  Pavement Strength .......................................................... II-10
  Subgrade Soil Strength .................................................... II-12
  Structural Adequacy .......................................................... II-12

**SECTION LIMITS** ............................................................. II-12

**REHABILITATION SELECTION** ............................................ III- 1

  Rehabilitation Philosophies ............................................... III- 2
    Routine Maintenance ...................................................... III- 3
    Functional Improvements ............................................... III- 3
    Structural Improvements ............................................... III- 4
    Preservation ..................................................................... III- 4
    Reconstruction .................................................................. III- 4
    Extend the life of the pavement ....................................... III- 4
    Control Costs ................................................................... III- 6
    Minimize Risks .................................................................. III- 6

  Matching Rehabilitation Method to Condition ....................... III- 7

  Narrowing Down the Selection ............................................ III- 8
    List the risks ..................................................................... III- 8
    Estimate life ....................................................................... III- 9
    Estimate costs ..................................................................... III- 9
    Selection ........................................................................... III-10

**APPENDIX A** (Flexible distresses) ................................. A-1
**APPENDIX B** (Rigid distresses) ......................................... B-1
**APPENDIX C** (Rehabilitation procedures) .......................... C-1
**APPENDIX D** (Traffic evaluation) ...................................... D-1
**APPENDIX E** (Thickness design) ........................................ E-1
I. INTRODUCTION

This manual is developed for Minnesota Cities and Counties as part of the Local Road Research Board Investigation No. 645, "Research Implementation and Technology Transfer".

The principal objective of this manual is to create a set of guidelines for selecting a pavement rehabilitation. This manual is intended for use by cities and counties as a reference in developing rehabilitation strategies.

Limited references or resources are available that discuss the rehabilitation of pavements. The Minnesota Department of Transportation Road Design Manual contains a section on new pavement design but does not contain specific information on rehabilitation. There are however, several references that deal with pavement rehabilitation which are now available. The "Guide for the Design of Pavement Structures" published by the American Association for State Highway and Transportation Officials (AASHTO) in 1986 (Ref. 1) contains a detailed section specifically discussing rehabilitation. A commonly used textbook on pavement design "Principals of Pavement Design" by Yoder and Witzak, (Ref. 2) includes a brief section with respect to pavement rehabilitation. The Federal Highway Administration (FHWA) has recently sponsored the development of several manuals (Ref. 3, 4, 5) that deal all or in part with pavement rehabilitation.

This manual describes the evaluation and design procedures for pavement rehabilitation. The evaluation emphasizes a number of variables or conditions that should be considered. This manual does not introduce any new technology.

Thickness designs of new pavements require two primary variables; traffic and soil strength. Rehabilitation design requires several additional variables such as: pavement structure, condition, and strength. Rehabilitation can involve more alternatives than normally considered for a new design. Several rehabilitation alternatives are often available for a specific project.

HOW TO USE THIS MANUAL

All users of this manual should first study and become familiar with the material in the Appendix. The Appendix contains sections that deal with the type of pavement deficiencies, general rehabilitation procedures, references and definitions. A common language and set of definitions is helpful in the discussion of rehabilitation. A wide variety of terms and definitions have developed and the same words may mean different things to different people. Appendix A and B contain the following pavement distress information for both flexible and rigid pavements:

- Definition and description of the distress
- Identifying procedure
- Possible causes
- Possible impact to the pavement structure
- Rehabilitation alternatives

An understanding of the information in Appendix A and Appendix B by everyone involved with pavement maintenance and rehabilitation is desirable. The information is beneficial for determining what is wrong with a pavement and is also helpful during presentations to a city council, county board, or a public hearing.

After becoming familiar with the material in Appendices A and B, the next step is to read through Chapter II of this manual. Chapter II describes how to gather the information necessary to design a pavement rehabilitation. Once familiar with the systematic procedure of gathering information necessary to select a rehabilitation, the process will become much quicker for future evaluations. For instance, consider a section needing a seal coat. A complete evaluation should be completed before applying the seal coat. This will help to determine if additional rehabilitation is required
such as a structural overlay, utility repair, alignment change, etc. Subsequent evaluations of the section would then update the information on the section and help monitor the pavement performance. A collection of this information will be very useful and will minimize the effort in designing future rehabilitations.

The completion of the evaluation described in Chapter II should result in:

1) Construction, maintenance and traffic histories
2) A list of deficiencies
3) The type of corrective actions required
4) The extent of the work required

Chapter III describes how to analyze this list to develop a rehabilitation design or design alternatives. The analysis should incorporate the following parameters:

- Total cost
- Expected life
- Life cycle costs
- User impact (with respect to delays and inconvenience)
- Aesthetics
- Function
- Risk

The remaining sections of this manual are the Appendices. Appendices A and B describe how to identify the various surface defects. Appendix C briefly describes common construction procedures for rehabilitating both flexible and rigid pavements. Appendix D is a brief description of the traffic evaluation procedures. This appendix includes the following:

- Vehicle classification
- Vehicle distribution
- Truck equivalencies
- ESAL calculations

Appendix E is a brief description of pavement thickness design for overlay purposes, maintenance and rehabilitation techniques, and repair procedures.
II. BACKGROUND INFORMATION

Background information or knowledge of the history of a pavement is very important in the selection of a pavement rehabilitation. It may, in fact, be the primary basis for rehabilitation selection by most agencies today.

The development of information to describe the history of a pavement can be approached in a systematic manner and all agencies would benefit from developing a formal inventory of their pavements for this purpose. Figure II.1 provides a checklist of the various types of data that are important in the selection of a rehabilitation. Key factors are the in-place structure, condition history, maintenance history, and traffic history.

Other background information, in addition to the "as-built" information, can be very useful. The past use and performance history will provide a good deal of insight when evaluating a pavement. Specific questions that can be asked when contemplating a pavement rehabilitation are:

- What is its construction history? When was it graded? When was it paved? Has it been overlaid and if so when? Did it carry traffic as a gravel road? If so, what type and for how long?

- What is its maintenance history? If it was a gravel road, was it re-graveled? For paved roads, has it required patching or repair and, if so, what type and for what reason? Has routine maintenance been performed such as joint sealing and undersealing on pcc pavement or seal coating and crack filling on asphalt roads and, if so, how often and/or when?

- What has its past usage been? What type of function does the road serve and has its function or usage changed recently? Take for example, a road that primarily serves a large landfill that a) just opened or b) just closed. It can be easily seen that the rehabilitation choice could be quite different for case (a) than case (b) even if everything else is equal.

Pertinent information to collect:

1) In-place material types and thicknesses
2) Subgrade soil types and strength
3) Type of road section, (rural or urban)
4) Functional class (local, collector or arterial)
5) Construction history (year of original construction, and overlays)
6) Use history (age of last surfacing, truck loadings)
7) Maintenance history
BACKGROUND INFORMATION
DATA AND CHECKLIST

IN-PLACE STRUCTURE (Bottom Up)

<table>
<thead>
<tr>
<th>Layer</th>
<th>Thickness</th>
<th>Plan Field</th>
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</table>

Subgrade
Year
Graded_______ Soil Classification______Subcut_________(ft)

TRAFFIC HISTORY

<table>
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<th>HCADT</th>
<th>ESAL</th>
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<tr>
<td>YEAR</td>
<td>AADT</td>
<td>HCADT</td>
<td>ESAL</td>
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</table>

Use:
(i.e. Industrial, landfill, quarry, city or school bus route, etc)

MAINTENANCE HISTORY

<table>
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<tr>
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</table>

CONDITION HISTORY

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Figure II.1  Background Information Checklist
SOURCES OF INFORMATION

The sources of information are quite varied as shown in Figure II.2. Office records are the most likely source. If an agency has an established inventory data base or a pavement management system, most or all of the information should be available. If an established data base is not available, the information can be compiled from:

- Plans
- Construction records
- Staff memory

Figure II.2 Sources of Background Information

It is not unusual, however, that some or all of this information may be missing or not recorded. In this case, hopefully, staff members are available that can provide information such as local soil conditions and past performance. In the worst case, the knowledgeable person may no longer be available. The only information available then is through inspection, testing and sampling of the pavement.

Regardless of the information available, additional field inspection and sampling may be necessary and is strongly recommended. The amount of additional inspection and sampling required is dependent on the information available. In the case where records exist, at least minimal sampling is recommended to confirm the recorded information and check the present condition of the in-place materials. When there is no information available, extensive field inspection and sampling may be necessary to determine the in-place material type, condition and uniformity.

Pavement composition information is generally obtained through coring and/or boring. Coring is the most common method for obtaining thickness information for concrete or asphalt surfaces. Individual asphalt layer thickness are also determined from cores. The cores can also be analyzed in the laboratory for additional information regarding the properties of the asphalt mix. Auger boring are then made through the core holes to obtain base and subbase thickness information. The subgrade soil is also identified from the auger boring. Another alternative is to conduct the auger boring directly through an asphalt surfacing for a quick determination of the thickness of the layers.
Thickness information obtained with power auger boring equipment is only accurate to 0.5 inches and layers of similar materials may not be distinguishable.

For certain situations, analysis may require a more detailed method of sampling such as cutting a test pit (18 by 18 inch or larger) into the pavement. Various field tests conducted on each base and subbase layer will determine the in-place characteristics. Direct measurements of in-place materials characteristics such as density and moisture content are made before disturbing the material. After the in-place testing is completed, the material is transported to the laboratory for further analysis. The test pit also allows for close visual inspection of the materials. Larger test pits can be used to determine which layer or layers are responsible for rutting on asphalt pavements.

CONSTRUCTION HISTORY

The history of a pavement section is important when considering any rehabilitation. Historical information can reveal why a particular pavement section is performing differently than another section with similar thickness. Some of the things to look for are as follows:

- **Embankment Construction:**
  - The embankment or subgrade is a critical part of the pavement system. The strength that a particular soil is capable of can vary considerably. Factors that influence soil strength include:

  1. Depth of subgrade excavation (sub-cut)
  2. Soil uniformity or blending
  3. Compaction control (density)
  4. Drainage considerations (moisture)

  Two factors which may provide an indication of the quality of the subgrade soil are the following:

  - Grading practices
  - Date of embankment construction

Grading practices for a particular agency may vary from time to time. The date of embankment construction can help determine what type of quality control and construction procedures were used. Embankment construction may vary from contractor to contractor and in cities may vary considerably from one developer to another. All of these factors are very much agency related and may not be applicable to a neighboring agency. If there are variations in grading practices either by time or in area, it is good practice to document such variations.

- **Use as a Gravel Road:**
  - If a section was used as a gravel road for a period of time, it could affect the quality of the base material. The gradations used for a gravel surface allow a higher amount of material passing the #200 sieve, for stability purposes. Also, truck traffic on a gravel road results in higher pressures at the bottom of the aggregate layer. This may lead to contamination of the bottom few inches of the base material. Aggregate loss can also occur from the traffic movement prior to surfacing the gravel road. Generally, sections that carry traffic as a gravel road have different aggregate base qualities than sections which did not carry any traffic before surfacing. It is therefore important to closely examine the quality and gradation of the base material prior to paving these types of roads.
Year of First Surfacing:
The age of the original pavement surface is another important parameter. The age is used to make an initial judgment of the soundness of the surfacing material. For instance, it would not be reasonable to assign the first 2 in. of asphalt surfacing placed 30 years ago a G.E. of 4.0 inches (Refer to Ref. 6 for details on calculating G.E.). There are few guidelines or references available to quantify the value of old bound layers. One available resource is Chapter 5 of the new AASHTO Guide for Design of Pavement Structure 1986 (Ref. 1). Before major rehabilitation is planned, field evaluation and testing is necessary to evaluate the properties of an older pavement section.

Overlay History:
The time between the original surfacing and the first overlay and also between subsequent overlays is another important variable. If the life of an overlay is less than 10 years, low structural capacity, unusually high traffic volumes, or material problems are possible causes for the short life. Field investigation and testing can help define the cause and assist in selecting the appropriate rehabilitation. There may be valid reasons for the short life, i.e. a thin overlay or short life intended. Whatever the case, the reasons should be identified and accounted for when designing the new overlay.

MAINTENANCE HISTORY

The maintenance history of a pavement section provides valuable insight into section deficiencies. High maintenance requirements may indicate that a section has permanently lost some of its structural capacity. A section that is in poor condition and continues to carry traffic may suffer accelerated degradation of the surface and aggregate base. Maintenance history of a pavement section is an important source of information. It also seems to be an item that has not been recorded until recently by many agencies. If there is no system in place to record maintenance activities, a method to do so should be established.

By looking at the maintenance history of a section insight can be gained regarding why certain sections have deteriorated or failed prematurely. The maintenance history records may reveal that routine/preservation maintenance has been neglected. The lack of routine maintenance will often result in a shorter life span compared to a similar, well maintained, section. The rehabilitation selected for a specific pavement section will likely be different depending on whether the condition is a result of a lack of maintenance rather than some other factor(s).

CONDITION HISTORY

Condition history of a pavement section can tell us when the cracks, ruts, and other distresses developed. Most agencies at this time do not have a formal recorded history of the condition of their pavement sections. It is recommended that the condition of a section be periodically observed and recorded.

The manner and rate in which a pavement deteriorates are good clues as to what problem(s) need to be corrected as part of the rehabilitation. The rehabilitation that is best suited for a certain condition may be different depending on whether that condition developed slowly over a number of years or occurred fairly rapidly, such as in one season. Consider for example, the case of rutting. A road where rutting is slowly progressing year after year in small increments until it finally reaches a point where it needs to be repaired, may require a different rehabilitation than one where the rutting occurred in one summer. Or consider the case where the rutting progression is slowing down versus the case where the rutting progression is increasing. The second case, where the rate of rutting is increasing, points toward load related or structural capacity problems whereas the first case points toward material consolidation as the cause of the rutting. In general it is the load related items, i.e. alligator cracking and rutting, that are of most concern if they
appear suddenly. Normally, distress such as transverse cracking, block cracking, weathering, and raveling, develop at a gradual, or at least at a consistent rate.

CURRENT SURFACE CONDITION

Poor pavement condition is the most common reason for doing rehabilitation work on a pavement. There are, however, several cases where rehabilitation should be performed when the road appears to be in good condition. One such case is applying a seal coat to a good pavement to protect it against raveling. Another case is the application of a structural overlay to improve the load carrying capacity of the pavement. On concrete pavements, undersealing may be conducted to re-establish subgrade support before any cracking or faulting can occur. These cases, however, are the exceptions rather than the rule in today's practice. Most rehabilitation work is scheduled in response to visible pavement deterioration.

Before going any further in discussing current surface condition, Appendices A and B on Surface Distresses should be reviewed. Become familiar with the various distress types, how they are identified, their causes and how they can be repaired. It is essential that the deficiencies be properly identified and their cause determined before the appropriate rehabilitation can be selected.

A pavement condition survey should be made on any pavement section that is being considered for rehabilitation. The survey should consist of identifying all of the distress types that are present along with their severity and extent.

Some of the surface condition rating procedures in use today do not provide the detail necessary to select a rehabilitation design. Therefore, a detailed survey is still needed once a pavement section is identified to be in need repair. The survey should be made at walking speed or less and the rater should have an unobstructed view directly down on the pavement. Fine cracks are easiest to see when looking toward the sun. This is because the shadow in the crack is the most visible attribute of a fine crack (Figure II.3). If the sun is behind the person doing the rating, the vertical face of the crack will be illuminated by the sun and may not be visible.
Specific conditions to be aware of while doing a condition survey are as follows:

**Recent Seal Coats:**
A seal coat can make even a very poor pavement appear to be in good condition for a short period. Medium to high severity block and alligator cracking will be hidden by a new seal coat but the cracking will reflect through within a short time. Condition ratings done shortly after a seal coat do not provide a true picture of the pavement condition.

**Patching:**
Pavement patches may provide evidence of possible load or material deficiencies. The reasons for the patching should be determined, if possible, as well as the method and materials used. In some cases, the patch may be the most sound area of the road, in others, it may be the weakest.

After the distress survey is complete, the distress should be sorted into these general categories according to its cause:

- Load distresses
- Weathering distresses
- Material distresses

The probable causes for each distress is described in Appendix A and B. Most distresses are attributed to one or more of these causes. Additional testing or evaluation may be required in some cases to identify the cause or causes.

Also listed in Appendix A and B are the types of rehabilitation commonly used to successfully repair the distress. The rehabilitations should be reviewed and the most dominant rehabilitation(s) would be the rehabilitation candidate for the section. The selection of the most dominant rehabilitation will take a certain amount of analysis.

Often a combination of distresses exist, each with a separate and specific rehabilitation. In these cases, the various strategies would be evaluated and compared on the basis of expected life and cost. If, for example, the section has medium to high severity alligator cracking on 20% of the area and medium to high severity weathering and abrasion on 100% of the surface. One alternative would be a deep patch on the alligatored area followed by a seal coat. Another alternative would be surface reconstruction. The costs and benefits of each of these alternatives should be weighed against each other before choosing a rehabilitation.

**USE HISTORY**

This topic relates directly to the calculation of Equivalent Single Axle Loads (ESALs) (See Appendix D on calculating ESALs) applied to the section from the time of last surfacing. Many low volume roads are specific use roads as opposed to arterial, state highways, or interstates. For example, residential streets specifically serve automobiles, garbage and delivery trucks, and possibly school or city buses. They also experience heavier loading during the initial development of a development or subdivision than they do once the construction is finished. A county road may serve a single heavy user such as a landfill. A county road may also be a general connection route carrying a mix of traffic similar to a state highway. Uses can change either completely or with season. These are important factors to consider when selecting a rehabilitation alternative.
TRAFFIC

This section will describe how traffic is to be considered in selecting pavement rehabilitation. The key traffic factors and the overall impact of these factors on pavement rehabilitation are:

**Volume:**
The first area of traffic considerations is the volume both now and in the future. It should first be decided whether the roadway has adequate capacity to carry the traffic volume projected over the next 20 years or if added capacity is needed. The need for added traffic capacity has a direct impact on the rehabilitation choice for the roadway. If it is found that added capacity is needed, the rehabilitation would have to include such things as additional driving lanes, turn lanes, shoulders or perhaps total reconstruction.

The roadway width requirements and other geometric requirements for horizontal and vertical alignment are listed in the Mn/DOT State Aid Manual (Ref. 7). The Manual also provides the information needed to determine whether an existing roadway has adequate traffic capacity.

If it is found that widening is required, the rehabilitation should evaluate whether widening can be made on the existing roadbed or whether total reconstruction is required. If the existing roadbed can be widened, then the rehabilitation becomes a combination of new design and rehabilitation design. The new design applies to the widening of the roadway and the rehabilitation design applies to the existing pavement.

In any case, the design must consider the total section and the relative compatibility of all the parts. The widening may be symmetrical, thereby resulting in an equal amount of widening on each side of the roadway, or offset to one side, resulting in a possible shift of centerline. The existing roadway, its crown and pavement type should be considered in a selection of how the widening would be placed. For instance, on a concrete pavement an offset widening may result in a longitudinal joint falling in the wheel-path of the new lanes. This undesirable condition may be avoided with careful planning.

**Loadings:**
The second area of traffic that needs to be considered is the loading effect. The common factor that is used to describe the effects of traffic loading on pavements is called the Equivalent Standard Axle Load (ESAL). A procedure for estimating the amount of ESALs for a pavement section is included in Appendix D.

The primary objective is to estimate the amount of ESALs expected during the design life of the pavement rehabilitation. It should be emphasized, particularly for low volume roads, that the traffic volume or Average Daily Traffic (ADT), which is commonly used as a basis to estimate traffic loadings, should not be considered a reliable predictor of ESALs. There are a number of items that need to be considered when estimating the ESALs on a low volume road.

First, consider the type of traffic using the road. Does the road serve an industrial park, a school, a sanitary landfill, a gravel pit, or some other type of industry that is a generator of heavy axle loads? Is the road on a public or commercial bus route? Does it go to a community that has a grain elevator? Do the heavy loads occur year around or are they concentrated during one specific time of the year such as the spring or winter. Is the traffic pattern expected to remain constant over the next 20 years? Think about railroad abandonments, landfills reaching capacity, gravel pits running out, etc. These kind of events can play a major role in the performance of a roadway system.

These traffic conditions will have a significant impact on the performance of the road over its lifetime and also on the selection of a rehabilitation. Since local roads provide the link
to an area's overall economy, it is very important that the nature of the traffic on the roadway be considered in evaluating and designing a rehabilitation.

The type of traffic that uses a collector or arterial, however, is also very important. In the Metropolitan area an MTC bus route on a roadway may by itself generate as many or more ESALs than the rest of the traffic combined. For example, if there are 2500 vehicles per day on the route, 20 of them MTC buses, the buses, in this case, would be responsible for about one third of the Equivalent Standard Axle Loads generated. In the case where the rest of the traffic are automobiles, buses account for nearly all (96%) of the ESALs.

The same argument can be made for the county road that serves a local community with a grain elevator. Only 5% of the total traffic volume may be due to the grain elevator, but that 5% could generate the major part of the traffic loadings. Unlike the MTC bus route which would tend to be a continuous number of vehicles per day year around, the county road serving the grain elevator may see a more seasonal trend in the traffic loading. This is important to keep in mind because if the thickness design is based on a truck count, the section could be significantly over or under designed depending on when the count was taken. If the count was taken when there was no grain traffic, the loadings would be underestimated. Certain types of traffic may be better estimated based on commodity production than traffic counts.

It can be seen by the examples given that each individual roadway must be evaluated on its own merits. In addition to determining the total number of ESALs expected in the rehabilitation design life, the seasonality of that traffic must be considered. If all of the heavy loads are in the spring, the pavement design thickness should be increased.

Although the trend is toward 9 or 10-ton roads, a 5 or 7-ton road can be a lower cost alternative. The need to carry 9 or 10-ton axle loads in the spring on a given road or the availability of an alternate route must be considered or taken into account. If the road can be posted, either the pavement thickness can be lowered or longer life can be expected. If the pavement thickness is reduced and a spring restriction is used to extend the life of the pavement, a risk is involved. The pavement is vulnerable to violators of the spring load restriction and other conditions that will temporarily reduce the pavement strength. No data exists to quantify that risk, therefore, judgment must be used. To help aid the judgment process, several risk conditions are described:

- Pavements that have less than three inches of asphalt surfacing are more vulnerable to heavy loads during times of low strength. They may break up during rapid thaw in the winter, before spring restrictions are placed, or when very wet conditions are present after spring restrictions are removed.

- A very heavy overload may cause instantaneous pavement damage.

- Variations in thickness, materials, and quality control will have a greater influence on pavement performance during the critical spring thaw period. For instance, if the surface design is 1.5 inches, a 0.5 inch deviation resulting in only 1.0 inch of surface will very likely lead to premature cracking or breakup of the pavement.

The final results of a traffic evaluation are used to determine:

- The alignment and width necessary to serve the existing and future traffic.

- The number of ESALs expected in the design lane of the roadway during the proposed life of the rehabilitation. In this case it should be noted that the design lane is whichever lane is expected to carry the heaviest amount of traffic in terms of ESALs.

- The number of ESALs the present surface has carried.
If there is a seasonal pattern to the traffic that can be taken advantage of either in terms of the thickness design or spring axle load limits.

**STRUCTURAL EVALUATION (Strength)**

The strength of a pavement section is provided by the combined strengths of the pavement layers and the subgrade soil. Most design procedures consider these separately. For example, the Mn/DOT design for flexible pavements (Ref. 6) uses the pavement granular equivalent thickness (G.E.) to describe the pavement strength and the Hveem stabilimeter R-value to describe the subgrade soil strength.

**Pavement Strength**

Evaluation of the pavement strength is a necessary step in pavement rehabilitation design. There are three basic methods that can be used to evaluate the structural adequacy of a pavement.

- Layer thicknesses from records.
- Layer thickness from field cores, boring and laboratory testing.
- Layer thickness from one of the above methods and deflection testing.

Obtaining layer thicknesses from office records was found to be unreliable in Mn/DOT Investigation 650 (Ref. 8). That project included auger borings from about 375 miles of county roads and 7 miles of city street. The results from the auger borings did not correlate very well with the thickness data on file. Whenever the thickness is uncertain, boring and/or coring is recommended.

**Subgrade Soil Strength**

One common method of determining subgrade soil strength is the laboratory R-value test. Soil samples are normally taken at several locations along the section by power auger boring and the soil samples are sent to a testing laboratory for the R-value test. The sample is prepared according to the test standards before the test is run. The result of the R-value test is used as an indicator of the amount of deformation that will occur in the soil when a load is placed on it (soil strength). To keep the soil deformation within allowable limits, a certain thickness of pavement is required according to the thickness design.

Any given soil can provide widely varying amounts of strength under different conditions. The two most common conditions that have a major affect on soil strength are moisture and density.

Figure II.4 shows the moisture-density-strength relationship typical of most soils. It shows the strength variation with moisture and density. The R-value (or any other laboratory test) predicts one strength value. Figure II.4 shows the relationship between strength as predicted by the R-value versus moisture; this relationship is expressed with respect to the density of the material.
Therefore, we must also know something about the in-place moisture and density conditions of the soil. Information regarding the variation in soil strength due to moisture and density is not readily available. As a rule of thumb, in terms of design, the soil strength loss due to a one percent loss in density must be made up for by a one inch increase in G.E. as shown in Figure II.5.
Structural Adequacy
An evaluation of structural adequacy consists of doing a thickness design in reverse. The in-place thickness (Granular Equivalent in inches) and subgrade soil strength (R-value) are used to determine the ESAL capacity. See Appendix E of this manual for an example of AASHTO's pavement thickness design procedure. The ESAL capacity is compared to the ESALs expected. If the number of ESALs expected in the design period exceed the ESAL capacity, the section is structurally deficient and structural rehabilitation would be necessary.

