PREFACE

Each year the Regional Transportation Commission of Washoe County (RTC) works with regional agencies on many roadway improvements throughout Washoe County. For each project, the RTC selects a local consultant to provide recommendations and prepare plans for the improvements. The large majority of roadways constructed in Washoe County utilize flexible pavement sections. For the design of pavement sections, the RTC requires the use of the 1993 edition of the American Association of State Highways and Transportation Officials (AASHTO) Guide for Design of Pavement Structures (1). Excerpts from this guide have been incorporated into this pavement design manual developed by Sierra Transportation Engineers, Inc.

The AASHTO Design Guide identifies several key inputs necessary for design of pavement structures. Design life, traffic (i.e., 18-kip equivalent single axle loads, ESAL's), reliability, subgrade resilient modulus, serviceability index, asphalt concrete modulus of elasticity and layer coefficients are some of the required inputs. One of the key inherent characteristics of the AASHTO Design Guide is that it is a Guide and it recognizes the need to provide flexibility in selecting the design inputs based on local practices, available local materials and economical considerations. Because each practicing engineer determines the input parameters based on individual experience, there is a significant potential for inconsistency between design engineers. To minimize the potential for variation, this manual provides values for each input parameter. Additional considerations are also detailed herein to further promote uniformity of the flexible pavement sections designed for the RTC projects.

This manual provides consultants retained by the RTC a uniform and detailed procedure for designing flexible pavements using AASHTO design procedures. Other agencies in Washoe County may also benefit from the information presented. The manual provides specific design input parameters and identifies the steps necessary to achieve consistent layer thickness designs based on local practices. The manual also describes the quantity of R-value tests that are recommended to provide consistent pavement designs.

In addition to this manual, a copy of the 1993 edition of the AASHTO Guide for Design of Pavement Structures is required for the pavement design process described herein.

Robert J. Russell, P.E.  
Date

Regional Transportation Commission  
Engineering Director
EXECUTIVE SUMMARY

This manual covers flexible pavement design for new construction/reconstruction and rehabilitation with overlays. Topics included are pavement design information, subgrade and base materials, design strategies, and appropriate format for the final pavement design selection report to the RTC. The following figure shows a general overview of how this manual is organized.
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CHAPTER 1 – PAVEMENT DESIGN INFORMATION

1.1 GENERAL
Appropriate information about the roadway and site is the key in providing the most economical and feasible pavement design. Figure 1.1 represents the typical structural sections of a flexible pavement. The design of pavement structural sections should be based on a thorough investigation of site specific conditions, projected traffic, conservation of materials and life cycle economics.

![Typical Sections of Flexible Pavement Structure](image)

1 – Fill Slope
2 – Natural Ground
3 – Subgrade
4 – Finished Subgrade Elevation
5 – Shoulder Surfacing
6 – Subbase Course
7 – Base Course
8 – Surface Course
9 – Fill/Embankment
10 – Cross Slope
11 – Cut Slope
12 – Pavement Structure
13 – Travel Lanes
14 – Shoulder
15 – Roadway
16 – Roadbed
17 – Finished Center Line Grade

Figure 1.1 Typical Sections of Flexible Pavement Structure
1.2 PROJECT FILES/RECORDS
Regardless of what type of design is involved (new construction, reconstruction, rehabilitation) the collection and analysis of the information available on a project is the foundation for the pavement design process. The design engineer must integrate this information into the final pavement design selection report, which provides the necessary documentation and communication of this design. The design engineer needs to keep organized files and records of all analyses. Due to the possibility of future maintenance, rehabilitation, and reconstruction activities, these records should be kept and be available to the RTC upon request.

1.3 DATA COLLECTION
The design engineer should obtain all the available information about the existing pavement structure or proposed new alignment. Such information should be obtained from historical files and may include as-built project data, date of construction, pavement layer types/thicknesses, materials/soil properties, and maintenance history. Pertinent reports on file may include, but is not limited to, the following:

- As-Built Plans
- Design and Construction Files
- Location Surveys
- Drainage Reports

In addition to the historical information, data should be collected to reflect the current condition of the existing roadway. Data collection will include a current pavement condition survey, traffic data in terms of annual average daily traffic (AADT) and vehicle classification (VC), subgrade soil properties, and environmental factors (e.g., temperature, rainfall, ice, or snow). Pavement condition information could be obtained from the Pavement Management System (PMS) of the local agency, which may include Pavement Condition Index (PCI), type and severity of cracking, patching, surface bleeding, rutting, and maintenance activities. As part of the design process, a pavement condition survey should be conducted by the design engineer to determine the cause of the pavement deterioration. Appropriate sampling and testing should be performed to determine the existing layer structure and the subgrade soil properties. Table 1.1 represents typical data required for different types of construction projects.
Table 1.1 Data Required for Different Types of Construction Projects

<table>
<thead>
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<th>Reconstruction</th>
<th>Maintenance</th>
<th>Rehabilitation</th>
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<tr>
<td>Existing As-built Information</td>
<td>N/A</td>
<td>Required</td>
<td>Desired</td>
<td>Required</td>
</tr>
<tr>
<td>Surface Distress (type and severity)</td>
<td>N/A</td>
<td>Desired</td>
<td>Required</td>
<td>Required</td>
</tr>
<tr>
<td>Deflection Testing</td>
<td>Optional</td>
<td>Optional</td>
<td>Optional</td>
<td>Desired</td>
</tr>
<tr>
<td>Environment and Drainage</td>
<td>Required</td>
<td>Required</td>
<td>Desired</td>
<td>Required</td>
</tr>
<tr>
<td>Material Sampling and Testing</td>
<td>Required</td>
<td>Required</td>
<td>N/A</td>
<td>Required</td>
</tr>
<tr>
<td>Traffic Data (AADT and VC)</td>
<td>Required</td>
<td>Required</td>
<td>N/A</td>
<td>Required</td>
</tr>
</tbody>
</table>

1.4 SITE INVESTIGATION

On new construction, reconstruction, rehabilitation, and maintenance projects, it is recommended that a site visit/survey be performed by the design engineer in conjunction with the geotechnical field review. These activities should also be coordinated with the RTC and the responsible local agency.

