**ARIZONA DEPARTMENT OF TRANSPORTATION**

# PAVEMENT DESIGN MANUAL

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ROADWAY ENGINEERING GROUP

PAVEMENT DESIGN SECTION

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# TABLE OF CONTENTS

# LIST OF TABLES



# LIST OF FIGURES

## PREFACE

The American Association of State Highway Officials (AASHO) issued its interim guides for the design of flexible and rigid pavements in 1961 and 1962 respectively, following the 1958–1960 Road Test. In 1986, the American Association of State Highway and Transportation Officials (AASHTO) published a comprehensive revision under the title *1986 AASHTO Guide for the Design of Pavement Structures*. Then, in 1993, the guide was updated to incorporate major changes in its overlay design procedure and related appendices.

The Arizona Department of Transportation (ADOT) has used the AASHO/AASHTO guides as its basis for design since it was first issued in 1961. Arizona's present pavement design guide was developed by the Materials Section in 1989 with revisions issued in 1991 and 1992. A revision was not issued to formally adopt the 1993 version of *AASHTO Guide for the Design of Pavement Structures* because ADOT had developed and adopted its own overlay design procedure in 1984 termed Structural Overlay Design for Arizona (SODA).

The purpose of this manual revision is to present guidance on how ADOT currently uses the *1993 AASHTO Guide for the Design of Pavement Structures* to design new pavements, and SODA to design asphalt overlays. Significant changes since the last manual update include: modifying the method of calculating the design R-value for highly variable subgrade soils, revising the combined standard error ($S_O$) for rigid pavements, updating the format and presentation of the Materials Design Package, updating the SODA equation to reflect roughness measurements based on International Roughness Index (IRI) rather than Mays Meter values, and a new procedure for calculating design equivalent single axle loads (ESAL's).

It should be noted that the structure and format of ADOT's pavement design guidance has changed since it was last revised in 1992. Previously, guidance for pavement design activities was included in the *Materials Preliminary Engineering and Design Manual*. However, reorganizational changes have resulted in a decision to issue this guidance as a stand-alone document under the title of *ADOT Pavement Design Manual*.

It should also be noted that in 2008, AASHTO released the *Mechanistic-Empirical Pavement Design Guide: A Manual of Practice* (MEPDG). The accompanying software, AASHTOWare Pavement ME Design, was released in 2011. In 2010, ADOT contracted with Applied Research Associates, Inc. (ARA) to perform a local calibration for the MEPDG procedure. Since completing the local calibration in 2012, ADOT has been performing parallel designs using both the *1993 AASHTO Guide for the Design of Pavement Structures* (or SODA for overlay design) and the MEPDG. MEPDG designs are currently being performed in accordance with a draft design guide titled *Arizona DOT User Guide for AASHTO DARWin-ME Pavement Design Guide*. Results from both procedures are typically considered when developing a final design solution for a project.

# 1.0 INTRODUCTION

This manual provides the procedures used by the Arizona Department of Transportation for the design of new pavements and rehabilitation of existing pavements; both rigid and flexible. It provides a guide for determining new pavement structures similar to the ones shown in Figure 1-1. The design procedures provided will include the determination of the total pavement thickness as well as the thickness and structural value of each of the individual pavement components. The determination of alternate designs and the selection of an optimum design based on costs, conservation of materials, etc., will also be discussed.

Regardless of what type of design is involved (new construction, rehabilitation, widening, etc.), the collection and analysis of the information available on a project is the foundation for all that follows in the pavement design process. The Pavement Design Engineer must integrate this information into the Materials Design Package (Materials Design Report, Pavement Design Summary and Preliminary Pavement Structure Cost Estimate) that will provide the necessary documentation and communication of this design process. The information provided in Table 1-1 gives an idea of some of the data required for the design analysis of different types of projects.

In the chapters that follow, the pavement design process will be discussed in detail.

## 1.1 Project Determination

Whether from the scope of work, project assessment, design concept report or from the original project request form, the determination of a project's location and intent is the starting point for the design process. With this information the preliminary data requirements for the project can usually be determined.

## 1.2 Data Collection

Existing information can be obtained from a variety of sources for projects on the State Highway System. ADOT’s Pavement Management System (PMS) is a database that stores pavement history (project/TRACS number, layer type and thickness, and date of construction), pavement condition survey results (smoothness, percent cracking, patching, flushing, skid resistance, and rutting), as well as pavement maintenance history and costs. Falling Weight Deflectometer (FWD) test results are also stored in the PMS database.

Other existing information may include, but is not limited to: record drawings, design and construction files, geotechnical and/or pavement design reports from past or adjacent projects, historic core logs, location surveys, drainage reports, etc. This data can be obtained from a variety of sources including ADOT’s Repository of Online Archived Documents (ROAD) website at https://road.azdot.gov, various ADOT technical sections (e.g. Drainage, Geotechnical, etc.), construction and/or maintenance districts, or from the project manager. The Data Warehouse, on the ADOT intranet site at http://aidw/aidw2/ , also has a wealth of information for both past and current projects.

For those projects not on the State Highway System, existing information is usually available from the responsible agency or the project manager.

**Table 1-1 Data Requirements for Different Types of Construction Projects**

| Data Required | New Construction | Reconstruction | Widening | AC Pavement Rehabilitation | PCCP Rehabilitation | Surface Treatments |
|---|---|---|---|---|---|---|
| Scoping Document | H | H | H | H | H | M |
| Record Drawings | N/A | H | H | H | H | H |
| Existing Pavement History | N/A | L | H | H | H | H |
| Pavement Cores | N/A | M | H | H | L | L |
| Deflection Testing | N/A | M | H | H | M | L |
| Field Investigation | H | H | H | H | H | H |
| Existing Pavement Condition | N/A | L | M | H | H | H |
| Environment & Drainage | H | H | H | M | M | L |
| Subgrade Sampling & Testing | H | H | M | L | L | N/A |
| Material Sources | H | H | H | M | M | L |
| Traffic Data | H | H | H | H | M | M |

Level of Need H = High, M = Moderate, L = Low N/A = Not Applicable

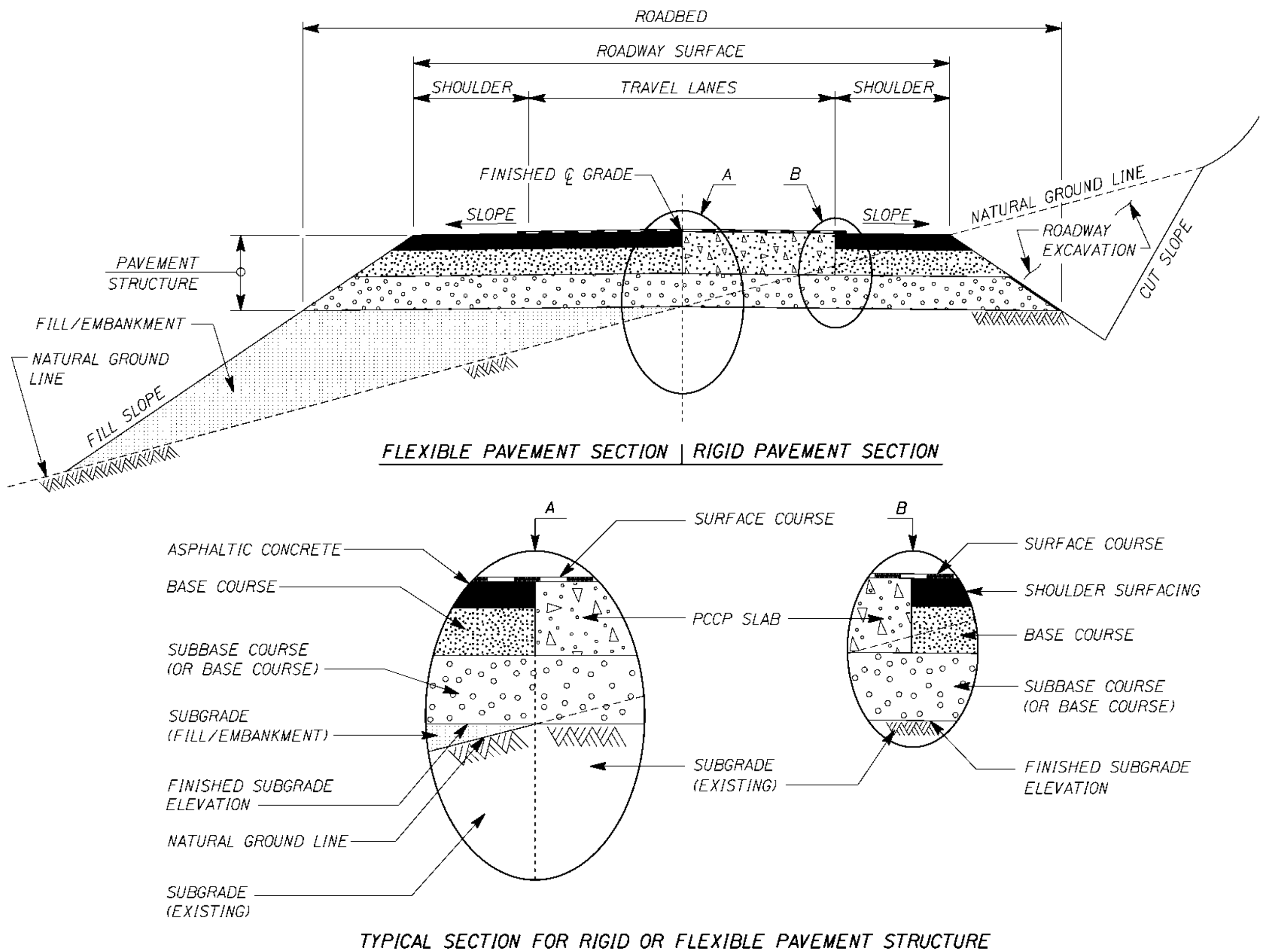



**Figure 1-1 Typical and Structural Sections**

## 1.3 Field Survey

A field survey should take place shortly after the existing information described in Section 1.2 has been collected and analyzed. The importance of a field survey on rehabilitation projects cannot be overemphasized. Information obtained on the existing pavement condition and apparent distress is necessary for selecting a reliable rehabilitation strategy. The Distress Identification Manual for the Long-Term Pavement Performance Program should be used as a reference for identifying and quantifying pavement distresses. The following is a partial check list of items that should be investigated during the field survey for pavement design projects:

A. Existing Pavement Condition

1. Cracking (Type, Severity and Quantity)
2. Rutting (Depth)
3. Other Pavement Distresses
4. Surface Course (Type, Condition and Width)
5. Maintenance (Type and Percentage)
6. Shoulder Condition
7. Change in Condition, Distress, or Surface Type

B. Related Items

1. Drainage
2. Terrain
3. Roadway Grade and Section (Cross Slope)
4. Soils

C. General

1. Project Limits (Verification and Reasoning)
2. Lane Configuration and Widths
3. Bridge Structures (Clearance and Surface Type)
4. Ramp, Crossroad and Turnout Pavement Condition
5. Ride Quality
6. Embankment Slopes and Guard Rail Height
7. Need for Shoulder Build-up
8. Curb Heights and Overlay Build-up in Gutter

## 1.4 Geotechnical Information

A geotechnical report is generally prepared for any paving project which involves earthwork or other subgrade preparation including new construction, reconstruction, or widening. Pavement rehabilitation projects with evidence of subgrade problems may also require a geotechnical report. The geotechnical report is prepared by or under the direction of ADOT's Geotechnical Services. The geotechnical report is required to summarize and document the geotechnical information obtained on a project, and to provide geotechnical related recommendations. This information is used during the pavement design process and for completing the geotechnical portion of the Materials Design Report. For new construction, reconstruction, and widening projects, the geotechnical report should contain the following information:

1. Subgrade Tabulations – Subgrade tabulations should consist of test hole locations, sample depths, sample depths relative to finished subgrade elevation, and test results relevant to the material's ability to support a pavement structure (i.e. AASHTO and Unified Soil Classification, Plasticity Index, percent passing the #200 sieve, tested and/or correlated R-values, etc.). See Section 1.7 for additional guidance.
2. Design and Construction Control R-values – Recommended values for the design R-value and construction control R-value. See Subsection 2.1.5 for additional guidance.
3. Subgrade Improvements – Recommendations for improving poor quality subgrade. Recommendations should include the top 3 feet of finished subgrade as well as any deeper problematic soils. Examples of deeper problematic soils include collapsible silts and sands, and soft, saturated clays.
4. Earthwork Factors – Recommended values for soil and rock shrink/swell factors for roadway excavation, and ground compaction values under embankments.
5. Slope Rates – Recommended values for cut and fill slope rates.
6. Corrosion Potential for Soils – Results of pH and resistivity testing.
7. Water Requirements – Recommended values for water requirements to compact subgrade and base materials, including losses due to seepage, evaporation, inadequate mixing, spillage, etc.
8. Other – Other geotechnical concerns or recommendations relevant to the design, construction, or service life of the pavement (i.e. poor drainage, landslides, etc.).

The Pavement Design Engineer should contact ADOT's Geotechnical Services for additional information regarding geotechnical investigations and reports.

## 1.5 Traffic Analysis

The calculation of the estimated cumulative number of 18-Kip equivalent single axle loads (ESAL's) for a design (or performance) period is performed in accordance with Appendix A of this manual for all ADOT projects. The calculations are typically performed using traffic data provided by ADOT's Multimodal Planning Division (MPD).

## 1.6 Preliminary Plans

The preliminary plans show the typical sections and geometrics of the proposed roadway. In addition to the major roadway, pavement designs should be provided for all ramps, crossroads, frontage roads, access roads, roadside rest areas, and ports of entry. Provisions should also be made where applicable for detours, turnouts, median paving, and other incidental work called for on the plans.

## 1.7 Subgrade Support Considerations – New Construction, Reconstruction and Widening

The performance of a pavement structure is directly related to the properties and condition of the roadbed soils. The design procedures in this manual are based on the assumption that most soils can be adequately represented for pavement design purposes by mean values of the soil's resilient modulus ($M_R$), for flexible pavements, or the modulus of subgrade reaction (k), for rigid pavements. However, certain soils such as those that are excessively expansive, resilient, frost susceptible, or highly organic may require that remedial steps be taken to provide adequate support for the pavement section.

### *1.7.1 Subgrade Tabulations*

The subgrade tabulations are part of the geotechnical report and consist of test hole locations, sample depths, sample depths relative to finished subgrade elevation, and test results relevant to the material's ability to support a pavement structure (i.e. AASHTO and Unified Soil Classification, Plasticity Index, percent passing the #200 sieve, tested and/or correlated R-values, etc.).

The subgrade tabulations should be studied carefully with the preliminary construction profile to determine the design controls for each pavement structure. Only that material which is expected to be placed within the top 3 feet of finished subgrade elevation should be included in the statistical analysis of R-values. At the time the pavement structure is designed, there is usually no earthwork computation available, therefore judgement should be exercised in determining the length of each pavement design section. Typically, a uniform pavement structural section is advisable throughout the limits of the project if possible.

Often it is difficult to anticipate what the material quality will be within the top 3 feet of finished subgrade. This is particularly true on projects with large cuts and fills together with variable quality materials. Projects with subgrade material coming from various sources (e.g. existing in-place material, roadway excavation, borrow) may also be difficult to analyze. In these situations, it is beneficial to develop a soil profile to help visualize the material quality along the length of a project and to help anticipate what materials are likely to end up within the top 3 feet of finished subgrade. A soil profile is prepared by plotting pertinent data on a copy of the roadway profile. The soil profile should show the existing and proposed ground line, the location of the test holes (including station and offset), their depth, and test data relevant to the understanding of the subgrade strength (i.e. Soil Classification, Plasticity Index, percent passing the #200 sieve, tested and/or correlated R-values, etc.).

See Subsection 2.1.5 for additional information on determining the subgrade strength value for design.

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. Often, the removed material may be placed in embankment sections a minimum of 3 feet below finished subgrade elevation.

In the analysis of the subgrade, careful consideration should be given to areas where test results indicate conditions that might generate problems in construction and performance of the pavement structure. Such conditions may include, but not necessarily be limited to, low R-values, high plasticity, high percentage passing the #200 sieve, expansive clays, high moisture content, frost susceptibility, settlement, collapsible soil, etc. Each such condition should be examined and engineering judgement applied to determine what should be recommended in the pavement design report to remedy such problems.

Other problems related to roadbed soils are the non-uniform support that results from wide variations in soil type or condition, the additional densification under traffic of soils that are not adequately compacted during construction, and construction difficulties, particularly those associated with compaction of cohesionless sands and wet, highly plastic clays.

With these problems in mind, the following adverse conditions listed below should be considered in design. It should be noted that the solutions given for each condition are not the only answer and each problem area should be studied on an individual basis. Appropriate statements of recognition of the problems and solutions should be included in the Materials Design Package.

1. Soils that are excessively expansive should receive special consideration. Generally, expansive soils have high plasticity indices, high percentage 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 depth of selected material to overcome the detrimental effects of expansion. Expansion may often be reduced by tight control of the compaction water content. In some cases, it may be more economical to treat expansive soils by stabilizing with suitable admixture, such as lime or cement, to over excavate and replace the material, or to encase a substantial thickness in a waterproof membrane to stabilize the water content. Also, widening and deepening the cut ditches and providing the shoulder slopes with a membrane may help to stabilize the roadway section.

2. Low shear strength soils generally are those soils that have low R-values (less than 20). Although these soils can sometimes be compensated for by increasing the structural thickness, it may be more economical in the long term to treat them with a suitable admixture such as lime or cement. In some cases geosynthetics, such as geogrid, may be appropriate. Additionally, the shear strength may be improved by blending with a granular soil. If the low shear strength soil is in limited areas, it may be most economically treated by over-excavating and replacing with a suitable material.

3. In areas with a freezing index, the pavement design should include an analysis of the effects of frost in addition to the analysis for traffic loadings. A complete explanation of the design procedures for frost conditions is contained in Appendix B.

4. Problems with highly organic soils are related to their highly compressible nature, and are accentuated when deposits are extremely non-uniform in properties or depth. Local deposits, or those of relatively shallow depth, may be more economically excavated and replaced with suitable material. Problems associated with deeper and more extensive deposits may be

alleviated by placing surcharge embankments for preconsolidation, sometimes with special provisions for rapid removal of water to hasten consolidation (e.g. wick drains).

5. Special provisions for unusually variable soil types and conditions may include:
    a. Scarifying and recompacting
    b. Treatment of an upper layer of roadbed soils with a suitable admixture
    c. Using appreciable depths of more suitable roadbed soils
    d. Overexcavating cut sections and placing a uniform layer of selected material in both cut and fill areas
    e. Adjusting the thickness of subbase at transitions from one soil type to another, particularly when the transition is from a cut to a fill section
    f. Using a geogrid and/or separation geotextile fabric

6. 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 the 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 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.

7. Certain roadbed soils can pose difficult problems during construction. These are primarily the cohesionless soils and wet clays. Unconfined, cohesionless soils may readily displace under equipment used to construct the pavement. Clay soils cannot be compacted at high water contents because of displacement under equipment and require long periods of time to dry to a suitable water content. Measures that may be used to alleviate such construction problems include blending these problem materials with other soils or admixtures to improve their performance, covering with a layer of more suitable material to act as a working platform for construction of the pavement, or use of a geogrid and/or separation geotextile fabric to provide additional stability.

### *1.7.2 Borrow*

Most projects will not have a Department designated borrow source and it will be the contractor’s responsibility to procure any needed material. In most cases the Pavement Design Engineer will establish borrow quality requirements to meet or exceed the design R-value calculated from relevant data provided in the subgrade tabulation. Consideration should also be given to the quality of borrow material available within a reasonable haul distance from the project site. The quality specified for borrow will correspond to a R-value of 20 or greater. When borrow is required on a project, a borrow control item will need to be included in the Materials Design Report to ensure the minimum requirement is met by the contractor.