A structural evaluation based on office records is limited by the fact that the strength of the materials has to be assumed. Laboratory testing of samples taken from the pavement or measurement of the strength by deflection testing eliminates the need to assume strengths of the pavement and subgrade materials. Material or deflection testing is recommended whenever there is a question about any of the materials in the pavement system or when the structural capacity by traffic analysis is marginal or deficient.

SECTION LIMITS

The optimum rehabilitation choice may not be the same over the entire length of the project. The initial termini of a pavement rehabilitation may be established for a variety of reasons. Within the overall project, it is likely that it can be divided into subsections for rehabilitation purposes. There can be substantial savings by dividing a project into subsections when materials can be saved. The extent to which a project is divided will vary. Urban sections could be broken down into block long segments or perhaps shorter while rural projects would have longer sections. However, sections should only be broken down into subsections if it is both practical, from a construction standpoint, and economical.

The primary reasons a project would be divided into subsections are:

- Changes in traffic volumes
- Changes in traffic loadings (ESALs)
- Change in pavement condition
- Change in pavement strength (design)
- Change in soil strength

Specific guidelines are not provided here regarding the amount of change in any of the above areas that would be necessary before a subsection is created. Local conditions will play heavily in making those decisions along with the information obtained in the evaluation necessary for developing a rehabilitation design.
III. REHABILITATION SELECTION

Selection of the proper rehabilitation for a pavement requires knowledge of the pavement condition, deficiencies, and needs. It also requires knowledge of the various rehabilitation procedures that are available, their strengths and weaknesses. Quite often there are several viable choices available, in which case, the selection is made on the basis of cost, affect to the users of the pavement and the chances of success. In this respect, rehabilitation selection is much more involved than selecting a new pavement design because of the additional factors involved. There is no simple way around this situation. Figure III.1 shows the data and thought process required when choosing a rehabilitation alternative.

```
Figure III.1 Rehabilitation Thought Process
```

This manual identifies many of the items that must be accounted for when selecting a rehabilitation. The objective of this manual is to provide the framework and sufficient information for a County or City Engineer or staff members with some knowledge of pavements to enable them to select the type of rehabilitation that is best for that particular pavement. Given a specific set of conditions, everyone should come up with a similar set of alternatives. The primary benefit of experience would be the amount of time to do so. A person experienced in pavement
evaluation and rehabilitation selection would normally be able to select the appropriate rehabilitation much quicker than someone just starting out.

This manual is intended to be used as a guide in the selection process. Many other information resources are necessary to select the best rehabilitation, including the "STANDARD SPECIFICATIONS FOR CONSTRUCTION" published by Mn/DOT and other technical manuals regarding thickness design, pavement materials and construction procedures. Knowledge of local materials, abilities of the maintenance staff and local contractors, and costs are also important and must be obtained independently.

Rehabilitation Philosophies

The primary objective of selecting a rehabilitation is to get the best return for the money spent. There are many factors that cause pavements to be rehabilitated. During the development of this manual several seminars focusing on pavement rehabilitation techniques and strategies were held throughout the State of Minnesota. These seminars were attended by public works directors from both municipalities and counties. During the seminar the participants were asked to complete a questionnaire with respect to their agencies rehabilitation practices.

The most common reasons for rehabilitation, based on responses to questionnaires, were:

- The pavement is too rough
- The pavement is breaking up
- The pavement will begin to break up soon if nothing is done

Figure III.2 is a list of some of the reasons to spend money on pavement rehabilitation. A mental check of the items in Figure III.2 will help keep things in perspective when considering a rehabilitation.
Typical Reasons to Rehabilitate Pavements

**Typical Reasons to Rehabilitate Pavements**

**Protect Investment**
- Routine maintenance
- Deteriorated condition (protect surface)
- Improve structure

**Reduce Maintenance Costs**

**Improve Safety**
- Alignment — Geometrics for volume
  - additional lanes or width
  - turn lanes
  - shoulder width
- Alignment — Geometrics for speed
  - cut hills for sight distance
  - widen curves
  - increase lane width
- Friction
- Roadside conditions
  - sleep ditches
  - clear zone

**Restore Function**
- Improve ride
- Improve appearance
  - many utility cuts
  - many maintenance patches

**Replace Failed Sections**

Figure III.2 Typical Reasons to Rehabilitate Pavements

Most rehabilitation work can be set into one of five broad categories:

- **Routine Maintenance**
  This category includes most normal maintenance activities such as crack filling or joint sealing, localized patching, and surface treatments.

- **Functional Improvements**
  This category includes overlays to improve the ride (but not the structure) friction treatments such as grooving, seal coat, or overlay and any other work that will result in a direct improvement to the user. An increase in structural capacity may be a result of the improvement but not a design requirement.

- **Structural Improvements**
  This category normally includes overlays to improve the structural capacity of the pavement. Pavements that reached the end of their design capacity (life) or pavements that will be exposed to more and/or heavier truck loads are in this category.
- **Preservation**
  This is the period of time where a pavement has been identified to need reconstruction. Minimal maintenance is done, only enough, to keep the surface in a safe condition until the pavement can be replaced. This is slightly different than the routine maintenance category in the fact that the maintenance selected will normally be lower cost and shorter lived than the procedures used for routine maintenance.

- **Reconstruction**
  Reconstruction is used when the pavement can no longer be improved by one of the first four categories. This category includes partial reconstruction if all of the pavement layers are not replaced and total reconstruction including regrading.

Figure III.3 shows the typical occurrences of these categories in the life of a pavement.

![Diagram of pavement surface condition vs age](image)

**Figure III.3  When to Perform the Appropriate Type of Maintenance**

Once a pavement is identified to be in need of rehabilitation, the process, beginning with selection and ending with construction, should be controlled by a set of specific goals. Three goals that should be kept in mind are:

- Extend the life of the pavement
- Control costs
- Minimize risks

These goals are common to many activities. The way they can be applied to the pavement selection process is described as follows:

- **Extend the life of the pavement**
  This may seem too obvious to mention but there are situations that can occur where this goal will make a difference. The life of the pavement, not the rehabilitation, must be a determining factor in the selection process. It is easy to get caught up in the question of how long will the rehabilitation last. The life of the rehabilitation is an important factor, but it is not the only factor that needs to be evaluated.
As an example, consider a new pavement that is properly designed in all respects. Suppose someone proposes a thin overlay for the pavement. The proposed overlay will most likely be rejected since it will serve no benefit. If the pavement is properly designed already, the thin overlay will not extend the overall life of the pavement. On the other hand, it could be estimated that the overlay will last 20 years and therefore will give excellent performance. The reason for not choosing the overlay, even though it will give such long life, is obvious here. It may not be as obvious in all cases and the impact on the overall life of the pavement must be kept in mind. Real life situations where this is important deals more so with normal maintenance activities such as crack treatments or surface treatments. It is easy to get caught up in the question of how long the treatment will last and forget about what it will do for the overall life of the pavement. Figure III.4 graphically shows this concept. It uses a term receptivity to describe how receptive the pavement will be to a particular treatment. The overlay illustration above would have a very low receptivity while an overlay near the end of the normal design life of the pavement would have a high receptivity.

To illustrate the concept of maintenance receptivity, consider a flexible pavement that will be evaluated for the benefit derived from a seal coat for each year of it’s service life. Figure III.4 graphically shows how much of an impact the seal coat has on its service life. The additional years of pavement life due to the seal coat is low at point A, peaks at point B and is low again at point C. The life of the seal coat itself is not the concern at point A, it is the additional service life from the pavement that is important.

![Figure III.4 Seal Coat Receptivity](image-url)
Control Costs.
One of the main functions of a pavement engineer is to provide cost effective designs. Several cost factors need to be considered when rehabilitation alternatives are evaluated. These are:

- Construction (first) costs
- Uniform Annual Cost
- Future costs
- Maintenance costs
- User costs
- Salvage return

Of those listed, construction (first) cost is probably the most common cost factor used for rehabilitation selection. Uniform annual costs, which should include all of the costs factored over the specified life of the pavement, is the cost factor recommended for use in most engineering texts. The calculation of the Equivalent Uniform Annual Cost (EUAC) requires information regarding the number of years of life expected from the rehabilitation plus all of the other associated pavement costs over the analysis period.

Future costs are the costs for future rehabilitations. They are used by Mn/DOT in the calculation of the EUAC used for the selection of the surface type for new construction but would apply as well to the selection of the type of major rehabilitation such as structural overlay or reconstruction. Future costs are normally incorporated in the calculation of the EUAC.

Maintenance costs are the reoccurring maintenance costs that occur periodically over the life of a pavement. These costs should be considered if they are expected to be significantly different for the rehabilitation alternatives being considered.

User costs are the costs incurred by the people who use the road. The most significant cost to consider is the delay cost caused by the rehabilitation and resulting future maintenance activities. Even though these costs are not the direct cost of the agency, it is important to be aware of these costs. A rehabilitation that is less disruptive to the traveling public should be given consideration.

Salvage return costs are considered in the calculation of EUAC. The salvage value is the value at the end of the analysis period. Normally, the in-place materials will have value either as the in-place foundation for future overlay or as materials that can be recycled. In rare cases, the material can deteriorate to such a point that it would need to be removed and used as a fill material or disposed of. If this is the case, it would be an expense rather than a value.

The following is an example of comparing alternatives and life cycle costs using the EUAC method. Suppose the average square yard cost for Alternate A is $2.80 per square yard and the average square yard cost Alternate B is $4.75. At first glance, the probable choice is Alternate A, but now consider that it is expected to provide 6 years of life and Alternate B is expected to provide 15 years of life. The equivalent uniform annual cost for the two alternatives (assuming 8% money) are $0.61/sq.yd. and $0.55/sq.yd. respectively. This shows that Alternate B, is the most cost effective.

Alternate A \[ (\$2.80) \times (A/P,8\%,6) = 2.80 \times 0.21632 = 0.61 \]
Alternate B \[ (\$4.75) \times (A/P,8\%,15) = 4.75 \times 0.11683 = 0.55 \]

Minimize Risks
Different pavement rehabilitations carry different levels of risk that need to be considered. The risks referred to here are the risks involved in successfully constructing the pavement
and the life of the rehabilitation. For example, if it is known that 3 out of 10 (given for example only) thin overlays placed in the late fall fail in the first year due to raveling, there would be a definite risk in selecting a thin overlay for late fall construction. The description of the various rehabilitation procedures in Appendix C identifies some of the risks associated with them. The risks are not quantified since specific data was not found. Figure III.5 illustrates a range of performance that may result for a surface treatment.

![Seal Coat Performance Chart](chart.png)

**Figure III.5 The Life of a Seal Coat**

When selecting a rehabilitation the three goals previously mentioned (Extend the life of the pavement, Control costs and Minimize risks) will help in establishing an outline or set of parameters to aid in the decision making process. At this time these goals should be considered as only a philosophy applied to the selection process. Agencies should develop a system of recording and storing information relevant to the life, cost, and risks associated with various rehabilitations. Such a data base will be a valuable resource as time goes by. Many pavement management systems have the ability to store much of the information necessary to do this.

**Matching Rehabilitation Method to Condition**

Once a pavement becomes a candidate for rehabilitation, it is likely to have several deficiencies that need repair. A complete evaluation of the condition of the pavement and all the other associated factors such as geometries should result in a list of deficiencies. Chapter II describes the process of gathering the information needed to select a rehabilitation.

Once such a list of deficiencies has been made, the repair required for each deficiency can be added to the list. The information in Appendices A, B, and C will aid in creating such a list. The appropriate rehabilitation for the section is the one that takes care of all of the deficiencies that need correction. A structural overlay, for example, will correct load capacity deficiencies as well as ride, weathering and raveling, and other surface deficiencies but it will not correct grade or width problems. A surface treatment will correct raveling and weathering problems that are not too severe but will not correct structural or capacity deficiencies. From this it can be seen that the rehabilitations for deficiencies on a particular section can be ranked in terms of effectiveness.
Consider, for example, a section that has a spring restriction of 5-ton per axle and a surface that is raveled and weathered. An evaluation of the truck traffic and local needs find that the section should have 9-ton axle load capacity. The rehabilitation alternative for each of the deficiencies are:

- The low strength deficiency calls for a structural overlay
- The raveling deficiency calls for a surface treatment

In this case, since a structural overlay will correct both the raveling and the axle load capacity, a surface treatment for the raveling and weathering is not necessary. This should be very obvious but is described here as an example of selecting the most appropriate rehabilitation (assuming that the width, overhead clearance, drainage, etc. are adequate for the overlay alternative).

When evaluating pavement distresses, it is helpful to separate the deficiencies into those caused by load from the rest of the distresses. The distresses that are load associated are rutting, potholes and alligator cracking on flexible pavements and corner cracks, faulting, punch outs and divided panels on rigid pavements. The presence of load associated distresses is evidence that a structural overlay or reconstruction is needed. In the absence of load related distresses, a less expensive rehabilitation such as a surface treatment or thin overlay may suffice.

Sections often can be divided into subsections based on the presence of load associated deficiencies. If the subsections are unique and large enough to be treated separately, the type of rehabilitation can be varied within the section. Caution must be used in this case to assure that the areas with no load related distresses are structurally adequate for the projected traffic. Field sampling and deflection testing should be used in these cases to evaluate the in-place pavement condition with respect to structural strength and material characteristics.

**Narrowing Down the Selection**

Once the section has been completely evaluated and rehabilitation alternatives have been selected, the final selection must be made. There are several factors that should be considered during this final selection process.

**List the risks**

There are always risks in doing any type of rehabilitation work. For example, surface treatments are more sensitive to weather conditions than an overlay and a poor job may result if it is cold or wet during application. The use of recycled materials is always recommended for consideration, however, the use of recycled material requires more quality control work to give good results.

At this time, there are no charts or tables listing the degree of risk associated with any particular construction procedure. Knowledge of local conditions, materials, and capabilities is necessary to judge the risks in doing any particular type of work. The risks need to be evaluated on a case by case basis.
Estimate life

The life of the rehabilitation alternatives need to be estimated. The life is used to compare the alternatives on the basis of their EUAC. If the is no difference in the expected life of the alternatives, the lowest construction cost would likely be the basis for the selection. In addition to estimating the life of the rehabilitation, it is also important to estimate the impact it will have on the long-term life of the pavement. Figure III.6 illustrates three scenarios:

1. No Rehabilitation
2. Selecting rehabilitation which does not increase the pavement life of the pavement (i.e. seal coating a pavement which has a high amount of alligator cracking).
3. Selecting a rehabilitation which directly increases the life of the pavement (i.e. removal and replacing load related distresses and seal coating the entire pavement).

![Diagram of rehabilitation impact](image)

**Figure III.6 Impact of Different Rehabilitation Methods**

Estimate costs

The cost of the rehabilitation alternatives should be estimated. This would include the construction costs plus the estimated maintenance costs over the life of the pavement. This will allow a comparison to be made on the basis of the construction (first) cost and also on the basis of EUAC. The lowest EUAC is the best choice overall, however, it may involve higher first costs than the agency has available. The total needs of the agency and the available budget have to be weighed against each other during rehabilitation selections. Agencies that have an older pavement system tend to find that the rehabilitation needs exceed the available funds. The agency may need to establish a rebuilding program which will require special fund raising such as assessments, MSA funds, bonds, etc.

The costs to the user is another very important factor to include in selecting the rehabilitation. Delays to people and impact on local business can severely impact a community. The longer the disruption to traffic will last, the greater the cost. In critical cases, a more expensive but faster rehabilitation will be a better choice. There must be political support for such a selection,
although, since it involves not only the people affected by the construction, but also the funds available for other projects.

Conversely, the "Cost per Mile" is a function of "Miles Rehabilitated" as indicted in Figure III.7. In general there will be a significant cost reduction if a number of roadways can be combined together into larger contracts. Therefore, another cost consideration when selecting an alternative would be the size and scope (Figure III.7) of the project.

![Graph showing cost per mile versus miles rehabilitated](image)

**Figure III.7** Cost per Mile Versus Miles Rehabilitated

**Selection**

Once all the factors are identified, listed and considered, the best rehabilitation is likely to be selected. The selection is not always made on the same basis. On one project, it may be best to choose the lowest EUAC alternative, but on another project, the lowest first cost alternative may be the best. Rehabilitation with low chance of failure should be selected on major arterials and collectors. Higher risk but lower cost rehabilitation alternatives can be tolerated more easily on lower volume roadways.

By now it should be obvious that there is no one best method of selecting a rehabilitation for all agencies or from one project to another within an agency. There is one common recommendation for all agencies, however, and that is obtain all of the information necessary to make a decision. If the information described in Chapter II is gathered and evaluated, the best available rehabilitation will be selected in most cases. There are many occasions where there is no clear choice between alternatives. In these cases, it may be helpful to prioritize the decision factors. For instance, if alternative A has lower cost but higher risk and alternative B has higher cost and lower risk, the selection should be based on whichever is the most important factor at the time.
APPENDIX A

ALPHABETICAL LISTING OF
DISTRESS TYPES
FOR
FLEXIBLE PAVEMENTS
Description of Format

The typical and some not so typical distresses found in flexible pavements are described in this appendix. Each of the distresses contained here are described in a standardized format as follows:

**Name of Distress:** The name or names by which the distress is commonly called.

**Description:** A physical description of the distress, what it looks like and how it can be identified. Pictures will be included for reference.

**Possible Causes:** Describes possible causes of the distress, whether environmental, material or load related.

**Impact:** Describes the consequences of the distress, what is expected to happen if left untreated.

**Severity Levels:** Describes up to three severity levels of the distress; low, medium and high.

**How to Measure:** How the distress is measured during a surface condition survey.

**Rehabilitation Alternatives:** Describes the rehabilitation alternatives that apply to the distress. A discussion of how the various severities and densities are treated is included where appropriate.

The definitions and descriptions of the distresses listed in this Appendix have been compiled from the following references:

1. Pavement Maintenance Management for Roads and Parking Lots, Ref. 20
2. Surface Condition Rating System "Field Guide", Ref. 21
4. Pavement Maintenance Guideline: Distress Maintenance Alternatives, Performance Standards, Ref. 23
5. Surface Condition Rating System for Bituminous Pavements, Ref. 24
6. Asphalt Overlays for Highway and Street Rehabilitation, Ref. 25
7. Pavement Moisture Accelerated Distress (MAD) Identification System, Ref. 26
ALLIGATOR CRACKING

Description: Alligator or fatigue cracking is a series of interconnecting cracks caused by fatigue failure of the asphalt concrete surface under repeated traffic loading. Alligator cracking occurs only in areas subjected to repeated traffic loading, such as wheelpaths. Therefore, it would not occur over the entire paved area unless the entire area were subjected to the traffic loading. (Pattern-type cracking, which occurs over an area that is not subjected to loading, is called block cracking. See "Block Cracking" in this report.)

Alligator cracking is usually considered a major structural distress. The degree of structural impact is dependent on the section. Alligator (fatigue) cracking, in its early stages, will show up as a low severity longitudinal crack in the wheelpath. This form of longitudinal cracking can, in most cases, be distinguished from cold joint cracks or cracking caused by the lateral movement of the subgrade (see longitudinal cracking).

Possible Causes: Alligator cracking begins at the bottom of the asphalt surface (or stabilized base) where tensile stress and strain are highest under a wheel load. The cracks propagate to the surface initially as a series of parallel longitudinal cracks. After repeated traffic loading, the cracks connect, forming many-sided, sharp-angled pieces that develop a pattern resembling chicken wire or the skin of an alligator. The pieces are less than 2 feet on the longest side. The size of the pieces is somewhat dependent on the thickness of the asphalt surface.

Alligator cracking failures which are deep-seated in the subbase or subgrade are progressive (i.e. under traffic they tend to spread rapidly and traffic causes areas of surfacing to be displaced and broken up). Alligator failures which are in the upper layers normally appear in the early spring. They generally progress after warmer spring weather first appears, mainly because of limited base drainage during the spring thaw and because the wet granular base has decreased the pavement strength.

Other general causes include: unstable base or roadbed (insufficient bearing support), weakening of pavement caused by poor base drainage, a stiff or brittle asphalt mix, and excessive heavy loads or repetitive traffic loadings for the designed structure.

Impact: Alligator cracking reduces the strength of the pavement. The impact of this strength loss depends on the thickness of the asphalt with respect to the overall thickness of the section.

5 and 7-ton section (Thin Surface):
For thin asphalt surfaces (less than 2 inches) most of the strength is provided by the aggregate base, therefore, the strength loss due to alligator cracking is low. An example is the following section:

<table>
<thead>
<tr>
<th>G.E. of New Pavement</th>
<th>G.E. of Alligatorated Pavement</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5 inches hot mix =</td>
<td>2.0 x 1.5 = 3.0 in.</td>
</tr>
<tr>
<td>8.0 inches Cl. 5 Aggregate =</td>
<td>1.0 x 8.0 = 8.0 in.</td>
</tr>
<tr>
<td></td>
<td>11.0 in.</td>
</tr>
<tr>
<td></td>
<td>1.0 x 1.5 = 1.5 in.</td>
</tr>
<tr>
<td></td>
<td>8.0 in.</td>
</tr>
<tr>
<td></td>
<td>9.5 in.</td>
</tr>
</tbody>
</table>

If the effective G.E. factor of the asphalt goes from 2.0 to 1.0 when it becomes alligatorated, there is a 14 percent loss in G.E. (See Ref. 6 for a description of G.E. factors)

A second impact of alligatorating is the amount of water that can flow into the base. Surface water from rain or snow melt will flow through the cracks into the base. An aggregate base is much weaker when it becomes saturated and is also more vulnerable to damage by heavy vehicles. Since it has lower strength when saturated, the base may also become contaminated due to the pumping of the subgrade. Freeze-thaw breakdown may also result when the base is saturated.

9 Ton Flexible sections:
These sections will have a minimum of 3.0 inches of asphalt but will have a significant amount of aggregate base. The section strength (G.E.) is divided about equally between the asphalt surface and the base. An example is:

<table>
<thead>
<tr>
<th>G.E. of New Pavement</th>
<th>G.E. of Alligatorated Pavement</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5 inches hot mix =</td>
<td>2.0 x 3.5 = 7.0 in.</td>
</tr>
<tr>
<td>8.0 inches Cl. 5 Aggregate =</td>
<td>1.0 x 8.0 = 8.0 in.</td>
</tr>
<tr>
<td></td>
<td>15.0 in.</td>
</tr>
<tr>
<td></td>
<td>1.0 x 3.5 = 3.5 in.</td>
</tr>
<tr>
<td></td>
<td>8.0 in.</td>
</tr>
<tr>
<td></td>
<td>11.5 in.</td>
</tr>
</tbody>
</table>

In this case, there is a 23 percent loss in strength due to the alligatorating. This amount of strength loss can lead to the development of other distresses such as rutting. Water can enter the base causing additional strength loss and contamination.
Full-depth and deep strength
These sections lose the most strength when alligator cracking develops in the pavement. The strength of a Full-depth or Deep-strength section comes from a slab effect much like a concrete pavement. An eight-inch Full-depth pavement has an effective G.E. factor of about 3.4 (Ref. 31). An alligatored Full-depth pavement, however, will have a G.E. factor of approximately 1.5. The following is a comparison:

\[
\frac{\text{G.E. of New Pavement}}{\text{G.E. of Alligatored Pavement}} = \frac{8.0 \text{ in. Full-Depth Asphalt}}{4.5 \times 8.0} = \frac{27.0 \text{ in.}}{12.0 \text{ in.}}
\]

This is a 56 percent strength loss and has significant impact on the structural capacity and remaining life of the section. The water that flows into the cracks may also cause the subgrade to become saturated in the area of the alligatoring.

Severity Levels:

Low severity: Fine, longitudinal hairline cracks running parallel to each other with none or only a few interconnecting cracks. The cracks are not spalled (See "Spalling" in this report). Initially there may be only a single crack in the wheelpath.

Medium severity: Further development of light alligator cracks into a pattern or network of cracks that may be lightly spalled.

High severity: Network or pattern cracking has progressed so that the pieces are well defined and spalled at the edges. Some of the pieces may rock under traffic. Pieces may begin to disintegrate forming potholes.

How to Measure: Alligator cracking is measured in square feet of surface area. The major difficulty in measuring this type of distress is that two or three levels of severity often exist within one distressed area. If the different levels of severity can be easily distinguished from each other, they should be measured and recorded separately. However, if they cannot be divided easily, the entire area should be rated at the highest severity level present.

Rehabilitation Alternatives:

If distress is localized:

Low severity: Apply surface seal coat. Rejuvenators may also be considered as an alternative. Minnesota's experience has been limited and there are no documented studies available relevant to their local use. A rejuvenator could be used if it will aid in healing the surface and reducing the amount of water that can enter the base. Expected life of the treatment will range from less than a year to 3 years, depending on the structure and the section traffic.

Medium severity: Partial depth patch; Full depth patch.

High severity: Partial depth patch; Full depth patch.

If distress is more wide spread:

All Severities: Structural rehabilitation including:
1. Overlay
2. Mill and overlay
3. Recycling
4. Reconstruction
LOW SEVERITY ALLIGATOR CRACKING

MEDIUM SEVERITY ALLIGATOR CRACKING
HIGH SEVERITY ALLIGATOR CRACKING
Name of Distress: BLOCK CRACKING

Description: Block cracks are interconnecting cracks that divide the pavement into blocks that range in size from approximately 1 by 1 ft to 12 by 12 ft in size depending on the asphalt mix properties and surface thickness. Block cracking is not load-associated and usually indicates a hard or brittle asphalt. Block cracking normally occurs over a large portion of pavement area, but sometimes will occur only in non-traffic areas. This type of distress differs from alligator cracking in that alligator cracks usually form smaller, many-sided pieces with sharp angles. Also, unlike block cracks, alligator cracks are caused by repeated traffic loadings, and therefore, found only in traffic areas (i.e. wheelpaths).