On rehabilitation projects a field survey should take place shortly after the available existing information has been analyzed. The importance of a field survey on rehabilitation projects cannot be overemphasized. The information gathered on the existing pavement condition is necessary for selecting an effective rehabilitation strategy. At a minimum the following items should be investigated during the field survey for rehabilitation projects:

- Existing Pavement Condition
  - Distress (type and severity)
  - PCI value
  - Past maintenance/rehabilitation activities (type and percentage)
  - Shoulder or edge of pavement condition
  - Change in condition, distress, or surface type along the project length
1.5 GEOTECHNICAL REPORT REVIEW
The design engineer needs to be involved in the geotechnical investigation and thoroughly review the final geotechnical investigation report. The following items should be evaluated by the design engineer during the geotechnical report review:

- Sampling Location – The location and depth of samples should be studied to determine if the roadway is reasonably represented.
- Types of existing layers, gradation, Plasticity Index (PI) and layer thicknesses.
- Existing subgrade strength.
- Miscellaneous Notes – Unusual conditions encountered during the investigation that are noted in the report. Examples include underground springs, slides or potential slides, piping, unusual erosion, isolated pockets of unusual subgrade conditions (e.g., clay, highly organic materials or large bedrock outcrops) or other phenomena.

1.6 ANALYSIS PERIOD
The analysis period (or design life) is the length of time that any design strategy must perform without major failure. For the RTC projects, the analysis period for new flexible pavement construction, reconstruction and rehabilitation is 20 years. A design period of less than 20 years needs to be supported by a life cycle cost analysis (LCCA) or other overriding considerations and shall be approved by the RTC.

1.7 TRAFFIC PROJECTIONS
The most current traffic data (i.e., AADT and VC) should be obtained with assistance from the RTC or the responsible local agency. The AADT and VC must be from the project site and should represent the design lane. If the traffic data is over 12 months old, continuous volume and vehicle classification data should be collected at the project site for at least a seven day period. In addition to the traffic data, the following parameters should be used in computing the 18-kip ESAL's:
• Growth Factor – 20 year growth factors should be obtained from the RTC Traffic Model. A negative growth factor shall not be used in the computation of ESAL's even if it is derived from the RTC Traffic Model. Assume a zero growth factor for those cases.

• ESAL Factor – The average ESAL factors by roadway functional classification for different vehicle groups are provided in the Nevada Department of Transportation’s (NDOT’s) Annual Traffic Report (2). The latest ESAL factors in combination with the project specific AADT and vehicle classification collected within the last 12 months shall be used in this computation. The following provides guidance on how to use NDOT’s ESAL factors:
  
  – For RTC designated arterial roadways and rural highways, the NDOT's Urban Other Principal Arterials’ ESAL factors should be used.
  
  – For RTC designated collector and industrial roadways, the NDOT's Urban Minor Collectors’ ESAL factors should be used. If that data is not reported for Minor Collectors then Minor Arterials’ ESAL factors should be used.
  
  – Residential roadways are not part of the RTC Regional Road System (RRS).
CHAPTER 2 – DESIGN CONSIDERATIONS FOR SUBGRADE AND BASE MATERIALS

2.1 INTRODUCTION
The performance of a pavement structure is directly related to the properties and conditions of the roadbed soils and pavement materials. The design procedures in this manual are based on the assumption that most soils can be adequately represented for flexible pavement design by their corresponding resilient modulus ($M_R$) values. However, certain soils such as excessively expansive, resilient, frost susceptible, or highly organic require additional attention for adequate pavement performance.

2.2 SUBGRADE
The geotechnical investigation report contains sampling locations and testing information that should be studied carefully with the preliminary construction profile to determine the design controls for each pavement structure. Only material that is expected to be placed within the top 3 feet of the finished subgrade should be used for determining the subgrade resilient modulus ($M_R$).

Isolated small areas of poor quality material may be omitted in the design by specifying that the material be removed to a depth of 3 feet below finished subgrade elevation and replaced with acceptable material. The removed material may be placed in embankment sections to a minimum of 3 feet below finished subgrade elevation.

Careful consideration should be given to areas where test results indicate conditions adversely affecting pavement construction and performance. Such conditions may include low R-values, high plasticity index, high fines content, expansive clays, high moisture content, frost susceptibility, high organic content, collapsible soil, etc. The following describes some of these conditions and possible remedies:

- Soils that are excessively expansive should receive special consideration. Generally, expansive soils have high plasticity indices, high percentages passing the #200 sieve, low R-values, and are A-6 and A-7 soils according to the AASHTO Soil Classification System. One solution may be to cover these soils with a sufficient layer of selected material to overcome the detrimental effects of expansion. In some cases, it may be more economical to treat expansive soils by stabilizing with a suitable admixture such as lime or cement. Over-excavating to at least 3 feet and replacing the material is another solution.