#### *1.7.3 Other Considerations*

As mentioned in Section 1.4, the geotechnical report includes recommendations for both design and construction control R-values, as well as recommendations to address problem soils. These recommendations and their supporting data should be reviewed by the Pavement Design Engineer to ensure they are in agreement prior to proceeding with the pavement design. The Pavement Design Engineer should also review previous Materials Design Packages for the roadway segment in question as well as adjacent segments to ensure geotechnical recommendations are reasonable and consistent with what has worked successfully in the past.

### 1.8 Pavement Coring

Pavement coring is one of the best ways to accurately determine the in-place design of a highway. Coring also provides the only practical way to visually assess the materials that make up the existing pavement section. A thorough understanding of each layer, including the material type, thickness, and condition, is necessary to perform a meaningful pavement analysis. Pavement cores are also used to better understand pavement distresses, including the severity and depth of cracks in the pavement.

Pavement cores can also help the Pavement Design Engineer to better understand the performance of a given pavement section. Cores allow the engineer to qualitatively assess the moisture sensitivity of a material as well as the bond strength between pavement layers. For example, moisture sensitivity will often lead to stripping in one or more layers. The location and extent of any stripping is critical in selecting an appropriate rehabilitation strategy. Without this knowledge, a milling depth may be proposed that is not sufficient to remove the moisture damaged material. Or, milling may terminate within a stripped layer resulting in an incompetent surface to pave on. Partial removal of a stripped layer may also cause difficulty during construction if large chunks of the weaker materials are dislodged by the milling teeth.

Pavement coring should be performed for all pavement rehabilitation and widening projects. In addition, coring should also be performed for pavement reconstruction projects to determine the type and thickness of materials to be removed, as well as the type, thickness, and quality of any materials to remain (including subgrade). Where pavement thickness and condition are relatively uniform, the minimum coring frequency is one core per ½-mile. Shorter intervals should be used when the condition is more diverse. The minimum core diameter is four inches.

Cores should be obtained from both competent and distressed pavement areas. Cores from distressed areas include those taken over cracks to determine the severity and depth of cracking. The number of cores taken at competent vs. distressed areas will vary by project. However, it is generally recommended that 1/3 of the cores be taken from distressed areas.

For projects involving pavement rehabilitation, it is strongly recommended that the Pavement Design Engineer be present during the coring operation. This allows the engineer to perform a detailed on-site core analysis as the cores are extracted from the pavement, and provides an opportunity to make minor adjustments to the core locations as a result of real-time findings. Being on-site during the coring operation also provides the engineer with a deeper understanding of the subsurface condition of the pavement which is critical in selecting an appropriate rehabilitation strategy.

For all coring operations, a log should be prepared to record relevant details about each core (i.e. sample #, location, layer type, thickness and condition, etc.), and the pavement condition where each core was taken. Photographs should be taken of each core and core location, and should be retained with the project records. Cores should be tagged with sample cards and carefully transported and stored until construction has been completed.

## 2.0 NEW PAVEMENT DESIGN

The Arizona Department of Transportation has adopted the *1993 AASHTO Guide for Design of Pavement Structures* for new construction of both flexible and rigid pavements. The reader is advised to obtain a copy of it for additional background material. ADOT's Pavement Design Manual presents how the AASHTO Guide will be applied for the Arizona Department of Transportation. Thus, much of what is presented here will be ADOT's modifications and conventions necessary to obtain designs that will perform as well or better than the AASHTO Guide and with greater reliability. In addition criteria are presented to facilitate the use of new materials and concepts consistent with construction control practices and pavement management policies. In general the Pavement Design Engineer should have opportunity to try different designs, with the goal of obtaining the most cost effective design. The design period for new flexible and rigid pavements is generally 20 years. Many of the following concepts can be applied to both flexible and rigid pavements; however, in keeping with the AASHTO Guide, flexible pavement will be discussed first.

### 2.1 Flexible Pavement Design

The basic design equation used for flexible pavements is as follows:

$$log_{10}(W_{18}) = Z_R S_O + 9.36 log_{10}(SN+1) - 0.20 + \left\{ \frac{log_{10}\left[\frac{\Delta PSI}{4.2-1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} \right\} + 2.32 log_{10}(M_R) - 8.07$$

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 |
| $\Delta PSI$ | = | $P_o - P_t$ |
| $P_o$ | = | initial serviceability index |
| $P_t$ | = | terminal serviceability index |
| $M_R$ | = | resilient modulus (psi) |
| $SN$ | = | structural number indicative of the total pavement section required |

Once the $SN$ is determined from the above equation, pavement layer thicknesses are established such that:

$$SN \leq a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3$$

Where:

$a_i$ = i$^{th}$ layer coefficient,

$D_i$ = i$^{th}$ layer thickness (inches) and

$m_i$ = i$^{th}$ layer drainage coefficient.

### *2.1.1 18-kip Equivalent Single Axle Loads ($W_{18}$)*

The calculation of the estimated cumulative number of 18-Kip equivalent single axle loads (ESAL's) for a design (or performance) period is performed in accordance with Appendix A for all ADOT projects. The calculation of the estimated ESAL is based on:

1. Average Annual Daily Traffic (AADT) Volume
2. Volume of Single-Unit and Combination Unit Trucks
3. Growth Rate of Traffic
4. Vehicle Class Distribution (VCD)
5. Truck Load Factors (or ESAL Equivalency Factors)
6. Directional and Lane Distribution Factors

The first three items listed above are typically obtained from ADOT's MPD for state highway project design. Local Governments will typically furnish the traffic information for their projects.

A detailed explanation of the assumptions, equations, and calculations for the determination of the traffic loading used for pavement design is given in Appendix A.

### *2.1.2 Standard Normal Deviate ($Z_R$)*

The standard normal deviate is a measure of how likely a pavement is to fail within the design period. If a $Z_R$ of -2.327 is selected, there is only one chance in a hundred that the pavement will fail during its design period. Conversely, there is a 99 percent chance a pavement will not fail within the design period, which can be called the level of reliability. Table 2-1 gives the level of reliability in percent, as well as the $Z_R$ values, that should be used for design.

### *2.1.3 Combined Standard Error ($S_0$)*

ADOT uses a combined standard error of 0.45 for flexible pavements.

**Table 2-1 Reliability and $Z_R$ Values**

| Roadway Type - Volume | Level of Reliability | $Z_R$ |
|---|---|---|
| Divided Highways, Freeways & Interstates | 99% | -2.327 |
| Non-Divided, Non-Interstate Highways, 10,000+ ADT | 95% | -1.645 |
| 2,001 – 10,000 ADT | 90% | -1.282 |
| 501 – 2,000 ADT | 85% | -1.037 |
| ≤ 500 ADT | 75% | -0.674 |

### *2.1.4 Change in Present Serviceability Index ($\Delta PSI$)*

Over the design period there will be a loss in the serviceability index. Arizona's pavement management data base indicates that this change is a function of roadway type as shown in Table 2-2.

**Table 2-2 Serviceability Index**

| Roadway Type - Volume | $P_o$ | $P_t$ | $\Delta PSI$ |
|---|---|---|---|
| Divided Highways, Freeways & Interstates | 4.2 | 3.0 | 1.2 |
| Non-Divided, Non-Interstate Highways, 10,000+ ADT | 4.2 | 2.8 | 1.4 |
| 2,001 – 10,000 ADT | 4.1 | 2.6 | 1.5 |
| 501 – 2,000 ADT | 4.1 | 2.6 | 1.5 |
| ≤ 500 ADT | 4.0 | 2.4 | 1.6 |

### *2.1.5 Resilient Modulus of Subgrade ($M_R$)*

For flexible pavement design, the primary soil strength measure used by ADOT is the resilient modulus, $M_R$, as determined thru R-value analysis. Due to the amount of time and expense of the R-value sampling and testing process, a method of estimating R-values and hence, $M_R$ values, from other more common tests has been developed.

#### 2.1.5.1 Correlated R-value ($R_C$)

Extensive regression and correlation analyses have been performed to develop a relationship between a material's R-value, and its gradation, plasticity index, liquid limit, and sand equivalent. Of the many candidate equations and relationships considered, the best workable relationship was found to be between a material's R-value, and its gradation and plasticity index. The equation is as follows:

$$log\ R_c\text{-}value\ at\ 300\ psi\ =\ 2.0 - 0.006(Pass\ \#200) - 0.017(PI)$$

Where:

$R_c$ = correlated R-value

$Pass\ \#200$ = percentage of material passing the #200 sieve

$PI$ = plasticity index

A soil strength correlation table has been developed to simplify the solution to the mathematical relationships developed between R-value, plasticity index and percent pass #200 sieve (Table 2-3). For example, given a PI of 12 and a percentage pass the #200 sieve of 39, Table 2-3 produces a correlated R-value of 36.

For design purposes, the design R-value should be determined from the correlated R-value ($R_c$) results (from PI and 200's) as well as from the tested R-value ($R_t$) results (AASHTO T 190).

All soil samples delivered to the testing laboratory should be accompanied by a field log and work instructions. In general, all samples will be tested for gradation (coarse screen and fine screen/elutriation) and plasticity index. Additionally, tests such as R-value, density, pH and resistivity, etc., will be performed as instructed. Samples to run actual R-values should be selected to ensure the full range of likely subgrade soil types and strengths are represented by both tested and correlated R-values. Additionally, those subgrade soil types which are expected to make up the majority of the top 3 feet of finished subgrade should have the largest representation of tested R-values.

At the discretion of the Pavement Design Section, tested R-values may be omitted (or testing frequencies reduced) on projects where the lowest correlated R-value is greater than 65. This should only occur when it has been determined that a higher R-value will not significantly change the pavement design, and for materials where correlated R-values are believed to accurately represent tested R-values. When tested R-values are omitted, the design will be based on the correlated R-values only.

## Table 2-3 Correlated R-value at 300psi. Exudation Pressure ($R_C$)

Percent Passing #200 Sieve

| PI | 0 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 | 33 | 36 | 39 | 42 | 45 | 48 | 51 | 54 | 57 | 60 | 63 | 66 | 69 | 72 | 75 | 78 | 81 | 84 | 87 | 90 | 93 | 96 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 100 | 96 | 92 | 88 | 85 | 81 | 78 | 75 | 72 | 69 | 66 | 63 | 61 | 58 | 56 | 54 | 52 | 49 | 47 | 45 | 44 | 42 | 40 | 39 | 37 | 35 | 34 | 33 | 31 | 30 | 29 | 28 | 27 |
| 1 | 96 | 92 | 89 | 85 | 81 | 78 | 75 | 72 | 69 | 66 | 64 | 61 | 58 | 56 | 54 | 52 | 50 | 48 | 46 | 44 | 42 | 40 | 39 | 37 | 36 | 34 | 33 | 31 | 30 | 29 | 28 | 27 | 26 |
| 2 | 92 | 89 | 85 | 82 | 78 | 75 | 72 | 69 | 66 | 64 | 61 | 59 | 56 | 54 | 52 | 50 | 48 | 46 | 44 | 42 | 40 | 39 | 37 | 36 | 34 | 33 | 31 | 30 | 29 | 28 | 27 | 26 | 25 |
| 3 | 89 | 85 | 82 | 79 | 75 | 72 | 69 | 67 | 64 | 61 | 59 | 56 | 54 | 52 | 50 | 48 | 46 | 44 | 42 | 40 | 39 | 37 | 36 | 34 | 33 | 32 | 30 | 29 | 28 | 27 | 26 | 25 | 24 |
| 4 | 86 | 82 | 79 | 76 | 72 | 70 | 67 | 64 | 61 | 59 | 56 | 54 | 52 | 50 | 48 | 46 | 44 | 42 | 41 | 39 | 37 | 36 | 34 | 33 | 32 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 |
| 5 | 82 | 79 | 76 | 73 | 70 | 67 | 64 | 62 | 59 | 57 | 54 | 52 | 50 | 48 | 46 | 44 | 42 | 41 | 39 | 37 | 36 | 34 | 33 | 32 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 |
| 6 | 79 | 76 | 73 | 70 | 67 | 64 | 62 | 59 | 57 | 54 | 52 | 50 | 48 | 46 | 44 | 42 | 41 | 39 | 37 | 36 | 35 | 33 | 32 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 |
| 7 | 76 | 73 | 70 | 67 | 64 | 62 | 59 | 57 | 55 | 52 | 50 | 48 | 46 | 44 | 43 | 41 | 39 | 38 | 36 | 35 | 33 | 32 | 31 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 |
| 8 | 73 | 70 | 67 | 65 | 62 | 59 | 57 | 55 | 52 | 50 | 48 | 46 | 44 | 43 | 41 | 39 | 38 | 36 | 35 | 33 | 32 | 31 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 |
| 9 | 70 | 67 | 65 | 62 | 60 | 57 | 55 | 53 | 50 | 48 | 46 | 45 | 43 | 41 | 39 | 38 | 36 | 35 | 33 | 32 | 31 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 19 |
| 10 | 68 | 65 | 62 | 60 | 57 | 55 | 53 | 51 | 49 | 47 | 45 | 43 | 41 | 39 | 38 | 36 | 35 | 33 | 32 | 31 | 30 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 19 | 18 |
| 11 | 65 | 62 | 60 | 57 | 55 | 53 | 51 | 49 | 47 | 45 | 43 | 41 | 40 | 38 | 36 | 35 | 33 | 32 | 31 | 30 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 20 | 19 | 18 | 17 |
| 12 | 63 | 60 | 58 | 55 | 53 | 51 | 49 | 47 | 45 | 43 | 41 | 40 | 38 | 36 | 35 | 34 | 32 | 31 | 30 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 20 | 19 | 18 | 17 | 17 |
| 13 | 60 | 58 | 55 | 53 | 51 | 49 | 47 | 45 | 43 | 41 | 40 | 38 | 37 | 35 | 34 | 32 | 31 | 30 | 29 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 20 | 19 | 18 | 17 | 17 | 16 |
| 14 | 58 | 55 | 53 | 51 | 49 | 47 | 45 | 43 | 41 | 40 | 38 | 37 | 35 | 34 | 32 | 31 | 30 | 29 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 21 | 20 | 19 | 18 | 17 | 17 | 16 | 15 |
| 15 | 56 | 53 | 51 | 49 | 47 | 45 | 43 | 42 | 40 | 38 | 37 | 35 | 34 | 32 | 31 | 30 | 29 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 21 | 20 | 19 | 18 | 17 | 17 | 16 | 15 | 15 |
| 16 | 53 | 51 | 49 | 47 | 45 | 43 | 42 | 40 | 38 | 37 | 35 | 34 | 33 | 31 | 30 | 29 | 28 | 26 | 25 | 24 | 23 | 22 | 21 | 21 | 20 | 19 | 18 | 17 | 17 | 16 | 15 | 15 | 14 |
| 17 | 51 | 49 | 47 | 45 | 44 | 42 | 40 | 38 | 37 | 35 | 34 | 33 | 31 | 30 | 29 | 28 | 26 | 25 | 24 | 23 | 22 | 22 | 21 | 20 | 19 | 18 | 17 | 17 | 16 | 15 | 15 | 14 | 14 |
| 18 | 49 | 47 | 45 | 44 | 42 | 40 | 39 | 37 | 35 | 34 | 33 | 31 | 30 | 29 | 28 | 27 | 25 | 24 | 23 | 22 | 22 | 21 | 20 | 19 | 18 | 18 | 17 | 16 | 15 | 15 | 14 | 14 | 13 |
| 19 | 48 | 46 | 44 | 42 | 40 | 39 | 37 | 36 | 34 | 33 | 31 | 30 | 29 | 28 | 27 | 26 | 24 | 23 | 23 | 22 | 21 | 20 | 19 | 18 | 18 | 17 | 16 | 16 | 15 | 14 | 14 | 13 | 13 |
| 20 | 46 | 44 | 42 | 40 | 39 | 37 | 36 | 34 | 33 | 31 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 18 | 17 | 16 | 16 | 15 | 14 | 14 | 13 | 13 | 12 |
| 21 | 44 | 42 | 40 | 39 | 37 | 36 | 34 | 33 | 32 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 18 | 17 | 16 | 16 | 15 | 14 | 14 | 13 | 13 | 12 | 12 |
| 22 | 42 | 41 | 39 | 37 | 36 | 34 | 33 | 32 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 18 | 17 | 16 | 16 | 15 | 14 | 14 | 13 | 13 | 12 | 12 | 11 |
| 23 | 41 | 39 | 37 | 36 | 34 | 33 | 32 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 18 | 18 | 17 | 16 | 16 | 15 | 14 | 14 | 13 | 13 | 12 | 12 | 11 | 11 |
| 24 | 39 | 37 | 36 | 35 | 33 | 32 | 30 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 19 | 18 | 17 | 16 | 16 | 15 | 14 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 |
| 25 | 38 | 36 | 35 | 33 | 32 | 31 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 19 | 18 | 17 | 16 | 16 | 15 | 14 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 |
| 26 | 36 | 35 | 33 | 32 | 31 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 19 | 18 | 17 | 16 | 16 | 15 | 15 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 | 10 |
| 27 | 35 | 33 | 32 | 31 | 29 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 19 | 18 | 17 | 16 | 16 | 15 | 15 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 | 10 | 9 |
| 28 | 33 | 32 | 31 | 30 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 19 | 19 | 18 | 17 | 17 | 16 | 15 | 15 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 | 10 | 9 | 9 |
| 29 | 32 | 31 | 30 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 20 | 19 | 18 | 17 | 17 | 16 | 15 | 15 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 | 10 | 9 | 9 | 9 |
| 30 | 31 | 30 | 28 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 20 | 19 | 18 | 17 | 17 | 16 | 15 | 15 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 11 | 10 | 10 | 9 | 9 | 9 | 8 |
| 31 | 30 | 29 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 20 | 20 | 19 | 18 | 17 | 17 | 16 | 15 | 15 | 14 | 14 | 13 | 12 | 12 | 11 | 11 | 11 | 10 | 10 | 9 | 9 | 9 | 8 | 8 |
| 32 | 29 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 21 | 20 | 19 | 18 | 17 | 17 | 16 | 15 | 15 | 14 | 14 | 13 | 12 | 12 | 11 | 11 | 11 | 10 | 10 | 9 | 9 | 9 | 8 | 8 | 8 |
| 33 | 27 | 26 | 25 | 24 | 23 | 22 | 21 | 21 | 20 | 19 | 18 | 17 | 17 | 16 | 15 | 15 | 14 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 | 9 | 9 | 9 | 8 | 8 | 8 | 7 |
| 34 | 26 | 25 | 24 | 23 | 22 | 21 | 21 | 20 | 19 | 18 | 17 | 17 | 16 | 15 | 15 | 14 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 |
| 35 | 25 | 24 | 23 | 22 | 22 | 21 | 20 | 19 | 18 | 17 | 17 | 16 | 15 | 15 | 14 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 |
| 36 | 24 | 23 | 22 | 22 | 21 | 20 | 19 | 18 | 18 | 17 | 16 | 15 | 15 | 14 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 6 |
| 37 | 23 | 23 | 22 | 21 | 20 | 19 | 18 | 18 | 17 | 16 | 16 | 15 | 14 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 7 | 6 |
| 38 | 23 | 22 | 21 | 20 | 19 | 18 | 18 | 17 | 16 | 16 | 15 | 14 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 7 | 6 | 6 |
| 39 | 22 | 21 | 20 | 19 | 18 | 18 | 17 | 16 | 16 | 15 | 14 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 7 | 6 | 6 | 6 |
| 40 | 21 | 20 | 19 | 18 | 18 | 17 | 16 | 16 | 15 | 14 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 | 10 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 7 | 6 | 6 | 6 | 6 |
| 42 | 19 | 19 | 18 | 17 | 16 | 16 | 15 | 14 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 | 10 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 7 | 6 | 6 | 6 | 6 | 5 | 5 |
| 44 | 18 | 17 | 16 | 16 | 15 | 15 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 | 10 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 7 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 |
| 46 | 17 | 16 | 15 | 15 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 | 10 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 5 | 4 |
| 48 | 15 | 15 | 14 | 13 | 13 | 12 | 12 | 11 | 11 | 11 | 10 | 10 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 |
| 50 | 14 | 14 | 13 | 12 | 12 | 11 | 11 | 11 | 10 | 10 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 |
| 52 | 13 | 13 | 12 | 12 | 11 | 11 | 10 | 10 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 3 |
| 54 | 12 | 12 | 11 | 11 | 10 | 10 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 |
| 56 | 11 | 11 | 10 | 10 | 9 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 7 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 |
| 58 | 10 | 10 | 10 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 7 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 |
| 60 | 10 | 9 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 7 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 |
| 62 | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 7 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 |
| 64 | 8 | 8 | 8 | 7 | 7 | 7 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 |
| 66 | 8 | 7 | 7 | 7 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 |
| 68 | 7 | 7 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 70 | 6 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 72 | 6 | 6 | 5 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 |
| 74 | 6 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 |
| 76 | 5 | 5 | 5 | 5 | 4 | 4 | 4 | 4 | 4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 1 | 1 | 1 |

### 2.1.5.2 Mean R-Value ($R_{mean}$)

The Mean R-value ($R_{mean}$) is determined by analysis of soils that will make up the top 3 feet of subgrade. Test results from soils that will not be part of the 3 feet immediately below finished subgrade elevation should not be included in this analysis. If Department furnished borrow will be used, the subgrade support of the borrow will either need to be incorporated into the analysis or analyzed separately.