Possible Causes: Block cracking is caused mainly by shrinkage of the asphalt concrete or daily temperature cycling (which results in daily stress/strain cycling) together with hardening and shrinkage of the asphalt. A special case of block cracking with a small block size pattern has been observed on thin road mixed surfaces. It is expected that this is still a form of shrinkage cracking due to evaporation of the cut back. The evaporation causes a shrinkage of the binder, eventually resulting in a form of block cracking which is not due to temperature cycling only.

Impact: Even though block cracking is caused by temperature cycling or shrinkage, it has an impact on the strength and durability of the pavement.

The structural impact itself is the loss in strength due to the cracks and to the effects of water flowing into the base. The structural loss may result in depressions and additional cracking developing in the wheelpaths which then leads to the development of alligator cracking and/or rutting.

The pavement may also be susceptible to deterioration of the asphalt layer at the crack caused by stripping. This would cause the crack width to open up due to the raveling that occurs on the vertical face of the crack.

Severity Levels:

Low severity: Blocks are defined by low severity cracks. (See definition of longitudinal and transverse cracking of this report).

Medium severity: Blocks are defined by medium severity cracks. (See definition of longitudinal and transverse cracking of this report).

High severity: Blocks are defined by high severity cracks. (See definition of longitudinal and transverse cracking of this report).

How to Measure: Block cracking is measured in square feet of surface area. It usually occurs at one severity level within the pavement section. However, any areas of the pavement section having distinctly different levels of severity should be measured and recorded separately.

Rehabilitation Alternatives:

Low severity: Do nothing; crack seal; apply rejuvenator; apply seal coat.

Medium severity: Apply seal coat or thin overlay.

High severity: Overlay, recycle or reconstruct.

The severity, density, thickness of asphalt, mix characteristics, and structural adequacy of the pavement all have to be considered in determining a rehabilitation.

At first signs of block cracking, rehabilitation should be selected that will minimize the impact of the block cracking and retard the growth and associated deterioration. The goal is to treat it in an economic fashion to control deterioration of the cracks, minimize the amount of water the cracks can intercept and thereby extend the life as long as possible.

Once the pavement has deteriorated to a point that it needs repair, a complete evaluation is required. If fatigue cracking or rutting is not present, the structural capacity is probably sufficient for the traffic
it has been exposed to. Future traffic projections can be compared to past traffic to determine if further structural evaluation is required. If the future ESALs are expected to be higher than the past ESALs, the structural evaluation section of this manual should be referred to.

Samples of the existing pavement surface need to be tested for in-place characteristics if hot mix recycling is to be considered. The recycled mix design must take into account the hardness of the recyclable asphalt.

LOW SEVERITY BLOCK CRACKING
MEDIUM SEVERITY BLOCK CRACKING

HIGH SEVERITY BLOCK CRACKING
Name of Distress: BUMPS AND SAGS

Description: Bumps are small, localized, upward displacements of the pavement. Sags are small, abrupt, downward displacements of the pavement surface. Distortion and displacement which occurs over large areas of the pavement surface, causing large and/or long dips in the pavement is called swelling (see the description of "Swelling/Frost Heave" in this report). Also, bumps differ from shoves in that shoves are caused by unstable pavement. Bumps on the other hand can be caused by several things as indicated below:

Possible Causes:
- Buckling or bulging of underlying portland cement concrete (pcc) slabs
- Frost heave or upward thrust of ice forming under the pavement
- Infiltration and buildup of material in a crack in combination with traffic loading (sometimes called tenting).
- Differential settlement of underlying soil.

Impact: Bumps and sags can have a variety of causes. The impact on future performance will vary with the cause. Tenting will eventually cause the pavement to spall away at the cracks or to be sheared off during snow plowing. Frost heaves may develop localized weaknesses during spring thaw causing breakup. Differential settlement or swelling soils indicate the soil strength is probably less than the pavement was designed for and may lead to load related failure.

Severity Levels:
Low severity: Bump or sag causing low severity ride quality. (Noticeable but not annoying.)
Medium severity: Bump or sag causing medium severity ride quality. (Beginning to be annoying.)
High severity: Bump or sag causing high severity ride quality. (Becomes safety hazard or requires traffic to slow down.)

How to Measure: Bumps or sags are measured in linear feet. If bumps appear in a pattern perpendicular to traffic flow and are spaced less than 10 feet, the distress is called corrugation. If the bump occurs in combination with a crack, the crack is also recorded.

Rehabilitation Alternatives:
Low severity: Do nothing.
Medium severity: Partial depth patch, full-depth patch, skin patch, overlay or reconstruct.
High severity: Partial depth patch, full-depth patch, skin patch, overlay or reconstruct.
LOW SEVERITY SAG

MEDIUM SEVERITY BUMP
Name of Distress: CORRUGATION

Description: Corrugation (also known as washboarding) is a series of closely spaced transverse undulations consisting of alternate valleys and crests (ripples) occurring at fairly regular intervals, usually less than 10 feet along the surface of the pavement. The ridges are perpendicular to the traffic direction. If bumps occur in a series less than 10 feet, due to any cause, the distress is considered corrugation.

Possible Causes: This type of distress is usually caused by:
- Traffic action combined with an unstable pavement or a pavement over an unstable roadbed.
- Surface course too soft to resist shoving.
- Faulty paver behavior with some mixes can cause corrugations to be built in during construction.
- Heavy traffic on steep grades and before stop signs, or pavement with too thick of tack coat.
- Low stability in asphalt mixes.

Impact: Corrugation is likely to continue to get worse as traffic continues to use the section. It will eventually lead to an unsafe driving surface due to the roughness and to possible structural failure.

Severity Levels:
- Low severity: Corrugation produces low severity ride quality. (Noticeable but not annoying)
- Medium severity: Corrugation produces medium severity ride quality. (Beginning to be annoying)
- High severity: Corrugation produces high severity ride quality. (Becomes a safety hazard or causes traffic to slow down)

How to Measure: Corrugation is measured in square feet of surface area.

Rehabilitation Alternatives:
- Low severity: Do nothing.
- Medium severity: Partial depth patch; full-depth patch; cold or hot planing, if extensive, with hot mix resurfacing.
- High severity: Partial depth patch; full-depth patch; cold or hot planing, if extensive, with hot mix resurfacing.

This condition is usually localized. If it is a stability problem, removal and replacement is required to correct it. If it was due to improper paving, it can be corrected by overlaying or milling and overlaying. Milling should be considered to prevent some of the corrugation from reflecting through due to differential compaction of the overlay.
LOW SEVERITY CORRUGATION
Name of Distress: DEPRESSION

Description: Depressions are localized areas of pavement with elevations slightly lower than those of the surrounding pavement. In many instances, light depressions are not noticeable until after a rain, when ponding water creates "birdbath" areas. On dry pavement, depressions can be spotted by looking for stains caused by ponding water. Depressions cause some roughness, and when filled with water of sufficient depth, can cause hydroplaning.

Possible Causes: Depressions are created by differential settlement of the foundation soil or are a result of:
- Improper construction
- Compression of roadbed materials
- Settlement of improperly compacted fill in trenches
- Patched or settled roadbeds

Impact: Depressions normally are not progressive after the initial settlement has occurred. The structural capacity may be lower than anticipated since the soil density is likely to be lower. The primary impact of medium to high severity depressions is driver comfort and safety. If the depression occurs on a patch, it will lead to breakup by water/traffic action.

Severity Levels:
- Low severity: Maximum depth of depression is 1/2 to 1 inch.
- Medium severity: Maximum depth of depression is 1 to 2 inches.
- High severity: Maximum depth of depression is more than 2 inches.

How to Measure: Depressions are measured in square feet of surface area.

Rehabilitation Alternatives:
- Low severity: Do nothing.
- Medium severity: Skin patch. Partial depth patch; full-depth patch.
- High severity: Skin patch. Partial depth patch; full-depth patch.

When repairs are made, correction of the underlying cause is necessary if the depression is progressing.
LOW SEVERITY DEPRESSION

MEDIUM SEVERITY DEPRESSION
Name of Distress: EDGE CRACKING

Description: Edge cracks are parallel to and usually within 1 to 2 feet of the outer edge of the pavement or may be a scalloped or alligator pattern type of cracking along the edge of the pavement. This distress is accelerated by traffic loading and can be caused by frost-weakened base or subgrade near the edge of the pavement or differential frost heave along the edge. The area between the crack and pavement edge is classified as raveled if it breaks up (sometimes to the extent that pieces are removed).

Possible Causes:
- Inadequate thickness of the pavement to support traffic
- Vertical settlement or lateral displacement of embankment or both if there are no traffic loads
- Differential frost heave between shoulder and pavement.
- Insufficient bearing support and/or excessive traffic loading at the pavement edge
- Poor drainage at pavement edge and shoulder
- Inadequate pavement width which forces traffic too close to the pavement edge
- Poor compaction at point where curb and gutter meet the asphalt surface

Impact: Edge cracking can lead to loss of strength of the pavement if excessive. Water which can enter the base will also contribute to a weaker pavement. Edge cracking can progress since it forms along a free edge. The pieces can easily break away and result in a loss of surface causing potential safety problems.

Severity Levels:
Low severity: Low or medium cracking with no breakup or raveling.
Medium severity: Medium cracks with some breakup and raveling.
High severity: Considerable breakup or raveling along the edge.

How to Measure: Edge cracking is measured in linear feet.

Rehabilitation Alternatives:
General: Improve shoulder drainage or seal shoulder from water; reconstruct edge and extend roadway width (if necessary).

Low severity: Do nothing; crack seal.

Medium severity: Crack seal if local; partial depth patch; full-depth patch.

High severity: Partial depth patch or full-depth patch.
LOW SEVERITY EDGE CRACKING

MEDIUM SEVERITY EDGE CRACKING
HIGH SEVERITY EDGE CRACKING
Name of Distress: FLUSHING

Description: Flushing is a film of bituminous material on the pavement surface which creates a shiny, reflecting surface that usually becomes quite sticky when hot. Flushing is a result of free asphalt migrating upward to the pavement surface. It occurs most often in the wheelpaths, especially during hot weather. Since the flushing process is not reversible during cold weather, asphalt will accumulate on the surface.

Flushing results in low frictional characteristics when the pavement is wet and is, therefore, a safety hazard. Rehabilitation of a flushed pavement normally cannot be deferred because of the risk exposure.

Possible Causes: Flushing is caused by excessive asphalt cement in the mix relative to the voids in mineral aggregate, excess application of a bituminous sealant, and/or low air void content. It occurs when asphalt fills the voids of the mix during hot weather and then expands onto the pavement surface. On hot days, the asphalt binder expands into air voids; if air voids are too low, continued expansion results in lower stability of the mix with the consequence that traffic will force the excess asphalt to the surface.

These conditions can occur due to:
- A poor mix design (hot or cold mix)
- Problems in mixing
- Segregation in silos, truck or paver
- Significant increase in wheel loadings during hot weather.

Impact: Flushing indicates a possible, unstable mix that could rut or corrugate under traffic. Its most immediate impact is low skid resistance and a safety hazard.

Severity Levels:

Low severity: Flushing has only occurred to a very slight degree and it is noticeable only during a few days of the year. Asphalt does not stick to shoes or vehicles.

Medium severity: Flushing has occurred to the extent that asphalt sticks to shoes and vehicles during only a few weeks of the year.

High severity: Flushing has occurred extensively and considerable asphalt sticks to shoes and vehicles during at least several weeks of the year.

How to Measure: Flushing is measured in square feet of surface area. If flushing is counted, polished aggregate should not be counted.

Rehabilitation Alternatives:

Flushing is not easily corrected. It may be possible to use infra-red heating units to soften the asphalt and blot the excess material with sand. An overlay or seal coat may not solve the problem if there is sufficient asphalt remaining in the existing layers that continue to pump up to the surface. Also it should be noted that the problem layer, or layer with the excess asphalt, does not have to be the wearing course; it could be the binder or base course.

Low severity: Do nothing; apply heat and roll sand.

Medium severity: Apply heat and roll sand.

High severity: Mill overlay; apply aggregate seal coat; apply heat and roll sand;
LOW SEVERITY FLUSHING

MEDIUM SEVERITY FLUSHING
HIGH SEVERITY FLUSHING
Name of Distress: LANE/SHOULDER DROP OFF

Description: Lane/shoulder drop off is a difference in elevation between the pavement edge and the shoulder.

Possible Causes: This distress is caused by shoulder erosion, shoulder settlement, or by building up the roadway without adjusting the shoulder level.

Impact: The presence of a drop-off at the edge of the pavement is a safety concern. Any high severity drop must be fixed. Another impact is entrapment of water along the pavement edge. This allows the water to soak into the base under the pavement causing strength loss. Edge cracking or alligator cracking could also result.

Severity Levels:

Low severity: The difference in elevation between the pavement edge and shoulder is under 1 inch.

Medium severity: The difference in elevation is over 1 to 2 inches.

High severity: The difference in elevation is greater than 2 inches.

How to Measure: Lane/shoulder drop off is measured in linear feet.

Rehabilitation Alternatives:

Low severity: Do nothing.

Medium severity: Do nothing; level off shoulder to pavement surface.

High severity: Level off shoulder to pavement surface.

On aggregate shoulders, leveling is accomplished by periodic blading. Paved shoulders can be leveled with a wedge overlay using a fine mix.

AREA OF LANE SHOULDER DROP OFF
(Measured from the top of the pavement to the top of the shoulder)

SHOULDER PAVEMENT

TYPICAL LANE/SHOULDER DROP-OFF
Name of Distress: LONGITUDINAL CRACKING

Description: Longitudinal cracks generally follow a course approximately parallel to the pavement’s centerline or lay-down direction. There are two types of longitudinal cracks, load related (located within the wheelpaths) and non-load related cracks that meander in and out of the wheelpath or longitudinal cold joint. The load related crack is defined to be fatigue cracking and is covered under alligator cracking. The first type of longitudinal crack is the type covered under this definition.

Possible Causes:
- Settlement of roadbed under traffic
- Possibly shrinkage of surface course or insufficient pavement thickness
- A frost heave differential between the center and edge of the pavement.
- Lateral movement or expansion of slope or subgrade
- Poor construction practices
- A cold or improperly constructed joint between pavement sections

Impact: If the longitudinal crack is load related, please see alligator cracking.

Non-load associated cracks have less of an effect on strength if they are not in the wheelpath. If the crack is in the wheelpath, it will lower the available strength. The amount of strength loss depends on the thickness of the asphalt and the amount of water that flows into the base through the cracks.

Cold joints that have opened up are normally not in a wheelpath. They do, however, still allow water to flow into the base. Cold joints usually also have raveling associated with the crack. This raveling can progress, resulting in a wide crack at the surface.

Severity Levels:

Low severity: One of the following conditions exist:
1. Non-filled crack width is less than 1/4 inch
2. Filled crack of any width (filler in satisfactory condition)

Medium severity: One of the following conditions exist:
1. Non-filled crack width is 1/4 to 1/2 inches
2. Non-filled crack of any width up to 1/2 inches surrounded by light and random cracking
3. Filled crack of any width surrounded by light random cracking

High severity: One of the following conditions exist:
1. Any crack filled or non-filled surrounded by medium or high severity random cracking
2. Non-filled crack over 1/2 inches
3. A crack of any width where a few inches of pavement around the crack is severely broken

How to Measure: Longitudinal cracks are measured in linear feet. The length and severity of each crack should be recorded. If the crack does not have the same severity level along its entire length, each portion of the crack having a different severity level should be recorded separately. If a bump or sag occurs at the crack, it is also recorded.
Rehabilitation Alternatives:

Low severity: Do nothing; crack seal or fill; rout and seal with an approved sealant.

Medium severity: Crack seal or rout and seal with an approved sealant; partial depth patch; full-depth patch; slope stabilization.

High severity: Partial depth patch; full-depth patch; slope stabilization.

LOW SEVERITY LONGITUDINAL CRACKING
MEDIUM SEVERITY LONGITUDINAL CRACKING (COLD JOINT)

HIGH SEVERITY LONGITUDINAL CRACKING
Name of Distress: PATCH

Description: A patch is an area of pavement that has been replaced or covered with new material. It can be identified by its color and texture. It can have an irregular shape when a pothole is filled or a rectangular shape such as a utility patch. A patch can range from less than 1 square foot to several thousand square feet. When a patch gets to be very large, it should be separated out as a separate pavement section. The maximum size will depend on the size of the original section. For instance, the maximum size a patch can be in a short city block would be much smaller than a patch on a five mile rural highway section. If a rating system is used which counts patches, a maximum size must be established.

There are several types of patches. A few types are identified as follows:

Temporary Patch
The so called "Throw and Go" patch such as a pothole that was hand filled with hot or cold mix. This is a temporary procedure that may last from just hours to several months or more depending on conditions.

Skin Patch
A thin blade laid or paver laid overlay that covers a small area.

Permanent Patch
Utility cut or permanent repair. These patches are normally rectangular patches where the original pavement material was removed and new material was placed. The surface of these patches is normally flush with the adjoining original pavement and they have straight edges.

Overlay Patch
An overlay patch may also be considered a permanent repair. It is not cut into the original materials and you will not be able to tell if there has been any removal of the original material. These are typically larger in size and found more often on rural sections.

Patches are repairs of some other type of distress and in that respect are unlike all of the other distresses that are described in this manual. They do, however, indicate a deficiency or weakness in the pavements and should be rated.

Reasons to Patch: A patch is a repair of a pavement failure, an underlying utility repair or installation, or a depressed area that has been filled.

Temporary patching is done to repair safety hazards, such as potholes or breakup areas of a pavement that is scheduled for reconstruction.

Permanent patches are made either to repair utility cuts or to repair localized pavement failures in an otherwise good pavement. A permanent pavement repair could either be a remove and replace form of patch or a small area asphalt overlay.

Possible Causes: N/A

Impact: The impact of patches is not as clearly defined. First, as described above, the reason for the patch is important to consider. A well placed patch in an otherwise good pavement may have minimal impact on the service life of the pavement. It may, however, be an indication of more problems to come.

Utility patches are common in urban sections. A high frequency of utility patches, in itself, can influence the rehabilitation choice. There are no guidelines available, but some cities indicate that excessive patching can be the reason for rehabilitation. The rehabilitation can take the form of a seal coat, overlay or reconstruction, depending on condition and age.
Severity Levels:

Low severity: Patch is in good condition and satisfactory. Ride quality is rated as low severity or better. (Noticeable but not annoying)

Medium severity: Patch is moderately deteriorated and/or ride quality is rated as medium severity. (Beginning to be annoying)

High severity: Patch is badly deteriorated and/or ride quality is rated as high severity (Becomes a safety hazard or causes traffic to slow down). Patch needs replacement soon.

How to Measure: Patching is measured in square feet of surface area. However, if a single patch has areas of differing severity, these areas should be measured and recorded separately. For example, a 25 square foot patch may have 10 square feet of medium severity and 15 square feet of low severity. These areas would be recorded separately. No other distresses (e.g. shoving or cracking) are recorded within a patch (e.g. even if patch material is shoving or cracking, the area is rated only as a patch). If a large amount of pavement has been replaced, it should not be recorded as a patch, but considered as new pavement (e.g. replacement of full intersection).

Rehabilitation Alternatives:

Low severity: Do nothing.

Medium severity: Crack seal, partial or full-depth patch (replace existing patch)

High severity: Partial or full-depth patch (replace patch). Subgrade deficiencies should be corrected before a new patch is placed. Patching can be performed according to the guidelines from the T² Center. The City Engineers Association of Minnesota (CEAM) also has guidelines for patching utility cuts.
HIGH SEVERITY TEMPORARY PATCH

MEDIUM SEVERITY UTILITY PATCH
HIGH SEVERITY SKIN PATCH
**Name of Distress:** POLISHED AGGREGATE

**Description:** This distress is caused by repeated traffic applications. When the coarse aggregate at the surface becomes smooth to the touch, adhesion with vehicle tires is considerably reduced. When the portion of aggregate extending above the surface is small, the pavement texture does not significantly contribute to reducing vehicle speed. Polished aggregate should be counted when close examination reveal the surface aggregate is smooth to the touch. This type of distress is indicated when the number on a skid resistance test is low or has dropped significantly from previous ratings.

**Possible Causes:** Coarse aggregates which are easily polished under traffic. Raveling or abrasion of the asphalt which exposes the course aggregate.

**Impact:** Polished aggregate is a safety item and must be corrected before it becomes too severe. It has no effect on the structural capacity of the pavement.

**Severity Levels:** No degrees of severity are defined. However, the degree of polishing should be significant before it is included in the condition survey and rated as a defect.

**How to Measure:** Polished aggregate is measured in square feet of surface area.

**Rehabilitation Alternatives:**
- Do nothing; resurface with seal coat or overlay.
Name of Distress: POTHOLES (CHUCKHOLES)

Description: Potholes are small (usually less than 3 feet in diameter), bowl shaped holes in the pavement surface. They generally have sharp edges and vertical sides near the top of the hole. Their growth is accelerated by free moisture collection inside the hole. Potholes are produced when traffic abrades small pieces of a pavement surface that has been weakened. The pavement then continues to disintegrate because of poor surface mixtures, weak spots in the base or subgrade, or because it has reached a condition of high severity alligator cracking. Potholes are generally structurally related distresses and should not be confused with raveling and weathering. Thus, when holes are created by high severity alligator cracking, they should be identified as potholes, not as weathering.

Possible Causes: Potholes are the advanced result of other surface distresses (ravelling, alligator cracking, weathering, etc.). They may be due to small, localized disintegration or failure of the pavement from traffic over weakened spots in the surface, poor construction technique and poor quality control or poor aggregates in the pavement.

Impact: Safety is the primary concern. Potholes represent a traffic hazard if they are medium or high severity. Potholes often are a progressive distress if left unrepairs. The severity of the impact is dependent on the cause of the pothole and the type and extent of the other distresses present. The traditional cause of a pothole is the deterioration that occurs after severity alligator cracking.

Severity Levels: The levels of severity for potholes under 30 inches in diameter are based on both the diameter and the depth of the pothole according to the following table:

<table>
<thead>
<tr>
<th>DEPTH</th>
<th>4 to 8 inch</th>
<th>&gt; 8 to &lt; 18 inch</th>
<th>&gt; 18 to &lt; 30 inch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1 inch</td>
<td>L</td>
<td>L</td>
<td>M</td>
</tr>
<tr>
<td>1 to 2 inches</td>
<td>M</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>More than 2 inches</td>
<td>M</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>

If the pothole is over 30 inches in diameter, the area should be determined in square feet and divided by 5 square feet to find the equivalent number of potholes. If the depth is 1 inch or less, they are considered medium severity. If the depth is over 1 inch, they are considered high severity.

How to Measure: Potholes are measured by counting the number that are low, medium, and high severity and recording them separately.

Rehabilitation Alternatives:

Low severity: Partial depth patch; full-depth patch; pothole filling.

Medium severity: Full-depth patch; pothole filling.

High severity: Full-depth patch; pothole filling.

Patching of potholes should follow the guidelines available from agencies such as the T² Center, APWA and FHWA. If the overall condition of the road is such that reconstruction (not overlay) is planned, pothole patching may be done on a temporary basis. If the pavement is to be overlaid, a permanent patch should be placed.
LOW SEVERITY POTHOLE

MEDIUM SEVERITY POTHOLE
HIGH SEVERITY POTHOLE
Name of Distress: RAVELING, WEATHERING OR ABRASION

Description: Raveling and weathering are progressive disintegrations of the pavement material from the surface downward caused by the loss of asphalt binder and dislodged aggregate particles. These distresses indicate that either the asphalt binder has hardened appreciably, or that a poor quality mixture is present. In addition, raveling may be caused by the abrasive action of sand and tires, especially at intersections. Softening of the surface and dislodging of the aggregates due to oil or fuel spillage is also included under raveling.

Possible Causes:
- Lack of bond between particles due to uneven distribution or insufficient bitumen (or binding agent) in the surface
- Stripping under the action of water
- Fracture of the particles under traffic loadings allowing the loosened pieces to be removed by traffic action
- Disintegration of particles (dirt, shale, etc.) which are highly absorptive, fracture and disintegrate upon repeated freezing and thawing
- Poor compaction during paving which permits the infiltration of water and salt. This can promote stripping of asphalt
- Asphalt hardening due to aging.

Impact: Raveling is a normal occurrence on asphalt pavements. It is the rate at which raveling occurs which is important to consider. Raveling, if allowed to progress to a severe level, results in a loss of thickness. Raveling is not expected to reach medium severity on rural highways for at least 12 to 15 years. A well compacted wearing course with good mix design characteristics would not normally need a surface treatment due to raveling in its normal design life on a rural road. City streets will need treatment sooner because of the abrasive action of tires and sand at the intersections.

A pavement that shows premature raveling may also have other durability problems such as brittleness or be more prone to cracking.

Severity Levels:

Low severity: The fine aggregate or binder has started to wear away. The large aggregate particles are exposed at the top. In some areas, the surface is starting to pit. In cases with oil or fuel spillage, the stain can be seen, but the surface is hard and cannot be penetrated with a coin.

Medium severity: The fine aggregate and/or binder has worn away. At least one-third of the diameter of the large aggregates is exposed. The surface texture is moderately rough and pitted. In cases with oil or fuel spillage, the surface is soft and can be penetrated with a coin.

High severity: The fine aggregate and/or binder has been considerably worn away and the large aggregate is coming off. The surface texture is very rough and severely pitted. In case of oil or fuel spillage, the asphalt binder has lost its binding effect and the aggregate has become loose.

How to Measure: Weathering and raveling are measured in square feet of surface area.

Rehabilitation Alternatives:

Low severity: Do nothing; apply a surface seal emulsion; apply rejuvenation.

Medium severity: Apply surface seal emulsion; apply aggregate seal coat.