- Low shear strength soils generally have R-values less than 20. The low shear strength can be compensated for by increasing the structural thickness. However, it may be more economical to treat those soils with suitable admixtures such as lime or cement. In some instances, the use of geosynthetics like geogrid or geotextile may also be a suitable alternative. Additionally, the shear strength may be improved by blending the existing soil with a granular soil. If the soil with low shear strength is in limited areas, it may be most economically treated by over-excavating (at least 3 feet) and replacing with a selected material.

- In areas that have frost heave soils, additional non-frost susceptible base material will need to be placed. For example, a granular base with less than 5% passing #200 sieve with good drainage properties or permeable bituminous treated base could be used.
• Problems with highly organic soils are related to their extremely compressible nature and are accentuated when deposits are extremely nonuniform. Local deposits, or those of relatively shallow depth, may be more economically excavated and replaced with suitable selected material. Problems associated with deeper and more extensive deposits may be alleviated by placing surcharge embankments for preconsolidation that can include special provisions for rapid removal of water to hasten consolidation.

• Although the design procedure is based on the assumption that provisions will be made for surface and subsurface drainage, unusual situations may require that special attention be given to design and construction of drainage systems. Drainage is particularly important where continual flows of water are encountered (i.e., springs or seeps); where detrimental frost conditions are present; or where soils are particularly susceptible to expansion or loss of strength with increase in water content. Special subsurface drainage may include a provision of additional layers of permeable material beneath the pavement for interception and collection of water, and pipe drains for collection and transmission of water. Special surface drainage may require such facilities as dikes, paved ditches, and catch-basins. For additional information on subsurface drainage, the design engineer should review Federal Highway Administration (FHWA) Reports RD-73-14, TS-80-224, and TS-86-208.

• Certain roadbed soils pose difficult problems during construction. These are primarily the cohesionless soils, which are readily displaced under construction equipment; and wet clay soils, which cannot be compacted at high water contents because of displacement under rolling construction equipment and require long periods of time to dry to a suitable water content. Remedies include blending with other soils or adding suitable admixtures to sands to provide cohesion, or to clays to hasten drying or increasing shear strength; covering with a layer of more suitable selected material to act as a working platform for construction of the pavement; or use of a geosynthetic to provide additional stability.

At the conclusion of the geotechnical investigation, the design engineer and geotechnical engineer should be in agreement that the top 3 feet of the subgrade is quality material. This subgrade material should provide relatively uniform support with an R-value of 20 or higher throughout the project length (refer to Section 3.2.6 of this manual for further details on subgrade strength).

2.3 BASE

The base can be a layer of treated or untreated granular aggregate placed immediately beneath the surface layer. The base could be treated with stabilizing admixtures like cement, asphalt, lime, cement-flyash and lime-flyash. These different base types may be used in various combinations to design the most economical structural section. The base must be permeable enough to prevent water entrapment and provide uniform support across the pavement. The RTC requires using crushed aggregates in the base layer to maintain good mechanical interlock.
CHAPTER 3 – DESIGN CONSIDERATIONS FOR FLEXIBLE PAVEMENTS – NEW CONSTRUCTION/RECONSTRUCTION

3.1 GENERAL INFORMATION
The RTC requires the use of 1993 AASHTO Guide for Design of Pavement Structures (1) for new construction and reconstruction of flexible pavements. The reader is advised to obtain a copy of the AASHTO Design Guide for additional background material. Because of the numerous design steps embodied in the AASHTO Design Guide, it is not possible in this manual to cover all design aspects for flexible pavements. In this respect, this manual presents how the AASHTO Design Guide will be applied for the RTC projects.

3.2 FLEXIBLE PAVEMENT DESIGN
The basic design equation used in the AASHTO Design Guide for determining the design structural number for flexible pavements is as follows:

\[
\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN + 1) - 0.20 + \log_{10}\left(\frac{\Delta PSI}{4.2 - 1.5}\right) + 2.32 \times \log_{10}(M_R) - 8.07
\]

\[
\log_{10}\left(\frac{4.2 - 1.5}{1094}\right) \left(\frac{\Delta PSI}{SN + 1}\right)^{1.19}
\]

Where
- \(W_{18}\) = Predicted number of 18-kip equivalent single axle load applications (flexible)
- \(Z_R\) = Standard normal deviate
- \(S_o\) = Combined standard error of the traffic prediction and performance prediction
- \(SN\) = Structural number indicative of the total pavement section required
- \(\Delta PSI\) = Loss in serviceability \((p_o - p_t)\)
- \(p_o\) = Initial design serviceability index
- \(p_t\) = Design terminal serviceability index
- \(M_R\) = Effective roadbed soil resilient modulus (psi)

Alternatively, the nomograph provided in Figure 3.1 of Part I of the AASHTO Design Guide may be used to determine the design structural number.

3.2.1 Summary Design Considerations
The definitions and design factors necessary for flexible pavement design are introduced in various sections in this manual. For quick reference, these are summarized in Table 3.1.
Table 3.1 Flexible Pavement Design Factors

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<td>Table 3.2</td>
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<td>Overall Standard Deviation ($S_o$)</td>
<td>Section 3.2.4</td>
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<td>Serviceability Loss ($\Delta$PSI)</td>
<td>Table 3.3</td>
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<tr>
<td>Effective Roadbed Soil Resilient Modulus ($M_R$)</td>
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<td>Section 3.3</td>
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<tr>
<td>Structural Layer Coefficient ($a_i$)</td>
<td>Table 3.4</td>
</tr>
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<td>Section 3.3.2</td>
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3.2.2 $W_{18}$ – Traffic Loading (18-kip ESAL’s Applications)

Details of the traffic loading (18-kip ESAL’s) calculation and estimation are described in Section 1.7 of this manual.