The following items should be considered when calculating the Mean R-value. Section 1.7 should also be consulted for additional guidance.

1. What soil types will make up the finished subgrade?
2. Will the subgrade consist of in-place material, roadway excavation or borrow?
3. If subgrade will consist of roadway excavation or borrow, to what limits will the material be placed?
4. What types of material (Soil Classification) are in the cuts?
5. What is the approximate volume of each material type?
6. Where is each material type located within the cuts (at grade, horizontal stratum, etc.)?
7. What is the length and depth of the fill areas adjacent to the cuts?
8. What is the feasibility of stabilizing (lime and cement) soils with a low R-value (less than 20)? Such stabilized layers will be characterized by a structural coefficient based upon strength.
9. What is the feasibility of controlling the placement of excavation?
   a. Specify station limits for hauling excavation.
   b. Specify that the material will not be used within 3 feet of finished subgrade elevation.
10. What is the feasibility of using a geogrid as a base reinforcement to compensate for low R-value soils? A geogrid should only be used when soils have an R-value between 10 and 19. For purposes of design, the Mean R-value should be increased by 10 when a geogrid is used.
11. What is the feasibility of using low strength material in a place where the soil strength is not critical (e.g., dike construction, slope plating, lower level of fills)? Wasting poor material should also be considered.
12. What is the feasibility of over excavation (especially at grade-in and grade-out points) and replacement with a better material?

Both correlated and tested R-values should be incorporated into the analysis. The averages of the $R_c$ and $R_t$ values are determined separately and combined using the following formula to arrive at the Mean R-value:

$$R_{mean} = \frac{N_t \overline{R_t} \sigma_c^2 + N_c \overline{R_c} \sigma_t^2}{N_t \sigma_c^2 + N_c \sigma_t^2}$$

Where:

$N_t$ = number of tested R-values

$N_c$ = number of correlated R-values (from PI & 200)

$\overline{R_t}$ = average of the tested R-values

$\overline{R_c}$ = average of the correlated R-values

$\sigma_t$ = standard deviation of the tested R-values

$\sigma_c$ = standard deviation of the correlated R-values

If the tested and/or correlated R-values indicate a significant change in the quality of subgrade along the length of the project, the Pavement Design Engineer should consider designing more than one pavement structural section. When recommending more than one section, consideration needs to be given to both the cost savings as well as the decrease in construction efficiency that will result from building multiple sections.

When the standard deviation of the tested and/or correlated R-values is greater than 10, the respective average R-value(s) should be reduced by a value equal to the standard deviation minus 10. No adjustment should be made when the standard deviation is less than or equal to 10. For example,

Let: $N_t$ = 16 $N_c$ = 57
$\overline{R_t}$ = 27.6 $\overline{R_c}$ = 36.8
$\sigma_t$ = 13.7 $\sigma_c$ = 9.2

Then: Adjusted $\overline{R_t}$ = 27.6 – (13.7 – 10) = 23.9 No adjustment made to $\overline{R_c}$ since $\sigma_c \leq$ 10

In this case, the adjusted average of the tested R-value is used to determine $R_{mean}$:

$$R_{mean} = \frac{(16)(23.9)(9.2)^2 + (57)(36.8)(13.7)^2}{(16)(9.2)^2 + (57)(13.7)^2}$$

When the calculated $R_{mean}$ is less than 20, subgrade improvements should be recommended to improve the quality of the subgrade. Subgrade improvement should be made to the extent that a minimum $R_{mean}$ of 20 can be used for design.

On the basis of the calculated $R_{mean}$ and engineering judgement, the designer will select a design $R_{mean}$ (sometimes referred to as design R-value). Once the design $R_{mean}$ has been selected, it should be converted to a resilient modulus value, $M_R$ using the following equation:

$$M_R = \frac{1815 + 225(R_{mean}) + 2.40(R_{mean})^2}{0.6(SVF)^{0.6}}$$

Where:

$SVF$ = seasonal variation factor from Figure 2-1 or Table 2-4. Where apparent contradictions exist between the figure and table, the larger value should be used.

This $M_R$ value is used as the input value for the AASHTO Flexible Pavement design equation. The $M_R$ value is also used to determine the modulus of subgrade reaction (k) for input in the rigid pavement design equation. Figure 2-2 graphically presents the relationship between $M_R$, $SFV$, and $R_{mean}$. The design $M_R$ value for subgrade materials should not exceed 26,000 psi.

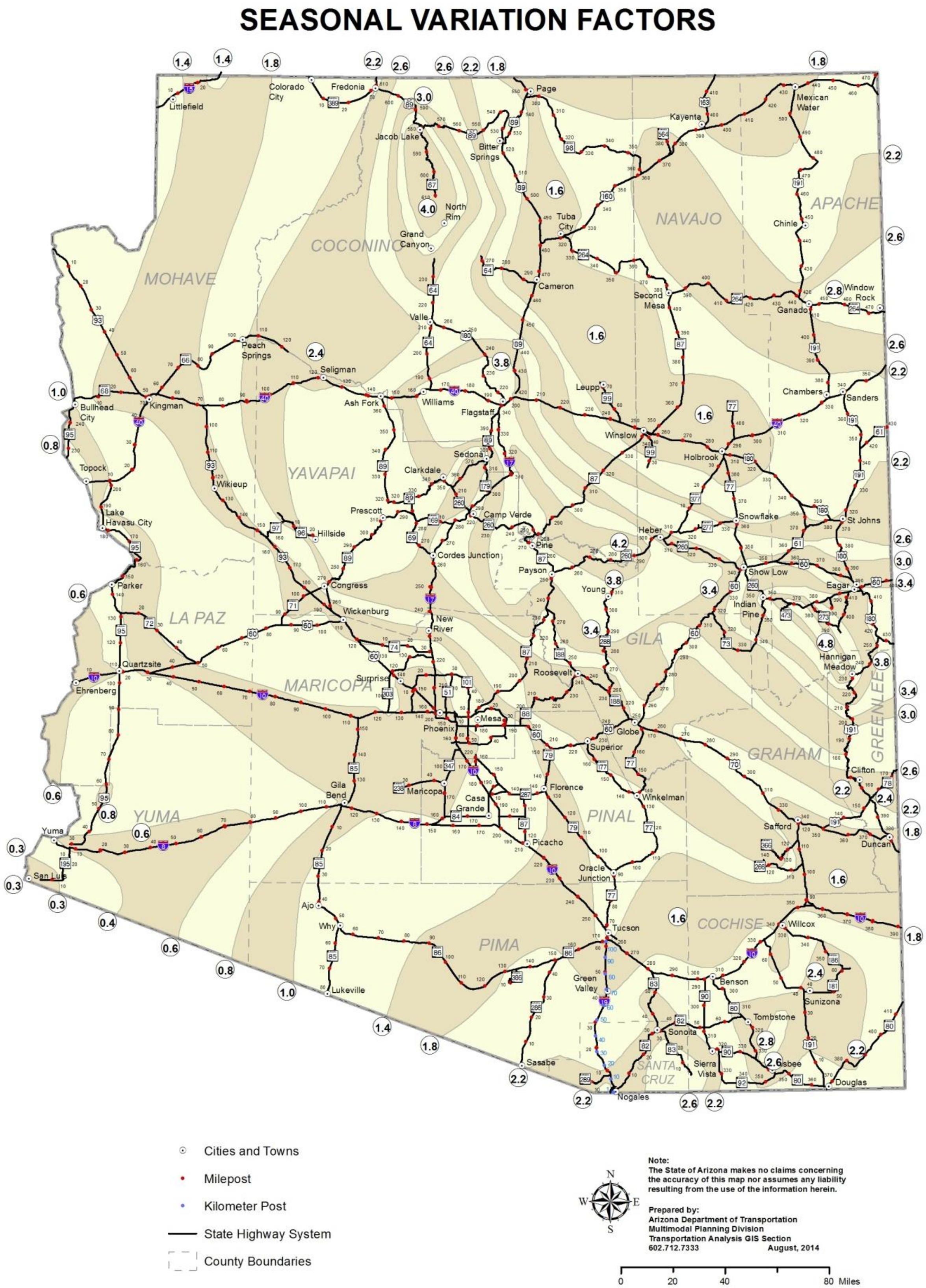



**Figure 2-1 Seasonal Variation Factors**

**Table 2-4 Seasonal Variation Factors (*SVF*)**

| Location | $SVF$ | Location | $SVF$ |
|---|---|---|---|
| Aguila | 1.1 | Fort Grant | 2.1 |
| Ajo | 1.2 | Fredonia | 1.9 |
| Alpine | 3.8 | Ganado | 2.6 |
| Apache Junction | 1.2 | Gila Bend | 0.8 |
| Ash Fork | 2.7 | Glendale | 1.0 |
| Avondale | 1.0 | Globe | 2.6 |
| Bagdad | 2.3 | Goodyear | 1.0 |
| Benson | 1.9 | Grand Canyon | 2.6 |
| Bisbee | 2.6 | Gray Mountain | 2.0 |
| Black Canyon City | 2.5 | Greer | 4.2 |
| Bonita | 2.1 | Heber | 3.1 |
| Bouse | 1.0 | Hillside | 2.6 |
| Bowie | 1.7 | Holbrook | 1.7 |
| Buckeye | 0.9 | Hoover Dam | 1.0 |
| Cameron | 1.5 | Hope | 1.0 |
| Camp Verde | 2.1 | Indian Pine | 4.1 |
| Carrizo | 3.3 | Jacob Lake | 3.1 |
| Casa Grande | 1.0 | Jakes Corner | 2.4 |
| Chandler | 1.0 | Jerome | 2.6 |
| Chinle | 2.1 | Joseph City | 1.7 |
| Chino Valley | 2.7 | Kayenta | 1.8 |
| Clarkdale | 2.3 | Keams Canyon | 2.4 |
| Clifton | 2.6 | Kearney | 2.1 |
| Clints Well | 4.1 | Kingman | 1.7 |
| Colorado City | 1.9 | Lake Havasu City | 0.5 |
| Concho | 2.2 | Leupp | 1.5 |
| Congress | 1.7 | Littlefield | 1.2 |
| Coolidge | 1.0 | Lukeville | 1.2 |
| Cordes Junction | 2.6 | Lupton | 2.2 |
| Cottonwood | 2.2 | Mammoth | 2.1 |
| Dewey | 2.7 | Marana | 1.6 |
| Dos Cabezas | 2.4 | Marble Canyon | 1.7 |
| Douglas | 1.9 | Mayer | 2.7 |
| Duncan | 1.7 | McNeil | 1.9 |
| Eager | 3.7 | Mesa | 1.0 |
| Ehrenberg | 0.5 | Mexican Water | 1.8 |
| Eloy | 1.1 | Miami | 2.8 |
| Flagstaff | 3.5 | Moenkopi | 1.7 |
| Florence | 1.3 | Mohawk | 0.5 |
| Florence Junction | 1.9 | Morenci | 2.6 |

**Table 2-4 Seasonal Variation Factors (*SVF*) (continued)**

| Location | $SVF$ | Location | $SVF$ |
|---|---|---|---|
| Morristown | 1.5 | Sells | 1.6 |
| New River | 1.5 | Seneca | 3.4 |
| Nogales | 2.3 | Sentinel | 0.6 |
| North Rim | 4.0 | Show Low | 3.4 |
| Oracle | 2.3 | Sierra Vista | 2.0 |
| Oracle Junction | 2.1 | Snowflake | 2.5 |
| Oraibi | 2.0 | Somerton | 0.3 |
| Overgaard | 3.3 | Sonoita | 2.1 |
| Page | 1.5 | Springerville | 3.7 |
| Parker | 0.5 | Strawberry | 4.1 |
| Patagonia | 2.5 | St. David | 2.1 |
| Payson | 3.5 | St. Johns | 2.1 |
| Peach Springs | 1.8 | Superior | 2.1 |
| Pearce | 1.9 | Taylor | 2.5 |
| Peoria | 1.0 | Teec Nos Pos | 2.1 |
| Phoenix | 1.0 | Tempe | 1.0 |
| Picacho | 1.3 | Thatcher | 1.6 |
| Pima | 1.6 | Tombstone | 2.2 |
| Pine | 3.9 | Tonalea | 1.9 |
| Pinedale | 3.1 | Tonopah | 1.0 |
| Prescott | 3.2 | Topock | 0.7 |
| Quartzsite | 0.6 | Tuba City | 1.7 |
| Quijota | 1.6 | Tubac | 2.0 |
| Robles Ranch | 1.8 | Tucson | 1.7 |
| Roosevelt | 2.3 | Valle | 2.6 |
| Round Rock | 1.9 | Wellton | 0.5 |
| Safford | 1.6 | Whiteriver | 3.6 |
| Salome | 1.0 | Why | 1.2 |
| San Carlos | 2.0 | Wickenburg | 1.5 |
| San Luis | 0.3 | Wide Ruins | 2.2 |
| San Manuel | 1.9 | Wikieup | 1.5 |
| San Simon | 1.6 | Willcox | 1.8 |
| Sanders | 2.0 | Williams | 3.3 |
| Sasabe | 2.2 | Winkelman | 2.1 |
| Scottsdale | 1.0 | Winslow | 1.7 |
| Seba Delkai | 1.8 | Yarnell | 3.1 |
| Second Mesa | 1.8 | Young | 3.4 |
| Sedona | 2.4 | Yucca | 1.2 |
| Seligman | 2.7 | Yuma | 0.4 |

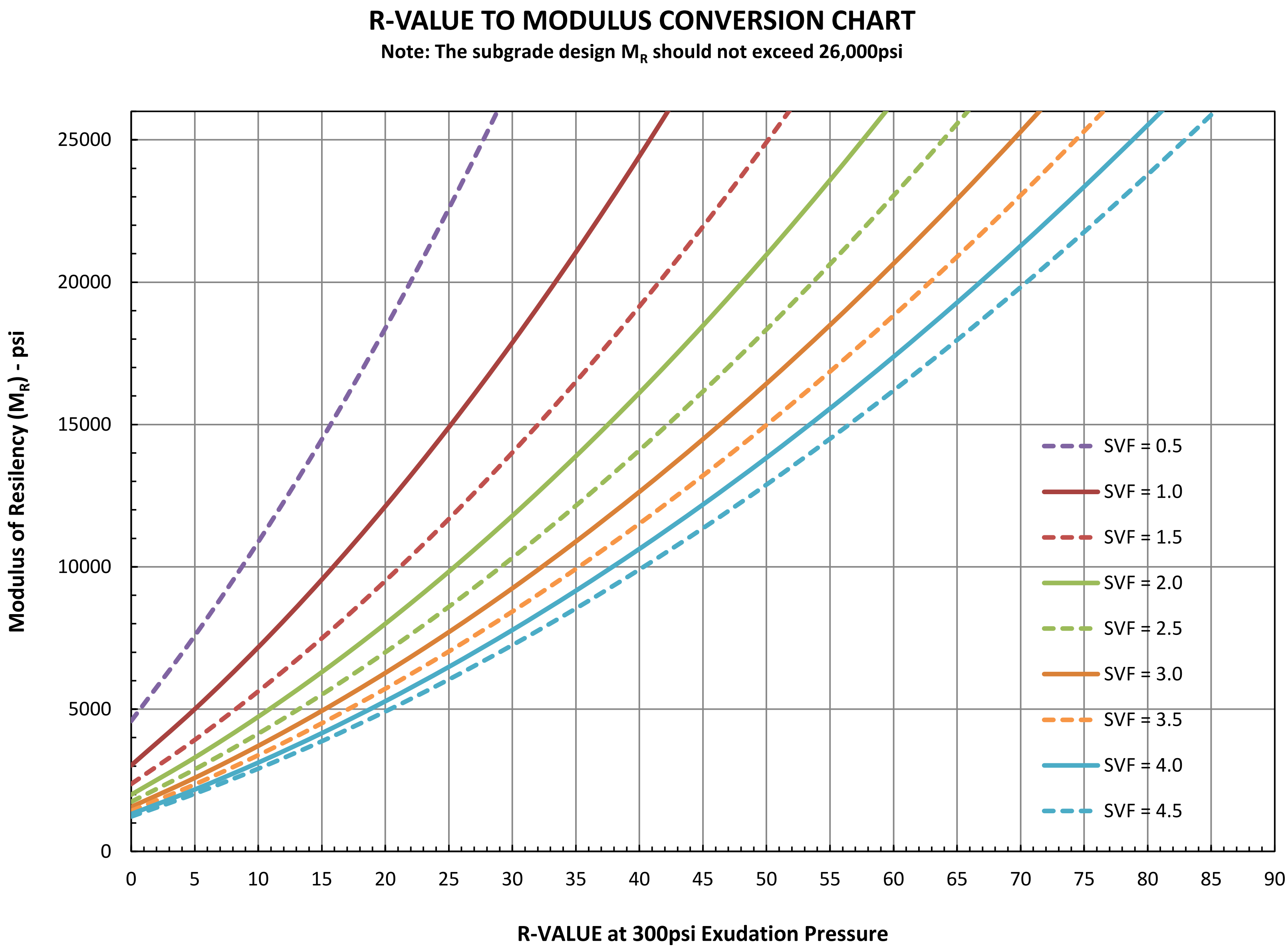



**Figure 2-2 R-value to Modulus Conversion Chart**

### 2.1.5.3 Construction Control R-Value ($Control\ R_C$)

The $Control\ R_c$ value is used as the basis for the subgrade acceptance chart, which is used during construction to determine the acceptability of finished subgrade soils. The $Control\ R_c$ is determined by analysis of soils that will make up the top 3 feet of subgrade (see Section 1.7). Test results from soils that will not be part of the 3 feet immediately below finished subgrade elevation should not be included in this analysis. For construction control, the minimum acceptable correlated R-value ($R_c$) should be determined as follows:

$$Control\ R_c = \overline{R_c} - (\sigma_c t_{90})$$

Where:

$\overline{R_c}$ = average of the correlated R-values (do not use adjusted value)(see Section 2.1.5.2)

$\sigma_c$ = standard deviation of the correlated R-values

$t_{90}$ = critical $t$ value at 90% confidence level (from Table 2-5)

**Table 2-5 Critical t Values**

| Degrees of Freedom (Number of Tests – 1) | 90% $t$ Value | Degrees of Freedom (Number of Tests – 1) | 90% $t$ Value |
|---|---|---|---|
| 2 | 1.886 | 19 | 1.328 |
| 3 | 1.638 | 20 | 1.325 |
| 4 | 1.533 | 21 | 1.323 |
| 5 | 1.476 | 22 | 1.321 |
| 6 | 1.440 | 23 | 1.319 |
| 7 | 1.415 | 24 | 1.318 |
| 8 | 1.397 | 25 | 1.316 |
| 9 | 1.383 | 26 | 1.315 |
| 10 | 1.372 | 27 | 1.314 |
| 11 | 1.363 | 28 | 1.313 |
| 12 | 1.356 | 29 | 1.311 |
| 13 | 1.350 | 30 | 1.310 |
| 14 | 1.345 | 40 | 1.303 |
| 15 | 1.341 | 60 | 1.296 |
| 16 | 1.337 | 120 | 1.289 |
| 17 | 1.333 | Over 120 | 1.282 |
| 18 | 1.330 | | |

Assuming the correlated R-values accurately represent the subgrade on a given project, the above equation should result in a $Control\ R_c$ value such that 90% of the subgrade will have a correlated R-value greater than or equal to the calculated $Control\ R_c$ value. However, on some projects (such as those with high variability or a low number of samples) the above equation may result in a nonrepresentative $Control\ R_c$. In this case, engineering judgment should be used to establish the $Control\ R_c$. In general, the $Control\ R_c$ established for a project should normally meet the following criteria:

1. It should be no less than 20 (no less than 10 if a geogrid is specified)
2. It should be less than or equal to the calculated $R_{mean}$
3. It should be no less than the design $R_{mean}$ minus 10 (minus 20 if a geogrid is specified)

In some cases, it may be more appropriate to lower the design $R_{mean}$ rather than increase the $Control\ R_c$ to meet criteria #3 above. This is particularly true in cases where increasing the $Control\ R_c$ will result in excessive quantities of subgrade material needing improvement, or removal and replacement, as a result of not meeting the subgrade acceptance chart.