High severity: Partial depth patch, if it is localized
- Apply an aggregate seal coat
- Thin overlay

Surface texture will dictate whether a seal coat can be used or an overlay is required. If the course aggregate is protruding over one-half inch, a seal coat may not be able to cover the pavement adequately.
LOW SEVERITY RAVELING

MEDIUM SEVERITY RAVELING
HIGH SEVERITY RAVELING
Name of Distress: REFLECTIVE CRACKING

Description: Reflective cracking is the cracking of a resurface or overlay above joints in underlying concrete pavements. This distress is not load related; however, traffic loading may cause a breakdown of the asphalt surface near the crack. If the pavement is fragmented along a crack, the crack is said to be spalled. A knowledge of the slab dimensions or crack condition beneath the asphalt surface will help identify these distresses.

Possible Causes: Reflective cracks are mainly caused by the thermal or moisture induced movement of the concrete slab beneath the asphalt overlay; other possible causes include a lack of bridging over underlying cracks or joints and shrinkage of an underlying layer.

Impact: Joint reflection cracks are usually the dominant distress on asphalt overlays of concrete pavements. The cracks normally deteriorate to a point where the ride is poor and the maintenance costs become high. Maintenance of the cracks will reduce the water damage of the cracks (spalling and raveling) and prolong the life of the overlay.

Severity Levels:

Low Severity: One of the following conditions exist:
1. Non-filled crack width is less than 1/4 inch
2. Filled crack of any width (filler in satisfactory condition)

Medium severity: One of the following conditions exist:
1. Non-filled crack width is greater than 1/4 inch and less than 3/4 inch.
2. Non-filled crack or crack with poor sealer of any width up to 3/4 inches with only minor spalling.
3. Filled crack of any width surrounded by low severity random cracking.

High severity: One of the following conditions exist:
1. Any crack filled or non-filled surrounded by medium or high severity random cracking.
3. A crack of any width where a few inches of pavement around the crack is severely broken.

How to Measure: Joint reflection cracking is measured in linear feet. The length and severity level of each crack should be recorded separately. Each severity would be recorded separately. If a bump occurs at the reflection crack, it is also recorded.

Rehabilitation Alternatives:

Low severity: Do nothing; crack seal or rout and seal with an approved sealant. If density is high, a seal coat will provide temporary protection.

Medium severity: Crack seal or rout and seal with an approved sealant.

High severity: Crack seal or rout and seal with an approved sealant; partial depth patch; if density is high, overlay, mill and overlay or reconstruction may be considered.
HIGH SEVERITY REFLECTION CRACKING
**Name of Distress:** RUTTING (GROOVING, CHANNELING, WHEELTRACKING)

**Description:** A rut is a longitudinal surface depression in the wheelpath. Pavement uplift may also occur along the sides of the rut. In many instances, ruts are more noticeable after a rainfall, when filled with water.

**Possible Causes:** The following are possible contributing factors to rutting:

- Localized and channelized wheel traffic over unstable pavement or foundation
- Traffic heavier than the design strength of the pavement structure; poorly compacted structural layers
- Unstable granular base or subbase created by positive pore pressure under loads at time of near saturation
- Unstable asphalt mixes (due to high temperature or low viscosity of binder)
- Unstable shoulder material (does not provide lateral support)
- High shear stress development in the wearing course due to high tire pressure and strong underlying layers such as an asphalt overlay over concrete

Rutting is a permanent deformation of the pavement surface; however, the deformation may also take place in any of the pavement layers or subgrade. It is usually caused by consolidated or lateral movement of the materials due to traffic loads. Significant rutting can lead to major structural failure of the pavement.

**Impact:** Areas of concern when rutting occurs include safety and shortened service life. Safety becomes a concern when the ruts collect water and lead to hydroplaning. Service life can be shortened by rutting due to the loss in structural integrity. The extent to which the service life is shortened is dependent on the materials and axle loading. If the rutting continues to progress, rehabilitation will be required.

In addition to the above, rutting may indicate that other problems are developing. Structural capacity could be lost. Rutting indicates that the pavement section is not sufficient for the axle loads it is exposed to.

The deficiency may be due to any of the following:

- Thickness required for the traffic and soil strength.
- Stability of the asphalt surface or base.
- Placement of the pavement materials (compaction).

Rutting should be investigated before a repair is chosen. A simple overlay may not provide a permanent repair.

**Severity Levels:**

- **Low severity:** 0 to < 1/2 inch.
- **Medium severity:** > 1/2 to < 1 inch.
- **High severity:** > 1 inch or when hydroplaning can occur.

**How to Measure:** Rutting is measured in square feet of surface area. It can also be measured in centerline distance. Its severity is determined by the average depth of the rut (see above). The average rut depth is calculated by laying a straight-edge across the rut, measuring its depth, then using measurements taken along the length of the rut to compute its depth in inches.

**Rehabilitation Alternatives:**

- **Low severity:** Do nothing; partial depth patch; skin patch.
- **Medium severity:** Partial depth patch; full-depth patch; skin patch, overlay, mill and overlay or reconstruct.
High severity: Partial depth patch; full-depth patch; skin patch, overlay, mill and overlay or reconstruct.

When rutting occurs, the section should be fully evaluated to determine the exact cause. It is necessary to determine what layer is responsible. A mix stability problem may require removal and replacement. Base deformation may require removal and replacement, if the cause is poor stability, or an overlay, if the cause is consolidation of a poorly compacted base.
HIGH SEVERITY RUTTING
Name of Distress: SHOving

Description: Shoving is a permanent, longitudinal displacement of a localized area of the pavement surface caused by traffic loading. Shoving is a transverse undulation in the pavement surface consisting of closely spaced alternate valleys and crests. When traffic pushes against the pavement, it produces a short, abrupt wave in the pavement surface (also see corrugation). This distress is more likely to occur in unstable liquid asphalt mix (cutback or emulsion) pavements.

Possible Causes:
- Surface course that is too soft to resist the horizontal pressure
- Lack of bond between the asphalt and the underlying layer
- Low stability mix
- Unstable granular base affecting surface stability
- Starting and stopping of vehicles at intersections where an unstable mix is present.

Impact: Shoving, if allowed to progress can lead to other forms of distress and eventual breakup. If the shoving becomes severe, a safety problem also develops because of its effect on vehicle control.

Severity Levels:

Low severity: Shove causes low severity ride quality. (Noticeable but not annoying)

Medium severity: Shove causes medium severity ride quality. (Beginning to be annoying)

High severity: Shove causes high severity ride quality. (Becomes a safety hazard or causes traffic to slow down)

How to Measure: Shoves are measured in square feet of surface area. Shoves occurring in patches are considered in rating the patch, not as a separate distress.

Rehabilitation Alternatives:

Low severity: Do nothing.

Medium severity: Full-depth patch.

High severity: Full-depth patch.
LOW SEVERITY SHOVING

HIGH SEVERITY SHOVING
Name of Distress: SLIPPAGE CRACKING

Description: There are two types of slippage cracks: Traffic related and non-traffic related.

Traffic Related:
Slippage cracks are crescent or half-moon shaped cracks. They are produced when breaking or turning wheels cause the pavement surface to slide or deform. This distress usually occurs when there is a low strength surface mix or a poor bond between the asphalt layers.

Non-Traffic Related:
Cracks which outline the edge of a fill settlement or slope failure. Generally takes the form of a large crescent. The pavement in the enclosed (inside) side of the crescent is depressed, or may have been filled with surfacing material.

Possible Causes: Traffic Related:
They are produced when breaking or turning wheels cause the pavement to slide or deform. This distress usually occurs when there is a low strength surface mix (soft asphalt) or a poor bond between the surface and the underlying layer in the pavement structure. It can also be caused by excessive deflection in new pavements causing excess shear pressure between pavement layers.

Non-Traffic Related
Embarkment slope failure.

Impact:

Traffic Causes: Loss of structure has occurred in a slippage cracked area. If the slippage crack is due to an unstable wearing course and breaking or turning action, the amount of localized structural loss is only from the loss of the surface layer. If the slippage crack is in a new pavement section, it may indicate a localized soft area in the subgrade. A soft subgrade may stabilize and gain strength if it is due to high moisture content, but it could be an area that needs to be removed and replaced before it will carry traffic.

Slope Failure: Slope failure can be a dangerous safety concern, depending on the nature of the slide and embankment. Any indication of a slide failure must be evaluated as soon as possible to assess the danger and the necessary action.

Severity Levels:

Low severity: Average crack width is less than 1/4 inch.

Medium severity: One of the following conditions exist:

1. Average crack width is between 1/4 and 1/2 inch.

2. The area around the crack is broken into tight-fitting pieces.

High severity: One of the following conditions exist:

1. The average crack width is greater than 1/2 inch.

2. The area around the crack is broken into easily removed pieces.

How to Measure: The area associated with a given slippage crack is measured in square feet and rated according to the highest level severity in the area.

Rehabilitation Alternatives:

Low severity: Do nothing; crack seal.

Medium severity: Partial depth patch.

High severity: Partial depth patch; reconstruction.
LOW SEVERITY SLIPPAGE CRACKING

MEDIUM SEVERITY SLIPPAGE CRACKING
HIGH SEVERITY SLIPPAGE CRACKING
Name of Distress: SWELL/FROST HEAVE

Description: A swell is characterized by an upward bulge in the pavement's surface: a long, gradual longitudinal or transverse undulation in the surface of the pavement of more than 10 feet long. Swelling and frost heaves can be accompanied by surface cracking. Most of the soils in Minnesota are not expansive and, therefore, swelling does not occur very frequently; frost heave, on the other hand, is common.

Possible Causes: This distress is usually caused by the formation of an ice lens in the subgrade or by swelling soil.

Impact: Swelling soils and frost heave both reduce the serviceability of the pavement and also cause a strength loss. The strength loss due to a frost heave is temporary. It exists only during the spring thaw period and normal strength returns once the frost heave has gone away. Swelling soils experience a strength loss that may be permanent.

Severity Levels:

Low severity: Swell or frost heave cause low severity ride quality (Noticeable but not annoying). Low severity swells and frost heaves are not always easy to see, but can be detected by driving at the speed limit over the pavement section.

Medium severity: Swell or frost heave cause medium severity ride quality (Beginning to be annoying). Frost heaves may cause excessive strength loss during the spring thaw.

High severity: Swell or frost heave cause high severity ride quality (Becomes a safety hazard or causes traffic to slow down). Frost heaves may cause excessive strength loss during the spring thaw.

How to Measure: The surface area of the swell is measured in square feet.

Rehabilitation Alternatives:

Low severity: Do nothing.

Medium severity: Full-depth patch. Pavement removal, subgrade correction and replacement of the pavement. Subgrade correction should include tapers at the ends (see below) to prevent additional problems with differential swell or heave.

High severity: Full-depth patch. Pavement removal, subgrade correction and replacement of the pavement. Subgrade correction should include tapers at the ends (see below) to prevent additional problems with differential swell or heave.
METHOD FOR EXCAVATION OF FROST HEAVE AREA

LOW SEVERITY FROST HEAVE
HIGH SEVERITY SWELL
Name of Distress: TRANSVERSE CRACKING (TEMPERATURE CRACKING)

Description: Transverse cracks extend across the pavement at approximately right angles to the pavement centerline. These types of cracks are not usually load-associated.

Possible Causes: - Shrinking of the surface courses, pavement structure or pavement and subgrade caused by large temperature cycling or a single occurrence of a very low temperature

- Temperature susceptible asphalt cement binder in asphalt mixes

Impact: Transverse cracks are a given in Minnesota's climate. There are, however, factors that can be incorporated into the design and construction that will minimize the frequency and severity of transverse cracks. In existing pavements, the impact of a transverse crack can vary tremendously. In some cases, the crack will form and will deteriorate very slowly. In other cases, the crack may ravel, develop associated cracking and depressions in the wheelpaths that require repair. The behavior of a crack, once it forms, depends on the pavement materials and traffic. There are no clear guidelines available at this time to predict how the crack will perform. There is a general agreement, however, that crack sealing or filling will retard the deterioration of the crack.

Severity Levels:

Low severity: One of the following conditions exist:

1. Non-filled crack width is less than 1/4 inch.

2. Filled crack of any width (filler in satisfactory condition).

Medium severity: One of the following conditions exist:

1. Non-filled crack width is 1/4 to 1/2 inch.

2. Non-filled crack of any width up to 1/2 inch surrounded by light and random cracking.

3. Filled crack of any width surrounded by light random cracking.

High severity: One of the following conditions exist:

1. Any crack filled or non-filled surrounded by medium or high severity random cracking.

2. Non-filled crack over 1/2 inch.

3. A crack of any width where a few inches of pavement around the crack is severely broken.

How to Measure: Transverse cracks are measured in linear feet. The length and severity of each crack should be recorded after identification. If the crack does not have the same severity level along its entire length, each portion of the crack having a different severity level should be recorded separately. If a bump or sag occurs at the crack, it is also recorded.
Rehabilitation Alternatives:

Low severity: Do nothing; crack seal or rout and seal with an approved sealant; apply a surface seal emulsion, or apply an aggregate seal coat.

Medium severity: Crack seal or rout and seal with an approved sealant; apply an aggregate seal coat.

High severity: Partial depth patch; apply an aggregate seal coat.

At some point, the frequency of cracks can be high enough that a more involved rehabilitation such as mill and overlay, reconstruct, etc. will be more economical than a crack treatment program.

Crack treatment provides two benefits:

1) It reduces the amount of water that can enter the pavement system.

2) It can retard the deterioration of the crack edges and the stripping that commonly occur at the bottom of the asphalt next to the cracks.

LOW SEVERITY TRANSVERSE CRACKING
MEDIUM SEVERITY TRANSVERSE CRACKING

HIGH SEVERITY TRANSVERSE CRACKING
APPENDIX B

ALPHABETICAL LISTING OF DISTRESS TYPES FOR RIGID PAVEMENTS
Description of Format

The typical and some not so typical distresses found in rigid pavements are described in this appendix. Each of the distresses contained here are described in a standardized format as follows:

**Name of Distress:** The name or names by which the distress is commonly called.

**Description:** A physical description of the distress, what it looks like and how it can be identified. Pictures will be included for reference.

**Possible Causes:** Describes possible causes of the distress, whether environmental, material or load related.

**Impact:** Describes the consequences of the distress, what is expected to happen if left untreated.

**Severity Levels:** Describes up to three severity levels of the distress; low, medium and high.

**How to Measure:** How the distress is measured during a surface condition survey.

**Rehabilitation Alternatives:** Describes the rehabilitation alternatives that apply to the distress. A discussion of how the various severities and densities are treated is included where appropriate.

The definitions and descriptions of the distresses listed in this Appendix have been compiled from the following references:

1. Pavement Maintenance Management for Roads and Parking Lots, Ref. 20
2. Surface Condition Rating System "Field Guide", Ref. 21
4. Pavement Maintenance Guidelines: Distress Maintenance Alternatives, Performance Standards, Ref. 23
5. Surface Condition Rating System for Bituminous Pavements, Ref. 24
6. Asphalt Overlays for Highway and Street Rehabilitation, Ref. 25
7. Pavement Moisture Accelerated Distress (MAD) Identification System, Ref. 26
**Name of Distress:** BLOW-UP / BUCKLING / SHATTERING

**Description:** Blow-ups, buckling, or shattering occurs in hot weather, usually at a transverse crack or at joints that are not wide enough to permit slab expansion. Blow-ups can also occur at utility cuts and drainage inlets.

**Possible Causes:** The insufficient joint width is usually caused by infiltration of incompressible materials into the joint space. When expansion cannot relieve enough pressure, a localized upward movement of the slab edges (buckling or shattering) will occur in the vicinity of the joint. When a blow-up renders the pavement inoperable, it should be repaired immediately.

**Severity Levels:**

- **Low severity:** Buckling or shattering causes low severity ride quality.
- **Medium severity:** Buckling or shattering causes medium severity ride quality.
- **High severity:** Buckling or shattering causes high severity ride quality.

**How to Measure:** At a crack, a blow-up is counted as being in one slab. However, if the blow-up occurs at a joint and affects two slabs, the distress should be recorded as occurring in two slabs.

**Rehabilitation Alternatives:**

- **Low severity:** Partial depth patch (bonded). Must provide expansion joint.
- **Medium severity:** Partial depth patch (bonded). Must provide expansion joint.
- **High severity:** Full depth patch; Slab replacement. In either case an expansion joint must be provided.

Preventive measures, such as maintaining good joint sealers and placement of expansion joints, will control blow-ups.
Name of Distress: CORNER BREAK

Description: A corner break is a crack that intersects the joints at a distance less than or equal to one-half the slab length on both sides, 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.

Possible Causes: Load repetition combined with loss of support and curling stresses usually causes corner breaks; overloading the pavement slabs at or near the corners; an unstable foundation or voids formed because of loss of the foundation materials under the slab.

Severity Levels:

Low severity: Break is defined by a low severity crack and the area between the break and the joint is not cracked or may be lightly cracked. See "Linear Cracking" for definition of low severity cracks.

Medium severity: Break is defined by medium severity crack and/or the area between the break and the joint is moderately cracked. See "Linear Cracking" for definitions of medium severity cracks.

High severity: Break is defined by a high severity crack and/or the area between the break and the joint is highly cracked. See "Linear Cracking" for definitions of high severity cracks.

How to Measure: Distressed slab is recorded as one slab if it:

1. Contains a single corner break.
2. Contains more than one break of a particular severity.
3. Contains two or more breaks of different severities.

For two or more breaks, the highest level of severity should be recorded. For example, a slab containing both low and medium severity corner breaks should be counted as one slab with a medium severity corner break.

Rehabilitation Alternatives:

Low severity: Do nothing; crack sealing, under sealing.

Medium severity: Crack sealing, under sealing; full-depth patch.

High severity: Crack sealing, under sealing; full-depth patch; slab replacement.
LOW SEVERITY CORNER BREAK

MEDIUM SEVERITY CORNER BREAK
HIGH SEVERITY CORNER BREAK
Name of Distress: DIVIDED SLAB

Description: Slab is divided by cracks into four or more pieces due to overloading and/or inadequate support. Unrestrained or uncontrolled irregular break or separation of the slab. If all pieces or cracks are contained within a corner break, the distress is categorized as a severe corner break.

Possible Causes: Overloading of concrete slab; insufficient thickness of pavement or lack of support from the roadbed; an unstable foundation or voids formed because of loss of foundation material under the slab.

Severity Levels:

<table>
<thead>
<tr>
<th>Severity of Majority of Cracks</th>
<th>Number of Pieces in Cracked Slab</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>4 to 5</td>
</tr>
<tr>
<td>M</td>
<td>6 to 8</td>
</tr>
<tr>
<td>H</td>
<td>More than 8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>L</th>
<th>M</th>
<th>H</th>
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</thead>
<tbody>
<tr>
<td>4 to 5</td>
<td>L</td>
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<tr>
<td>6 to 8</td>
<td>L</td>
<td>M</td>
<td>H</td>
</tr>
<tr>
<td>More than 8</td>
<td>M</td>
<td>H</td>
<td>H</td>
</tr>
</tbody>
</table>

How to Measure: If the slab is medium or high severity, no other distress is counted.

Rehabilitation Alternatives:

Low severity: Crack sealing, under sealing.

Medium severity: Crack sealing, under sealing; slab replacement.

High severity: Slab replacement.
MEDIUM SEVERITY DIVIDED SLAB

HIGH SEVERITY DIVIDED SLAB
Name of Distress: DURABILITY ("D") CRACKING

Description: This distress usually appears as a pattern of cracks running parallel and close to a joint or linear crack. A series of fine, hairline crescent-shaped cracks in the concrete surface usually curving across the slab corners. If the concrete becomes saturated near joints and cracks, a dark-colored deposit can usually be found around fine "D" cracks. This type of distress can eventually lead to disintegration of the entire slab.

Possible Causes: Durability or "D" cracking is generally caused by freeze-thaw expansion of the large aggregate which over time gradually breaks down the concrete. Another possible cause for "D" cracking is paste deterioration or reactive aggregate. It has been found that close evaluation or laboratory study may be necessary to identify the deterioration mechanism.

Severity Levels:

Low severity: "D" cracks cover less than 15 percent of slab area. Most of the cracks are tight, but a few pieces may have popped out.

Medium severity: One of the following conditions exist:

1. "D" cracks cover less than 15 percent of the area and most of the pieces have popped out or can be easily removed.

2. "D" cracks cover more than 15 percent of the area. Most of the cracks are tight, but a few pieces may have popped out or can be easily removed.

High severity: "D" cracks cover more than 15 percent of the area and most of the pieces have popped out or can be easily removed.

How to Measure: When the distress is located and rated at one severity it is counted as one slab. If more than one severity level exists, the slab is counted as having the higher severity distress. For example, if low and medium "D" cracking are on the same slab, the slab is counted as having medium severity cracking only.

Rehabilitation Alternatives:

Low severity: Do nothing; crack sealing; joint sealing; (Note: If "D" cracks exist, seal all cracks and joints). Moisture plays a role in the development of D-cracking and a good joint sealing program may retard the development.

Medium severity: Partial depth patch (bonded). Full-depth bonded patch.

High severity: Full depth patch; Slab replacement.

Laboratory freeze/thaw testing has found that D-cracking may be controllable if the course aggregate that is causing D-cracking is kept to less than 3/4 inch in size.
LOW SEVERITY "D" CRACKING

MEDIUM SEVERITY "D" CRACKING
HIGH SEVERITY "D" CRACKING
Name of Distress: FAULTING

Description: Faulting is the differential vertical displacement of abutting slabs at joints or cracks creating a "step" deformation in the pavement surface.

Possible Causes: Some of the common causes of faulting are: one slab settling more than the adjacent slab because of a soft foundation; lack of subgrade support or uneven roadbed support under the slab; pumping or eroding of material from under the slab; heaving of one of the slabs; frost action or curling of the slab edges due to temperature and moisture changes. Faulting often occurs at the junction of a rigid and a flexible pavement.

Severity Levels: Severity levels are defined by the difference in elevation across the crack or joint.

<table>
<thead>
<tr>
<th>Severity Level</th>
<th>Difference in Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>L</td>
<td>0 to 1/2 inch</td>
</tr>
<tr>
<td>M</td>
<td>&gt; 1/2 to &lt; 1 inch</td>
</tr>
<tr>
<td>H</td>
<td>&gt; 1 inch</td>
</tr>
</tbody>
</table>

How to Measure: Faulting across a joint is counted as one slab. Only affected slabs are counted. Faults across a crack are not counted as distress, but are considered when defining crack severity.

Rehabilitation Alternatives:

Low severity: Do nothing.

Medium severity: Grinding slab; slab jack w/grout.

High severity: Grinding slab; slab jack w/grout; slab replacement.
**Name of Distress:** JOINT SEAL DAMAGE

**Description:** Joint seal damage is any condition which enables incompressible material such as sand or rocks to accumulate in the joints plus allows significant water infiltration. Accumulation of incompressible materials prevents the slabs from expanding and may result in buckling, shattering, or spalling. A pliable joint filler bonded to the edges of the slabs protects the joints from material accumulation and prevents water from seeping down and softening the foundation supporting the slab.

**Possible Causes:** Typical types of joint seal damage and their possible causes are:

- Stripping of joint sealant (joint filler coming out of the joint)
- Lack of adhesion to the joint edges; incompatible joint material, contaminated joint edges from previously used joint filler;
- Extension of joint sealant (joint filler protruding above joint edges)

**Other types of joint seal damage include:**

- Weed growth
- Hardening of the filler (oxidation)
- Loss of bond to the slab edges
- Lack or absence of sealant in the joint

**Severity Levels:**

**Low severity:** Joint sealant is in generally good condition throughout the section. Sealant is performing well, with only minor damage.

**Medium severity:** Joint sealant is in generally fair condition over the entire section, with one or more of the above types of damage occurring to a moderate degree. Sealant needs replacement within 2 years.

**High severity:** Joint sealant is in generally poor condition over the entire section, with one or more of the above types of damage occurring to a severe degree. Sealant needs immediate replacement.

**How to Measure:** Joint seal damage is not counted on a slab-by-slab basis, but rated based on the overall condition of the sealant over the entire area.

**Rehabilitation Alternatives:**

**Low severity:** Do nothing.

**Medium severity:** Joint sealing (joint seal local areas)

**High severity:** Joint sealing (joint seal all areas); joint repair.
HIGH SEVERITY JOINT SEAL DAMAGE
Name of Distress: LANE/SHOULDER DROP OFF

Description: Lane/shoulder drop off is a difference in elevation between the pavement edge and the shoulder.

Possible Causes: This distress is caused by shoulder erosion, shoulder settlement, or by building up the roadway without adjusting the shoulder level.

Severity Levels:
- Low severity: The difference in elevation between the pavement edge and shoulder is less than 1 inch.
- Medium severity: The difference in elevation is between 1 and 2 inches.
- High severity: The difference in elevation is greater than 2 inches.

How to Measure: Lane/shoulder drop off is measured in linear feet.

Rehabilitation Alternatives:
- Low severity: Do nothing.
- Medium severity: Do nothing; level off shoulder to pavement surface.
- High severity: Level off shoulder to pavement surface.

LOW SEVERITY LANE/SHOULDER DROP-OFF
Name of Distress: LINEAR CRACKING (LONGITUDINAL, TRANSVERSE, AND DIAGONAL CRACKS)

Description: These cracks, which divide the slab into two or three pieces, are usually caused by a combination of repeated traffic loading, thermal gradient curling, and repeated moisture loading and/or differential heave or settlement of the subgrade. (Slabs divided into four or more pieces are counted as Divided Slabs). Low severity cracks are usually related to warp or friction and are not considered major structural distresses. Medium or high severity cracks are usually working cracks and are considered major structural distresses. Hairline cracks that are only a few feet long and do not extend cross the entire slab are counted as shrinkage cracks.

Possible Causes: Lateral contraction, bending or curling; fill settlement downward and/or outward; thermal expansion or contraction; over-long joint spacing; insufficient bearing support; swelling or shrinkage of subsoil; poor aggregates in concrete mix; poor joint performance due to improper construction; pumping through an adjacent transverse joint due to traffic action; concrete shrinkage; improper construction procedure; excessive compressive stresses; frost action (freeze-thaw).