3.2.3 $Z_R$ – Combined Standard Error (Standard Normal Deviate)

Standard normal deviate is a measure of how likely a pavement is to fail within the design period. If $Z_R$ of -1.282 is selected, there are only ten chances in a hundred that the pavement will fail during its design period. Conversely, there is a 90 percent chance (level of reliability) that the pavement will not fail within the design period. Table 3.2 gives the level of reliability and the $Z_R$ values that should be used for the RTC projects.

Table 3.2 Level of Reliability (Percent) and Standard Normal Deviate for Different Roadways

<table>
<thead>
<tr>
<th>Functional Classification</th>
<th>Reliability (%)</th>
<th>Standard Normal Deviate ($Z_R$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterials</td>
<td>90</td>
<td>-1.282</td>
</tr>
<tr>
<td>Collectors and Rural Highways</td>
<td>85</td>
<td>-1.037</td>
</tr>
<tr>
<td>Industrials</td>
<td>85</td>
<td>-1.037</td>
</tr>
</tbody>
</table>

Note: Residential roadways are not part of the RTC Regional Road System (RRS).
3.2.4 $S_0$ – Overall Standard Deviation

$S_0$ is the combined standard error of the traffic prediction and performance prediction. A standard error of 0.45 should be used.

3.2.5 $\Delta\text{PSI}$ – Serviceability Loss

The change in serviceability index is shown in Table 3.3 for a 20 year design.

<table>
<thead>
<tr>
<th>Functional Classification</th>
<th>Initial Serviceability Index ($P_o$)</th>
<th>Terminal Serviceability Index ($P_t$)</th>
<th>Change in Serviceability ($\Delta\text{PSI}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterials</td>
<td>4.2</td>
<td>2.5</td>
<td>1.7</td>
</tr>
<tr>
<td>Collectors and Rural Highways</td>
<td>4.2</td>
<td>2.0</td>
<td>2.2</td>
</tr>
<tr>
<td>Industrials</td>
<td>4.2</td>
<td>2.0</td>
<td>2.2</td>
</tr>
</tbody>
</table>

Note: Residential roadways are not part of the RTC Regional Road System (RRS).

3.2.6 $M_R$ – Effective Resilient Modulus of Subgrade

For flexible pavement design, the most common soil strength measure is the resilient modulus ($M_R$) determined by R-value testing. Other methods for determining the resilient modulus of subgrade include California Bearing Ratio (CBR), falling weight deflectometer (FWD) and laboratory resilient modulus. These alternate methods may be acceptable based upon consultation with the RTC. The Federal Highway Administration’s LTPP Manual for Falling Weight Deflectometer Measurements Version 4.0 (3) is recommended for additional details on FWD testing. The references (4) through (12) provided in the reference section of this manual are informational material on backcalculation analysis.

Since R-value testing is the predominant state-of-the-practice in Washoe County, this manual’s focus is on standardizing the application of R-value testing. Due to the embedded variability in R-value testing, the RTC requires two R-value tests per sampling location at least every 1,000 feet along the project. The two R-value tests should be compared for reasonableness given the ASTM precision statement for R-value testing. The two R-values should be averaged to determine the average R-value for that particular location. Different pavement sections should be considered if average R-values are significantly different along the project.

If the average R-value at a sampling location is below 20, a corrective measure should be taken to improve the condition of the local subgrade. Where practical the design engineer should consider the removal and replacement of at least 3 feet of soil with new soil having an R-value above 20.

For situations such as shallow utilities, removal and replacement may not be practical. In those situations, treatment of the top 6 inches of subgrade with an admixture (cement or lime) or placement of a high
survivability geosynthetic should be considered. If any of these corrective measures are used in the design process, the R-value of the affected subgrade soil should be considered as 20.

The following equation represents the relationship between $M_R$ and R-value in the AASHTO Design Guide:

$$M_R(\text{psi}) = A + B \times (R-value)$$

For the RTC projects, use the following values for $A$ and $B$ to compute $M_R$ (psi) from R-value:

$A = 772$
$B = 369$

### 3.2.7 SN – Structural Number

The design structural number represents the overall structural capacity needed in the base and surfacing to accommodate the expected traffic loading. It is solved iteratively to the nearest hundredth of a decimal point.

### 3.3 DETERMINATION OF LAYER THICKNESSES

Once the design structural number is determined, the design layer thicknesses can be computed by considering the relationship between the thickness and the layer type using the following equation:

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3$$

Where

- $a_i = i^{th}$ layer coefficient
- $D_i = i^{th}$ layer thickness (inches)
- $m_i = i^{th}$ layer drainage coefficient

The design thickness of the flexible pavement layers should be rounded to the nearest 0.5 inch. The details of the layer coefficients for various layer types and drainage coefficients are provided in the following sections.

#### 3.3.1 Layer Coefficient ($a_i$)

The layer coefficients used for a variety of subbase, base, and surfacing materials are shown in Table 3.4. These layer coefficients are recommended based on the minimum R-values required in the RTC’s Standard Specifications for Public Works Construction (13) also known as the Orange Book.