### 2.1.6 Structural Number ($SN$)

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

### 2.1.7 Layer Coefficient ($a_i$)

Following the solution of the structural number, the layer coefficient is determined for each supporting layer. Table 2-6 provides maximum coefficients to be used for a variety of base and surfacing materials.

**Table 2-6 Structural Coefficients for Surfacing and Base Materials**

| Material Type | Layer Designation | Maximum Coefficient |
|---|---|---|
| Asphaltic Concrete (ADOT Section 409, 413, 415, 416 and 417 mixtures) | $a_1$ | .44 |
| Cold In-Place or Plant Recycling or Hot In-Place Recycling | $a_1$ | .28 |
| Cement Treated or Bituminous Treated Base | $a_2$ | .28 |
| Cement or Lime Treated Subgrade | $a_2$ | .23 |
| Aggregate Base | $a_2$ | .14 |
| Aggregate Subbase | $a_3$ | .11 |

Circumstances may exist that warrant the use of new materials and/or new variations of materials in such a way that normal coefficients may need to be checked. In addition to this, some materials may be substantially altered during construction to the extent that the structural coefficient may need to be changed. If the material in question is statistically controlled with a penalty schedule, then coefficient adjustment may not be necessary. With the above conditions in mind, Figures 2-3, 2-4 and 2-5 should be used to determine the coefficient in question.

Asphaltic Concrete (AC)

For AC mixes such as a 1/2" AC, 3/4" AC, recycled AC, bituminous treated base, or any other asphalt bound material, Figure 2-3 can be used to estimate the coefficient.

Cement Treated Base (CTB)

Figure 2-4 shows that the CTB coefficient is a function of the seven (7) day unconfined compressive strength (ARIZ 241). If the compressive strength is less than 200 psi, then the material should be considered an aggregate base and the coefficient re-calculated. A coefficient of 0.28 will apply to CTB with a compressive strength of 800 psi or more.

Bituminous Treated Base (BTB)

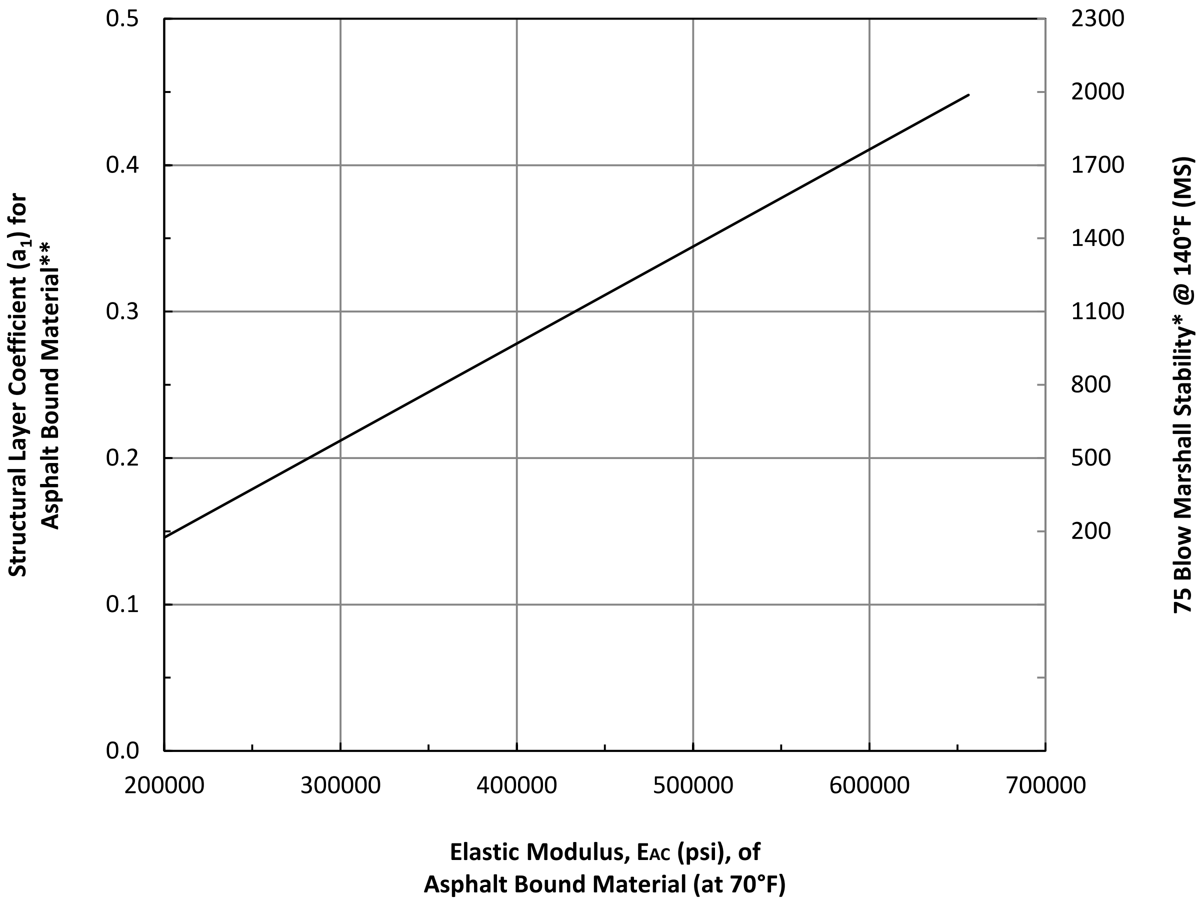
This base will be used primarily as a drainage layer and should be given a maximum coefficient of 0.28.

Soil Cement or Lime Treated Subgrade

Figure 2-4 shows that for these materials the coefficient is a function of the seven (7) day unconfined compressive strength (ARIZ 241). The coefficients are less than CTB because of subgrade variability and construction control. If the compressive strength is less than 200 psi, then the material should be considered a subgrade. A coefficient of 0.23 will apply to those materials with a compressive strength of 800 psi or more.

Aggregate Base (AB) and Subbase

Figure 2-5 shows that the aggregate base and subbase coefficient is a function of the R-value (tested or correlated). For aggregate base material with an R-value of 79 or greater, the coefficient is 0.14. For a subbase material with an R-value of 73 or greater, the coefficient is 0.11. For both materials, if the R-value is less than 63, then the material is considered a subgrade.



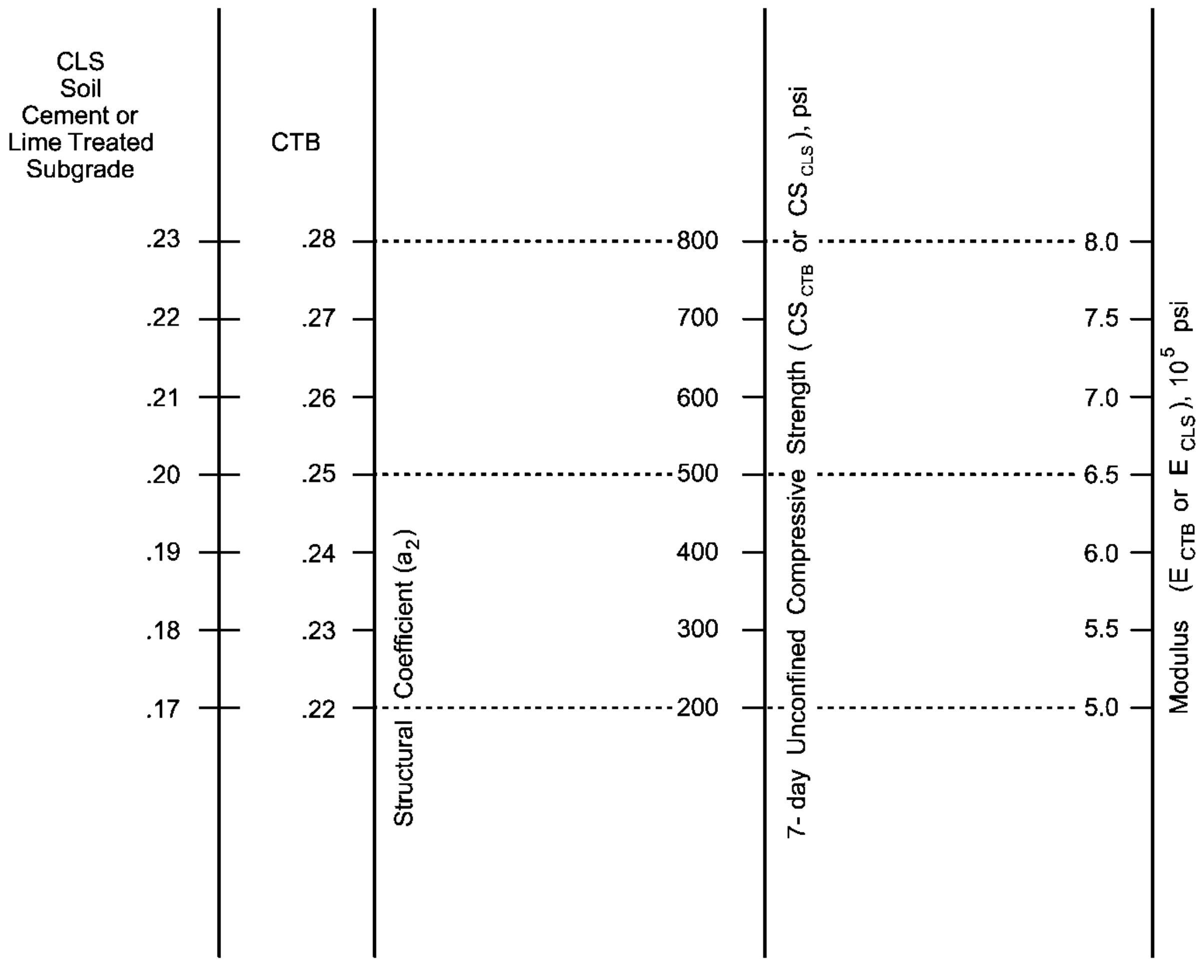

*Flow must be between 8 and 12.

**Coefficient cannot be lower than 0.15 or higher than 0.44.

$a_{1=0.02+6.4X10^{-7}(E_{AC})}$

$a_{1=0.12+1.61X10^{-4}(MS)}$

**Figure 2-3 Structural Layer Coefficient of Asphalt Bound Materials**
**(Chart for estimating structural layer coefficient of asphalt bound material based on elastic modulus or Marshall stability)**



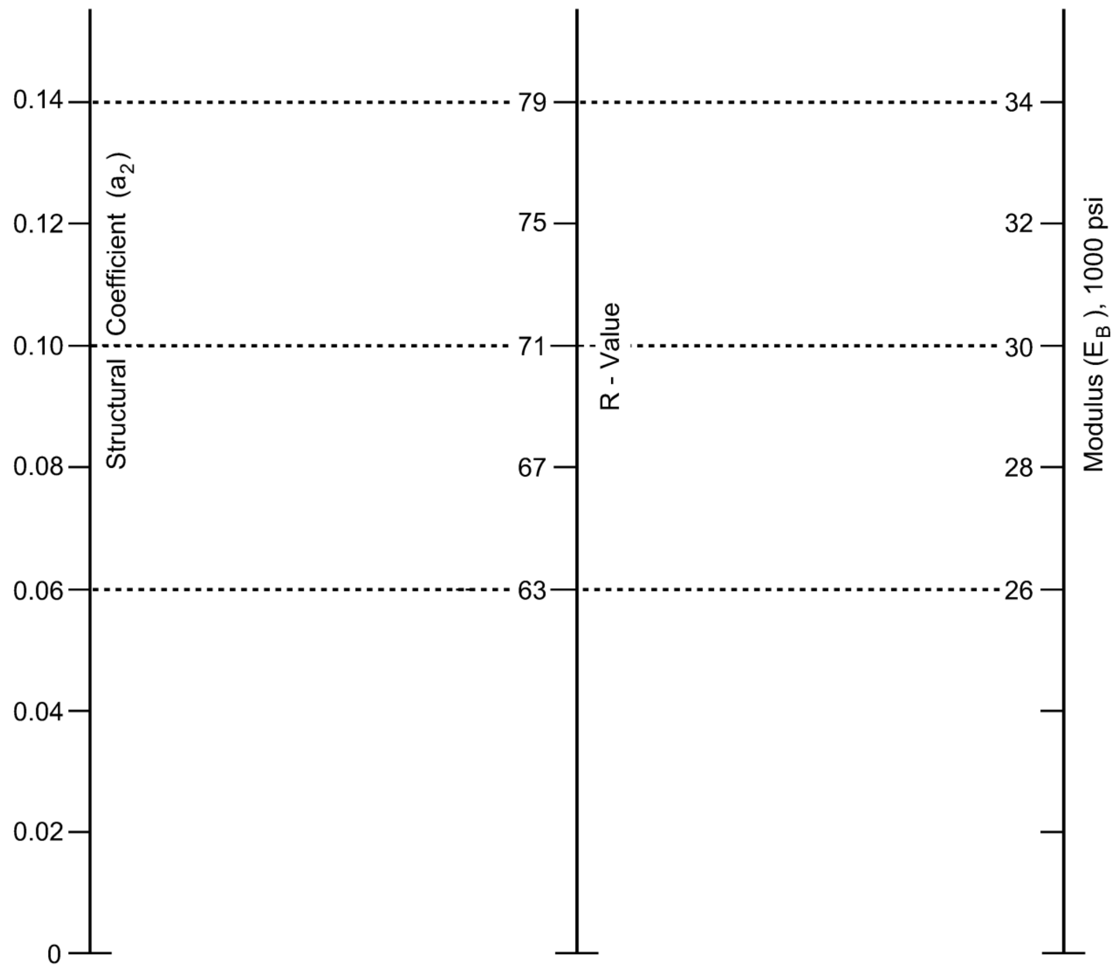

$a_2 = 0.20 + 0.0001\ (CS_{CTB})$

$a_2 = 0.15 + 0.0001\ (CS_{CLS})$

$a_2 = 0.12 + 2 \times 10^{-7} (E_{CTB})$

$a_2 = 0.07 + 2 \times 10^{-7} (E_{CLS})$

**Figure 2-4 Structural Layer Coefficient of Chemically Stabilized Base and Subgrade (Chart for estimating structural layer coefficient of cement treated base (CTB) and stabilized soil subgrade based on unconfined compressive strength or elastic modulus)**




$$a_2 = -0.2550 + 0.0050\ (\text{R-Value})$$

$$a_2 = 0.20 + 1.00 \times 10^{-5}\ (E_B)$$

**Figure 2-5 Structural Layer Coefficient of Unbound Granular Base**
**(Chart for estimating structural layer coefficient of unbound granular base determined by R-value or elastic modulus.)**

### 2.1.8 *Drainage Coefficient ($m_i$)*

Table 2-7 should be used to determine the drainage coefficient for base materials. The drainage coefficient is a function of the SVF (Figure 2-1 and Table 2-4) and the quality of drainage provided by the base material.

Definitions for Quality of Drainage are:

Excellent - Specially designed bound or unbound porous aggregate drainage layer with a minimum permeability of 2,000 ft./day, connected to a drainage system (Trenches and Pipes)

Good - Specially designed bound or unbound porous aggregate drainage layer with a minimum permeability of 2,000 ft./day, and no drainage system (Trenches and Pipes)

Fair - Typical Aggregate Base

Poor - Typical Aggregate Subbase

Very Poor - Subgrade-like material

**Table 2-7 Drainage Coefficients ($m_i$)**

| Quality of Drainage | SVF < 1.7 | SVF = 1.7 – 2.7 | SVF > 2.7 |
|---|---|---|---|
| Excellent | 1.15 | 1.23 | 1.32 |
| Good | 1.07 | 1.17 | 1.27 |
| Fair | 1.00 | 0.92 | 0.84 |
| Poor | 0.93 | 0.83 | 0.74 |
| Very Poor | 0.86 | 0.75 | 0.64 |

### 2.1.9 *Asphalt Grade Selection*

The asphalt grade should be determined by the Pavement Design Engineer with concurrence of the Bituminous Engineer.

## 2.2 Rigid Pavement Design

The basic design equation for rigid pavements is as follows:

$$log_{10}(W_{18}) = Z_R S_O + 7.35 log_{10}(D+1) - 0.06 + \left\{ \frac{log_{10}\left[\frac{\Delta PSI}{4.5-1.5}\right]}{1 + \frac{1.624 \, x \, 10^7}{(D+1)^{8.46}}} \right\}$$

$$+(4.22 - 0.32 p_t) \, log_{10} \left\{ \frac{[S_c' \, C_d (D^{0.75} - 1.132)]}{215.63 \, J \, [D^{0.75} - 18.42/(\frac{E_c}{k_{corr}})^{0.25}]} \right\}$$

Where:

$W_{18}$ = predicted number of 18-kip equivalent single axle load applications (Rigid) (see Appendix A)

$Z_R$ = standard normal deviate from Table 2-1 (same as flexible pavement design)

$S_O$ = combined standard error of the traffic prediction and performance prediction, equal to 0.25

$D$ = thickness of the pavement slab in inches (minimum 9 inches)

$S_c'$ = average modulus of rupture (psi) for Portland cement concrete, fixed at 670 psi

$C_d$ = drainage coefficient from Table 2-7 (same as flexible pavement coefficient, $m_i$ ). When an asphalt concrete base is used, assume "Good" quality drainage.

$E_c$ = modulus of elasticity (psi) for Portland cement concrete. It can be estimated from concrete compressive strength ($f'_c$) by the following formula:

$$E_c = 57000(f'_c)^{0.5}$$

For purpose of design, $f'_c$ is equal to 5,000 psi and $E_c$ is equal to 4,000,000 psi (based on a minimum $f'_c$ equal to 4,000 psi and an average $f'_c$ of 5,000 psi at 28 days as determined by ARIZ 314).

$\Delta PSI$ = $P_o - P_t$

$P_o$ = initial serviceability index from Table 2-2 (same as flexible pavement design)

$P_t$ = terminal serviceability index from Table 2-2 (same as flexible pavement design)

$J$ = load transfer coefficient used to adjust for load transfer characteristics of a specific design (see Table 2-8)

$k_{corr}$ = design modulus of subgrade reaction, which is determined as follows:

For full depth sections (PCCP placed directly on subgrade) -

1. Determine the subgrade modulus ($M_R$) using the same procedure used for flexible pavements (See Subsection 2.1.5).
2. Convert the subgrade modulus to modulus of subgrade reaction using the following formula:

$$k = \frac{M_R}{19.4}$$

3. Determine the design $k$ value ($k_{corr}$) by correcting $k$ for loss of support using Figure 2-6 and Table 2-9.

For sections using unbound or bound base or subbase -

1. Determine the subgrade modulus ($M_R$) using the same procedure used for flexible pavements (See Subsection 2.1.5).
2. Determine the elastic modulus of the base or subbase from Table 2-9.
3. Determine the composite $k$ value ($k_\infty$) using Figure 2-7. Note that the starting point in this figure is the base/subbase thickness.
4. Determine the design $k$ value ($k_{corr}$) by correcting $k_\infty$ for loss of support using Figure 2-6 and Table 2-9.