Severity Levels:

Low severity: Non-filled cracks less than or equal to 1/4 inch or filled cracks of any width with the filler in satisfactory condition. No faulting exists.

Medium severity: One of the following conditions exists:
- Nonfilled crack with a width between 1/4 and 1/2 inch.
- Nonfilled crack of any width up to 1/2 inches with faulting of less than 1/2 inch.
- Filled crack of any width with faulting less than 1/2 inch.

High severity: One of the following conditions exists:
- Nonfilled crack with a width greater than 1/2 inches.
- Filled or nonfilled crack of any width with faulting greater than 1/2 inch.

How to Measure: Once the severity has been identified, the distress is recorded as one slab. If two medium severity cracks are within one slab, the slab is counted as having one high severity crack. Slabs divided into four or more pieces are counted as divided slabs. Slabs longer than 30 feet are divided into approximately equal length 'slabs' having imaginary joints assumed to be in perfect condition.

Rehabilitation Alternatives:

Low severity: Do nothing; crack sealing (rout and seal with an approved sealant).

Medium severity: Crack sealing.

High severity: Crack sealing; partial depth patch (bonded; allow crack to continue through patch except when using AC); full-depth patch; slab replacement.
LOW SEVERITY LINEAR CRACKING (Transverse)

MEDIUM SEVERITY LINEAR CRACKING (Transverse)
HIGH SEVERITY LINEAR CRACKING (Diagonal)

HIGH SEVERITY LINEAR CRACKING (Transverse)
Name of Distress: PATCHING, LARGE (MORE THAN 5 SQUARE FEET AND UTILITY CUTS)

Description: A patch is an area where the original pavement has been removed and replaced by a filler material. A utility cut patch is a patch that has replaced the original pavement to allow the installation or maintenance of underground utilities. The severity levels of a utility cut patch are the same as those for a regular patch.

Possible Causes: N/A

Severity Levels:

Low severity: Patch is functioning well, with little or no deterioration.

Medium severity: Patch is moderately deteriorated and/or moderate spalling can be seen around the edges. Patch material can be dislodged with considerable effort.

High severity: Patch is badly deteriorated. The extent of the deterioration warrants replacement of the patch.

How to Measure: If a single slab has one or more patches, with the same severity level, it is counted as one slab containing that distress. If a single slab has more than one severity level, it is counted as one slab with the higher severity level.

Rehabilitation Alternatives:

Low severity: Do nothing.

Medium severity: Crack sealing (rout and seal with an approved sealant); replace patch.

High severity: Replace patch; slab replacement.
**Name of Distress:** PATCHING, SMALL (LESS THAN 5 SQUARE FEET)

**Description:** A patch is an area where the original pavement has been removed and replaced by a filler material.

**Possible Causes:** N/A

**Severity Levels:**
- **Low severity:** Patch is functioning well with little or no deterioration.
- **Medium severity:** Patch is moderately deteriorated. Patch material can be dislodged with considerable effort.
- **High severity:** Patch is badly deteriorated. The extent of deterioration warrants replacement of the patch.

**How to Measure:** If a single slab has one or more patches with the same severity level, it is counted as one slab containing that distress. If a single slab has more than one severity level, it is counted as one slab with the higher severity level. If the cause of the patch is more severe, only the original distress is counted.

**Rehabilitation Alternatives:**
- **Low severity:** Do nothing.
- **Medium severity:** Crack sealing (rout and seal with an approved sealant); replace patch.
- **High severity:** Replace patch.
MEDIUM SEVERITY SMALL PATCH

HIGH SEVERITY SMALL PATCH
Name of Distress: POLISHED AGGREGATE

Description: When the aggregate in the surface becomes smooth to the touch, adhesion with vehicle tires is considerably reduced. When the portion of aggregate extending above the surface is small, the pavement texture does not significantly contribute to reducing vehicle speed. Polished aggregate should be recorded when close examination reveals that the aggregate extending above the concrete is negligible, and the surface aggregate is smooth to the touch. This type of distress is indicated when the number on a skid resistance test is low or has dropped significantly from previous ratings.

Possible Causes: This distress is caused by repeated traffic applications on coarse aggregate, which are easily polished by traffic.

Severity Levels: No degrees of severity are defined. However, the degree of polishing should be such that it will become a safety problem in the next couple of years or already is. Before it is included in the condition survey and rated as a defect.

How to Measure: A slab with polished aggregate is counted as one slab.

Rehabilitation Alternatives: If polished aggregate is predominant, rehabilitation could include overlaying, grooving or grinding.
**Name of Distress:** POPOUTS

**Description:** A popout is a small piece of pavement that breaks loose from the surface. Popouts usually range in diameter from approximately 1 to 4 inches and in depth from 1/2 to 2 inches.

**Possible Causes:** Popouts are generally caused by a freeze-thaw action combined with aggregate expansion which causes small pieces to break loose or popout of the pavement surface.

**Severity Levels:** No degrees of severity are defined for popouts. However, popouts must be extensive before they are counted as a distress. Average popout density must exceed approximately three popouts per square yard over the entire slab area.

**How to Measure:** The density of the distress must be measured. If there is any doubt that the average is greater than three popouts per square yard, at least three randomly selected areas should be checked to determine the number of occurrences per square yard. When the average is greater than this density, the slab should be counted.

**Rehabilitation Alternatives:** Not applicable. Popouts generally occur early in the pavement's life, and do not result into a severe distress of the pavement or rideability.
Name of Distress: PUMPING

Description: Pumping is the ejection of material (water, clay, silt, etc.) from the slab foundation through joints or cracks. Pumping can be identified by surface stains and evidence of base or subgrade material on the pavement or shoulder close to joints or cracks. Pumping can also occur along the slab edge, causing loss of support.

Possible Causes: This is caused by deflection of the slab by passing loads. As a load moves across the joint between the slabs, water is first forced under the leading slab, and then forced back under the trailing slab. This erodes and eventually removes soil particles, resulting in progressive loss of pavement support. Pumping near joints is caused by poor joint sealer and indicates loss of support; repeated loading will eventually produce cracks.

Severity Levels: No degrees of severity are defined. It is sufficient to indicate the pumping exists.

How to Measure: One pumping joint between two slabs is counted as two slabs. However, if the remaining joints around the slab are also pumping, one slab is added per additional pumping joint.

Rehabilitation Alternatives: Crack sealing or repair (rout and seal with an approved sealant); Joint sealing or repair; Undersealing; Improve drainage; edge drains, etc.
Name of Distress: PUNCHOUT

Description: This distress is a localized area of the slab that is broken into pieces. The punchout can take many different shapes and forms but it is usually defined by a crack and a joint, or two closely spaced cracks (usually 5 feet wide).

Possible Causes: This distress is caused by heavy repeated loads, inadequate slab thickness, loss of foundation support, and/or a localized concrete construction deficiency (e.g. honeycombing).

Severity Levels:

<table>
<thead>
<tr>
<th>Majority Of Cracks</th>
<th>Number of Pieces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Severity</td>
<td>2 to 3</td>
</tr>
<tr>
<td>L</td>
<td>L</td>
</tr>
<tr>
<td>M</td>
<td>L</td>
</tr>
<tr>
<td>H</td>
<td>M</td>
</tr>
</tbody>
</table>

How to Measure: If a slab contains one or more punchouts, it is counted as containing a punchout at the severity level of the most severe punchout.

Rehabilitation Alternatives:

Low severity: Do nothing; crack sealing (rout and seal with an approved sealant); underseal.

Medium severity: Crack sealing; under seal; full-depth patch.

High severity: Full-depth patch; slab replacement.
HIGH SEVERITY PUNCHOUT
Name of Distress: SCALING / MAP CRACKING / CRAZING

Description: Map cracking or crazing refers to a network of shallow, fine, or hairline cracks which extend only through the upper surface of the concrete. The cracks tend to intersect at angles of 120 degrees. Map cracking or crazing may lead to surface scaling, which is the progressive disintegration and loss of the concrete slab wearing surface to a depth of approximately 1/4 to 1/2 inch. The type of scaling defined here is not caused by "D" cracking. If scaling is caused by "D" cracking, it should be counted under that distress only.

Possible Causes: Map cracking or crazing is usually a result of a weak surface of the slab caused by excessive finishing. Scaling is caused by the eroding of the surface by reaction from de-icing materials; repetitive freezing and thawing cycles; weakened surface caused by overfinishing; and poor construction technique and poor quality control and lack of air entrainment.

Severity Levels:

Low severity: Crazing or map cracking exists over most of the slab area; the surface is in good condition, with only minor scaling present.

Medium severity: Slab is scaled, but less than 15 percent of the slab area is affected.

High severity: Slab is scaled over more than 15 percent of its area.

How to Measure: A scaled slab is counted as one slab. Low severity crazing should only be counted if the potential for scaling appears to be imminent, or few small pieces have come out.

Rehabilitation Alternatives:

Low severity: Do nothing.

Medium severity: Partial depth patch (bonded)

High severity: Partial depth patch (bonded); full-depth patch; bonded overlay.
MEDIUM SEVERITY SCALING

HIGH SEVERITY SCALING
Name of Distress: SHRINKAGE CRACKS

Description: Shrinkage cracks are hairline cracks that are usually only a few feet long and do not extend across the entire slab.

Possible Causes: They are formed during the setting and curing of the concrete and usually do not extend through the depth of the slab.

Severity Levels: No degrees of severity are defined. It is enough to indicate that shrinkage cracks are present.

How to Measure: If one or more shrinkage cracks exist on one particular slab, the slab is counted as one slab with shrinkage cracks.

Rehabilitation Alternatives: Not applicable. Shrinkage cracks generally occur early in the pavement's life, and do not result into a severe distress.
Name of Distress: SPALLING, CORNER

Description: Corner spalling is the breakdown of the slab within approximately 2 feet of the corner. A corner spall differs from a corner break in that the spall usually angles downward to intersect the joint, while a break extends vertically through the slab corner. Spalls less than 5 inches from the crack to the corner on both sides should not be counted.

Possible Causes: Breakdown of pavement joint edges from traffic action and progressive destruction of the surface adjacent to the damaged area; possible weakening of the surface caused by overfinishing of the slab at the corner.

Severity Levels:

<table>
<thead>
<tr>
<th>Depth of Spall</th>
<th>Dimensions of Sides of Spall</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1 in.</td>
<td>5 x 5 in. - Over</td>
</tr>
<tr>
<td></td>
<td>12 x 12 in. - 12 x 12 in.</td>
</tr>
<tr>
<td>&gt; 1 to &lt; 2 in.</td>
<td>L</td>
</tr>
<tr>
<td>&gt; 2 in.</td>
<td>M</td>
</tr>
</tbody>
</table>

Corner spalls having an area of less than 10 square inches are not counted.

How to Measure: If one or more corner spalls with the same severity level are in a slab, the slab is counted as one slab with corner spalling. If more than one severity level occurs, it is counted as one slab with the higher severity level.

Rehabilitation Alternatives:

- **Low severity:** Do nothing; partial depth patch (bonded).
- **Medium severity:** Partial depth patch (bonded).
- **High severity:** Partial depth patch (bonded).
Name of Distress: SPALLING, JOINT

Description: Joint spalling is the breakdown or disintegration of the slab edges within 2 feet of the joint. A joint spall usually does not extend vertically through the slab, but intersects the joint at an angle. The breaking or chipping of the pavement joints, usually results in fragments with feathered edges.

Possible Causes: A spall results from: Infiltration of debris; movement of slabs is thus prevented by excessive compressive stresses created by thermal expansion; weak concrete at the joint caused by overworking; Water accumulation in the joint and freeze-thaw action; expansive internal pressure due to corrosion of rebar or dowels; seized dowel bars combined with thermal expansion; misalignment of dowel bars and base movement.

Severity Levels:

<table>
<thead>
<tr>
<th>Spall Pieces</th>
<th>Width of Spall</th>
<th>Length of Spall (% of length)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tight: Cannot be easily removed (maybe a few pieces missing)</td>
<td>&lt; 4 inch</td>
<td>L</td>
</tr>
<tr>
<td>Loose: Can be removed and some pieces are missing: If most or all pieces are missing, spall is shallow, less than 1 in. (25 mm)</td>
<td>&lt; 4 inch</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>&gt; 4 inch</td>
<td>L</td>
</tr>
<tr>
<td>Missing: Most or all pieces have been removed</td>
<td>&lt; 4 inch</td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>&gt; 4 inch</td>
<td>M</td>
</tr>
</tbody>
</table>

A frayed joint where the concrete has been worn away along the entire joint is rated as low severity.

How to Measure: If the spall is along the edge of one slab, it is counted as one slab with joint spalling. If spalling occurs at more than one edge of the same slab, the edge having the highest severity is counted and recorded as one slab. Joint spalling can also occur along the edges of two adjacent slabs. If this is the case, each slab is counted a having joint spalling.

Rehabilitation Alternatives:

Low severity: Do nothing; joint sealing.

Medium severity: Partial depth patch (bonded); full-depth patch.

High severity: Partial depth patch (bonded); full-depth patch (If caused by keyway failure, provide load transfer).
LOW SEVERITY JOINT SPALL

MEDIUM SEVERITY JOINT SPALL
APPENDIX C

PROCEDURES AVAILABLE
FOR
REHABILITATION
APPENDIX C  PROCEDURES AVAILABLE FOR REHABILITATION

There are a variety of procedures available for rehabilitation. This section contains a description of the more common rehabilitations. They are categorized by surface type and the category of rehabilitation it fits in. This section does not attempt to provide specifications or design procedures for any of the rehabilitations. Other resources, such as the Mn/DOT "Standard Specifications for Construction" (Ref. 10), should be used for information regarding specifications or other details.

The rehabilitation procedures are presented in four general categories for the pavement types of flexible and rigid. The four categories are:

ROUTINE MAINTENANCE which consists of those activities that are used to extend the life of the pavement but do not improve the functionality or structural capacity of the pavement.

FUNCTIONAL IMPROVEMENTS which restore the pavement to a usable condition but are not designed for definite improvements in structural capacity.

STRUCTURAL IMPROVEMENTS which are designed to improve the strength and therefore the axle load capacity of the pavement.

RECONSTRUCTION which is required when it is determined that the in-place pavement can no longer be economically improved by any of the other methods.

FLEXIBLE PAVEMENT REHABILITATIONS

ROUTINE MAINTENANCE

Surface Treatments:
Surface treatments are used when there is a need to improve the surface condition of the pavement to correct the effects of weathering and traffic abrasion. It can also be used to restore a uniform appearance of the pavement in areas of numerous patches. The most common form of surface treatments in use today are:

Fog Seal:
A fog seal consists of a thin coating of liquid asphalt applied to the pavement, usually at a rate of 0.05 gallons per square yard. The coating usually consists of a dilute liquid asphalt emulsion, a coal tar emulsion or a proprietary material. The primary function of a fog seal is to retard raveling. The fog seal will help the pavement retain the fine aggregate matrix for several years. If left untreated, a pavement will ravel until the coarse aggregate is left protruding from the surface of the mix. Fog seals should not be used on surfaces where tire friction is critical since the treatment can cause slippery surfaces when wet.

A fog seal is expected to provide one to three years of protection for an asphalt surface. The life expected depends on the pavement condition and traffic.

Seal Coat:
A seal coat consists of a layer of a bitumen placed on the pavement which is then covered by an aggregate. The bitumen is usually a liquid asphalt. The aggregate cover can consist of a variety of materials such as sand, uniform sized small stone (pea rock or "buckshot") or crushed stone commonly called chips. A graded fine aggregate also has been used.

A seal coat has been used for a wide variety of maintenance needs, sometimes in situations of limited benefit. The main reason to use a seal coat is to protect an asphalt surface against the forces of weathering and traffic abrasion. It does not strengthen the pavement
and cannot be counted on to waterproof the pavement. A seal coat should be applied only when a pavement needs a surface treatment and not when it needs a more substantial improvement such as a structural overlay. Seal coats can be applied in certain cases to improve the frictional characteristics of the pavement surface. A seal coat should be applied when one-fourth to one-third of the diameter of the course aggregate is protruding from the surface.

Seal coats are very susceptible to the quality of workmanship and to weather conditions during placement. If poorly constructed, the bitumen may not retain the cover aggregate. Even in a good job, there will be some loose aggregate which is only partially coated. The most common problem with the loose aggregate is chipped head lights or windshields of passing vehicles. In areas with pedestrian traffic this loose aggregate and excess asphalt can be tracked into buildings. If the aggregate loss is severe, the surface may need to be seal coated again. This is important because a seal coat that has lost its cover aggregates is potentially unsafe. The surface will become slippery, particularly when wet.

Seal coats will last 5 to 8 years when they are applied successfully. Life history of seal coats has not been documented in any of the literature evaluated. If data regarding the life of a seal coat were available, it may look like the following graph:

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**SEAL COAT PERFORMANCE CHART**

**(FOR ILLUSTRATION ONLY)**

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**PERCENT SURVIVING**

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**SEAL COAT LIFE (YEARS)**

<table>
<thead>
<tr>
<th>Year</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
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</table>

- **Poor Project**
- **Good Project**

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*Figure C.1 The Life of a Seal Coat*
**Slurry Seal:**
A slurry seal consists of a specially designed mixture of emulsion and fine aggregate mixed with portland cement, fly-ash and/or lime. The materials are combined into a slurry and placed on a pavement at a uniform thickness of one-third (1/3) to five-eighths (5/8) of an inch. A slurry seal is normally placed on the pavement by using a squeegee type of screed set at the desired height above the pavement surface. Once the slurry is placed, it is allowed to cure before traffic is allowed on the section. The slurry is not rolled but only allowed to cure. A slurry seal is used for the same reasons that a seal coat is used, that is, to protect the surface from the effects of weathering and traffic abrasion, to restore surface friction or provide a uniform appearance. The same criteria used for the placement of a seal coat should be used for a slurry seal.

Slurry seals are not used very much in Minnesota; therefore, there is no basis on which to estimate the life of a slurry seal in Minnesota. Slurry seals are used in other states and the information available regarding the life of a slurry seal indicates that it is similar to a seal coat.

The life of a slurry seal is susceptible to surface preparation, placement conditions, and quality control. The most common modes of failure noted are lack of bond and raveling. Limited observations of problems occurring with slurry seals include lack of bond and surface stripping of the original asphaltic concrete.

It is recommended that if a surface treatment is selected to repair raveling resulting from a lean mix, that a seal coat or some other surface treatment be used rather than a slurry seal. This will minimize the potential of stripping of the asphalt surface.

**Plant Mix Seal:**
A plant mix seal is a thin asphalt overlay. It uses a very fine aggregate mix and can be placed in thicknesses of one-half (1/2) inch to one (1) inch. It is applied for the same reasons as other surface treatments, that is, to protect against weathering and abrasion, restore friction or provide a uniform appearance. It can also be used in new construction as a wearing course such as Mn/DOT 2361 specification. The 2361 specification uses a hard durable aggregate and is placed over a binder or base course which is made from softer aggregates that cannot resist the wear and abrasion of traffic.

There are two (2) advantages to using a plant mix seal rather than a seal coat or slurry seal. The first is its longer life expectancy. The second is the absence of loose stone or free asphalt associated with other seals that can be picked up by tires or shoes. One significant disadvantage of using a plant mix seal is its sensitivity to cold weather placement. Severe raveling will occur if placed or compacted when too cold.

A thin overlay is also more susceptible to errors in quality control of the mix and placement procedures than is a conventional overlay. It retains the heat that is necessary to achieve proper compaction during rolling for only a short period of time. Even on warm days, a thin overlay needs to be rolled within just a few minutes after it is laid. Differential compaction under a steel drum roller also is a problem when there is even a slight amount of rutting (See Figure C.2). If the target density for a 3/4-inch overlay is 95% after rolling, a 1/4-inch depression will result in 90% density or less in that area if a drum roller bridges the depression. Raveling is a common characteristic of low density.

A 2361 wearing course is expected to have a 12 to 15 year life in normal conditions. If mix design or placement problems occur, the life could be as little as 1 to 2 years.
The seal coat is the most common surface treatment. The need for the application of seal coats has changed over the years. When much of the asphalt surfacing consisted of road mix, seal coats were necessary to keep the newly placed road mix from raveling. The shift to paver laid, hot mixed asphalt removed the need to apply a seal coat to the new pavement surface (provided the surface mix was properly designed and placed). However, areas that have high shale content in their aggregate use a surface treatment on new surfaces to control spalling of the shale.

Rejuvenators:
Rejuvenators are used for surface treatments in some areas and also in other applications such as recycling. Rejuvenators are not commonly used in Minnesota and have been viewed with some skepticism. There has not been enough attention in this area to direct adequate independent research on these products, most of which are proprietary. Perhaps with greater attention paid to rejuvenators in the future, answers will develop which will provide users the guidelines needed to specify the use of rejuvenators. No recommendations are offered at this time either for or against their use.

Crack Treatment:
Crack treatment may not at first seem like much of a rehabilitation procedure. It is, however, a procedure that can either stand alone as a rehabilitation choice or be a repair done prior to another rehabilitation such as a seal coat or overlay. Before crack treatments are described, a description of the various types of cracks will be provided. For the topic of crack treatments, the type of crack of most concern is the single linear crack (transverse or longitudinal). Alligator and block cracking are not the type of cracks that are efficient to treat. Before a crack treatment is selected, it would be useful to determine the nature of the crack. Cracks may be divided into two major categories; subgrade cracks and surface cracks (See Figure C.3).
The treatment and expectations from the treatment will be different for these two types of cracks.

The subgrade crack is a crack that goes down through the surface, base, and into the subgrade and forms when the subgrade is frozen. It may even originate in the subgrade and propagate up to the surface. Once the subgrade freezes, it is subject to the same thermal expansion and contraction as any other material. As the frozen subgrade continues to cool, it will contract and at some point the tension developed will be greater than the combined strength of the pavement and subgrade causing a crack. One can imagine cracks of this type randomly meandering across the landscape in a large block pattern. Such a crack will tend to cross a roadbed at right angles (transverse crack) because the roadbed and pavement section would be exposed to different cooling and thermal contraction characteristics than the surrounding soil. Initially these cracks may not be recognizable, but after a number of years they may show up as cracks that have depressions associated with them.

Another form of subgrade crack is the long meandering longitudinal crack in the pavement. (Figure C.4). This type of crack can become quite wide and may appear to be faulted. This type of crack is common on embankments constructed in areas of very soft or weak soils such as fat clays or embankments floating over peat deposits. This type of crack develops because of a lack of lateral restraint. Consider an embankment that was placed and
compacted over a peat deposit. Compaction squeezes the embankment soils together and at any point, the subgrade soil is exerting a lateral force (confining force) against itself. This lateral force does not have a reactive force at the ditch slopes creating an unbalanced or a statically unstable condition. Normally this unbalanced condition is countered by the transverse resistive frictional forces available from the soils under the embankment. In the case of a floating embankment, the peat can not offer that resistive force and the embankment will relax; in time expanding in a transverse direction, causing cracking in the surface. Subgrade soil conditions that are susceptible to this type of cracking are peat deposits or other soils that are very soft and embankments constructed from soft soils such as the Duluth and Red River Valley clays.

![A Longitudinal Subgrade Crack](image)

Construction of new embankments over soft soils can benefit from the use of a geotextile. The role of a geotextile is lateral reinforcement. During compaction, the fabric will stretch in the transverse direction and will provide the transverse confining force necessary to prevent the meandering longitudinal crack from occurring. This lateral confinement will also allow the soil to retain much higher load carrying capacity (Ref. 13).

Surface or pavement cracks on the other hand are those cracks that originate in the asphalt surfacing and progress downward through the surfacing. These cracks tend to stay narrower in width than subgrade cracks and do not develop depressions as quickly which makes them easier to keep sealed. Two of the major type of crack treatments are described as follows:

1. **Crack filling/sealing** consists of cleaning the crack and filling it with a liquid asphalt or hot pour asphalt. This procedure should be done only on those cracks which are in sound pavements and have no associated family cracking or other deterioration in the vicinity of the crack. The crack can be either air blown or routed and cleaned. If the crack is very deep, a backing material should be used to control the amount of material to be placed into the crack. Consideration must also be given to the thickness of the asphalt surfacing when evaluating a crack for sealing. A pavement that consists of
several bituminous courses and is more than two inches thick could have stripping occurring in the lower layers in the vicinity of the crack. There is no easy way to treat such a condition. If it is expected that the underlying layers are susceptible to stripping, it may be reasonable to treat the cracks sooner and more often to retard or control the stripping. If stripping occurs next to the crack, the pavement will be structurally weakened in that area and will deteriorate.

2. Crack repair consists of more major action such as routing or removing the pavement in the area of the crack and placing a specially designed patch mix and possibly some sort of reinforcing geotextile in the area that was routed out. As an example, the City of Minneapolis routes the pavement to a depth of three-fourths of an inch over a width of four to six inches on either side of the crack and fills the crack with an asphaltic mix (Ref. 14). Cracks that should be routed out and filled are those that have developed into multiple cracks and/or have developed depressions in the vicinity of the crack. Thin pavements may be routed full depth during the repair of the crack where thick pavements would normally not be routed full depth. Some examples of crack repair are shown in Figure C.5.

![Figure C.5 Crack Repair Techniques](image_url)

Local Repairs:
Local repairs are used to fix an otherwise good pavement. It is only advisable to use local repairs when a quick repair is needed for safety or when most of the pavement is in otherwise good condition. Care must be taken when localized repairs are done. Local repairs normally have very high costs on a square yard basis compared to the same work on a large scale basis. For example, a patch consisting of removing and replacing three inches of pavement can cost four times as much on a square yard basis as removing and replacing three inches of asphalt over the entire section. If twenty five percent (25%) of the section needs repair, localized deep patching could cost as much as complete removal and replacement and result in a road that has a much higher probability of developing additional failures in the future. As soon as the amount of repair reaches ten percent (10%) of the total area, a hard look at the costs and expected life should be made. There are two good references available that deal with local repairs. One is from the Local Road Research Board.
on pothole repair titled "Correct Procedures for Localized Pavement Removal and Replacement". Another is from the U.S. Army Corps of Engineers Cold Regions Research & Engineering Laboratory titled "The Engineer's Pothole Repair Guide."