Circumstances may warrant the use of new materials that are not specified in the Standard Specifications for Public Works Construction. Under these circumstances, the layer coefficients may be derived from the nomographs in Figures 2.5 to 2.9 of Part II of the AASHTO Design Guide. These special circumstances shall be handled in consultation with the RTC and clearly reported in the pavement design selection report.
### Table 3.4 Surfacing, Base, and Subbase Layer Coefficients

<table>
<thead>
<tr>
<th>Layer Type</th>
<th>Layer Coefficient (a_i)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plantmix Bituminous Surface</td>
<td>0.39</td>
</tr>
<tr>
<td>Plantmix Bituminous Base</td>
<td>0.32</td>
</tr>
<tr>
<td>Cement Treated Base</td>
<td>0.23</td>
</tr>
<tr>
<td>Roadbed Modification</td>
<td>0.18</td>
</tr>
<tr>
<td>Aggregate Base – Type 2, Class B</td>
<td>0.12</td>
</tr>
<tr>
<td>Aggregate Base – Type 1, Class A</td>
<td>0.10</td>
</tr>
<tr>
<td>Pit Run Subbase</td>
<td>0.06</td>
</tr>
</tbody>
</table>

#### 3.3.1.1 Plantmix Bituminous Surface

Plantmix bituminous (or asphalt concrete) layer is used as the surface course for flexible pavements. A layer coefficient of 0.39 should be used for this layer.

#### 3.3.1.2 Plantmix Bituminous Base

The plantmix bituminous base (or plantmix bituminous treated base) layer is of similar materials as the surface course in most instances. The major difference is in the compaction of the layer (slightly lower compaction). A layer coefficient of 0.32 should be used for this layer. If the material is different than the surface layer, then it should be handled as a special case in consultation with the RTC.

#### 3.3.1.3 Cement Treated Base (CTB)

The CTB layer coefficient can be expressed as a function of the 7-day unconfined compressive strength. A minimum of 300 psi 7-day unconfined compressive strength is desired. A layer coefficient of 0.23 should be used for CTB layers with 300 psi or more strength. If the compressive strength of the layer is less than 300 psi, the treated base material should be considered as an aggregate base and a reduced layer coefficient should be selected in consultation with the RTC.

#### 3.3.1.4 Roadbed Modification

Roadbed modification is pulverizing, blending with cement, and compacting an existing roadway including asphalt concrete, aggregate base and native soils. This may also include imported recycled asphalt concrete. The layer coefficient of a roadbed modified material is a function of the 7-day unconfined compressive strength of the compacted material. A minimum of 300 psi strength is desired. A layer coefficient of 0.18 should be used for roadbed modified layers with 300 psi or more strength. If the
compressive strength of the layer is less than 300 psi, the reduced layer coefficient should be selected in consultation with the RTC.

### 3.3.1.5 Aggregate Base

Aggregate base materials shall meet the requirements for Type 2, Class B or Type 1, Class A crushed aggregate base types specified in the *Standard Specifications for Public Works Construction*. For Type 2, Class B aggregate base materials, the layer coefficient should be considered as 0.12. For Type 1, Class A aggregate base materials, the layer coefficient should be considered as 0.10.

### 3.3.1.6 Pit Run Subbase

The aggregate (pit run) subbase materials shall meet the requirements specified in the *Standard Specifications for Public Works Construction*. For these subbase layers, a layer coefficient of 0.06 should be used.

### 3.3.2 Drainage Coefficient ($m_i$)

Adequate drainage must be provided for all pavement structures. The RTC recommends using a drainage coefficient of 1.0 for crushed aggregate bases routinely used in roadway construction. Should other base materials be used in the pavement design, the design engineer is referred to the AASHTO Design Guide for selecting an appropriate drainage factor.

### 3.4 MINIMUM PAVEMENT DESIGN CONTROLS

The AASHTO Road Test structural design equations are based on traffic induced fatigue failures. There are other criteria, which must be considered to avoid impractical designs. Some of these are:

- Ease of construction
- Maintenance considerations
- Failure under the action of a few heavy wheel loads
- Future land development and construction traffic
- Current engineering judgment and practice

Taking these criteria into account, minimum design requirements for flexible pavements are developed for the RTC projects. The minimum structural numbers listed in Table 3.5 should be used to check the adequacy of the design.

In addition, a minimum thickness of 4 inches of aggregate base shall be used on layered sections with aggregate base. The design engineer should verify that the recommended design layer thicknesses meet or exceed minimum thickness standards set forth by the appropriate local agency. The results of this comparison shall be explicitly reported in the pavement design selection report.
Table 3.5 Minimum Structural Numbers for Flexible Pavement Design

<table>
<thead>
<tr>
<th>Functional Classification</th>
<th>Minimum Structural Number</th>
<th>Minimum Surface Layer Thickness (Inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arterials</td>
<td>2.5</td>
<td>4.0</td>
</tr>
<tr>
<td>Collectors and Rural Highways</td>
<td>1.9</td>
<td>3.0</td>
</tr>
<tr>
<td>Industrials</td>
<td>1.9</td>
<td>3.0</td>
</tr>
</tbody>
</table>

Note: Residential roadways are not part of the RTC Regional Road System (RRS).
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CHAPTER 4 – DESIGN CONSIDERATIONS FOR FLEXIBLE PAVEMENTS – REHABILITATION

4.1 INTRODUCTION

In this manual, rehabilitation is defined as the removal and replacement of the surface layer, a mill & overlay or an overlay. The rehabilitation with overlay is further defined as 2 inches or more of asphalt concrete. For a discussion of other treatment activities (i.e., preventive maintenance, corrective maintenance), the reader is referred to the following documents: Regional Rehabilitation and Reconstruction Program (14) and Regional Preventive Maintenance Program (15). Copies of these documents can be obtained from the RTC.