**Table 2-8 Load Transfer Coefficients (*J* Factor) for Rigid Pavement with Tied Concrete Shoulders**

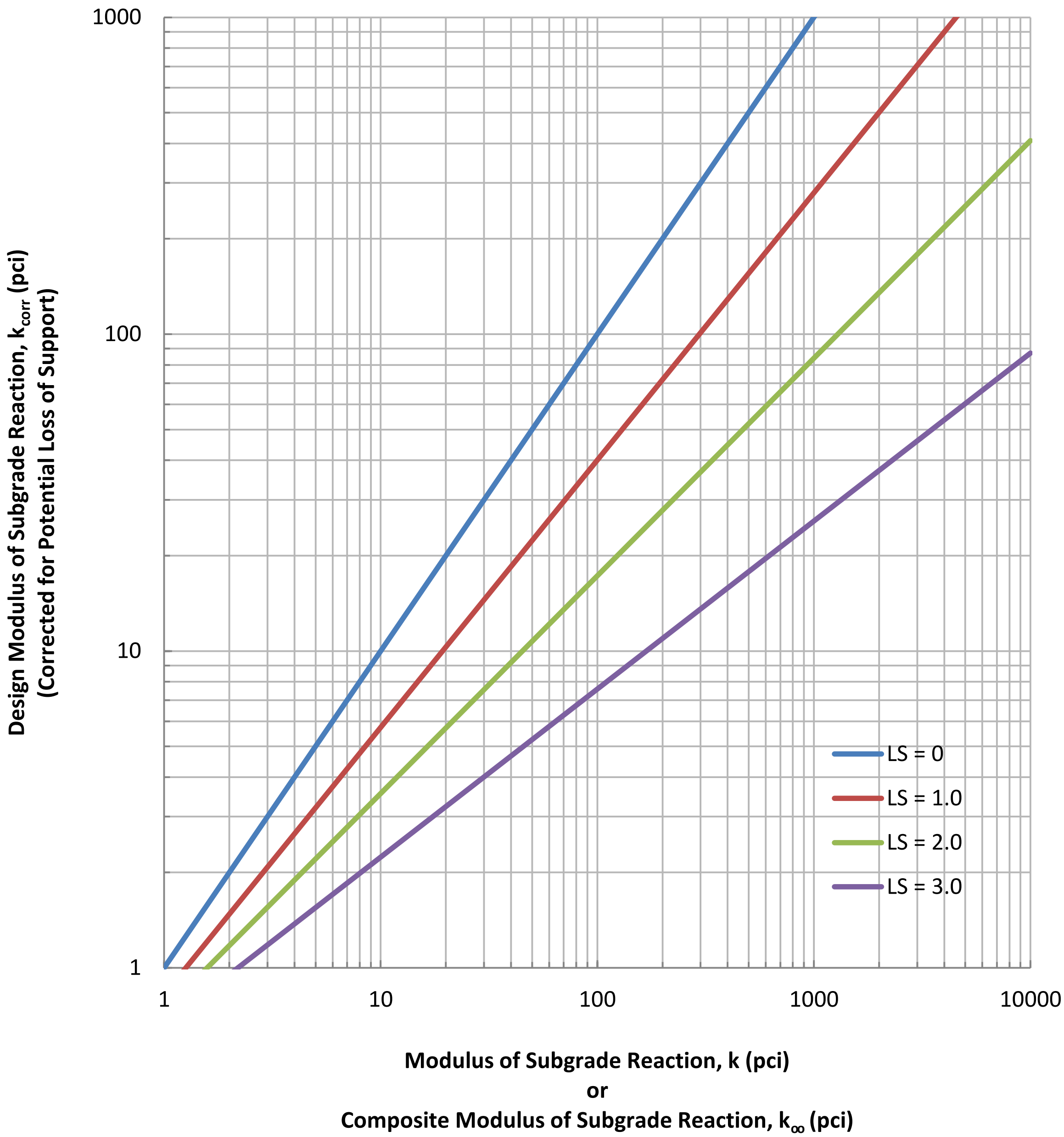
| Rigid Pavement Type | $J$ Factor |
|---|---|
| Plain Jointed (No Dowels) | 3.9 |
| Plain Jointed (Dowels) | 2.8 |
| CRCP | 2.5 |

Note: For asphalt or other untied shoulders see guidance provided in the *1993 AASHTO Guide for Design of Pavements, Vol 1*, Chapter 2, Section 2.4.2.

**Table 2-9 Loss of Support**

| Base Material Type | Elastic Modulus (psi)* | SVF < 1.7 | SVF = 1.7 – 2.7 | SVF > 2.7 |
|---|---|---|---|---|
| Asphaltic Concrete | 650,000 | 0 | 0 | 0 |
| Lean Concrete Base | 650,000 | 0 | 0 | 0 |
| Cement Treated Base | 600,000 | 0 | 0 | 0 |
| Cement Treated Subgrade | 500,000 | 0 | 0.5 | 1.0 |
| Lime Treated Subgrade | 500,000 | 0 | 0.5 | 1.0 |
| Aggregate Base | 36,000 | 0 | 0.75 | 1.5 |
| Aggregate Subbase | 23,000 | 0 | 1.0 | 2.0 |
| Subgrade | -- | 0.5 | 1.5 | 2.5 |

* Typical values for use in Figure 2-7




$Log_{10}(k_{corr}) = A_o + A_1 Log_{10}(k)$

Where: $A_o = -0.0844LS^{0.6924}$

$A_1 = 1.0 - 0.1566LS$

LS = Loss of Support

**Figure 2-6 Correction of Modulus of Subgrade Reaction for Potential Loss of Base/Subbase Support**

Example:

$D_{SB}$ = 6 inches

$E_{SB}$ = 20,000 psi

$M_R$ = 7,000 psi

Solution: $k_\infty$ = 400 pci

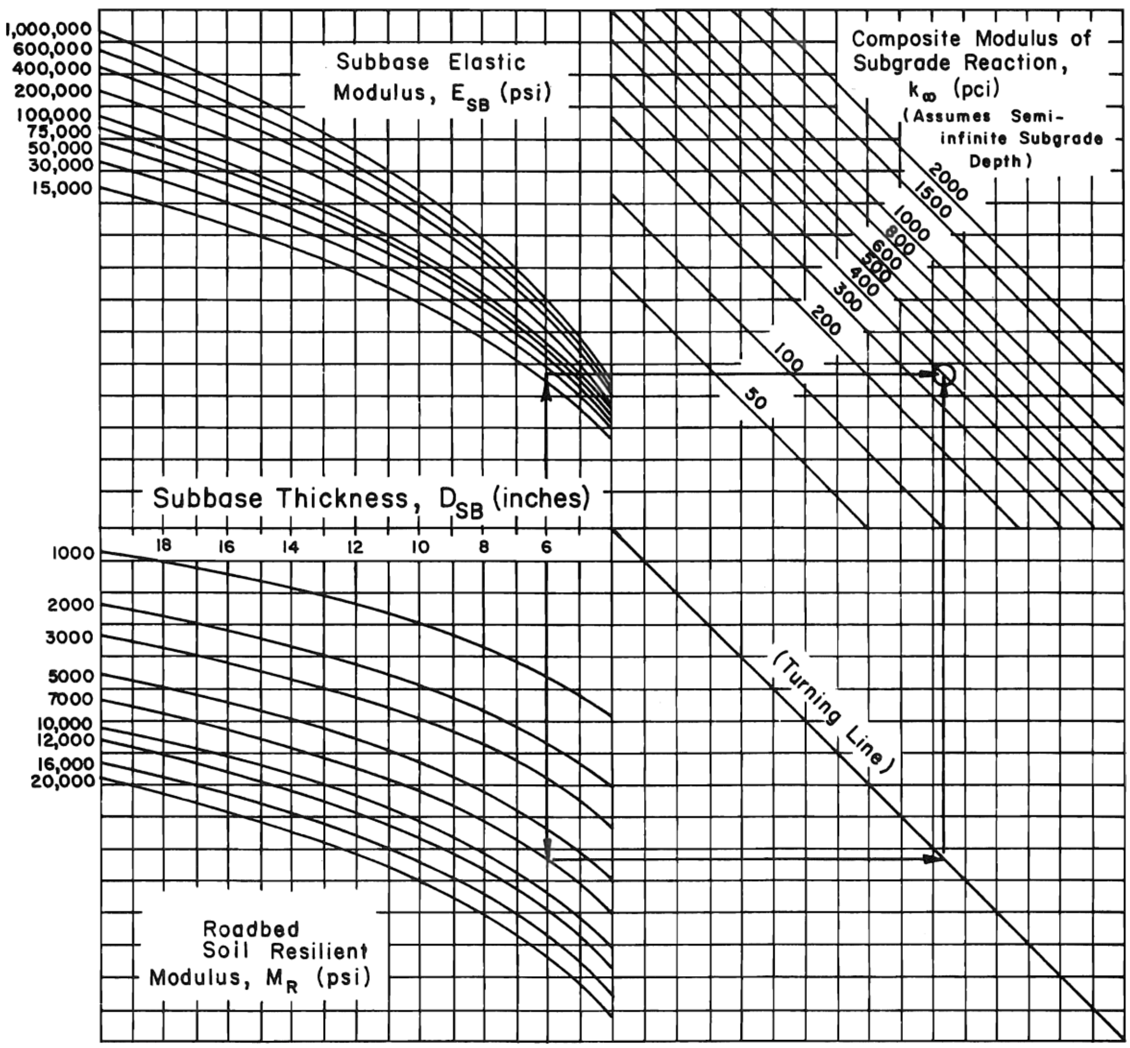



**Figure 2-7 Composite Modulus of Subgrade Reaction ($k_\infty$)**

**(Chart for estimating composite modulus of subgrade reaction, $k_\infty$, assuming a semi-infinite subgrade depth. For practical purposes, a semi-infinite depth is considered to be greater than 10 feet below the surface of the subgrade.)**

## 2.3 Minimum Pavement Design Controls

The AASHTO 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:

1. Ease of construction
2. Maintenance considerations
3. Current engineering judgment and practice
4. Failure under the action of a few heavy wheel loads

Taking this criteria into account, minimum designs for flexible and rigid pavements were developed.

The minimum structural number table (Table 2-10) should be used to check the adequacy of a design. In addition, it can be used to estimate a design section when it is not possible to complete the design due to unusual circumstances. Note that these values should not be used to replace or circumvent the final design process. For turning bays, bridge replacement, culvert replacement, minor roadway widening, or any other highway work involving small areas or small quantities of mainline highway paving, the design structural section should match the as-constructed structural number of the in-place pavement. If the existing structural section is less than the minimum required in Table 2-10, then use the larger value.

Flexible Pavements

For flexible pavements, the minimum is expressed as a structural number which is further qualified by the minimum asphaltic concrete thickness. Additionally, on layered sections using aggregate bases, a minimum thickness of 4" shall be used for the base material. Table 2-10 shows the minimum requirements for flexible pavements.

Rigid Pavements

For rigid pavements, the minimum is expressed as a minimum pavement section. The minimum rigid pavement section for all roadways is 9" of Portland Cement Concrete Pavement on 4" of base material.

Gravel Roadways

At least 6" of aggregate material should be placed. ADOT's standard aggregate base is generally not suitable due to a lack of cohesive strength. The Pavement Design Engineer should consult other relevant resources when designing gravel roadways.

**Table 2-10 Minimum Structural Numbers and Composite Thicknesses (Flexible Pavements)**

| Roadway Functional Classification | Minimum Structural Number | | | Minimum AC Thickness |
|---|---|---|---|---|
| | Rural | Rural | Urban | |
| Freeways, all Interstates, non-Interstates with greater than 10,000 ADT | ESAL's <10,000,000 | ESAL's ≥10,000,000 | | |
| Main Roadways | 3.00 | 3.50 | 3.50 | 5.0" |
| Ramps & Crossroads | 2.25 | 2.25 | 3.50 | 4.0" |
| Frontage Roads | 2.25 | 2.25 | 2.75 | 4.0" |
| Detours | 2.25 | 2.40 | 2.40 | 3.0" |
| Arterials (ADT 2,000 – 10,000) | ESAL's <2,500,000 | ESAL's ≥2,500,000 | | |
| Main Roadways | 2.50 | 2.75 | 2.75 | 4.0" |
| Ramps & Crossroads | 2.25 | 2.25 | 2.75 | 4.0" |
| Detours | 1.75 | 2.00 | 2.00 | 2.5" |
| Collectors (ADT 500 – 2,000) | ESAL's <750,000 | ESAL's ≥750,000 | | |
| Main Roadways | 2.00 | 2.25 | 2.25 | 3.0" |
| Detours | 1.50 | 1.75 | 2.00 | 2.0" |
| Local (ADT <500) | ESAL's <100,000 | ESAL's ≥100,000 | | |
| Main Roadways | 1.35 | 1.75 | 1.75 | 2.0" |
| Detours | 0.75 | 1.50 | 1.50 | 1.5" |
| Other Miscellaneous Pavements | ESAL's <100,000 | ESAL's ≥100,000 | | |
| Rest Areas & Parks | 2.25 | 2.25 | 2.25 | 4.0" |
| Turnouts & Driveways | 1.35 | 1.35 | 1.35 | 2.0" |

Note: For cases where there is a discrepancy between Functional Classification and ADT, select the larger minimum SN and AC Thickness. Also note that none of the roadways within the State Highways System are classified as Local roads.

## 2.4 Selection of Optimal Design

In choosing the optimal design for the pavement structure, there are many things to consider.

1. Continuity of Pavement Type - To maintain uniform driving conditions for the motoring public, consideration should be given to continuing the same type of existing pavements. This is especially important for relatively short projects.
2. Location and Local Conditions - Typically there are multiple pavement structural sections that will meet the requirements of the design equation. Local conditions, such as shallow underground utilities, very heavy slow-moving truck traffic, depth of frost penetration, poor drainage, etc., may make one alternative preferable over the others. Past experience and judgment should be used in the final selection of the design.
3. Conservation of Natural Resources - Conservation of natural resources should be considered in the evaluation of the pavement design alternatives, particularly in areas where aggregates or other materials are scarce.
4. Anticipated Construction Problems - Consideration should be given to the feasibility of the proposed design in regard to standard construction methods.
5. Costs - Comparative costs should be given consideration in the selection of the pavement design.
    a. Initial Construction Cost
    Initial construction cost data is available from the ADOT Contracts and Specifications (C&S) Section in their application known as Estimated Engineering Construction Costs (E2C2). The application is available at https://apps.azdot.gov/e2c2/HistoricalPrice.aspx. Pavement Design Engineers are encouraged to use this application as a guide and to document the sources of all cost estimates. Generally, ADOT C&S data will be used to referee any disputes regarding cost estimates.
    b. Life Cycle Cost
    When required, a life cycle cost analysis (LCCA) should be performed to determine the most cost effective structural design. RealCost software developed by the Federal Highway Administration, or a similar method, should be used for the LCCA. Although structural designs typically encompass a 20 year period, highway facilities are generally in service much longer. Therefore, a minimum 35 year analysis period should be used.

Normally, the pavement design that satisfies the structural requirements and represents the least cost would be selected. However, as discussed previously, there may be times when the least cost design would not necessarily be the most appropriate design. To the degree possible, the Pavement Design Engineer should take these considerations into account in determining the recommended pavement section. Alternative designs for further review may be appropriate in a situation where no one design seems capable of satisfying all of the constraints. For additional information on design considerations, the Pavement Design Engineer should consult the 1993 AASHTO Guide.

# 3.0 PAVEMENT REHABILITATION

Rehabilitation generally involves restoring the ride to a like new condition, repairing surface problems such as cracking, rutting and pothole patches, and providing good skid resistance. Techniques to accomplish this may include overlaying, milling, recycling, grinding, grooving, crack and/or joint sealing, or other rehabilitation activities. A combination of techniques may also be used. Design for rehabilitation differs from new construction in that considerable information about the pavement structure and performance already exists. In addition, structural capacity can be measured with deflection equipment. Rehabilitation design at ADOT is based on deflection measurements augmented by experience and does not directly follow the 1993 AASHTO Design Guide. Table 1-1 shows the data required for a rehabilitation design. In addition, the designer should be familiar with the traffic loading information presented in Appendix A, as well as the cost data compiled by the Contracts and Specifications Section. As in pavement design for new construction, rehabilitation design should reflect the most cost effective solution although life cycle cost analysis is not routinely conducted.

## 3.1 Flexible Pavement Rehabilitation

The procedure used to design overlays in Arizona is to determine the structural adequacy by deflection testing. Typically, measurements are taken every 0.2 mile in each traffic lane using the falling weight deflectometer (FWD) or Dynaflect. The design period for overlay/rehabilitation projects is generally 10 years and the corresponding traffic loading is used for design. Design ESAL's shall be determined in accordance with Appendix A.

When the 18k ESAL applications is less than 50,000 for the design period, deflection testing and detailed design is rarely warranted. For these type projects, the Pavement Design Engineer should consider the performance of past rehabilitation strategies for the given roadway, as well as the minimum treatments found in Table 3-1, when establishing the pavement rehabilitation requirements.

ADOT uses the Structural Overlay Design for Arizona (SODA) method, which is based on an analysis of all 7 FWD or all 5 Dynaflect sensor readings. Note that the SODA method was developed using deflection data from the Dynaflect, as well as roughness data from the Mays Meter. In order to use this method, FWD and International Roughness Index (IRI) data must be converted to equivalent Dynaflect and Mays Meter results as shown in the following Subsection.

### *3.1.1 SODA Method*

The basic design equation used to estimate the overlay thickness for a flexible pavement is as follows:

$$T = \frac{\left\{(Log_{10}W_{18} - 3.255) + (0.104SVF) + \left[\frac{0.000578(P_o - 4.255)}{0.54}\right] - (0.0653SI_{B-DYN})\right\}}{\{0.0587[2.6 + (32.0D5_{DYN})]^{0.333}\}}$$

Where:

$T$ = Estimated Overlay Thickness in inches

$W_{18}$ = Design 18 kip ESAL's (see Appendix A)

$SVF$ = Seasonal Variation Factor

$P_o$ = Mays Meter Roughness in inches/mile

For IRI,

$$P_0 = (0.88IRI) - 1.3397$$

Where:

$IRI$ = International Roughness Index in inches/mile

$D5_{DYN}$ = #5 Dynaflect sensor reading in mils

For the FWD,

$$D5_{DYN} = 0.16(D7_{FWD})^{1.115}$$

Where:

$D7_{FWD}$ = #7 FWD sensor reading in mils

$SI_{B-DYN}$ = Spreadability Index before Overlay from Dynaflect results

For the FWD,

$$SI_{B-DYN} = 2.7(SI_{B-FWD})^{0.82}$$

Where:

$SI_{B-FWD}$ = Spreadability Index before Overlay from FWD results

= $[(D1_{FWD} + D2_{FWD} + \dots + DN_{FWD})/(ND1_{FWD})](100)$

Where:

$D1_{FWD}$ = #1 FWD sensor reading in mils

$D2_{FWD}$ = #2 FWD sensor reading in mils

$DN_{FWD}$ = Nth number FWD sensor reading in mils

$N$ = total number of sensors

If milling is involved, then the roughness is set to 50 inches per mile. In addition, the spreadability index before overlay is calculated to be a function of the depth of milling, representative of the new asphaltic concrete that will be placed in the milled out trench, and is set equal to the $SI_M$ value in the following equations.

$$SI_M = 0.899ET + SI_{B-DYN}$$

$$ET = [2.6 + (32D5_{DYN})]^{0.333}\ (Mill)$$

Where:

$SI_M$ = Spreadability Index after milling and replacement

$ET$ = Equivalent thickness adjusted to reflect milling and replacement

$Mill$ = Depth of mill out and replacement in inches

The thickness should be determined at each test location and the mean value of thickness for all test locations in a design section is then used as the overlay thickness. Any individual test location results less than zero are assigned a value of zero, and any results over 6 inches are assigned a value of 6 inches. No other statistical manipulations are needed as they were incorporated into the development of the SODA method. In some cases, it may be appropriate to develop more than one design section along the length of a given roadway. Multiple design sections should be considered when the variability of the estimated overlay thickness is high, and can be reduced by breaking the roadway into shorter sections. When recommending more than one section, consideration needs to be given to both the cost savings as well as the decrease in construction efficiency that will result from building multiple sections.