Another factor that needs to be considered is the amount of structure provided by the asphalt surfacing compared to the entire structure. Streets and roads with two inches of asphalt or less do not derive much of their overall strength from the asphalt layer. Pavements which have 3 or more inches of asphalt, however, derive a great deal of their structural strength from the asphalt layers (See the section on the structural evaluation of pavements for more information on this subject.) Three common repair procedures are summarized below:

**Partial Depth Patches** are patches that do not go completely through the asphalt surfacing. They are used to repair a damaged wearing course where the base course is still in good condition or in some cases to provide a good wearing course repair for a shorter period of time. The type of deficiencies that can be repaired with a partial depth patch include localized severe raveling and localized mix deficiencies.

**Deep patches** are patches that go the full depth of the asphalt surfacing or deeper. It is used normally to correct a localized weak area that has severe load related distress such as a pothole or high severity alligator cracking. A thickness design analysis is sometimes needed to determine the appropriate depth of the patch.

**Skin Patches** are used either as quick short term repairs for structural defects or as more long term repair for distresses such as localized settlements or depressions. Localized advanced ravelling or abrasion can also be repaired with a skin patch.

Refer to Appendix A for details of patch types and distresses.

It may be quite common for several of these routine maintenance procedures to be used together in one project; for instance, local repairs consisting of partial depth patching and crack repair to correct local deficiencies are commonplace prior to a surface treatment being applied.

**FUNCTIONAL IMPROVEMENTS**

Functional improvements are made to improve the functionality of the pavement for the user. These type of improvements can include such things as additional turn lanes to aid in the flow of traffic or pavement repairs to improve such things as rideability or skid resistance. Turn lanes, alignment changes, widening and other such improvements must be considered to determine if they are necessary before pavement repairs are done. This manual does not concentrate on those items but only items that deal with the in-place pavement. This leaves only two categories of functional improvements; rideability and skid resistance. Both of these pavement attributes can deteriorate without a significant loss in strength or capacity. Many of the Mn/Dot pavement rehabilitation projects are initiated to improve rideability. Improvements of this type involve a resurfacing of the pavement. Unlike the surface treatment, the resurfacing must also be able to correct the longitudinal and transverse profile of the pavement in order to improve the rideability. The most common methods of doing this are:

**Leveling and Overlay:**

Those pavement sections that are very rough, have an irregular cross slope, rutting or other form of distortion that interferes with the rideability of the pavement would need to be improved with a multiple lift overlay. In these cases, the first lift is called the leveling course since its function is to take out much of the irregularity before the wearing course is placed. The compaction of a leveling course should be accomplished with pneumatic rollers which can compact the material that is placed in depressions or low points. Steel rollers are not
recommended for use on leveling courses because they will not fully compact the asphalt mix in the low areas. Several lifts are required since the paver uses a straight screed and the thicker areas will compact further down than the thin areas (See Figure C.2). Several lifts will minimize the variations in the surface, restore ride and cross-slope and provide a well compacted mix.

**Overlay:**
Overlay with a single lift is appropriate for those pavements that have low to moderate roughness that is correctable with one layer. Overlay thicknesses of one to two inches are normally sufficient for functional improvements.

**Mill and Overlay:**
When conditions exist, such as the presence of curb & gutter or overhead constraints, that prevent raising the grade of the pavement, it will be necessary to first lower the grade through milling and then restore the grade to its original level with an overlay (see figure C.6). Keep in mind that milling does not work well on pavements that are only 1.5 to 2.0 inches thick as they are on many of the low volume roads. If the depth of milling is close to the total thickness of the bituminous material, chunks of bituminous may be picked up. This will destroy the structural integrity of the remaining asphalt and provide an unsuitable surface on which to overlay.

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**Figure C.6** Overhead Restrictions May Dictate Milling Prior to Overlay

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**Heater Scarification:**
This is a procedure which typically precedes an overlay or surface treatment. Heater scarification consists of heating the surface of an asphalt pavement to about 400°F with infra-red heaters to soften the top inch of the pavement. Immediately behind the heater is a scarifier which consists of a bar with a number of tines mounted at two to three inch intervals that scarify the surface. Hot mix asphalt is usually laid behind the scarifier and compacted over the scarified pavement. More recent applications blend the hot mix asphalt with the scarified asphalt before compaction. The reasons given for heater scarification are to develop a better bond with the existing surface, minimize the number of surface cracks
that reflect through the overlay and create a more continuous structural layer. The process has been used in Minnesota several times on an experimental basis. No judgement is provided here as to its benefits. It is used more commonly in the central and southwest part of the country.

STRUCTURAL IMPROVEMENTS

These improvements are required when it has been determined that either the axle loadings are higher than the pavement's structural capacity or the volume of equivalent 18,000 pound axle loads (ESALs) expected is higher than the pavement's ability to resist the fatigue caused by them during its design life. In either case, strengthening of the pavement would increase the axle load or ESAL capacity and extend the life of the pavement.

If a structural improvement is planned for a road that is in otherwise good condition, certain attention and criticism may come from the public or the governing body; particularly if other roads within the jurisdiction are in poorer condition. The question of whether it is more economical to strengthen the pavement now or wait until the road has deteriorated requires some specific information regarding the life expectancy of the pavement and of the rehabilitations. Generally it is felt among pavement experts that it is more economical to strengthen before the pavement deteriorates rather than wait until deterioration has occurred and then repair and strengthen (Figure C.7). The results of actual case by case cost evaluations of individual sections depend on the cost and life expectancy of the pavement plus the strengthening compared to the cost and life expectancies of the alternatives. These comparisons require information on life expectancy of pavements and rehabilitations which must be locally developed.

![The Cost of "Timely" Maintenance](image)

Figure C.7 The Advantage of Doing Timely Maintenance
Overlay:
The overlay is the most common rehabilitation for structural improvement. Once a section has been determined to be deficient in thickness (structure), the most obvious way of increasing the thickness is to add more pavement material. An overlay consists of placing additional asphalt layer(s) over the existing pavement. If the overlay is thick enough, it should be placed in two layers, the first layer being a lower cost binder course and the top layer being a higher quality wearing course.

Mill and Overlay:
Mill and overlay is normally used when there are grade constraints. One very common constraint is the need to maintain the existing curb and gutter. Before an overlay is placed, the in-place pavement can be milled to allow room to place an overlay without building a drop-off at the gutter, filling the gutter with asphalt, or building too steep of cross slope. The milling can be done in several ways as shown in Figure C.8. The milling can remove pavement to a planned elevation and cross slope. One may think of this as reverse leveling. If there is minimal cross slope, milling is not required across the entire surface; milling a notch or wedge next to the gutter will allow an overlay to be placed which will still match the gutter for urban sections.

Figure C.8 Urban Overlay Methods
In rural sections, milling may be considered if there is sufficient structure to allow milling and there are concerns about the overall elevation, shouldering costs, cross slope concerns, overhead structures, or the steepness of the resulting ditch slopes (Figure C.9). It also can be used to remove an unstable wearing course or an intermediate layer such as a binder course that has stripped. In fact, if there is a stripped binder course, it should be removed to assure good performance.

**Figure C.9 Overlay Impact on Rural Sections**

**Recycling:**
Recycling involves the reuse of pavement material, either in the same pavement section or in another pavement. If a pavement material needs to be removed for any reason, it should be considered as a material resource. The quality of the material should be evaluated to determine how it can be used. The asphalt binder in a pavement can be reused in hot mix recycling and the aggregates can be reused if they are of suitable quality. Quality and consistency are the keys here. The materials must be evaluated and should only be used in an application where they are expected to work.

As mentioned earlier, if the depth of milling is close to the total thickness of the bituminous material, chunks of bituminous may be picked up. The material will then require screening and crushing before it can be used in recycling or any other pavement purpose. If most or all of the bituminous surface is to be removed, cost savings are likely by using techniques other than milling to remove the pavement.
CAUTION: Quality control procedures must be closely followed when recycling. Variation in the materials is the reason for many problems associated with recycling. Controlled mixing or blending of materials along with frequent testing is necessary to maintain consistency. This is not meant to discourage the use of recycling, but rather to promote the use of successful recycling. The failure of a recycled pavement does more to discourage its use than the extra amount of work necessary to construct a good product. If the added cost of testing and inspection is a concern, these costs should be included in the cost analysis for selecting the best alternative.

Cold Mix Recycling:
A wide variety of procedures fit under the subject of cold mix recycling. The use of a bituminous mix is common to all forms of cold mix recycling. An attempt is made here to describe some of the more common cold mix recycling methods that have been used. One of the older methods involves the pulverization of the bituminous surfacing and compaction as a base without adding any additional asphalt. This can either be a pulverization of the surface alone or blending with part of the underlying aggregate base. Blending is recommended since it results in a more stable base. Carried one step further, a liquid asphalt can be added. This can be done during the pulverization process or mixed in later. Inspection and quality control are important to insure the correct amount of asphalt is added. Too much liquid asphalt will cause the mix to be unstable and the asphalt to pump up to the surface under traffic. Too little asphalt will result in less strength than expected and poor performance.

Hot Mix Recycling:
Hot mix recycling involves passing the recycled asphalt pavement or RAP through a hot mix plant where it is heated and blended with new aggregate and asphalitic cement. The asphalt binder in the recycled mix is heated and should be blended with the new asphalt. Plant and mix control are very important in obtaining a good recycled product. Any variation in the aggregate, asphalt content, or asphalt properties in the RAP will change the properties of the mix coming out of the plant. The uniformity of the RAP is an additional variable that doesn’t exist in the production of hot mixed asphalt with virgin materials. Another point that is very important, is that hot mix recycling involves a heat transfer process. The virgin aggregate is heated to a very high temperature and is then mixed with cold RAP. The RAP, in most plants, is heated by the heat transferred from the super-heated aggregate. If the RAP is wet, a lot of the heat will be lost in vaporizing the water rather than heating the mix. The moisture in the RAP therefore is an important factor to consider in hot mix recycling. It is very helpful and often cost effective to protect the RAP from getting wet while it is stockpiled at a plant for recycling. An exposed RAP pile can adsorb a lot of water. Also it is also important to prevent the RAP from becoming contaminated. Contaminated RAP should never be used in hot mix recycling.

Reconstruction
Reconstruction should be considered as a rehabilitation alternative whenever the pavement has deteriorated to a poor condition or major structural improvement is required. Other reasons for reconstruction include geometric and other non-pavement considerations dealing with cross section, alignment, etc. Reconstruction is necessary to rehabilitate underlying layers of the pavement that have deteriorated or are deficient. The future life of the pavement may be limited if the material is left in place. Stripping of the asphalt binder and base materials, contamination of aggregate base due to break down from freeze-thaw cycles and pumping of the subgrade soils are some of the conditions that require partial or total reconstruction to correct. Non-uniformity of subgrade materials or poor subgrade soils, particularly in embankments constructed from top soil, are also conditions that would require reconstruction to correct.

Partial Reconstruction involves removal and replacement of some of the upper layers of a pavement system over the entire length of the project or total reconstruction over part of the length of the project. Mill and overlay can be an example of partial reconstruction.
Complete Reconstruction as the name implies, involves total removal of the pavement and perhaps some of the embankment and construction of a new pavement structure. Complete reconstruction can utilize recycling of any materials in the original pavement structure that were found to be suitable. Also, materials from one project can be hauled to another, provided the work can be coordinated. Reconstruction closely resembles new construction. A new thickness design is developed for the project, materials are excavated, the embankment is prepared and a new pavement is constructed. One difference between new construction and reconstruction is the amount of embankment disturbance. Usually, the surface of the embankment needs only to be prepared for the new pavement. On a city street where all of the utilities need to be replaced or a roadway that has unsuitable materials in the embankment, the embankment may need to be entirely reconstructed.
RIGID PAVEMENTS

ROUTINE MAINTENANCE

Joint Sealing.
Joints are necessary in concrete pavements to control cracking, to allow movement in the pavement due to volume changes and to prevent damages to fixed structures. Most joints are designed to transfer the load from one panel to the next. Load transfer may be accomplished by aggregate interlock at the joint or through the use of load transfer devices such as dowel bars.

The process of joint sealing and its effectiveness in extending the pavement life have been a debatable issue among transportation officials and maintenance personnel. The Permanent International Association of Road Congress' (PIARC) Technical Committee on Concrete Roads (Ref. 15) presented a report stating other countries have successfully built pavements with unsealed joints. The PIARC report concludes that unsealed joints are applicable if the joint spacing is between 13-20 feet and the traffic is light (heavy traffic is permissible if the climate is dry or if the pavement is doweled).

The two major problems with inadequately sealed joints are as follows:

- Poorly sealed joints increase the possibility of pavement failures caused by water entering the pavement structure.

- Poorly sealed joints allow sand and other incompressibles to enter the joint particularly when the joints are wide such as during cold weather. These incompressibles can interfere with the normal expansion of the slabs when the temperature increases. This limited movement may initially cause joint spalling, and other compression related distress. If not corrected, the incompressibles could reach a level where they fill the joint to an extent that they cause a blow-up (see Appendix B for details of a blow-up).

Joint sealants are designed to provide a flexible interface between the concrete panels. The sealants are intended to provide a waterproof barrier through the numerous cycles of tension and compression the pavement experiences. However, the service life of most sealants is limited (2 years for hot-pour asphalt, 5-10 years for pre-formed sealants) and to maintain their serviceability, joints must be resealed periodically.

Four general categories of sealants are:

- Field poured sealants (self-leveling)
  - Hot poured
  - Cold poured

- Field poured sealants (non self-leveling)

- Preformed Compression seals

The poured (liquid) sealants are designed to bond to the side of the joints and work in tension and compression; the preformed seals are designed to work in compression only. Each sealant has been designed with specific parameters for various field conditions.

The four basic design parameters include durability, extensibility, cohesiveness, and adhesiveness. The selection of a sealant is based on how these parameters incorporate the differential movement of the joint, the shape of the joint reservoir, and the bonding between the sealant and the sidewalls.
The actual rehabilitation method for sealants varies from source to source. In general the following procedure should be used:

- Determine the salvageability of the old sealant.
- If the sealant is still active and a good bond is present. Clean the joint using compressed air and apply additional sealant.
- If the sealant has completely oxidized remove it by any of the following procedures:
  - High-pressured water
  - Joint plow
  - Diamond saw blade
  - Manually (for pre-formed sealants)

If needed, reface the joint surface to provide a clean surface for bonding. Refacing can be done with a diamond or carbide saw (the saw blade’s width corresponds to the joint width). After the joint is completely clean and dry, apply new sealant to the joint reservoir.

With respect to liquid sealants, care should be taken to install the sealant in a uniform manner from the bottom of reservoir to the top without entrapping any air bubbles. The joint should not be overfilled; the surface of the sealant should be 0.125-0.25 (1/8-1/4) inches below the pavement surface (Ref. 5). The joint should be lined with a Backer rod or other material such as sponge rubber, plastic or tape, which is both non-rigid and non-absorptive. The sealant should never adhere to the bottom of the joint (Figure C.10). The stresses at the joint bottom are too high and the sealant will soon pull away and permit intrusion of water and incompressibles.

![Diagram](image)

Figure C.10 Correct Method for Joint Sealing

**Undersealing.**
Voids or loss of fines under a concrete pavement allow a slab to move excessively under loadings resulting in accelerated deterioration of the pavement structure. Excessive movement will result
in a faulted panel and/or the pumping of fines in an erodible base. One way of stabilizing the movement of these panels is the process of undersealing.

When rehabilitating a concrete pavement, identifying which slabs should be undersealed is very crucial. Incorrect use of undersealing can result in a negative effect resulting from non-uniform slab support and/or limiting the effectiveness of subsurface drainage/drainage. In recent years various methods have been developed to measure the amount of slab movement due to loads. The two most common methods are as follows:

- Static measurements using a dial gauge to measure the movement of a slab corner under an 18-kip load.
- Measuring the deflection response using non-destructive testing such as a Falling Weight Deflectometer, Road Rater or Dynaflect.

Although no definitive criteria have been established, undersealing is usually recommended if the corner deflection is greater than 0.025 inches under an 18-kip load (Ref. 4). Evidence of pumping during a visual inspection has also been used to select undersealing as a rehabilitation choice. Ground Penetrating Radar has also been used recently to locate large voids under concrete slabs.

Two strategies in applying undersealing material are:

- Localized coverage where pumping or voids occur in isolated areas.
- General coverage where the undersealing is applied over an entire project.

Another consideration in determining the placement of undersealing is the type of concrete. Within continuously reinforced concrete pavements, voids and pumping can occur anywhere under the pavement. Deflection testing should be conducted to identify the areas where undersealing is required. If relatively high deflections occur throughout the section, general coverage undersealing should be applied under the entire pavement. On jointed concrete pavements, pumping usually occurs at joints and higher severity transverse cracks. Therefore, undersealing is localized to these areas. Additional undersealing is generally applied to visibly noticeable areas of:

- Settlement (depressions)
- Pumping
- Permanent patching

Once the areas to be undersealed have been identified, the next step is to select or design the type of material to be used in the undersealing process. The material is commonly referred to as grout. For maximum effectiveness the grout must be both fluid and durable. With respect to the fluidity, if the grout is too stiff it will not be dispersed uniformly under the slab, leaving voids. On the other hand if the grout is to fluid or "runny" there is a loss of strength and a significant amount of shrinkage can occur. The Corps of Engineers has developed the flow cone method (CRD-C611-80 or ASTM C939-81) to determine the fluidity of the grout. The type of grout used is dependent on the on-site conditions and cost effectiveness of the materials. Various mixtures have been tested and evaluated. Some general conclusions are as follows:

- Pozzolanic/cement yields a high strength durable mix which can adequately support slabs.
- Mixtures with some additives (e.g. fly ash) have less strength due to the additional water required to obtain the correct fluidity. An exception to this is the use of powdered ammonium lignin sulphonate which increases the fluidity of the grout without increasing the water content.
Some agencies have determined grout mixtures made with sand are not suitable for undersealing except when filling large voids at bridge approaches.

After the required placement and type of grout has been selected the hole pattern must be established. Experimentation is usually conducted at the beginning of a project to determine which pattern is most effective for the actual field conditions. Figure C.11 shows typical hole patterns for both plain pavement and CRCP (Ref. 4).

![Diagram showing hole patterns for undersealing](image)

**Figure C.11 Typical Hole Patterns for Undersealing**

There have been contradictory approaches with respect to the depth to which the holes should be drilled. Some agencies drill to just below the concrete slab, some drill into the subbase if it is stabilized, others drill through the stabilized subbase into the subgrade.

Once the holes are drilled, a pressurized grout hose is lowered into the hole and the actual undersealing begins. During this procedure the basic concept of undersealing should be emphasized: Undersealing is a means of slab stabilization by replacing existing voids with a grout material, not to elevate the slab back to its original grade. Excessive undersealing (elevating the panel) can create voids elsewhere in the pavement along with over-stressing the panel, eventually causing cracking to occur within that panel. The amount of grout being pumped should be closely monitored. Pumping should cease when one of the following conditions occur:
- the panel has been raised more than 0.125 inches, this should be monitored during the pumping process with some form of vertical displacement measurement device

- the displacement of grout or water from under the slab occurs at either joints, cracks, or adjacent holes (for drilling)

- no evidence of grout or panel lifting after a reasonable amount of time (especially near the centerline in areas with a permeable base)

After the grouting has been completed the hole should be capped off with a temporary wooden plug, and the operation should advance to the next hole. When the grout has set, the wooden plug should be replaced with a fast setting sand/cement or other approved concrete mixture. Traffic should not be allowed on the pavement during the curing of the grout (minimum of three hours).

Each panel that was undersealed should be re-evaluated to verify the voids have been filled, the pumping has ceased, and/or the deflection response is less than 0.025 inches. If any of these parameters have not been successfully accomplish the undersealing process should be reapplied to the panel.

Panel Patching.
Certain types of distress found on rigid pavements can only be effectively repaired by removing the distressed area and replacing the pavement. This can be done by either removing and replacing the entire slab or by patching the distressed portion of the slab. Some of these distresses are blow-up, corner break, durability or "D"-cracking, load transfer deterioration, patch/adjacent slab deterioration and spalling. Refer to Appendix B for details on these and other distresses which list patching as a rehabilitation choice.

Patching of rigid pavements is very expensive due to the care which must be taken to ensure proper load transfer. Patching is recommended only on a small scale basis and only if the rest of the pavement is expected to have 10 years or more of remaining life. If the amount of patching required within a panel is high, it will likely be more cost effective to remove the entire panel. Also, due to its limited life expectancy compared to a totally new slab, a life/cost analysis is strongly recommended prior to selecting patching as a rehabilitation.

If a concrete patch is constructed properly, a minimum of 10 years performance should be attainable.

We will deal only with concrete patches under this topic. Asphalt patches have been used on rigid pavements but only as short term cures. They have been used to hold the distressed area of the pavement together during winter months or until proper patching can be done. Asphalt patches normally are not considered to be a viable long term rehabilitation on a rigid pavement.

A detailed condition survey should be performed at the start to determine the type and cause of distress, the magnitude of the problem, and the type of patch to construct. With certain types of distress, such as spalling, it may be possible to construct a partial-depth patch if the distress is contained only in the upper portion of the pavement. However, with most distresses, a full-depth patch is required because most concrete pavement problems extend through the slab.
Some of the advantages of performing a partial-depth patch rather than a full-depth patch are:

1. Lower cost since usually no repair of load transfer mechanism at the joint is required.
2. Minimal disturbance of the subbase/subgrade layer.
3. Retains some aggregate interlock between patch and existing pavement.

Some of the disadvantages are:

1. If a jack hammer is used, and the force applied is too great, the bottom of the slab may spall creating the need for more repair. If this extra repair is not performed, patch life will be minimal.
2. No repair of load transfer mechanism is done. This may be a problem if load transfer is inadequate. Again, patch life will be minimal if this is the case.

As you can see, there are tradeoffs. In many cases, a partial-depth patch will simply not be an option. However, if it is, a partial-depth patch should be given consideration, and, if viable, should be used.

Partial-Depth Patch
Once it has been determined that a partial-depth patch is both practically and economically feasible, the areas to be patched must be determined. The pavement should be marked 12-18 inches away from the actual distress. This is to assure that no unsound pavement remains adjacent to the patch. Once the areas have been marked, the boundaries of the patch are saw cut. Care must be taken to overlap the cuts to ensure all of the patch faces will be vertical. The pavement is then removed, usually with a jack hammer. Highly pressurized water has also been used to remove concrete pavement for this type of patch. As mentioned previously, if the jack hammer spalls the bottom of the slab, the cut must be made deeper and a smaller jack hammer used. After the debris is removed, a grout material of cement, water and sand is broomed into the patch and the concrete patch material is placed and finished. Proper curing procedures should follow.

Full-Depth Patch
In most cases, a full-depth patch will be required to repair the distressed areas of a concrete pavement. The most critical factor that affects full-depth patch performance is load transfer at transverse joints. The three (3) most common load transfer techniques are:

1. Dowel bars
2. Tie bars
3. Aggregate interlock
Dowel Bars have proven to be the most reliable method. Dowel bars should always be used at joints where movement is desired and/or if dowel bars were present at the joint before the patch. They are smooth, corrosion resistant, steel bars at least 1-⅜ inches in diameter. The bars are inserted into holes drilled into the pavement allowing for free movement.

Tie bars are used only at fixed or non-moving joints. They are deformed steel bars which are grouted into the pavement.

Aggregate interlock is marginally effective at providing load transfer. It is only effective when used with short joint spacing. This method is especially unreliable in cold weather areas. However, this is the type of load transfer mechanism used after a crack & seat rehabilitation.

Due to its importance, the joint design process should be a careful one. If dowel bars are used, the bar size, spacing, coating, length, etc. will have to be determined. Although it sounds like a lot of extra work, short cutting this procedure will almost certainly guarantee premature patch failure.

The next step in constructing a full-depth patch is to outline the patch boundaries and location. Two cases of patch location exist:

1. Partial-lane patch
2. Full-lane patch

Partial-lane patches can be constructed if the distress to be repaired extends less than half way into the lane. If the distress occurs on only one side of the joint, only the side where the distress is located needs to be repaired. If during repair it is found that the distress extends across the joint in the lower levels of the pavement, both sides of the joint should
be repaired. No joint repair is needed for a mid-slab distress, if it is far enough (6 ft) away from any joint.

**Full-lane patches** are required when the distress extends beyond the mid-point of a slab. A partial-lane patch in this instance could cause damage to the small remaining portion of the slab. If these patches occur at mid-slab, no joint transfer repair is needed. Again, these patches can be done on one or both sides of a joint. No expansion joints should be used at the patch boundaries.

If multiple lane patching is to be done, construction should proceed one lane at a time to avoid traffic congestion. Also, the slab with the highest elevation should be done first if cross slope is desired across multiple lanes.

The next step is to saw cut the patch boundaries, usually done with a diamond blade saw. As with a partial-depth patch, the saw cuts must overlap approximately 10 inches to ensure vertical faces in the corners of the patch. The extra length of cut can be filled with epoxy after the patch is completed.

Removal of the concrete surrounded by the saw cuts can be done using one of two methods:

1. Break-up/clean out
2. Lift out

**Break-Up/Clean Out** consists of using a pavement breaker to shatter the concrete. The breaker begins in the center of the area to be patched and works outward. Since the concrete breaks by sending shock waves into it, some of the subbase/subgrade is disturbed. The sawing also disturbs this layer. Once the concrete is broken, it is removed.