Maintenance/rehabilitation generally involves either partially or completely restoring the surface of a pavement. This is typically accomplished by repairing surface problems such as cracking, rutting, potholes, and providing an acceptable level of skid resistance. Treatment activities may include crack sealing, patching, slurry sealing, micro-surfacing, thin overlay, thick overlay, mill and overlay, and removal and replacement of the surface layer.

Information on existing pavement structure and its performance are essential for selecting a proper maintenance/rehabilitation strategy. As shown previously, Table 1.1 represents the types of data required and desired for different maintenance/rehabilitation projects. Figure 4.1 shows the maintenance/rehabilitation selection process. Consultation with the RTC is required if life cycle cost analysis is performed.

![Figure 4.1 Maintenance/Rehabilitation Selection Process](image-url)
4.2 PAVEMENT CONDITION EVALUATION

As part of the maintenance/rehabilitation selection process, an evaluation of the pavement is required. This is achieved by a pavement condition survey, which includes examining the extent and severity of the existing distresses. Detailed information on a pavement condition survey can be found in the US Army Corps of Engineers’ “PAVER Asphalt Distress Manual-Pavement Distress Identification Guide for Asphalt-Surfaced Roads and Parking Lots” (16). This distress identification manual is extensively used by the agencies in Washoe County to evaluate the pavement condition using the MicroPAVER program. It is required that the MicroPAVER distress identification manual be used for pavement condition evaluation on the RTC projects. The most common distresses (i.e., cracking, potholes, rutting, bleeding, and weathering and raveling) and their likely treatments are described in the following sections. Pre-overlay treatments are described in Section 4.4.

Additional details about pavement condition evaluation are provided under Part III, Section 5.3 of the AASHTO Design Guide.

4.2.1 Cracking

The most common forms of cracking are fatigue, longitudinal, transverse, and block.

4.2.1.1 Fatigue Cracking

Fatigue or alligator cracking is generally associated with heavy truck traffic, a weak or wet base, and/or a poor subgrade condition. Figure 4.2 shows typical fatigue cracking in the wheel path. Low severity fatigue cracking consisting of limited pumping, potholes, and patches can be treated by crack sealing, full-depth patching, slurry sealing, or micro-surfacing. Full-depth patching and crack sealing should be used as pretreatments before applying slurry seals or micro-surfacing. For higher severity fatigue cracking where pumping, potholes, and patches are present, the potential treatments are mill and overlay, removal and replacement of surface layer, and reconstruction.

Figure 4.2 Fatigue Cracking
4.2.1.2 Longitudinal Cracking

Longitudinal cracking is generally associated with an early stage of fatigue, a construction pavement joint, an underlying trench or cracks associated with temperature cycling. Figure 4.3 shows a typical longitudinal crack. Low severity longitudinal cracking can be treated by crack sealing. Higher severity longitudinal cracking can be treated by full-depth patching or a thin overlay.

![Figure 4.3 Longitudinal Cracking](image)

4.2.1.3 Transverse Cracking

Transverse cracking is similar to longitudinal cracking except the cracking occurs perpendicular to the direction of travel. Figure 4.4 shows typical transverse cracking. Low severity transverse cracking can be treated with crack sealing. At higher severity, transverse cracking can be treated by crack sealing in conjunction with a slurry seal or micro-surfacing, mill and overlay, or removal and replacement of the surface layer. In those cases where an overlay and/or removal and replacement are warranted, it is important to select the appropriate grade of asphalt to prevent the occurrence of transverse cracks in the future.

![Figure 4.4 Transverse Cracking](image)
4.2.1.4 Block Cracking

Block cracking is generally caused by shrinkage of the asphalt concrete and/or the cement treated base. The causes of block cracking are not load associated. Figure 4.5 shows typical block cracking. Crack sealing, slurry sealing or micro-surfacing are potential treatments for low severity block cracking. Depending on the extent, higher severity block cracking can be treated by a thin overlay, mill and overlay, or removal and replacement of the surface layer. In those cases where an overlay, mill and overlay, or removal and replacement are warranted, it is important to select the appropriate grade of asphalt to prevent the occurrence of block cracking in the future.

![Figure 4.5 Block Cracking](image)

4.2.2 Potholes

Potholes are the ultimate deterioration of the pavement to an unserviceable state. Figure 4.6 shows a typical pothole. Potholes need to be patched as soon as practical with suitable patching material. Short term remedies can include slurry sealing and micro-surfacing. Ultimately an overlay or removal and replacement of surface will be needed.

![Figure 4.6 Pothole](image)
4.2.3 Rutting

Rutting is generally the result of heavy traffic loads applied to a weak or unstable pavement structure. Figure 4.7 shows typical rutting. If the rutting is related to problems with the asphalt layer (i.e., poor compaction, poorly designed mix), the asphalt layer needs to be milled or removed and then replaced with a stable asphalt layer. If the cause is due to a weak and/or wet base or subgrade, the pavement will need to be reconstructed with the surface and base layers removed and the subgrade stabilized.

![Figure 4.7 Rutting](image)

4.2.4 Bleeding

Bleeding is due to an excessive amount of asphalt in the existing pavement. Figure 4.8 shows typical bleeding. A potential treatment for this condition is to mill and overlay.

![Figure 4.8 Bleeding](image)
4.2.5 Weathering and Raveling

Weathering and raveling are the wearing away of the pavement surface due to a loss of asphalt and dislodged aggregates. Figure 4.9 shows typical weathering. The causes of weathering and raveling can be hardening of the asphalt binder, poor quality mix, certain types of traffic, and oil spillage. A potential treatment for these conditions is to mill and overlay.