#### *3.1.2 Other SODA Considerations*

From past experience, the overlay thickness at a given test location will probably be too thick if the #7 FWD sensor reading is less than 0.67 mil (or the #5 Dynaflect sensor reading is less than 0.1 mil). Given the other physical distress measurements, such as ride and/or cracking, the designer may elect to reduce the overlay thickness at that location to a value sufficiently thick to meet or exceed Table 3-1 guidelines.

If the #7 FWD sensor reading is greater than 2.4 mil (or the #5 Dynaflect sensor reading is greater than 0.4 mil), the subgrade is weak and the overlay thickness may be underestimated. For this case, historical soil support logs, R-value tests, and drainage should be investigated. Increased thickness and/or subgrade drainage may be necessary.

If the SODA design thickness is less than 2.0 inches or the traffic is less than 50,000 18 kip ESAL's, the Pavement Design Engineer should review the pavement management database as well as personal project review notes in light of Table 3-1. This table contains the most common type of repair activities and range of thicknesses for each particular distress. The selected design should consist of a sufficiently thick overlay and/or mill and replace section to meet or exceed Table 3-1 guidelines, or the SODA results, whichever is greater.

**Table 3-1 Minimum Rehabilitation Treatment for Flexible Pavements**

| | | | |
|---|---|---|---|
| Roughness (IRI): | | | |
| Satisfactory | 0 – 107 in/mile | No Action or Seal Coat | |
| Tolerable | 108 – 163 in/mile | Minimum 2" AC, with or without milling | |
| Objectionable | 164+ in/mile | Minimum 2.5" AC, with or without milling | |
| Note: See Table 3-2 for additional leveling thickness. | | | |
| Percent Cracking: | | | |
| Low | Less than 10 | No Action or Seal Cracks | |
| Medium | 10 – 30 | Minimum 2" AC, with or without milling | |
| High | Greater than 30 | Minimum 2.5" AC, with or without milling | |
| Note: Consider special treatments for reflective cracking. | | | |
| Friction Number (Dynatest HFT) (Wetted Surface Friction): | | | |
| | Test Speed | | |
| | 60 mph | 40 mph | |
| High | Greater than 43 | Greater than 50 | No Action |
| Medium | 34 - 43 | 44 - 50 | ACFC or Seal Coat |
| Low | Less than 34 | Less than 44 | ACFC or Seal Coat |
| Note: Milling should also be considered. | | | |
| Rut Depth: | | | |
| Low | 0 – 0.25 in. | No Action | |
| Medium | 0.26 – 0.50 in. | Minimum 2" mill out and replace | |
| High | 0.51+ in. | Minimum 2.5" mill out and replace | |

Note: The asphaltic concrete thicknesses in the above table may not be sufficient for Interstates or other high volume roadways. On these high volume routes the design thickness may need to be increased.

### *3.1.3 Overlays Other Than SODA*

There may be circumstances where an overlay is warranted for reasons of stage construction, continuity (widening, structures), or preventative maintenance. For these cases a minimum two inch overlay should be considered.

In addition to overlay thickness, the designer should consider the use of special treatments to alleviate specific distress or performance related problems. Wide transverse or longitudinal cracks are difficult to control with just an overlay and can result in reflective cracking at a relatively early age. Special treatments such as full depth removal and replacement of asphaltic concrete on each side of the crack should be considered. Reflective cracking may also occur if the overlay thickness or the combined thickness of mill and replace pavement plus the overlay is less than the thickness of the remaining or existing old pavement. In order to minimize the incidence of reflective cracks, the thickness of the new asphaltic concrete layer should be at least equal to the thickness of the remaining or existing old pavement. If this is not practical, then other special treatments such as the use of a modified binder should be considered. Rutting problems may not be alleviated with just an overlay. Milling of any unstable material should also be considered. Bleeding pavements may also need to be milled prior to placing a thinner overlay or surface treatment. If cracks have been sealed within the previous 12 months, or the existing crack seal has a heavy overband of material, the pavement surface should be milled off before overlay to improve the overlay ride. To correct ride or rutting problems by an overlay alone, a leveling quantity as shown on Table 3-2 should be specified.

**Table 3-2 Leveling Requirements on Overlay Projects**

| Roughness (IRI) | Additional Thickness for Leveling (inches) |
|---|---|
| 0 – 107 | 0 – 1/4 |
| 108 – 163 | 1/4 - 1/2 |
| 164 – 221 | 1/2 – 3/4 |
| 222+ | 3/4+ |
| Rut Depth | Leveling Required per Lane (tons/mile)* |
| ¼ inch | 50 |
| ½ inch | 100 |
| ¾ inch | 150 |
| 1 inch | 200 |
| 1 ¼ inch | 250 |
| 1 ½ inch | 300 |

* Leveling based on a three foot rut width

Recycling of either milled material or stockpiled salvaged AC from other projects should be considered on all AC paving projects. If recycling is not possible, but milling is necessary, milled material may be either stockpiled or used for shoulder buildup. Unusual drainage problems, such as springs, should be addressed with pavement reconstruction incorporating a drainage layer and/or geotextile separation layer. If swelling soil is evident, then waterproof membranes such as asphalt rubber or a geomembrane should be considered.

#### *3.1.4 Rehabilitation Design Validation*

Once a rehabilitation design has been performed, the proposed pavement section should be checked to ensure it is structurally adequate to handle the design traffic. This validation will typically involve estimating reasonable values for existing subgrade modulus and layer coefficients, and then calculating the SN to be provided by the proposed rehabilitation design. The SN provided by the proposed rehabilitation design can then be compared to the SN that would be required for a new pavement design to see if it is structurally adequate.

### 3.2 Rigid Pavement Rehabilitation

Rigid pavement rehabilitation can be categorized as structural or non-structural. Structural rehabilitation is appropriate when the pavement is at or near the end of its service life and may be considered as an alternative to reconstruction. Structural rehabilitation typically consists of a relatively thick asphaltic concrete or Portland cement concrete overlay. The demand for structural rehabilitation of rigid pavements on ADOT roadways is low. Therefore, specific design methods are not addressed in this manual.

Non-structural rehabilitation is used to correct concrete surface problems such as excessive roughness (with or without faulting) or inadequate friction. Table 3-3 shows typical rehabilitation methods to be considered for bare concrete pavements.

**Table 3-3 Concrete Non-Structural Rehabilitation**

| Roughness (IRI) | | Rehabilitation Action |
|---|---|---|
| 0 – 107 in/mile | | No Action |
| 108+ in/mile | | Grind* or AR-ACFC overlay |
| Friction Number (Dynatest HFT)<br>(Wetted Surface Friction): | | Rehabilitation Action |
| Test Speed | | |
| 60 mph | 40 mph | |
| Greater than 43 | Greater than 50 | No Action |
| 34 - 43 | 44 - 50 | Groove* |
| Less than 34 | Less than 44 | Groove* |

* Joints should typically be sawed and resealed.

NOTE: Localized spalled areas at joints should be patched. In addition, cracked slabs may need to be repaired or replaced.

## 4.0 WIDENING

Some projects may involve widening the existing highway together with rehabilitating the existing pavement. If the widening is less than a full lane width (12 feet), or is of a temporary nature (intersection, or stage design), then the existing pavement and pavement structure should be used to design the overlay and widening. Normally, the widening would match the as-constructed structural number of the in-place pavement, or the minimum structural number and component thickness from Table 2-10, whichever is greater. The scope for rehabilitating the existing pavement should be determined by the flexible overlay method in Section 3.1. If SODA indicates no overlay is needed, a minimal treatment (e.g. thin mill and fill or overlay, or remove and replace friction course) should be placed for continuity. If the widening is less than a full lane width, but there is a reasonable possibility that the pavement will be used in the future as a traveled way, then it should be designed in accordance with Chapter 2.0.

If the widening is one lane or wider and is at least 1,500 feet long, it should be designed in accordance with Chapter 2.0. The remaining in-place pavement should be designed in accordance with Section 3.1 using a 20 year design life. Assuming the widening is to the outside and will result in two lanes of traffic in the design direction, the new widening would be designed with 90 percent traffic loading and the existing with 40 percent traffic loading (see Table A-2). If the existing pavement did not need an overlay, then a minimal treatment (e.g. thin mill and fill or overlay, or remove and replace friction course) should be placed for continuity.

For all permanent widening, the total thickness of the new AC and base should closely match the thickness of the existing section when possible. This will help promote positive drainage along the top of subgrade into the roadside ditch, and minimize any trapped water within the pavement section.

# 5.0 DESIGN DOCUMENTATION AND PRESENTATION

This chapter deals with the documentation and presentation of the information developed during the design process. The method used to present this information is called the Materials Design Package. The Materials Design Package consists of three separate parts: the first is the Pavement Design Summary, the second is the Materials Design Report and the third is the Preliminary Pavement Structure Cost Estimate. The Materials Design Package is distributed as both an “Initial” and “Final” submittal. A description of each part and the function it serves is presented in the following sections.

## 5.1 Pavement Design Summary

A Pavement Design Summary is prepared for each project to show the basis for the proposed design. It provides information necessary for review of the design and supports the design recommendations.

The Pavement Design Summary should include the description, location, and reason for a project. Visual observations made by the Pavement Design Engineer should be listed, especially on rehabilitation projects. Subsoil conditions and test results pertinent to the pavement design should be presented.

For new construction, reconstruction and widening projects, the selection of the design resilient modulus value (including design $R_{mean}$) and construction control R-value should be discussed. Other factors important in the design should be listed including traffic data and their source, Seasonal Variation Factor, terminal serviceability index, drainage coefficients, and structural coefficients for materials considered. For rehabilitation projects, important design inputs and the SODA results should be discussed. When performing parallel designs using the MEPDG, a summary of the input values as well as the results of the analysis should be included. If the project is to be divided into sections with different design recommendations, support data such as variation in soil support, traffic loading, or existing pavement condition should be shown for each division.

The Pavement Design Summary should list different design alternatives, a cost comparison and a discussion explaining the reason for each alternative chosen. Unit costs and total costs should be listed for each design considered.

To be complete, the Pavement Design Summary will give the recommended pavement structure and reasoning for selecting one alternate over the others. A support argument for the design chosen should be made.

The Pavement Design Summary is submitted as both an “Initial” and “Final” document. The Final Pavement Design Summary shall bear the seal and signature of a Professional Engineer registered in the State of Arizona.

## 5.2 Outline of Pavement Design Summary

The following outline provides the components required in a typical Pavement Design Summary. Items should be added or omitted as needed to address the specific materials related design requirements on a given project. Much of the information required in Section I, II and III of the outline can be obtained from the scoping document for the project (i.e. Project Assessment, Design Concept Report, etc.).

I. Document Heading and Introduction
   A. Document Title (e.g. Pavement Design Summary)
   B. Project Name
   C. Project Number (Full TRACS Number and Federal Aid Number)
   D. Introductory Paragraph – Briefly describe the contents of the document and also reference the associated Materials Design Report.
II. Roadway Description
   A. Project Location (i.e. Route, MP, County, ADOT District, Land Ownership, Functional Classification, etc.)
   B. Geometric and Cross Sectional Elements – Describe features relevant to the pavement design including maximum grades, total width, number and width of lanes (including shoulders), cross slope, etc.
   C. Other Features or Characteristics – (i.e. posted and design speed, AADT, project elevation, etc.)
III. Project Scope
   A. Purpose of Project
   B. Scope of Work (with emphasis on pavement and materials related aspects)
   C. Programming/Funding Status
IV. Pavement History and Visual Observations
   A. Existing Pavement Section – Provide component thicknesses and dates constructed from the Pavement Management System (PMS) database, record drawings and existing core logs (if available).
   B. Existing Pavement Condition – Provide a detailed description of the existing pavement condition based on observations made during the field review. Include distress data such as fatigue cracking, longitudinal cracking, transverse cracking, smoothness, rutting, flushing, and patching. The surface type and condition should also be noted.
   C. Other Conditions – Describe other conditions relevant to the pavement design such as terrain, geologic conditions, drainage conditions, low bridge clearances, cattle guards, railroad crossings, curb and gutter, guardrail height, etc.
V. Test Data
   A. Pavement Management System Information – Provide condition data as recorded in the PMS database (i.e. cracking, flushing, friction, patching, rutting and smoothness).
   B. Geotechnical Data – Summarize the relevant geotechnical data from the geotechnical report including R-values, soil classifications and descriptions, unsuitable or problematic soils, etc.
   C. Pavement Cores – Describe the pavement cores including thickness, composition, uniformity, condition, evidence of stripping, debonding, etc.
VI. Design Calculations and Discussion
   A. New Pavement Design

1. List the input values used in the design equation. Provide justification for those values requiring any significant engineering judgment (i.e. design ESAL's, resilient modulus, modulus of subgrade reaction, etc.).
2. Discuss alternative designs considered and justify the design selected. Provide the required SN as well as component layer and drainage coefficients, costs, and any other special considerations.
3. Geotechnical Issues – Provide any geotechnical related design solutions from the geotechnical report including treatment of unsuitable subgrade, selection of the construction control R-value, borrow quality requirements, etc.

B. Pavement Rehabilitation Design
1. Provide the basis of need for rehabilitation (i.e. structural deficiency, fatigue related, age/climate related, smoothness, deflection design, etc.).
2. Discuss the design strategies considered and justify the one selected.
3. List the input values used in the design process. Provide justification for those values requiring any significant engineering judgment.
4. Discuss the results of the design process including the SODA results.
5. Provide and justify the recommend rehabilitation strategy.

VII. Recommendations – Summarize the final pavement section recommendations including the location and limits of each pavement section, type and thickness of each component/treatment, surface treatment selection, and any special considerations. The total thickness should be included on new or widened pavements.

## 5.3 Materials Design Report

A Materials Design Report is prepared for each project to present the outcome of the design process and to provide details and specifications for the recommended pavement structure. The information provided in the Report is supported by the recommendations made in the Pavement Design Summary and the geotechnical report.

The Report provides the recommended pavement structure for each design section, including the location and limits of each pavement section, type and thickness of each component/treatment, surface treatment selection, and any special considerations. The total thickness should be included on new or widened pavements.

In addition to providing the pavement structure for each design section, the Report provides the procedures and specifications for each pavement component or process, which may include the following: existing pavement removal, subgrade preparation, subgrade acceptance, subbases, bases, surface treatments, pavements, etc. If the item of work is covered by either the Standard Specifications or the Stored Specifications, then reference to the appropriate specification(s) is all that is needed.

Also included in the Report is relevant information provided by the geotechnical report including: Materials Sources and Haul Distances, Earthwork Factors and Slopes, Ground Compaction Factors, Subgrade Improvements, Water Requirements, Corrosion Potential of Soils, Special Conditions, etc.

Much of the Report is made up of Pavement Design Standard Items, which should be used whenever applicable. These Standard Items provide a consistent format in which to present design related information including callouts for both Standard and Stored Specifications.

The format of the Materials Design Report should follow as closely as practical the outline shown in the following section. The Report is submitted as both an "Initial" and "Final" report. The Final Materials Design Report shall bear the seal and signature of a Professional Engineer registered in the State of Arizona.

### 5.4 Outline of Materials Design Report

The following outline provides the components required in a typical Materials Design Report. Items should be added or omitted as needed to address the specific materials related requirements on a given project. When available, Pavement Design Standard Items should be used to present typical materials design information.

- I. Cover Sheet
  - A. Report Title (e.g. Materials Design Report)
  - B. Report Type (e.g. Initial or Final)
  - C. Report Number – Materials Design Reports are numbered consecutively beginning with the number one (01), with a prefix consisting of the last two digits of the year in which it is written, and a suffix consisting of the report type (e.g. Initial, Final). For example, the first project of 2017 would be assigned the following report numbers, 17-01-I for the Initial Report, and 17-01-F for the Final Report. Any changes to a Final Report will be issued as a revision rather than an addendum. In the above example, the first revised Final would be identified as 17-01-RF1. If the original Report becomes very old or completely obsolete, a new number may be assigned.
  - D. Project Reference – Each Report refers to a specific project. To identify the project, the following information is listed:
    1. Highway Name
    2. Project Name
    3. Project Number (Full TRACS Number and Federal Aid Number)
    4. Type of Construction
    5. Beginning and Ending Milepost and Corresponding Stationing
    6. Report Author
- II. Design Information – The design information is presented in sections with each section broken into items as follows:
  - A. Section I – Pavement Structure
    1. Item 1 – Structural Thickness (In Inches) – Each structural section should be presented in a table which includes:
       - a) Route designation, direction, and limits (e.g. milepost or station)
       - b) Roadway location (e.g. travel lane, passing lane, inside shoulder, etc.)
       - c) Milling depth

d) Type and thickness of each pavement component
e) Total thickness (The total thickness need not be included on rehabilitation projects)
f) Notes needed to clarify the contents of the table

2. Item 2 – Additional Quantities for Leveling - On rehabilitation projects where the existing roadway is out of section or has a rough ride an item designating additional quantities for leveling should be included.
3. Vicinity Map – A vicinity map should be included if route and milepost limits are not adequate to describe the specific project location.
4. Typical Sections – The typical sections show a graphic illustration of the roadway typical sections and the pavement structural sections. The roadway typical sections show roadway, lane and paving widths, as well as surfacing and shoulder build-up if needed. The pavement structural sections show the type, thickness, and placement of each pavement component and lift. The location and limits of each typical section should be included.

B. Section II – Subgrade, Subbases and Bases – This section provides the recommended specifications for subgrade, subbases and bases. These items should be listed in the order of their placement during construction and may include, but are not limited to, the following:
   1. Item 1 – Subgrade Construction Control – This item is to be included on projects that involve new subgrade construction. The subgrade acceptance chart shall be included in the Report following the typical sections.
   2. Item 2 – Geosynthetics (e.g. geotextiles and geogrids)
   3. Item 3 – Cement Treated Subgrade
   4. Item 4 – Aggregate Subbase
   5. Item 5 – Cement Treated Base
   6. Item 6 – Lean Concrete Base
   7. Item 7 – Aggregate Base

C. Section III – Surface Treatments and Pavements – This section provides the recommended specifications for the various pavement components. Components should be listed in the order of their placement during construction and may include, but are not limited to, the following:
   1. Item 1 – Prime Coat
   2. Item 2 – Tack Coat
   3. Item 3 – Asphalt Rubber Stress Absorbing Membrane
   4. Item 4 – Asphaltic Concrete
   5. Item 5 – Asphaltic Concrete Friction Course
   6. Item 6 – Portland Cement Concrete Pavement
   7. Item 7 – Chip Seal Coat
   8. Item 8 – Fog Coat
   9. Item 9 – Blotter Material
   10. Item 10 – Pavement Smoothness
   11. Item 11 – Bridge Overlay

12. Item 12 – Overlay Tapers

D. Section IV – Material Sources & Geotechnical Analysis – This section provides the recommended specifications for materials sources and geotechnical design parameters, as provided in the geotechnical report. Items may include, but are not limited to, the following:
   1. Item 1 – Material Sources and Haul Distances – The Department does not typically mandate a specific materials source. Rather, it is the contractor's responsibility to obtain sources that meet the project requirements. The estimated haul distances for most material types can be obtained from the Geotechnical Services Section.
   2. Item 2 – Borrow – Quality requirements for borrow are included in this item when there is no Department mandated source of material.
   3. Item 3 – Ground Compaction
   4. Item 4 – Earthwork Factors (Shrink/Swell)
   5. Item 5 – Slope Factors
   6. Item 6 – Water Requirements
   7. Item 7 – Corrosion Potential of Soils (pH & Resistivity)
   8. Item 8 – Subgrade Improvements or Removal of Unsuitable Material

E. Section V – Miscellaneous – This section includes items that would not be covered under other sections, such as:
   1. Item 1 – Disposal of Existing Asphaltic Concrete
   2. Item 2 – Bituminous Pavement Removal by Milling
   3. Item 3 – Shoulder Build-Up
   4. Item 4 – Turnout Construction
   5. Item 5 – Temporary Connections and Detours

## 5.5 Preliminary Pavement Structure Cost Estimate

The Preliminary Pavement Structure Cost Estimate is developed based on the recommended pavement structure. This estimate represents the anticipated bid prices of the recommended pavement section, and should not be confused with the cost comparison of alternate designs found in the Pavement Design Summary. This cost estimate gives only the costs for the pavement structure and related items, and does not represent the total costs for a project. The Preliminary Pavement Structure Cost Estimate is used for comparison purposes to ensure reasonable compliance with the programmed amount for pavements on each project.