**Lift Out** means exactly that. The pavement is saw cut into small enough pieces to lift and the pavement is lifted out using a front end loader or other equipment using chains, lift pins, etc.

The Break-up/clean out method is quicker and produces smaller pieces of pavement which can be readily hauled away, but may cause more subbase/subgrade damage then the lift-out method. The subbase/subgrade is then repaired prior to patch placement. If the subbase/subgrade must be corrected, it is recommended that concrete be used for patches less than 10 ft long. The subbase/subgrade should be wetted down just prior to placement of the concrete into the patch to avoid having any of the water needed for proper curing of the concrete drain into the soil.

Once the subbase/subgrade is ready, the joint transfer mechanism is installed. If rebars are required (CRCP, JRPC), they are also installed at this point. The concrete is then placed and finished. Curing can be monitored in 2 ways:

1. By waiting until a certain strength is reached.
2. By waiting a certain length of time.

Refer to PCA publication "Design and Control of Concrete Mixtures" (Ref. 34), AASHTO M-148, ASTM C-494-80 or AASHTO M-194-82 for more information on concrete, concrete curing and admixtures.
FUNCTIONAL REHABILITATION

As with asphalt pavements, functional rehabilitation of rigid pavements relates to ride quality and skid resistance. While it is true that most pavement distress contributes in some way to poor ride quality, this section will deal only with rehabilitation techniques not previously mentioned. Perhaps the largest single contributor to poor ride quality on a rigid pavement is bad joints. The cause of joint problems is found in Appendix B. The procedures for joint repair can be found under the preservation rehabilitation section previously described.

Certain distress types such as raveling, polished aggregate and spalling may be present on a pavement but not pose a threat to the structural capacity of the pavement. Rather, they may pose a safety threat by providing very low skid resistance (polished aggregate) or provide an annoyance to the public because of poor ride and/or excessive noise generated by traffic on the rough surface (raveling, faulting or spalling). Usually two or more of these distresses are found in combination.

Three rehabilitation methods which have been used to correct these problems are diamond grinding, grooving and cold milling.

Diamond grinding is used to provide a smooth surface and remove material. A pattern is cut with a diamond bladed cutting head usually 36 to 50 inches wide. In some cases, the diamond grinding machine can provide a smoother profile than a new pavement. Diamond grinding must be done after any rehabilitation listed under the preservation rehabilitation section with the exception of resealing joints. All patching, spall repair and undersealing is done first so that a smooth, uniform surface will be obtained after the grinding. To obtain the best possible ride, the pavement should be continuously ground within the traffic lane. The machine uses a reference arm to raise or lower the blades to match the profile of adjacent slabs. Grinding can also be used to correct faulted panels on a short term basis until a more permanent repair can be made.

Grooving is used primarily to prevent hydroplaning. Grooves are cut into the pavement usually 3/4 inch apart using diamond cutting blades. Normally, grooving is done over the entire lane. The grooves are cut longitudinally into the pavement and help to keep surface water off of the pavement, which in turn helps to prevent hydroplaning.

Cold Milling is used to give texture to the pavement surface and also to remove material. Carbide cutting teeth are mounted on a revolving drum which chip away at the pavement giving it a more uniform profile while improving skid resistance.

Two good references on grinding, grooving and cold milling are the FHWA Contract No. DOT-FH-11-9580 "Techniques for Pavement Rehabilitation" Training Course (Ref. 5) and AASHTO "Guide for Design of Pavement Structures" (1986) (Ref. 1).

STRUCTURAL REHABILITATION

The need for a structural rehabilitation occurs when a pavement has reached the stage when it no longer can handle the volume and/or the weight of the traffic. This condition is evident by the presence of high severity load related distresses such as broken panels or corner breaks (See Appendix B for details on rigid pavement distress). Studies have shown that it is far more expensive to repair a pavement once it has reached a poor or failed condition than it is to maintain a pavement in relatively good condition (See Figure C.7). Therefore, the goal in pavement rehabilitation is to perform the proper maintenance or rehabilitation at the proper time during the life of the pavement.

This emphasizes the value of doing surface condition surveys and deflection testing. The condition surveys will monitor the progression of the visible distress while the deflection testing will determine
the structural (load carrying) capacity of the pavement. A pavement with no visible distress may be structurally inadequate to carry the traffic it is subjected to. Conversely, a pavement with lots of visible distress may be structurally sound (the distress may be caused by age, weathering, etc.). Becoming familiar with the types and causes of distress will give great insight into the probable rehabilitation technique that will be effective.

Overlays:
An overlay is the placement of additional pavement material over the existing wearing surface. The overlay may be flexible or rigid. If rigid, it can be bonded, partially bonded or unbonded. Before choosing an overlay as a rehabilitation, a life/cost analysis is recommended. Since an overlay will not correct any deficiencies in the base or subgrade layers, it must be thick enough to overcome them. In some cases, if the distress on a pavement has its roots well below the pavement surface, it may be more cost effective to first correct these deficiencies and apply a thinner overlay. The analysis should compare the cost and life expectancy of first patching, or other repair, and placing a thinner overlay versus doing no correction and placing a thicker overlay. In the new AASHTO "Guide for Design of Pavement Structures" (Ref. 1), there is a coefficient known as the "remaining life factor (F_\text{RL})". The purpose of this factor is to increase the overlay thickness to compensate for the condition of the pavement prior to the overlay. If there are two pavements with the same structure, one with no visible surface distress and the other with large areas of high severity distress, the pavement with the distress will obviously require a thicker overlay to compensate for the lesser support provided by the distressed surface and base. The cost of this extra thickness must be weighed against the cost of repairing the pavement first and then placing a thinner overlay.

When overlaying a rigid pavement, there are several methods which may be used:

- PCC Overlay (bonded)
- PCC Overlay (partially bonded)
- PCC Overlay (unbonded)
- Asphalt Overlay

**PCC Overlay (bonded).**
Bonded pcc overlays are used to increase the structural capacity of a concrete pavement with a minimum amount of material. Referring to the Mn/DOT Road Design Manual (Ref. 6), a 9-inch pavement on a subgrade with a K-value of 150 pci can carry 750 Tractor-semi-trailers (TST) per day over a 20 year design life. A 7-inch pavement on the same soil can only carry 25 TSTs per day over the same design life. Thus, by using a 2 inch bonded pcc overlay the load carrying capacity of the section can be substantially increased.

Bonded overlays tend to range from two to four inches thick. The concrete surface must be specially treated to assure a proper bond. The treatment of the surface of the old concrete is critical to the performance of this rehabilitation. Treatment often includes scarification of a thin layer of the old concrete and the placement of a special bonding material directly before the overlay is placed. If the bond does not develop, no structural benefit will result and early maintenance will be needed as the overlay cracks and spalls away from the underlying concrete. Therefore, this procedure demands extreme care and quality control in order to be successful.

This type of overlay should not be used if there is poor load transfer across the joints of the existing pavement. If a good bond is developed on a pavement which has poor load transfer, the overlay will try to carry the full load across the adjacent slab. The overlay is not strong enough to withstand this load and will fail prematurely. If this type of overlay is used, the joint pattern in the overlay must match that of the underlying pavement. This will provide for proper load transfer at the joints.
PCC Overlay (partially bonded)
Partially bonded PCC overlays are placed directly on an existing concrete pavement. No special efforts are made to bond the overlay to the old pavement and, therefore, it is called partially bonded. A partially bonded overlay is generally much thicker than a bonded overlay. The thickness design is similar to that of new construction on a very firm base.

Like a bonded PCC overlay, a partially bonded overlay should not be placed on a rigid pavement that has load transfer problems due to its bridging effect. The joint pattern must also match that of the underlying pavement. The overlay slabs will expand and contract together with the underlying slabs.

PCC Overlay (unbonded)
An unbonded overlay is a thick concrete overlay with a special bond-breaking layer between the overlay and the existing PCC pavement. The thickness design for an unbonded overlay would be based on a new pavement design. The subgrade k-value is normally increased to account for the support available from the underlying pavement.

This type of overlay is a good one to use to help correct strength deficiencies on a rigid pavement with poor load transfer across the joints. Since it is not bound to the underlying pavement, it will tend to expand/contract independently.

Asphalt overlay
This is perhaps the most inexpensive overlay to use on rigid pavement but may have to be very thick to compensate for underlying distress at the joints. As the concrete slabs expand and contract, the pressure from the movement, along with the deflections at the joints due to loads, will cause reflective cracking to occur in the asphalt overlay. This type of overlay has a life expectancy of only 2 to 5 years for high traffic volumes and 10 to 15 years for medium thickness overlays with medium traffic volumes. This type of pavement is known as a "Composite Pavement". This type of rehabilitation is good for obtaining a few years of service before reconstruction of a rigid pavement. It provides a temporary smooth, protected surface.

Reconstruction
Reconstruction should be considered as a rehabilitation alternative whenever major patching or overlaying are also being considered. The cost may actually be less to totally rebuild the road than to attempt to repair the in-place pavement.

Some advantages of reconstruction are:

- Longer life
- Subgrade corrections can be made, including installation or repair of drainage systems.
- Load transfer is re-established.

Some disadvantages are:

- Possible higher cost.
- Longer delays for the public.

The key components for a new rigid pavement design are pavement thickness, base type and thickness, expansion joints, contraction joints, longitudinal joints and reinforcing steel (Ref. 6). The pavement and base thickness are determined by the Modulus of subgrade reaction (k-value in pounds per cubic inch) and Tractor-semi-trailer (TST) component of the 20 year projected ADT
volume. Dowel bars, tie bars and reinforcing depend on slab thickness, panel length and traffic volume. Several good design manuals can be found for designing rigid pavements including: Mn/DOT Design Manual (Ref. 6), AASHTO "Guide for Design of Pavement Structures" (1986) (Ref. 1), and the Portland Cement Association (Ref. 12).

Recycling
Recycling of concrete pavements has become a viable rehabilitation choice when reconstruction is involved. If the plant location is far from a good aggregate source, the high quality aggregate used in the pavement can be reclaimed, crushed and reused as a base material under the new pavement. Mn/DOT Investigation No. 203 (Ref. 33) compared concrete crushed to pass the 3/4 inch sieve remixed with virgin fine material to conventional virgin aggregate base. The study found no difference in performance. This recycled material can be used under either PCC or Asphalt pavements as a base material. Unsuitable material should not be used but be replaced with virgin material.

Any steel in the concrete is removed following primary crushing with either an electro-magnet or by hand.

The recycled concrete can be used 4 ways:

- As granular base under PCC
- As aggregate in new concrete pavement
- As granular base under asphalt pavement
- As aggregate in new asphaltic concrete

The concrete is crushed to different sizes depending on its use. Testing should be done to determine if the recycled aggregate is suitable for reuse prior to placement.

Crack and Seat
This rehabilitation has been used in Minnesota since the 1950’s, although not very successfully at first. It involves cracking the pavement into pieces small enough to reduce the stresses that build up due to the slab movement which cause reflective cracking, yet, large enough to retain load transfer through aggregate interlock and to provide a strong enough pavement to withstand traffic once an overlay is placed. Crack and seating is always followed by either an asphalt or concrete overlay. The seating of the pieces helps to eliminate voids which existed under the uncracked slab.

Deflection testing can play a key role in this process. First, it can be used to determine the in-place strength of the subgrade soil and the pavement as well as load transfer across the joints before cracking. Second, it can be used to determine if the pavement was cracked enough. The slab must be cracked through its entire thickness in order for crack and seat to be effective. Without testing in some way it is very difficult to determine the extent of pavement cracking. Random coring can also be used as a check for full depth cracking.

The cracking can be done with a numbers of devices such as a truck mounted pile driver, a guillotine hammer, a hydrohammer or other devices.

Mn/DOT normally cracks the pavement into 3-4 foot transverse slabs.

The seating is done with a special pneumatic roller which is normally loaded to 50 tons.

The minimum thickness of asphaltic concrete overlay recommended over a crack and seat pavement by Mn/DOT is 5.0 inches. Thinner overlays may work on lower volume roads. Mn/DOT also
assigns the cracked pavement an effective thickness equal to 0.7 its original value, assumes it is a bituminous base and uses its full-depth design chart to arrive at the desired thickness (Ref. 6). The AASHTO "Guide for Design of Pavement Structures" (Ref. 1) also has a thickness design procedure for crack and seat and overlay.
APPENDIX D

TRAFFIC EVALUATION
APPENDIX D  TRAFFIC EVALUATION

Pavement evaluation requires the consideration of many factors, one of which is axle loads. Nearly all pavement thickness designs are based on axle loads and soil strength.

There are a variety of axle configurations, such as:

- Single axle
- Tandem or double axles
- Tridem or triple axles

A truck may have one or all three of the above axle configurations and be either be empty, partially loaded, fully loaded or overloaded. In general, a road experiences a mix of vehicle types each with different axle configurations and loadings. In order to account for the variety of traffic on a roadway, a method is used to reduce truck volumes and weights to one common measurement called the Equivalent Single Axle Load (ESAL). The load effect of every vehicle that travels on a pavement can be reduced to an equivalent single axle load value.

The Equivalent Single Axle Load (ESAL) is usually an 18,000 lb. single axle with dual tires. A 32,000 tandem axle is considered to be about equal to an 18,000 pound single axle. Factors are available that can convert any of the three axle configurations listed above at any weight to an ESAL. If the number of trucks using a roadway is known along with how much they weigh, the number of ESALs for the roadway per day, per year or for the design life can be calculated. The pavement thickness can be determined once the total number of ESALs have been estimated for the desired design life.

The evaluation of an existing pavement should include an evaluation of the total number of ESALs that have been applied to the pavement in addition to the ESALs expected to be applied in the future. This information, along with the subgrade soil strength and pavement thickness, can then be used to determine whether the pavement is strong enough to support the expected ESALs over the design life. If the pavement is not strong enough, additional strength is needed. Anytime a pavement is to be resurfaced whether with a sealcoat or an overlay, or if the pavement is to be reconstructed, a traffic evaluation should be conducted to determine what the ESALs are expected to be. The evaluation may be needed to simply confirm that conditions have not changed from the last evaluation. It doesn’t have to involve a detailed analysis each time. This will prevent spending money on a sealcoat, for instance, when an overlay is needed; or spending money on an overlay when only a sealcoat is necessary.

The Minnesota Department of Transportation Road Design Manual Part II (Ref.6) chapter 7 on pavement design contains a good description of how to estimate the total ESALs for a roadway.

Currently, the most common method of estimating the ESALs for a section is to use the traffic volume as shown on a traffic flow map and the typical statewide distribution factors that are provided in the Road Design Manual. The following is an example of the calculations necessary to estimate the ESALs from the AADT.

TRAFFIC EVALUATION

When determining the type of rehabilitation for a pavement, some of the most important parameters to evaluate are the effects of vehicle type, vehicle weight, and traffic volume. Mn/DOT uses the Equivalent Single Axle Load (ESAL) method for estimating the total traffic effect. The ESAL is a composite value which represents the cumulative damage effect of all vehicles during the design life of a pavement. The following synopsis, from the Mn/DOT Road Design Manual Part II (Ref. 6), explains how to convert available traffic information into ESALs. This synopsis uses an Average
Annual Daily Traffic (AADT) from a 2-way AADT map. However, if an actual traffic count/classification was taken, refer to the Mn/DOT Road Design Manual Part II Section 7-5.03.01.

The ESAL traffic evaluation method determines the effect of each axle load relative to the effect of a single axle load (an 18,000-pound single axle with dual tires is the Mn/DOT single axle load). The following data are needed to calculate the ESAL value:

- AADT and the year the traffic count/classification was conducted. A common source for the two-way AADT is a traffic flow map. Traffic flow maps are generated by Mn/DOT from field traffic counts gathered on a periodic schedule.

- The traffic counts are subdivided into ten vehicle classes shown in Figure D.1. The classes are defined by vehicle size, vehicle weight, number of axles, and number of tires.

- Annual Growth Factor (%) Figure D.2 (detailed in the Road Design Manual).

- Type or classification of roadway. This is relative to the location and use of the roadway.
  - Trunk highways and major arterials in the Metro area
  - Trunk highways in the rural area
  - Local rural roads (County State Aid Highways and County Roads).

After the required data has been collected, the two-way AADT is converted to a design-lane AADT using the following steps:

1. The present AADT is calculated from the AADT at time N using the following equation:

   \[
   \text{AADT}_p = \text{AADT}_n \times (\text{Growth})^n \quad \text{where,}
   \]

   - \( \text{AADT}_p \) = Projected Present Annual Average Daily Traffic
   - \( \text{AADT}_n \) = Annual Average Daily Traffic at year n
   - Growth = Traffic Growth Factor. The percent growth in AADT expected on an annual basis.
   - \( n \) = (Present year - Year \( \text{AADT}_n \) was conducted)

2. Next convert the \( \text{AADT}_p \) into design-lane AADT by multiplying the \( \text{AADT}_p \) by 0.5 for a two lane roadway or 0.45 for a four-lane roadway.

3. Select the distribution factors for each vehicle class. The vehicle distribution factors are a function of the roadway classification. Unless more precise distribution factors are available, use Table 7-5.03B "Assumed Distribution Factors by Vehicle Type" (Road Design Manual). This table was created from the database Mn/DOT has accumulated from their traffic counts/classifications. In some cases the roadway could have a specific use
VEHICLE TYPES

<table>
<thead>
<tr>
<th>Vehicle Type Number</th>
<th>Illustrated Example</th>
<th>Vehicle Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><img src="image1" alt="Passenger Car" /></td>
<td>Passenger Cars</td>
</tr>
<tr>
<td>2</td>
<td><img src="image2" alt="Panel and Pickup" /></td>
<td>Panel and Pickups (Under 1 ton)</td>
</tr>
<tr>
<td>3</td>
<td><img src="image3" alt="Single Unit 2 axle, 4-tire" /></td>
<td>Single Unit — 2 axle, 4-tire</td>
</tr>
<tr>
<td>4</td>
<td><img src="image4" alt="Single Unit 2 axle, 6-tire" /></td>
<td>Single Unit — 2 axle, 6-tire</td>
</tr>
<tr>
<td>5</td>
<td><img src="image5" alt="Single Unit 3 axle and 4 axle" /></td>
<td>Single Unit — 3 axle and 4 axle</td>
</tr>
<tr>
<td>6</td>
<td><img src="image6" alt="Tractor Semitrailer Combination — 3 axle" /></td>
<td>Tractor Semitrailer Combination — 3 axle</td>
</tr>
<tr>
<td>7</td>
<td><img src="image7" alt="Tractor Semitrailer Combination — 4 axle" /></td>
<td>Tractor Semitrailer Combination — 4 axle</td>
</tr>
<tr>
<td>8</td>
<td><img src="image8" alt="Tractor Semitrailer Combination — 5 axle" /></td>
<td>Tractor Semitrailer Combination — 5 axle</td>
</tr>
<tr>
<td>9</td>
<td><img src="image9" alt="Tractor Semitrailer Combination — 6 axle" /></td>
<td>Tractor Semitrailer Combination — 6 axle</td>
</tr>
<tr>
<td>10</td>
<td><img src="image10" alt="Trucks with Trailers and buses" /></td>
<td>Trucks with Trailers and buses</td>
</tr>
</tbody>
</table>

Figure D.1 Vehicle Types
### TIME - GROWTH FACTORS FOR DESIGN PERIODS OF 10 OR 20 YEARS

<table>
<thead>
<tr>
<th>Annual Growth Factor in Present Daily N18</th>
<th>DESIGN PERIOD</th>
<th>20 Year Projection Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10 Years</td>
<td>20 Years</td>
</tr>
<tr>
<td>0%</td>
<td>10.00</td>
<td>20.00</td>
</tr>
<tr>
<td>0.5%</td>
<td>10.23</td>
<td>20.98</td>
</tr>
<tr>
<td>1%</td>
<td>10.46</td>
<td>22.02</td>
</tr>
<tr>
<td>1.5%</td>
<td>10.70</td>
<td>23.12</td>
</tr>
<tr>
<td>2%</td>
<td>10.95</td>
<td>24.30</td>
</tr>
<tr>
<td>2.5%</td>
<td>11.20</td>
<td>25.54</td>
</tr>
<tr>
<td>3%</td>
<td>11.46</td>
<td>26.87</td>
</tr>
<tr>
<td>3.5%*</td>
<td>11.73</td>
<td>28.28</td>
</tr>
<tr>
<td>4%</td>
<td>12.01</td>
<td>29.78</td>
</tr>
<tr>
<td>4.5%</td>
<td>12.29</td>
<td>31.37</td>
</tr>
<tr>
<td>5%</td>
<td>12.58</td>
<td>33.07</td>
</tr>
<tr>
<td>5.5%</td>
<td>12.88</td>
<td>34.87</td>
</tr>
<tr>
<td>6%</td>
<td>13.18</td>
<td>36.79</td>
</tr>
</tbody>
</table>

Figure D.2 Time - Growth Factors
(e.g. main route to landfill), and the distribution should be modified from the state averages listed in the manual.

4. After the vehicle type distribution factors have been selected, they are multiplied by the design-lane AADT to yield a Design Lane Distribution for each vehicle type.

5. Multiply the Design Lane Distribution for each vehicle type by its respective Vehicle Factor to yield a Design Lane Daily ESAL.

The average Vehicle Factors reflect the typical axle loads of the vehicles travelling on Minnesota highways. Typical Vehicle Factors, in ESALs, for each vehicle types are listed by roadway classification in Table 7-5.03D of the Road Design Manual.

6. The last step in the Present Daily ESAL calculation is the summation of the respective Design Lane Daily ESALs for each of the ten vehicle types. This summation yields the Present Daily ESAL used in the analysis of pavement design and rehabilitation.

EXAMPLE:

The following is an example calculation of the Present Daily ESAL.

Calculate the Present Daily ESAL for County State Aid Highway 22 which is a two-lane roadway with a 1985 two-way AADT of 1285, an annual growth rate of 2.5% and a design life of 20 years.

1. First calculate the design-lane AADT:

\[
\text{AADT}_p = \text{AADT}_n \times (\text{Growth})^n = 1285 \times (1.025)^3 = 1,384
\]

where,

- \( \text{AADT}_p \) = Projected Present Annual Average Daily Traffic
- \( \text{AADT}_n \) = 1285
- Growth = 1.025 (2.5% growth per year)
- \( n \) = 1988 - 1985 = 3

2. The AADT\(_p\) is then converted to a design-lane AADT by multiplying the AADT\(_p\) by 0.5 for a two lane roadway \((1384 \times 0.5) = 692\).

This design-lane AADT is then used in the spreadsheet below to calculate the Present Daily ESAL. The "Assumed Distribution Factors" and the "ESAL Vehicle Factors" listed in the spreadsheet are from Tables 7-5.03B and 7-5.03D respectively of the Road Design Manual. These factors were obtained using the "Local Rural Roads" roadway classification.
<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>Assumed Distribution Factors</th>
<th>Design Lane AADT</th>
<th>Design Lane Distribution</th>
<th>ESAL Vehicle Factors</th>
<th>Design Lane ESAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>75.7% x</td>
<td>692</td>
<td>523</td>
<td>x</td>
<td>0.0004</td>
</tr>
<tr>
<td>2</td>
<td>16.0% x</td>
<td>692</td>
<td>111</td>
<td>x</td>
<td>0.0070</td>
</tr>
<tr>
<td>3</td>
<td>2.4% x</td>
<td>692</td>
<td>17</td>
<td>x</td>
<td>0.0100</td>
</tr>
<tr>
<td>4</td>
<td>2.6% x</td>
<td>692</td>
<td>18</td>
<td>x</td>
<td>0.2100</td>
</tr>
<tr>
<td>5</td>
<td>1.7% x</td>
<td>692</td>
<td>12</td>
<td>x</td>
<td>0.4500</td>
</tr>
<tr>
<td>6</td>
<td>0.0% x</td>
<td>692</td>
<td>0</td>
<td>x</td>
<td>0.1500</td>
</tr>
<tr>
<td>7</td>
<td>0.1% x</td>
<td>692</td>
<td>1</td>
<td>x</td>
<td>0.3000</td>
</tr>
<tr>
<td>8</td>
<td>0.5% x</td>
<td>692</td>
<td>3</td>
<td>x</td>
<td>0.5900</td>
</tr>
<tr>
<td>9</td>
<td>---</td>
<td>692</td>
<td>0</td>
<td>x</td>
<td>0.0000</td>
</tr>
<tr>
<td>10</td>
<td>1.0% x</td>
<td>692</td>
<td>7</td>
<td>x</td>
<td>0.3400</td>
</tr>
<tr>
<td></td>
<td>100.0% x</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The daily ESAL estimate is multiplied by 365 to obtain the annual ESAL estimate. The annual ESAL estimate is then multiplied by the appropriate factor for the expected rate of growth of the traffic and the design period. Typical design period is 20 years and the typical rate of growth is 2.5%. The time-growth factor for 2.5% annual growth for 20 years is 25.54. For this example the 20 year ESAL value is 138,000. As a quick check, if the statewide factors for a rural CSAH are used and the growth rate was 2.5%, the 20 year ESAL value should be approximately 100 times the present daily AADT. If the values are very different, then quite likely an error was made or substantially different factors were used.