![Figure 4.9 Weathering](image)

4.3 MAINTENANCE/REHABILITATION TREATMENTS

A variety of maintenance/rehabilitation treatments are available for different distresses. Some of these treatments were discussed in the previous section. Table 4.1 shows typical maintenance/rehabilitation treatments for each distress type and severity.
### Table 4.1 Maintenance/Rehabilitation Treatments

<table>
<thead>
<tr>
<th>Distress Type</th>
<th>Distress Severity</th>
<th>Slurry Sealing</th>
<th>Micro Surfacing</th>
<th>Crack Sealing</th>
<th>Patching</th>
<th>Thin Overlay</th>
<th>Thick Overlay</th>
<th>Mill and Overlay</th>
<th>Remove and Replace</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1-2 Inches</td>
<td>2-4 Inches</td>
<td>2-4 Inches</td>
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<td>Patching &amp; Potholes</td>
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</tbody>
</table>

### 4.4 PRE-OVERLAY TREATMENTS

Before placing an overlay, the existing pavement distresses need to be repaired. The following are some of the key distresses that should be repaired prior to an overlay:

- **Fatigue Cracking** – Low severity fatigue cracking should be crack sealed. All areas of medium and high severity fatigue cracking must be patched.
- **Longitudinal, Transverse, and Block Cracking** – Low to medium severity cracks must be crack sealed. High severity cracks should be patched. Crack sealing should be performed at least one year in advance of an overlay to allow sufficient curing time for the sealant.
- Rutting – Remove rutting by milling and/or placement of a leveling course. If rutting is severe, an investigation into which layer is causing the rutting should be conducted to determine whether or not an overlay is a good strategy.
- Surface Irregularities – Depressions, humps, and corrugations require investigation and treatment of their cause. In most cases, removal and replacement of surface irregularities will be required.

Additional details about pre-overlay treatments for flexible pavement are provided under Part III, Sections 5.4.2 and 5.4.3 of the AASHTO Design Guide. Details of pre-overlay treatments for portland cement concrete (PCC) pavements are provided under Part III, Section 5.5.2, 5.5.3, 5.6.2, and 5.6.3 of the AASHTO Design Guide.

4.5 OVERLAY DESIGN

This section describes the design process for plantmix bituminous overlay of flexible pavements. This process is based on Part III, Section 5.4.5 of the AASHTO Design Guide. Because of the limited number of rigid pavements in Washoe County, the plantmix bituminous overlay of rigid pavements is not described in this manual. Refer to Part III, Section 5.5 and Section 5.6 of the AASHTO Design Guide for more information on overlay of rigid pavements.

The overlay thickness is a function of the structural capacity of the combined pavement to handle the future traffic loading during the overlay design life and the structural capacity of the existing pavement. The required overlay thickness needed to increase the structural capacity is determined by the following equation.

\[
SN_{ol} = a_{ol} \times D_{ol} = SN_f - SN_{eff}
\]

Where
- \(SN_{ol}\) = Required overlay structural number
- \(a_{ol}\) = Structural coefficient for the plantmix bituminous overlay
- \(D_{ol}\) = Required overlay thickness
- \(SN_f\) = Structural number required to carry future traffic
- \(SN_{eff}\) = Effective structural number required of the existing pavement

The following step by step procedures should be used to determine the required overlay thickness:

Step 1: Obtain existing pavement structural information
   a) Thickness and material types of each layer
   b) Subgrade soil properties including \(M_R\), R-value, PI, and percent passing #200

Step 2: Traffic analysis
   a) Obtain the past cumulative 18-kip ESAL’s \((N_p)\)
   b) Predict the future 18-kip ESAL’s \((N_f)\) for the design period as described in Section 1.7
Step 3: Condition survey
Distress types and severities as discussed previously under Section 4.2. Condition survey
should be conducted on the most heavily trafficked lane.
  a) Percent surface area with fatigue cracking under each severity level.
  b) Number of transverse cracks per segment under each severity level.
  c) Mean rut depth in inches.
  d) Evidence of pumping at cracks or pavement edges.

Step 4: Deflection testing (recommended)
Perform deflection testing on the outer wheel path at every 100 feet of the project. The testing
locations should be staggered for different/opposite lanes to collect maximum possible data.
Areas that have already been identified for removal should not be tested. A Falling Weight
Deflectometer (FWD) device with load magnitude of approximately 9,000 pounds (half the legal
axle load) is recommended. The FHWA’s LTPP Manual for Falling Weight Deflectometer
Measurements Version 4.0 (3) is a recommended reference for additional information.
  a) Measure deflections at the center of the load and other distances away from the centerline to
capture the strength of each layer.
  b) Use AASHTO backcalculation method or other techniques (e.g., Evercalc, Modulus, etc.) to
get subgrade resilient modulus and effective moduli of all other pavement layers. Report
explicitly the technique used for backcalculation in the pavement design selection report.
The references (4) through (12) of this manual provide additional information on
backcalculation analysis.
  c) The normalized deflections could also be used to identify weak areas that should be
replaced or treated as described in Section 3.2.6 of this manual.

Step 5: Coring and material testing
  a) Resilient modulus of subgrade
     If deflection testing is performed, use backcalculation analysis to determine the resilient
     modulus of subgrade. Otherwise, use R-value testing as described under Section 3.2.6 of
     this manual.
  b) Bituminous surface, base, and subbase layer thicknesses obtained during sampling and
testing should be verified with the as-built information. Any major discrepancies should be
resolved in consultation with the RTC.
  c) Samples of surface and stabilized base layers should be visually inspected to assess asphalt
     stripping, degradation, and erosion.
  d) Samples of granular base and subbase layers should be visually examined and gradation
tests be performed to assess degradation and contamination by fines.