The Preliminary Pavement Structure Cost Estimate is submitted as both an "Initial" and "Final" document.

# 6.0 DESIGN REVIEW AND DISTRIBUTION

## 6.1 Review, Approval and Distribution of Initial Materials Design Package

After the Pavement Design Engineer has prepared the Initial Materials Design Package, it is checked by contributing sections within the Department to ensure items within their areas of responsibility are correct. This will typically include review by the following:

1. Geotechnical Services – to ensure correct R-values, shrink and swell, slope ratios, and other geotechnical related items are specified
2. Pavement Materials Testing Section – to ensure correct asphaltic concrete and other materials specifications are included
3. Pavement Design Section – to perform an overall quality control and constructability review, and ensure correct binder grades, materials unit weights, etc. are specified
4. Pavement Design Section Manager – review and final approval

Following this limited review, comments are incorporated as needed and the Initial Materials Design Package is then distributed to the Project Manager and other project team members for review and comment, as well as for use in preparing the preliminary plans, specifications and estimate (PS&E).

## 6.2 Review, Approval and Distribution of Final Materials Design Package

Once comments on the initial submittal are received from the project team, the Final Materials Design Package is prepared. The final submittal is then checked by contributing sections as outlined above in Section 6.1. Following this limited review, comments are incorporated as appropriate and the Final Materials Design Package is distributed to the Project Manager and others within the project team for use in the final PS&E.

# 7.0 ADDITIONAL RESPONSIBILITIES

## 7.1 Reviewing Contract Documents

Throughout the project development process, the Pavement Design Engineer should review all PS&E submittals to ensure they are consistent with the intent of the Materials Design Package. Comments should be made when any discrepancies exist.

## 7.2 Construction Support

When a project has gone to contract, the Pavement Design Engineer should be prepared to answer questions pertaining to the pavement design or pavement related field problems which may be encountered during construction. These questions need to be handled expeditiously in order to prevent construction delays.

One common problem requiring quick resolution is the discovery of unsuitable subgrade material. On projects involving subgrade preparation, the Materials Design Report contains a subgrade acceptance chart. The chart is used by field construction personnel to determine the design acceptability of the subgrade soils. When a subgrade sample falls within the unacceptable region of the chart, the field personnel notifies the Pavement Design Engineer of the tests results. The Engineer compares this information with the results of the original design. The construction personnel continue sampling the unacceptable material in increments of 100 feet until the limits of the failing material have been determined. Using this information, the Pavement Design Engineer, in consultation with the Geotechnical Engineer, determines the best method of dealing with the unacceptable subgrade material. Some of the methods used to treat this material are as follows:

1. Overexcavate and replace with acceptable material
2. Cement or lime stabilization
3. Use geosynthetics (fabrics, geogrids, etc.)
4. Increase the pavement structural number to compensate for weaker soils

In addition to unacceptable subgrade material, other construction problems relating to pavements may occur. A few examples of these are as follows:

1. Subgrade moisture problems
2. Drainage or erosion problems
3. Out of specification material

As with all questions relating to field problems, these items should be analyzed and expedited by the Pavement Design Engineer as judiciously as possible. Other technical sections (e.g. Geotechnical Services, Drainage Design) should also be consulted as necessary.

# APPENDIX A – TRAFFIC DATA AND ANALYSIS (CONVERTING MIXED TRAFFIC TO EQUIVALENT SINGLE AXLE LOADS FOR PAVEMENT DESIGN)

## Introduction

In order to design pavements in accordance with the 1993 AASHTO Guide and this manual, it is necessary to estimate the number of 18-kip equivalent single axle load (ESAL) applications for the roadway segment under consideration. This requires the designer to convert a mixed traffic stream into an equivalent number of 18-kip equivalent single axle loads (ESAL's) and then to sum these loads over the design period. An accurate estimate of the design ESAL's is critical in obtaining an appropriate pavement design because traffic loading has a significant impact on the anticipated performance of the pavement. Therefore, it is important that the designer obtain current and representative traffic data for use in calculating the design ESAL's for a project.

Much of the traffic data required to determine the design ESAL's for a project can be obtained from ADOT's Multimodal Planning Division (MPD). This data includes traffic volumes, percent trucks, and growth rate. Care must be taken by the designer to evaluate the traffic data available for the current as well as previous years to make sure the data is reasonable and there are no abrupt unexplainable changes in the data. Traffic data for segments of roadway adjacent to the project location should also be reviewed for consistency. Any apparent anomalies in the data should be reconciled prior to using the data in the design process. In general, traffic data from ADOT's MPD should be used for all pavement design work on State highways unless a project and/or site specific traffic study has been performed and approved for use by the Department.

Traffic data for the design of roadways off the State Highway System should come from a project and/or site specific traffic study, or should be provided by the local entity with jurisdiction over the subject roadway.

The following sections describe the traffic principles, data requirements, and specific procedures necessary to calculate design ESAL's for a project on the State Highway System.

## Traffic Volumes

One of the most basic measures of traffic volume is Annual Average Daily Traffic (AADT). The AADT is the annual average two-way daily traffic volume. It includes both weekday and weekend traffic and represents the total annual traffic for the roadway segment divided by 365. The AADT includes all vehicle classifications.

It should be noted that the AADT used for determining the design ESAL's is the Build Year AADT, or the AADT for the year the improved roadway will be opened to traffic. The Build Year AADT is determined by applying the growth rate to the Data Year AADT.

## Vehicle Classification

Vehicles are classified into three major groups including Light-Weight Vehicles, Single-Unit Vehicles, and Combination Unit Vehicles. Within these major groups are a total of thirteen vehicle classes as defined below. Vehicle classifications are also illustrated in Figure A-1.

***Light-Weight Vehicles (Class 1 through Class 3):***

**Class 1** - Motorcycles: All two or three-wheeled motorized vehicles.

**Class 2** - Passenger Cars: All sedans, coupes, and station wagons manufactured primarily for the purpose of carrying passengers and including those passenger cars pulling recreational or other light trailers.

**Class 3** - Other Two-Axle, Four-Tire Single Unit Vehicle: All two-axle, four-tire, vehicles, other than passenger cars. Included in this classification are pickups, panels, vans, and other vehicles such as campers, motor homes, ambulances, hearses, carryalls, and minibuses. Other two-axle, four-tire single-unit vehicles pulling recreational or other light trailers are included in this classification.

***Single-Unit Vehicles (Class 4 through Class 7):***

**Class 4** - Buses: All vehicles manufactured as traditional passenger-carrying buses with two axles and six tires or three or more axles.

**Class 5** - Two-Axle, Six-Tire, Single-Unit Trucks: All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., with two axles and dual rear wheels.

**Class 6** - Three-Axle Single-Unit Trucks: All vehicles on a single frame including trucks, camping and recreational vehicles, motor homes, etc., with three axles.

**Class 7** - Four or More Axle Single-Unit Trucks: All trucks on a single frame with four or more axles.

***Combination Unit Vehicles (Class 8 through Class 13)***

**Class 8** - Four or Fewer Axle Single-Trailer Trucks: All vehicles with four or fewer axles consisting of two units, one of which is a tractor or straight truck power unit.

**Class 9** - Five-Axle Single-Trailer Trucks: All five-axle vehicles consisting of two units, one of which is a tractor or straight truck power unit.

**Class 10** - Six or More Axle Single-Trailer Trucks: All vehicles with six or more axles consisting of two units, one of which is a tractor or straight truck power unit.

**Class 11** - Five or fewer Axle Multi-Trailer Trucks: All vehicles with five or fewer axles consisting of three or more units, one of which is a tractor or straight truck power unit.

**Class 12** - Six-Axle Multi-Trailer Trucks: All six-axle vehicles consisting of three or more units, one of which is a tractor or straight truck power unit.

**Class 13** - Seven or More Axle Multi-Trailer Trucks: All vehicles with seven or more axles consisting of three or more units, one of which is a tractor or straight truck power unit.

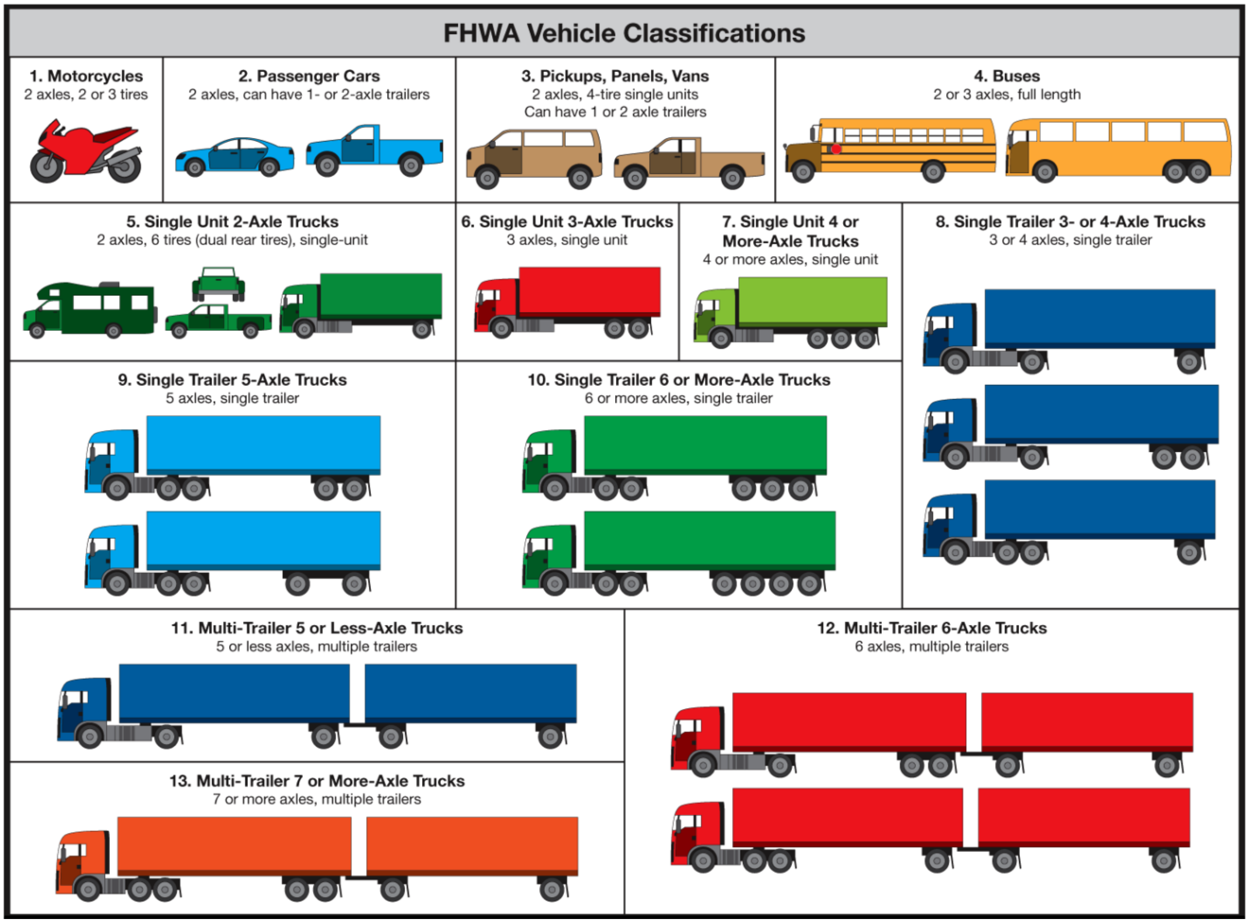



**Figure A-1 FHWA Vehicle Classifications (Source TXDOT Online Manual)**

## Vehicle Class Distribution (VCD)

Vehicles of different size and weight exert different loads onto the pavement structure. Therefore, it is important to know the volume of each vehicle class utilizing the roadway. The distribution of volumes for each vehicle class is known as the vehicle classification distribution (VCD). Ideally, this distribution will come from Weigh-In-Motion (WIM) data for the specific roadway segment in question. However, WIM data may not be readily available and the VCD will need to be determined from other available data.

Since Light-Weight Vehicles (Class 1 though Class 3) exert negligible loads on the pavement structure it is not necessary to distribute these vehicles into their individual classes for purposes of pavement design. Instead, Class 4 through Class 13 vehicles are the classes of primary concern due to their weight and resulting damage to the pavement. In the absence of WIM or other site specific study data, the distribution of Class 4 through Class 13 vehicles is accomplished by utilizing the appropriate truck traffic classification (TTC). The following TTC's were derived specifically for roadways within the State of Arizona and should be used to distribute truck traffic for purposes of pavement design. Currently, ADOT utilizes six different default TTC's to distribute truck volumes as shown in Table A-1.

**Table A-1 Truck Traffic Classifications**

| Truck Traffic Classification (TTC) | | Vehicle Class Distribution (VCD) (Percentage of Trucks Only) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| TTC | % Combo Units | Class 4 | Class 5 | Class 6 | Class 7 | Class 8 | Class 9 | Class 10 | Class 11 | Class 12 | Class 13 | Total |
| AZ-1 | 80 - 100 | 1.8 | 6.5 | 1.9 | 0.2 | 10.3 | 73.2 | 1.0 | 3.1 | 1.9 | 0.1 | 100 |
| AZ-2 | 70 - 79 | 3.1 | 14.7 | 2.9 | 0.1 | 9.3 | 64.4 | 1.3 | 1.9 | 1.5 | 0.8 | 100 |
| AZ-3 | 51 - 69 | 3.7 | 21.3 | 5.7 | 0.4 | 19.0 | 45.6 | 1.7 | 1.5 | 0.7 | 0.4 | 100 |
| AZ-4 | 43 - 50 | 5.3 | 38.6 | 6.2 | 0.2 | 9.0 | 36.9 | 1.8 | 1.3 | 0.3 | 0.4 | 100 |
| AZ-5 | 23 - 42 | 5.3 | 46.3 | 5.7 | 0.7 | 16.1 | 24.1 | 1.1 | 0.3 | 0.1 | 0.3 | 100 |
| AZ-6 | 0 - 22 | 7.8 | 65.8 | 4.4 | 0.2 | 11.7 | 9.1 | 0.7 | 0.2 | 0.0 | 0.1 | 100 |

Note: The above distributions are from ADOT Research Report SPR-672

The appropriate TTC is selected based on the volume of Combination Unit vehicles (Class 8 through Class 13), expressed as a percentage of the total number of trucks (Class 4 through Class 13). The volume of Single-Unit and Combination Unit trucks for all routes on the State Highway System is available through ADOT's MPD.

### Percent Trucks (T Factor)

The Percent Trucks (T Factor) is the percentage of the AADT volume made up of trucks or commercial vehicles. This includes Class 4 through Class 13 vehicles.

### Truck Volumes

The Annual Average Daily Truck Traffic (AADTT) is the total annual average two-way daily truck traffic. It can be calculated by multiplying the AADT by the T Factor. It can also be determined by adding the number of Single-Unit trucks and Combination unit trucks from ADOT MPD data.

### Growth Rate

The growth rate ($r$) is the average annual growth rate for the traffic stream. It can be used to produce a general traffic projection for future years, as well as to determine the growth factor. Traffic projections should be made using the following formula:

$$Future\ AADT = Present\ AADT(1 + r)^n$$

Where $n$ = number of years between the present and future year
$r$ = growth rate expressed as a decimal

Note: For purposes of this design manual, the "$Present\ AADT$" will typically be the most current AADT available. This may also be referred to as the Data Year AADT. The "$Future\ AADT$" will be the projected AADT for the year the project is opened to traffic. This may also be referred to as the Build Year AADT.

Ideally, a growth rate should be assigned separately for each vehicle class. However, this data is seldom available and a single growth rate for all traffic will be used. The growth rate provided by ADOT's MPD should be used unless a project and/or site specific study can substantiate a different rate. The minimum growth rate to be used is 1.0%.

## Growth Factor

The growth factor ($G$) is used to convert an annual traffic volume to a cumulative traffic volume over the design period. The growth factor is based on a compound growth rate over the design period and is calculated using the following formula:

$$Growth\ Factor\ (G) = \frac{(1+r)^Y - 1}{r}$$

Where $Y$ = design period
$r$ = growth rate expressed as a decimal

## Directional Distribution Factor ($D_D$) and Lane Distribution Factor ($D_L$)

If traffic volumes represent the total for all lanes and both directions of travel, they must be distributed by direction and by lanes for design purposes. The directional distribution factor ($D_D$) is normally assumed to be 50% unless site specific traffic data warrants some other distribution. ADOT's MPD has positive and negative direction AADT available for some roadway sections that can be used to determine the directional distribution factor. (Note: The "D-Factor" values provided by ADOT's MPD are not the same as the directional distribution factor and are not to be used for this purpose.)

The percentage of trucks using the design lane is known as the lane distribution factor ($D_L$) and is primarily a function of the number of lanes available. Lane distribution factors to be used for all pavement design work on ADOT projects are shown in Table A-2.

**Table A-2 Lane Distribution Factors ($D_L$)**

| Number of Lanes in the Design Direction | Lane Distribution Factor ($D_L$)[1] | | | | |
|---|---|---|---|---|---|
| | New Construction, Widening & Re-construction[2] | Rehabilitation Lane 1 | Rehabilitation Lane 2 | Rehabilitation Lane 3 | Rehabilitation Lane 4[3] |
| 1 | 100% | 100% | N/A | N/A | N/A |
| 2 | 90% | 40% | 90% | N/A | N/A |
| 3 | 80% | 40% | 80% | 80% | N/A |
| 4 or more | 70% | 40% | 40% | 70% | 70% |

Notes: 1. These $D_L$ factors are to be considered minimum values for design. Larger factors should be used when site and/or project specific data is available to warrant their use.
2. For new construction, widening, and re-construction projects, all travel lanes (including auxiliary lanes and high occupancy vehicle lanes) will be designed using the same $D_L$.
3. For rehabilitation projects with more than 4 lanes, the two rightmost through lanes will be designed with a $D_L$ of 70%. All lanes to the left of these two lanes will be designed with a $D_L$ of 40%.

Traffic estimates can be difficult to obtain for ramps, crossroads, frontage roads, rest areas and parks. Therefore, these facilities are generally designed using a percentage of the total mainline one-way ESAL's. Table A-3 provides minimum percentages to be used on ADOT projects. These values should be used unless traffic data indicates a higher value is warranted.