Caution should be used when using the AADT as a basis for calculating the ESALs. Large variations can occur in the actual traffic loadings particularly on low volume roads. The calculation procedure used to estimate the ESALs should be reviewed to verify that the ESAL value is appropriate for the roadway in question. Check the design lane distribution to see if it makes sense. The four vehicle types to be most concerned with are:

- Vehicle Class 4: Two axle truck
- Vehicle Class 5: Three axle truck
- Vehicle Class 8: Five axle semi
- Vehicle Class 10: Buses and combinations of vehicles

For instance, with the above example, refer to the number of Class 5 vehicles. Does it make sense that there are approximately 12 of these vehicles on that section (design lane) of pavement every day, on average? For low volume, collector, and local roads it is a good practice to ask: Where do the trucks come from? How heavy are they likely be? Repeat the same questions for the Class 4, Class 10 and Class 8 vehicles. If the numbers are quite different, document the differences and go back and adjust the values in the table used for calculating the daily ESAL value. The two columns where adjustments are commonly made are the design lane distribution column and the ESAL vehicle factors column. After the adjustment are made, recalculate the daily ESAL value and determine a new design ESAL value. For a more in depth discussion of possible ESAL variations on low volume roads, read the traffic section in Chapter 2 of this manual.
APPENDIX E

PAVEMENT THICKNESS DESIGN
APPENDIX E  PAVEMENT THICKNESS DESIGN

GENERAL OVERVIEW

In the past half-century there have been several road test facilities constructed and tested. The test facilities consisted of both rigid and flexible pavements and were specifically built to evaluate various pavement characteristics, design parameters, and design procedures. The AASHO (American Association of State Highway Officials) Road Test was constructed in Ottawa, IL in the late 1950's and resulted in a very thorough statistical analysis of the test results. From this, AASHTO (American Association of State Highway and Transportation Officials) has developed the Guide for Design of Pavement Structures (1986). This document, and the previously published Interim Guide, is currently the most universally used reference with respect to pavement design. Throughout the years, numerous other design procedures have been proposed and developed for determining an appropriate pavement thickness. These design procedures vary in such parameters as:

- Complexity
- Required input parameters
- Regional considerations/limitations
- Construction materials characteristics
- Environmental influences
- Traffic calculations and considerations

Many of the current design procedures in use today have been adapted from the data obtained during the AASHO Road Test. These design procedures have been generally modified to meet regional design conditions. In Minnesota a study was conducted by the Minnesota Highway Department to expand the results of the AASHO Road Test by evaluating the various subgrades, construction procedures, construction materials, and climatic effects commonly used or encountered in Minnesota. This study, Investigation No. 183, entitled "Application of AASHO Road Test Result to Design of Flexible Pavements in Minnesota" (Ref. 17), began in 1963 with the final report printed in 1980. The investigation consisted of 58 field test sections established throughout the state. These test sections were selected to encompass the full range of subgrades, pavement structures, and traffic typically found in Minnesota. The sections were evaluated through deflection response and long term pavement performance monitoring. The findings of this study resulted in a new flexible pavement design procedure which is currently in use by Mn/DOT. This design procedure is commonly referred to as the "Minnesota R-Value Flexible Pavement Design" and is described in Part II of the current Mn/DOT Road Design Manual (Section 7-5.0) (Ref.6).

RESEARCH IN PAVEMENT DESIGN

Currently the National Academy of Sciences and the National Research Council are sponsoring a national research project entitled the Strategic Highway Research Program (SHRP) (Ref. 28,29). SHRP focuses on six critical areas pertaining to highway research:

- Asphalt characteristics
- Long Term Pavement Performance
- Maintenance cost-effectiveness
- Protection of concrete bridge components
- Cement and concrete in highway pavements and structures
- Chemical control of snow and ice on highways

The majority of the research is being conducted on field test sections. The test sections are either existing in-place pavements in the General Pavement Study (GPS) or specially
constructed pavements in the Specific Pavement Study (SPS). The test sections are located throughout the 50 states and Canada. The strong support and participation of the state highway agencies has made this program possible and provides assurance that the results will be widely applicable and implemented.

AVAILABLE DESIGN PROCEDURES

The Mn/DOT Road Design Manual contains thickness procedures for flexible aggregate base pavements, full-depth asphalt pavements and rigid pavements (plain and reinforced). The Minnesota State Aid Manual also contains a thickness design table for flexible pavements commonly referred to as the "Soil Factor" method. Either of these methods are presently available. Another design procedure is the AASHTO method (original and overlay design for both flexible and rigid pavements).

With the various design procedures available each agency must determine the most economical and feasible procedure to evaluate their particular conditions. Additionally with the current data handling, testing, and evaluation procedures, it is possible to better monitor the performance of the pavement and thus be able to better determine the thickness required for specific conditions. The following is brief summary of how to use Chapter 3 "Highway Pavement Structural Design" of Part II of the AASHTO Guide for Design of Pavement Structures (1986) (Ref. 1).

AASHTO GUIDE

The AASHTO design method consists mainly of evaluating design input parameters through a nomograph or computerized spreadsheet. The design input parameters consist of the following:

- Design Confidence Limit
- Estimated Total 18-kip Equivalent Single Axle Load (ESAL)
- Effective Roadbed Soil Modulus
- Design Serviceability Loss

DESIGN CONFIDENCE LIMIT

This allows the user to select a design thickness that has a specific probability of being serviceable throughout it's design life. Say, for instance, the user wants to be 95% sure this will occur - the AASHTO design procedure uses the following two factors to obtain this confidence.

Reliability Factor

The Reliability Factor ($Z_R$) is used to introduce a degree of certainty into the design process to ensure that the rehabilitation will last the design period. Basically, the Reliability Factor exists to account for the variations in both traffic and performance predictions. The Reliability Factor is discussed in section 2.1.3 of the AASHTO Guide. The value of $Z_R$ is read directly from Table 4.1 of Part I of the AASHTO Guide. For example, if the selected Design Confidence Level is 95% then $Z_R$ is -1.645.
Overall Standard Deviation

Any specific design will have a range in performance life. The overall standard deviation represents the variation in performance expected. The Standard Deviation (S_o) is used with the Reliability Factor. The Standard Deviation should be selected to represent local conditions with respect to confidence in traffic and pavement performance prediction. The recommended range for the S_o is from 0.4 to 0.5. In general, 0.45 is recommended for use until a value is developed for local conditions.

ESTIMATED ACCUMULATIVE EQUIVALENT SINGLE AXLE LOAD (ESAL)

The definition and calculation of ESAL has been described in Appendix D of this report. The Accumulated ESAL calculated in Appendix D can be entered directly into the design nomograph or computerized spreadsheet.

EFFECTIVE ROADBED SOIL MODULUS

The Effective Roadbed Soil Modulus or Resilient Modulus can be obtained either through laboratory or field testing. The laboratory test (AASHTO T274) should be performed on samples simulating those found during the critical time of year with respect to stress and moisture conditions. The field testing consists of back calculating the modulus from some type of deflection response measurements (i.e. Falling Weight Deflectometer (FWD), Road Rater, Dynaaflect, etc.)

DESIGN SERVICEABILITY LOSS

The serviceability is a measurement of how well the pavement is serving the public. Serviceability is usually measured by an index rating between 0 to 5 known as the Present Serviceability Index (PCI). The index is correlated to pavement roughness experienced by the traveling public as determined by a rating panel. The primary factor that determines the serviceability index is the longitudinal roughness of the pavement. Generally, a terminal serviceability index (P_t) of 2.5 is suggested for major highways and 2.0 for lower volume roads. A new pavement normally starts out with an original serviceability (P_o) of 4.2.

Once these above factors have been determined the values can then be directly applied to design nomograph (Figure E - 1). The output from the design nomograph is the Design Structural Number (SN_D).

FLEXIBLE THICKNESS DESIGN FOR RECONSTRUCTION

Once a rehabilitation alternative has been selected the SN_D can then be used to calculate the required overlay or reconstruction thickness. If the rehabilitation selected is reconstruction the SN_D is used in the following equation:

\[ SN_D = (a_1)(D_1) + (a_2)(D_2) + (a_3)(D_3) \]

where;

- \( SN_D \) = Design Structural Number
- \( a_1 \) = Layer coefficient of surface
- \( D_1 \) = Thickness of surface
\begin{align*}
a_2 & = \text{Layer coefficient of base} \\
D_2 & = \text{Thickness of base} \\
a_3 & = \text{Layer coefficient of subbase} \\
D_3 & = \text{Thickness of subbase}
\end{align*}

The layer coefficient can be determined from lengthy procedures described in the AASHTO Design Guide. The average values can be assumed to be:

\begin{align*}
0.44 & = \text{Asphaltic concrete surface courses (i.e. for Mn/DOT 2341)} \\
0.14 & = \text{Crushed stone base courses (i.e. for Mn/DOT Class 5)} \\
0.11 & = \text{Sandy gravel subbase (i.e. Mn/DOT Class 3 or 4)}
\end{align*}

The layer thicknesses can be determined by applying the layer coefficients into the $S_{NP}$ equation. When designing the layer thicknesses, economic factors and availability of materials should be considered. Below are the minimum thicknesses the AASHTO Guide recommends for asphalt concrete and aggregate base.

\begin{center}
\begin{tabular}{|c|c|c|}
\hline
DESIGN ESALs & ASPHALT CONCRETE & AGGREGATE BASE \\
\hline
Less than & 50000 & 1.0 & 4.0 \\
50001 & 150000 & 2.0 & 4.0 \\
150000 & 500000 & 2.5 & 4.0 \\
500001 & 2000000 & 3.0 & 6.0 \\
2000001 & 7000000 & 3.5 & 6.0 \\
Greater than & 7000000 & 4.0 & 6.0 \\
\hline
\end{tabular}
\end{center}

The layer thicknesses should be rounded up to the nearest one-half inch. The layer thicknesses can be selected in any combination as long as the $S_{NP}$ is satisfied along with the minimum thickness established by the governing agency.

\section*{THICKNESS DESIGN OF ASPHALT OVERLAYS OR ASPHALT PAVEMENTS}

The thickness design procedure is somewhat modified if the rehabilitation alternative is an overlay rather than reconstruction. In the overlay process the in-place pavement structure has an effective Structural Number ($S_{NE}$). One of the tasks in designing an overlay is to determine what the effective Structural Number is. The determination of the $S_{NE}$ is very important in the overlay calculation process. Although the pavement surface might be in poor condition requiring resurfacing, the pavement still possesses some structural strength. The $S_{NE}$ can be obtained through either field testing, laboratory testing or estimation.

The determination of the $S_{NE}$ through field testing is accomplished by a back calculation process using deflection tests conducted on the pavement structure. This back calculation method is lengthy and usually is computer assisted. The back calculation process is described in the AASHTO Guide. If the subgrade soil modulus was determined from deflection testing, the $S_{NE}$ can be back-calculated from the same data.

If laboratory testing was conducted on the subgrade soil to determine the modulus, similar procedures are available for testing the asphalt and aggregate properties. Although this is not a back-calculation analysis of the in-place materials, the laboratory test will yield a good indication of the material characteristics and a representative $S_{NE}$. Care must be taken to assure that the laboratory test are representative of the actual field conditions.
The third method of evaluating the SN_E estimation, should be used as a last alternative. In general if deflection testing or laboratory testing is not available the SN_E can be estimated using the average Layer coefficients (a₁, a₂, a₃) listed above along with the construction thickness of each layer (D₁, D₂, D₃). The values are then applied to the SN_D equation described in the previous section. This value then becomes the SN_E. Generally if the pavement requires an overlay one or more of the pavement layers has a lower layer coefficient than it had when originally constructed. If this is the case engineering judgement should be used to reduce the average Layer Coefficient(s).

The AASHTO overlay design incorporates a Remaining Life Factor (F_RL) which accounts for the pavement deterioration due to weathering and traffic. The F_RL is obtained from Figure 5.17 of Part III of the AASHTO Guide. The F_RL ranges between 0.57 and 0.70 for most overlays designs. This means that only 57-70 percent of the SN_E is used when calculating the overlay thickness.

The required thickness is then calculated from the Overlay Structural Number (SN_Ol). The SN_Ol is calculated from the following equation:

\[
\text{SN}_{\text{Ol}} = \frac{\text{SN}_D \times (F_{\text{RL}}) \times (\text{SN}_E)}{(0.44)}
\]

**SYNOPSIS**

There are many alternatives when selecting a thickness design procedure. The AASHTO Design Guide is a universal method of design. While this appendix briefly describes the design procedure the AASHTO Guide should be used as the reference when actual design work is being conducted. The following are two examples of thickness design calculations.

**EXAMPLE OF THICKNESS DESIGN FOR RECONSTRUCTION**

For this example the following parameters will be used:

- **RELIABILITY FACTOR:** = 95 (High degree - Urban collector)
- **STANDARD DEVIATION:** = 0.45 (Assumed)
- **ESTIMATED TOTAL ESAL:** = 138000 (From example in Appendix D)
- **EFFECTIVE SOIL MODULUS:** = 8000 (in psi Typical for Minnesota Measured in the field by FWD)
- **SERVICEABILITY LOSS:** = 1.7 (Average for major highway)

These parameters can then be used in the design nomograph from the AASHTO Guide or can applied to a Lotus 1-2-3® spreadsheet available from McTrans (Ref. 19). From the Lotus spreadsheet a Design Structural Number (SN_D) of 2.60 is obtained. Using this SN_D and the Layer Coefficients the Layer Thicknesses can be calculated:

- 1.5-inches 2341 Wear \( (a_1 = 0.44) = 0.66 \)
- 2.5-inches 2331 Binder \( (a_2 = 0.36) = 0.90 \)
- 7.5-inches Class 5 \( (a_3 = 0.14) = 1.03 \)
  \[ = 2.61 \]

A Check of the minimum thicknesses shows that this design is adequate.
EXAMPLE OF THICKNESS DESIGN FOR OVERLAY DESIGN

For this example the same parameters from the previous example will be used:

RELIABILITY FACTOR: = 95 (High degree - Urban collector)
STANDARD DEVIATION: = 0.45 (Assumed)
ESTIMATED TOTAL ESAL: = 138000 (From example in Appendix D)
EFFECTIVE SOIL MODULUS: = 8000 (in psi Typical for Minnesota
Measured in the field by FWD)
SERVICEABILITY LOSS: = 1.7 (Average for major highway)

From the previous example the SN_D is known to be 2.6. Since the Effective Soil Modulus was obtained through deflection testing this data can be used to back-calculate the in-place Effective Structural Number (SN_E). For this example, the SN_E = 2.0. This is a typical value if the roadway has been in service for 10-12 years under normal loadings and has medium severity rutting and areas of medium severity alligator cracking. Also assume that 20% of the original pavement life remains (R_L_x = 0.2) before failure and that the overlay will have 20% of its life remaining at the end of the design period (R_Y = 0.2). The Remaining Life Factor F_R_L = 0.57 from Figure 5.17 of the AASHTO Guide. The Structural Number of the Overlay SN_O_L is calculated as follows:

$$SN_{OL} = SN_{D} - [(F_{RL}) \times (SN_{E})] = 2.60 - [(0.57) \times (2.0)] = 1.46$$

Overlay thickness (inches) = $$(SN_{OL}) / (0.44) = 1.46 / (0.44) = 3.32\text{ inches}$$

Round to 3.5 inches of 2341 overlay

Before the overlay is placed local repairs and closer investigation of the pavement's distress should be conducted as outlined in the structural overlay section of Appendix C.
GLOSSARY

AASHTO American Association of State Highway Transportation Officials.

ADT/AADT General unit of measure for traffic volumes. ADT is the Average Daily Traffic, whereas the AADT is the Annual Average Daily Traffic. The AADT is an adjusted ADT which reflects any seasonal variations (i.e. some roads carry higher traffic volumes during tourist season or harvest time versus the remainder of year). The ADT can be adjusted by seasonal factors to determine the AADT.

AGGREGATE INTERLOCK Mechanism for load transfer across joints and cracks in concrete pavement by the connections that form when a pavement cracks down around the aggregates in a jagged fashion.

ALLIGATOR CRACKING A flexible pavement distress which is defined in Appendix A of this report. Alligator cracking is also referred to as alligating, chicken wire cracking, or crocodile cracking.

ARTERIAL A highway primarily for through traffic, usually on a continuous route.

AS-BUILT Records developed from construction notes and plans.


AXLE LOAD The load an axle places on the pavement.

BACKER ROD A flexible packing material placed in concrete joints and routed cracks to help prevent sealant bonding to the bottom of the joint. Allows sealant more room to deform minimizing the stresses that occur. Also reduces amount of sealant required to fill joint or crack.

BENKELMAN BEAM (BB) Deflection measurements measured with a Benkelman Beam. The Benkelman Beam was devised in the early 1950’s by A.C. Benkelman to measure pavement deflections under a moving wheel load.

BITUMEN A class of black or dark-colored cementitious substances which contain asphalts, tars, pitches, or asphaltines.

BLOCK CRACKING A flexible pavement distress which is defined in Appendix A of this report. Block cracking is also referred to as map cracking, pattern cracking, or thermal cracking.

BONDED The adhesion of a pavement layer to the layer below.

BORING Technique usually using an auger to obtain material samples and measure layer thickness.

CAPACITY (See Structural Capacity and Traffic Capacity)

COLD JOINTS The joint between passes of an asphalt paver.

COLLECTOR A highway designed to serve as a collector or distributor of traffic between an arterial and local highway system.
GLOSSARY

CONDITION SURVEY Method of evaluating a pavement section to identify the visible surface distress types and their severities.

CONSOLIDATION Natural or mechanical densification of a soil.

CONTAMINATION Mixing of undesirable material such as soil into a base material.

CORES Cylindrical samples taken from a pavement.

CORRUGATION A flexible pavement distress which is defined in Appendix A of this report. Transverse depressions and ridges due to acceleration, braking, and turning unstable asphalt mix.

CRACK SEAL/ROUT Cracks in a pavement that are treated by routing out the crack area and sealing.

CRCP Continuously Reinforced Concrete Pavement.

CSAH County State Aid Highway.

DE-ICING MATERIAL Chemicals that melt or provide breakup of ice and packed snow on roadways.

DEFICIENCY Sub-standard or abnormal characteristic of the pavement.

DEFLECTION Movement of the pavement response caused by an applied load which produces tensile and compressive stresses.

DEFLECTION TESTING Method to determine the strength of a pavement section and subgrade by placing a known load on it and measuring its verticle.

DEFORMATION A change of shape of a pavement or material.

DEGRADATION The breakdown of aggregates used in pavement and bases due to crushing, freeze thaw, or chemical action.

DEPRESSION Area of pavement where settling has occurred in one or more of the layers or subgrade.

DETERIORATION The breakdown of a pavement due to chemical reactions, weathering, and/or traffic loadings.

DIFFERENTIAL SETTLEMENT Non-uniform settlement of the underlying soil.

DISTRESS Visible symptom of a pavement related problem.

DOT Department of Transportation.

EMULSION An mixture of asphalt cement and water. Small particles of asphalt cement are suspended in water with the aid of an emulsifying agent.
GLOSSARY

EQUIVALENCIES Values used as granular equivalents to compare the strength of the various layers in a flexible pavement.

EQUIVALENT UNIFORM ANNUAL COST (EUAC) A method of comparing alternatives which vary in initial cost, life and maintenance.

ESALs Equivalent Single Axle Loads. A unit of measure with respect to the damage effect of an axle load.

EXPECTED LIFE The length of time a pavement section is expected to perform satisfactorily for the purpose it was designed for.

FAILED The pavement is no longer in a serviceable condition. Traffic can no longer use the pavement as originally intended. Axle loads may be reduced or travel speeds may be lower due to roughness.

FALLING WEIGHT DEFLECTOMETER/ROAD RATER/DYNAFLECT Testing devices that measure the pavement response (deflection) to an applied load.

FATIGUE The result of repeated loading which causes distress in flexible pavements.

FHWA Federal Highway Administration.

FLEXIBLE PAVEMENT A pavement constructed to transmit the stresses incurred by heavy loads to the layers underneath the surface. These pavements can have asphalt gravel surfaces.

FLUSHING A flexible pavement distress which is defined in Appendix A of this report. Flushing is also referred to as bleeding or oil bleeding.

FREEZE-THAW The action of freezing and subsequent thawing of the pavement layers. The more freeze-thaw cycles there are, the more susceptible the materials are to breakdown.

FROST HEAVE A flexible pavement distress upward undulatory in a pavement surface caused by expansion of frozen soil. (See alligator cracking.)

FULL-DEPTH A registered term by the Asphalt Institute which certifies that the pavement consists of asphalt mixtures for all courses above the subgrade or improved subgrade. A Full-Depth asphalt pavement is laid directly on the prepared subgrade.

FUNCTIONAL The roadway that serves the public the way it was designed to.

FUNCTIONAL IMPROVEMENTS This category includes activities that improve the ride ability of the roadway. This includes grooving, seal coat, overlays, and any other improvement that benefits the user.

FUNCTIONAL CLASS Describes the general function of the roadway (i.e. local, collector, arterial).

FUTURE COST Costs that are expected for future maintenance and rehabilitation.
GLOSSARY

GE Granular Equivalent. The value used to relate the strength of pavement materials to a similar thickness of a high quality granular base. For example, 1.0 inch of a hot mixed asphalt material (such as Mn/DOT Spec. 2331) has a G.E. of 2.0 inches and is structurally equivalent to 2.0 inches of a high quality granular base (Mn/DOT Spec. 3138 Class 5).

GEOTEXTILES Woven or non-woven material used as separation layers or for tensile reinforcement of pavements and/or soils. Also referred to as fabric, engineering fabric, geosynthetic, cloth.

GRINDING A method used to remove material to improve the rideability (smoothness) of the concrete pavement.

HCADT Heavy Commercial Average Daily Traffic. A representative number of trucks, busses, semis, etc. that travel both directions on the highway or street.

INCOMPRESSIBLE MATERIALS Materials that collect in joints and cracks of concrete pavements which prevent normal thermal expansion of the concrete (sand, stones, etc.). Excess incompressible materials in joints and cracks can lead to blow-ups.

KIP Unit of force equal to 1000 lbs

LABORATORY R-VALUE A measurement of subgrade soil strength.

LIFE CYCLE COSTS The total costs of construction, rehabilitation and maintenance over the service life of the pavement.

LOAD RELATED DISTRESSES Pavement distresses that develop due to the weight of passing vehicles. Some examples are rutting, alligator cracking, faulting or corner cracks.

LOCAL ROAD RESEARCH BOARD (LRRB) A special research committee which includes representatives from Mn/DOT, four county engineers, and two city engineers that select and fund research projects.

LOW VOLUME ROADS Term used to describe roads for traffic under 1000 AADT and sometimes less than 500 ADT.

MATERIAL RELATED DISTRESSES Pavement distresses that develop due to poor quality or moisture susceptible materials. Examples are raveling or D-cracking.

MILL AND OVERLAY The process of removing a layer or layers of asphalt pavement by milling followed by an asphalt overlay. This process is used to remove undesirable asphalt materials before overlay, or to maintain the existing grade.

PAVEMENT PERFORMANCE Refers to how well a pavement is performing the function it was designed for.

PAVEMENT MANAGEMENT SYSTEM A systematic procedure which aids in the selection and scheduling of pavement rehabilitation. This is accomplished by comparing rehabilitation alternatives at both network and project levels.
GLOSSARY

POTHOLES A flexible pavement distress which is defined in Appendix A of this report. Also referred to as chuckholes.

RAP Recycled Asphalt Pavement

RECEPTIVITY Describes how well a pavement can use a certain rehabilitation to extend its normal design life.

RECYCLING Re-using a material from an existing pavement.

REJUVINATORS A material (usually proprietary) used on asphalt with the intent of extending the pavement’s life or restoring asphalt properties.

RIDEABILITY A general term describing the pavement ride.

RIGID PAVEMENT Pavement which derives most of its strength from a stiff or rigid surface layer, such as concrete pavement.

ROUTE The removal of material from around a joint or crack.

ROUTINE MAINTENANCE Lower cost rehabilitation done when a pavement is still in good to fair condition. Seal coating, crack filling, localized patching, etc. are examples.

RUTTING A flexible pavement distress which is defined in Appendix A of this report. Also referred to as grooving, channeling, or wheel tracking.

SCALING A rigid pavement distress which is defined in Appendix B of this report. Also referred to as crazing or map cracking.

SCARIFICATION A method "roughing up" an existing asphalt pavement surface to improve bond with subsequent overlay.

SERVICE LIFE The useable life of a pavement.

SERVICEABILITY A term describing the concept of how well the pavement section is serving the traveling public.

SHRP Strategic Highway Research Program.

SLAB JACKING A method where material is pumped under a concrete pavement to lift and stabilize a section up to its desired position.

SLURRY SEAL An asphalt emulsion mixed with water and a fine aggregate to form a slurry. Used as a surface treatment and sometimes to fill cracks.

SPRING LOAD RESTRICTION A seasonal axle weight used to restrict heavy loads on designated roads to reduce the risk of premature deterioration of the pavement.

STRUCTURAL IMPROVEMENTS This improvement includes overlays that help the pavement section carry heavier loads or a greater volume of heavy loads.
GLOSSARY

**STRUCTURAL CAPACITY** The axle load capacity of a pavement which if exceeded will cause the pavement to fail before its design life.

**STRUCTURAL DISTRESS** Pavement distress generally caused by fatigue. This type of distress affects the load carrying capacity of the pavement.

**SURFACE TREATMENT** A thin layer of material placed on a flexible (asphalt) surface to rejuvenate and temporarily seal the existing asphalt surface. This helps to slow the deterioration of the pavement section. Examples are seal coat, fog seal, chip seal, slurry seal, and thin overlays.

**SURFACING MATERIALS** Material used in the surface (wear) course of a pavement.

**T^2 CENTER** An organization that transfers transportation technology and new information between local universities, cities and counties.

**TRAFFIC VOLUME** The number of vehicles that use the existing roadway.

**TRAFFIC CAPACITY** The number of vehicles that can be adequately handled by the existing roadway geometric and intersection configurations (number of lanes, turn lanes, etc.).

**UNBONDED** A concrete overlay placed on a material which prevents a bond from forming between the overlay and the underlying concrete pavement.

**USER COSTS** Refers to the costs a vehicle owner incurs for fuel, maintenance, repairs, and traffic delays due to road conditions.

**WEARING COURSE** The surface layer in a flexible pavement system.

**WEATHERING** A flexible pavement distress which is defined in Appendix A of this report. Also referred to as raveling or abrasion.
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