Step 6: Determination of required structural number of future traffic load (SNf)
  a) Effective subgrade resilient modulus should be determined using Step 5. If resilient modulus
     is backcalculated, it should be adjusted per recommended correction method described in
     Part III, Section 5.4.4 Step 6 of the AASHTO Design Guide.
  b) The effective design subgrade resilient modulus must be adjusted for seasonal effects in
     accordance with procedures described in Part II, Section 2.3.1 of the AASHTO Design
     Guide.
  c) Design loss of serviceability as described in Section 3.2.5 of this manual.
  d) Overlay design reliability as described in Section 3.2.3 of this manual.
e) Overall standard deviation as described in Section 3.2.4 of this manual.
f) Determine SN\textsubscript{f} with the above design input as described in Section 3.3 of this manual.

Step 7: Determination of effective structural number (SN\textsubscript{eff}) of the existing pavement using one of the following methods. Additional details are available in Part III, Section 5.4.5, Step 7 of the AASHTO Design Guide.

a) SN\textsubscript{eff} from Nondestructive Testing

Follows an assumption that the structural capacity is a function of pavement thickness and overall stiffness.

\[
SN_{\text{eff}} = 0.0045D\sqrt[3]{E_p}
\]

Where
- \(D\) = Total thickness of all pavement layers above the subgrade
- \(E_p\) = Effective modulus of pavement layers above the subgrade (Step 4 of this manual)

b) SN\textsubscript{eff} from condition surveys

\[
SN_{\text{eff}} = a_1D_1 + a_2D_2m_2 + a_3D_3m_3
\]

Where
- \(a_i\) = \(i\)th layer coefficient of the existing pavement (Part III, Table 5.2 of AASHTO Design Guide)
- \(D_i\) = \(i\)th layer thickness of existing pavement
- \(m_i\) = \(i\)th layer drainage coefficient (Section 3.3.2 of this manual)

c) SN\textsubscript{eff} from remaining life

\[
SN_{\text{eff}} = CF \times SN_o
\]

Where
- \(CF\) = Condition factor determined from Part III, Figure 5.2 of the AASHTO Design Guide using Remaining Life (RL)

\[
RL = 100 \left[ 1 - \left( \frac{N_p}{N_{1.5}} \right)^{1.5} \right]
\]

Where
- \(RL\) = Remaining life (percent)
- \(N_p\) = Total traffic to date (ESAL’s)
- \(N_{1.5}\) = Total traffic to pavement failure (ESAL’s)

\(SN_o\) = Structural number of original pavement since the last construction or rehabilitation

Step 8: Determination of overlay thickness

\[
D_{ol} = \frac{SN_{ol}}{a_{ol}} = \frac{(SN_f - SN_{\text{eff}})}{a_{ol}}
\]

Where
- \(SN_{ol}\) = Required overlay structural number
- \(a_{ol}\) = Structural coefficient for plantmix bituminous overlay
- \(D_{ol}\) = Required overlay thickness (inches)
- \(SN_f\) = Structural number determined in Step 6
- \(SN_{\text{eff}}\) = Effective structural number of the existing pavement from Step 7
CHAPTER 5 – PAVEMENT DESIGN SELECTION REPORT

At the completion of the design process, appropriate project information and findings are presented in a pavement design selection report. The report includes:

- Project information and design summary
- Existing pavement history and visual observation
- Test data
- Design calculations and discussion
- Recommended pavement design
- Signature

Additional details about each of these items are provided in the following sections.

5.1 PROJECT INFORMATION AND DESIGN SUMMARY

- RTC project number
- RTC project name
- RTC project manager, prime contractor project manager, design engineer
- Project location (include limits) and vicinity map
- Description of project
- Scope of work
- Summary design recommendations

5.2 EXISTING PAVEMENT HISTORY AND VISUAL OBSERVATION

- Type of roadway by functional class
- Existing as-built pavement structural information including a description of each layer and its thickness
- Dates of construction, reconstruction, rehabilitation, and/or maintenance activities
- Description of roadway including length and width, number of lanes, presence of curb & gutter and sidewalks
- Existing pavement condition (i.e., report type and severity of distresses and corresponding PCI)
- Description of terrain and drainage conditions
- Unusual conditions (e.g., railroad crossings, equipment crossings, utilities, etc.)

5.3 TEST DATA

- Thickness of existing layers (HMA, base, subbase)
- Soils information (e.g., R-values, PI, gradation, pH, resistivity, moisture, frost susceptibility, swell, soil classification and description, etc.) and any improvements needed to enhance the strength of the subgrade (e.g., over excavation and replacement, lime or cement treatment, usage of geotextile or geogrid, etc.)
5.4 DESIGN CALCULATIONS AND DISCUSSION

- New Pavement Design
  - List all design parameters and assumptions (i.e., traffic \( W_{18} \), reliability, effective resilient modulus \( M_R, S_0 \), PSI, SN required, etc.)
  - Discuss considered design alternatives and selected final design

- Pavement Rehabilitation Design
  - List all design parameters and assumptions (i.e., traffic \( W_{18} \), reliability, effective resilient modulus \( M_R, S_0 \), PSI, SN required, etc.)
  - Discuss considered strategies and selected final design

5.5 RECOMMENDED PAVEMENT DESIGN SECTION

- Provide recommended pavement design section
- Discuss pavement layers and any special considerations

5.6 SIGNATURE

Pavement design selection report will be checked, approved, and signed by a Licensed Nevada Professional Civil Engineer with pavement design experience.
REFERENCES