**Table A-3 Design ESAL's for Ramps, Crossroads, Frontage Roads, Rest Areas and Parks**

| Facility Type | Percent of Mainline ESAL's (minimum) |
|---|---|
| Ramps | 10% |
| Crossroads | 5% |
| Frontage Roads, Rest Areas and Parks | 1% |

### Truck Load Factor ($T_{LF}$)

A truck load factor ($T_{LF}$) is defined as the average number of ESAL's applied to a pavement for each application of a given vehicle class. It is used to convert the application of a single vehicle of a given class to an equivalent number of ESAL's. Truck load factors vary depending on a wide range of variables including the number and spacing of axles, axle weights, pavement type (flexible vs. rigid), pavement thickness, route, etc. For pavement design on ADOT projects, truck load factors are selected based on pavement type and roadway functional classification. Pavement type is important because the damaging effect of a load is different for a flexible pavement and a rigid pavement. Roadway functional classification is important because average truck loads vary by roadway type (i.e. Interstate, Freeway/Expressway, Minor Collector, etc.).

A typical functional classification map is shown in Figure A-2. For design purposes, more current and detailed maps are required and are available at http://www.azdot.gov/maps/functional-classification-maps. The more detailed maps are particularly important to determine functional classification boundaries as well as to distinguish between urban and non-urban (i.e. rural) areas.

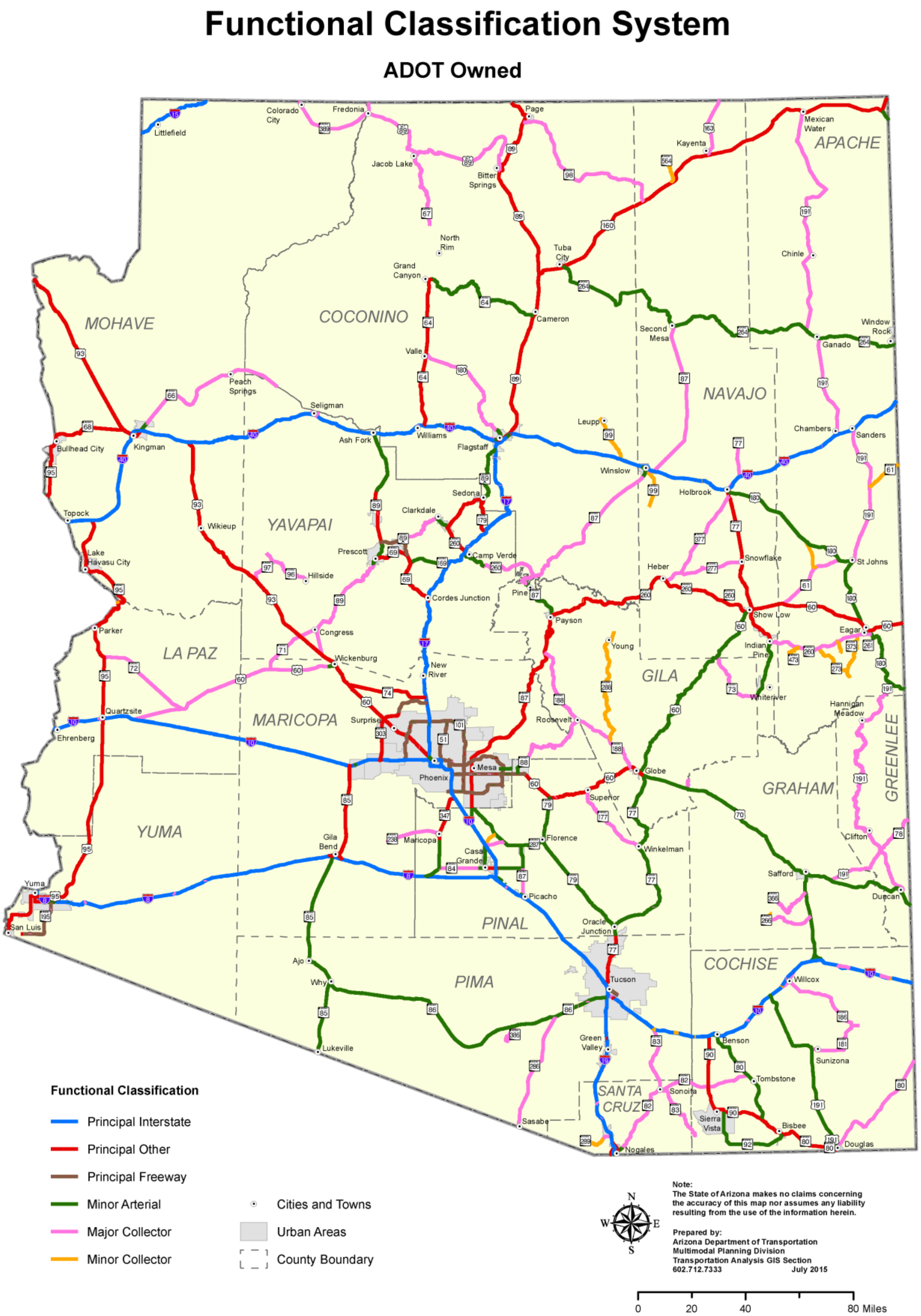



**Figure A-2 Typical Functional Classification Map**

For pavement design purposes, roadway functional classifications have been grouped into three clusters which are known to have similar truck load factors. Truck load factor clusters to be used for all pavement design work on State highways are shown in Table A-4.

**Table A-4 Truck Load Factor Clusters**

| Roadway Functional Classification | Cluster Number | |
|---|---|---|
| | Rural | Urban |
| Principal Arterial (Interstate) | 1 | 1 |
| Principle Arterial (Freeway/Expressway) | N/A | 2 |
| Principal Arterial (Other) | 3 | 2/3* |
| Minor Arterial | 2 | 2/3* |
| Major Collector | 2 | N/A |
| Minor Collector | 2 | N/A |

* Designer to evaluate Cluster 2 and 3. Final design should be based on the cluster that results in the most ESAL's.

Once the truck load factor cluster is determined the truck load factors are selected from Table A-5 or Table A-6.

**Table A-5 Truck Load Factors for Flexible Pavements**

| **Truck Load Factors (Flexible Pavement)** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cluster 1 | | | | | | | | | | |
| Class 1-3 | Class 4 | Class 5 | Class 6 | Class 7 | Class 8 | Class 9 | Class 10 | Class 11 | Class 12 | Class 13 |
| 0.0008 | 1.07 | 0.33 | 0.64 | 0.58 | 0.61 | 1.62 | 1.43 | 1.75 | 1.31 | 3.51 |
| Cluster 2 | | | | | | | | | | |
| Class 1-3 | Class 4 | Class 5 | Class 6 | Class 7 | Class 8 | Class 9 | Class 10 | Class 11 | Class 12 | Class 13 |
| 0.0008 | 1.06 | 0.39 | 0.96 | 0.61 | 0.91 | 1.34 | 1.53 | 1.96 | 1.33 | 3.50 |
| Cluster 3 | | | | | | | | | | |
| Class 1-3 | Class 4 | Class 5 | Class 6 | Class 7 | Class 8 | Class 9 | Class 10 | Class 11 | Class 12 | Class 13 |
| 0.0008 | 1.20 | 0.13 | 0.86 | 0.64 | 0.52 | 1.93 | 1.78 | 2.25 | 1.17 | 2.07 |

**Table A-6 Truck Load Factors for Rigid Pavements**

| **Truck Load Factors (Rigid Pavement)** | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Cluster 1 | | | | | | | | | | |
| Class 1-3 | Class 4 | Class 5 | Class 6 | Class 7 | Class 8 | Class 9 | Class 10 | Class 11 | Class 12 | Class 13 |
| 0.0008 | 1.29 | 0.30 | 0.82 | 0.80 | 0.62 | 2.35 | 2.32 | 1.61 | 1.19 | 5.53 |
| Cluster 2 | | | | | | | | | | |
| Class 1-3 | Class 4 | Class 5 | Class 6 | Class 7 | Class 8 | Class 9 | Class 10 | Class 11 | Class 12 | Class 13 |
| 0.0008 | 1.26 | 0.36 | 1.31 | 0.85 | 1.00 | 1.96 | 2.46 | 1.90 | 1.19 | 5.74 |
| Cluster 3 | | | | | | | | | | |
| Class 1-3 | Class 4 | Class 5 | Class 6 | Class 7 | Class 8 | Class 9 | Class 10 | Class 11 | Class 12 | Class 13 |
| 0.0008 | 1.48 | 0.12 | 1.15 | 0.90 | 0.55 | 2.80 | 2.94 | 2.09 | 1.12 | 3.20 |

## Design ESAL'S Calculation

The process of calculating the total design ESAL's is described as follows. First, the Build Year AADT is calculated from the Data Year AADT using the appropriate growth rate and formula. The Build Year AADT is then distributed into individual vehicle classifications. These daily volumes are then multiplied by the growth factor and 365 to determine the total number of vehicles in each vehicle class over the design period. These class totals are then multiplied by the appropriate truck load factor and summed to determine the total ESAL's for the roadway segment. The design ESAL's are then determined by multiplying the total ESAL's by the directional distribution and lane distribution factors. This process is best illustrated by the formula below as well as the worksheet shown in Figure A-3.

$$Design\ ESAL's = \sum_{c=1}^{13} \{(AADT_c)(G_c)(365)(T_{LFc})\} \times (D_D)(D_L)$$

Where $AADT_c$ = Traffic Volume for each vehicle class
$G_c$ = Growth Factor for each vehicle class
$T_{LFc}$ = Truck Load Factor for each vehicle class
$D_D$ = Directional Distribution Factor
$D_L$ = Lane Distribution Factor

| | C | D | E | F | G | H | I | J | K | L | M | N | O | P |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | Design ESAL Calculation Worksheet | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | |
| 5 | TRACS: | H586501C | | Project No. | 040-D(230)T | | | | Project Name: | I-40 County Line - Minnetonka | | | | |
| 6 | Route: | I40 | BMP: | 250.24 | Design Life (years): | | 10.0 | | Functional Class: | Rural Principle Arterial (Interstate) | | | | |
| 7 | | | EMP: | 259.00 | Growth Rate (%): | | 1.5 | | Pavement Type: | Flexible | | | Cluster Number: | 1 |
| 8 | | | | | | | | | | | | | | |
| 9 | | | | | | | Percent Trucks | | | | | | | |
| 10 | | | | | Truck Volumes | | (% of total AADT) | | (% of total AADTT) | | | | | |
| 11 | | | | | Singles | Combos | Singles | Combos | Singles | Combos | TTC | | | |
| 12 | AADT | 2012 | 17,876 | Data Year | 1758 | 6901 | 9.83% | 38.60% | 20% | 80% | AZ-1 | | | |
| 13 | AADT | 2015 | 18,693 | Build Year | | | | | Select appropriate TTC from Table A-1 using % Combos above | | | | | |
| 14 | | | | | | | | | | | | | | |
| 15 | | | | | | | | | | | | | | |
| 16 | | | | | | | | | | | | | | |
| 17 | Vehicle Class | | 1 - 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | Total |
| 18 | Distribution (%) | | N/A | 1.8 | 6.5 | 1.9 | 0.2 | 10.3 | 73.2 | 1.0 | 3.1 | 1.9 | 0.1 | 100.0 |
| 19 | Class Volume (daily) | | 9,640 | 163 | 588 | 172 | 18 | 932 | 6626 | 91 | 281 | 172 | 9 | 18692 |
| 20 | Growth Factor (G) | | 10.70 | 10.70 | 10.70 | 10.70 | 10.70 | 10.70 | 10.70 | 10.70 | 10.70 | 10.70 | 10.70 | |
| 21 | Class Volume (total) | | 37649020 | 636597 | 2296434 | 671746 | 70299 | 3639926 | 25877843 | 355401 | 1097446 | 671746 | 35150 | |
| 22 | Truck Load Factor ($T_{LF}$) | | 0.0008 | 1.07 | 0.33 | 0.64 | 0.58 | 0.61 | 1.62 | 1.43 | 1.75 | 1.31 | 3.51 | |
| 23 | Class ESAL's | | 30119 | 681159 | 757823 | 429917 | 40773 | 2220355 | 41922106 | 508223 | 1920531 | 879987 | 123377 | 49,514,370 |
| 24 | | | | | | | | | | | Total Number of Trucks | | | 35,352,588 |
| 25 | | | | | | | | | | | Directional Distribution Factor ($D_D$) | | | 0.50 |
| 26 | | | | | | | | | | | Lane Distribution Factor ($D_L$) | | | 0.90 |
| 27 | | | | | | | | | | | Design ESAL's | | | 22,281,467 |

Notes:

1) Shaded cells are user input values. Data in light blue cells will generally come from ADOT's MPD published sources. All other cells are calculated values.
2) All values are rounded to the number of decimal places shown in each cell.
3) Cell E13 (Build Year AADT) calculated using traffic projection equation, Future AADT = Present AADT x $(1 + r)^n$
4) Cell I12 = G12 / E12. Cell J12 = H12 / E12
5) Cell K12 = I12 / (I12 + J12). Cell L12 = J12 / (I12 + J12)
6) Row 18 is populated with VCD data (Class 4 through 13) from Table A-1. Proper TTC is selected based on the % Combos from Cell L12.
7) Cell E19 = E13 x {1 - [(I12 + J12) / 100]}. Cell F19 = (E13 - E19) x (F18 / 100), Cells G19 through O19 similar.
8) Cell E20 through O20 calculated using the growth factor equation.
9) Cell E21 = E19 x E20 x 365. Cells F21 through O21 similar.
10) Row 22 is populated with Truck Load Factors from Table A-5 (Flexible Pavement) or Table A-6 (Rigid Pavement).
11) Cell E23 = E21 x E22. Cells F23 through O23 similar.
12) Cell P24 = Sum of F21 through O21
13) Cell P27 = P23 x P25 x P26

**Figure A-3 Design ESAL Calculation Worksheet**

## APPENDIX B – PAVEMENT DESIGN FOR FROST ACTION

Frost action involves the formation of ice within or below the pavement section. Depending on site conditions, including availability of water, ice crystals can grow into ice lenses through capillary rise. These ice lenses then thicken or expand until the water supply is depleted or the ice lenses are below the frost line.

Frost action can cause damage to pavements in two different ways. The first way is frost heave, which involves an upward movement of the pavement due to the expansion of water as it freezes. Frost heave is most likely to be differential resulting in pavement damage in the form of cracks and roughness. The second way frost action can cause damage is by thaw weakening. Thaw weakening occurs as ice melts leaving a temporary water-filed void with little or no bearing strength in the material. Thaw weakening can result in subgrade strength reductions of 40 to 75 percent depending on material type. This strength reduction can result in premature fatigue cracking during the spring season.

In order for ice lenses to form, the following conditions must be present:

1. Frost susceptible material (significant amount of fines)
2. Prolonged freezing temperature
3. Adequate supply of water (i.e. high soil water content, shallow groundwater, surface water infiltration, etc.)

Frost action can be prevented by eliminating any of the conditions listed above. The most straightforward way to prevent frost action is to design a pavement section that includes non-frost susceptible materials to the depth of frost penetration.

Depth of frost penetration is related to the freezing index. Figure B-1 shows Arizona freezing index values representing the average of the four coldest winters between 1931 and 1970. This figure should be used to estimate the depth of frost penetration using the following formula.

$$D_F = (FI)^{0.5}$$

$D_F$ = Depth of frost penetration in inches

$FI$ = Freezing index from Figure B-1

For purposes of pavement design, all highways constructed within an area of the state with some freezing index shall consist of non-frost susceptible materials. These materials include pavement, bound and unbound bases, and other materials with no more than ten (10) percent passing the number 200 sieve.

Typically, non-frost susceptible materials should extend to the full depth of frost penetration. If constraints such as utilities, drainage, traffic access, etc., prohibit the construction of a completely frost free structural section, then the thickest section practical should be built.

A pavement thickness less than the depth of frost penetration may be appropriate in cases where past performance indicates that frost action is not a problem. To justify this approach, consideration must be given to the performance of existing pavements in the vicinity of the project with similar soil and water supply conditions. If the long term (i.e. 20+ years) performance of these pavements has been satisfactory, with no evidence of frost related damage, the depth of non-frost susceptible materials need not exceed that of the existing well performing pavements. When reviewing the long term performance of a pavement, consideration should be given to potential damage caused by both frost heave as well as subgrade weakening during the spring thaw.

**FREEZING INDEX**

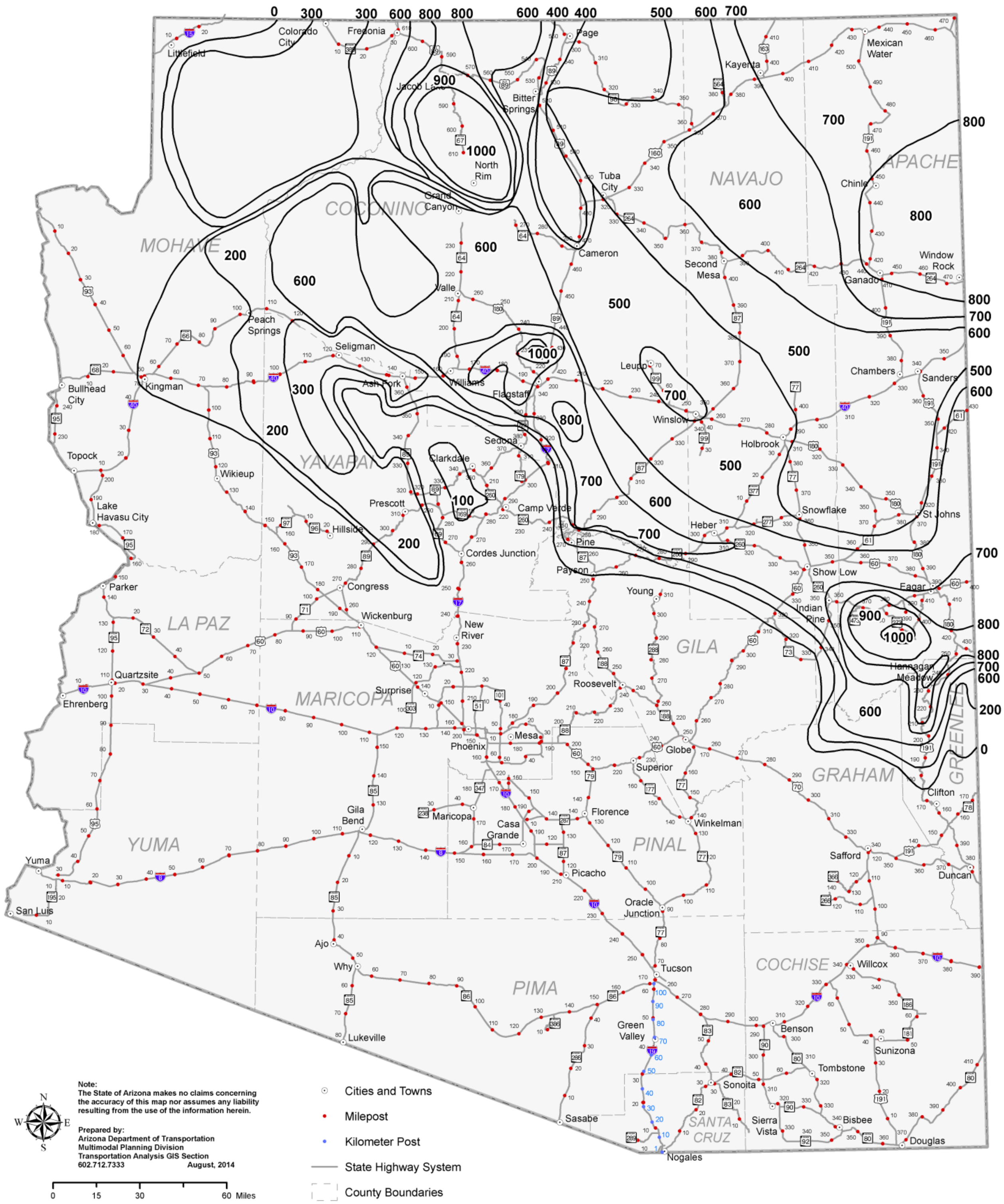



**Figure B-1 Freezing Index Map**