Pavement Design Guide: A Short Course

Kentucky Transportation Center
PAVEMENT DESIGN GUIDE
A SHORT COURSE

For Projects
Off The National Highway System,
less than 20,000,000 ESAL's, less than 15,000 ADT,
and less than 20% trucks

Developed By
Kentucky Transportation Center

for
Kentucky Transportation Cabinet
Division of Highway Design

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Purpose and Scope

The purpose of this short course is to provide information to the registered engineer (with no previous background in pavement design or pavement technology) on the structural design of pavements. Included in this course is a summary of background information on the materials used in pavement construction and on the history and evolution of pavement design. Included with this course is an updated Design Guide or catalog to be used for designing new pavements in Kentucky. The intent of the guide or catalog is to provide the roadway designer with a simplified, straightforward methodology for developing structural designs of pavements.

The methodology as presented herein has roots in both the AASHTO Guide for Design of Pavement Structures and also the Kentucky mechanistic-empirical pavement design systems which are used for structural design of pavements in Kentucky. The procedure as presented herein uses an AASHTO structural number concept to define the structural requirements of the pavement section. However, the minimum required structural number has been determined on the basis of the Kentucky mechanistic-empirical pavement design procedure.

The pavements that are to be designed by the information presented in this course and the accompanying design guide are to be limited to:

- Pavements off the National Highway System,
- Pavements with less than 20,000,000 EASL's per 20 years in the design lane,
- Pavements with less than 20% trucks,
- Pavements with less than 15,000 Average Daily Traffic.

Presentation of Material

It is assumed that the participant has no knowledge of pavement technology and/or pavement design procedures. Therefore, the material begins with elementary principles and definitions. The material is presented in seven parts which can be classified into five general categories:

Definitions — Part I,
Materials — Part II, Part III, and Part IV,
Overview of Design — Part V,
Pavement Failure Mechanisms — Part VI,
Design Catalog — Part VII.
Course Manual

A manual accompanies the short course. Included in the manual are the following items:

1. A black-and-white copy of all the slides presented in this course,
2. The Design Catalog,
3. Applicable Standard Drawings, specifications, and special notes.

Course Notes

The slides are normally printed three to a page; however, when charts or graphs are shown that contain an appreciable amount of detail, they are then printed two per page or one per page. The pages that have three slides per page also have space provided by each slide for the participant to write notes.

At the beginning of each part, the objectives for that part are listed, as well as the topics to be discussed in that part. Pertinent comments relating to topics to be discussed in a particular part are also listed in the beginning of the section.

Computer Programs

Included with this short course is a CD-ROM that contains a full-color version of all the slides presented in this course. In addition, the CD-ROM contains an EXCEL spreadsheet program that calculates the life-cycle costs for a particular design project. The CD-ROM also contains an ACCESS program to calculate ESAL forecasts. Both programs will be demonstrated during the course.
Part I: Pavement Design Definitions

Objectives:

To familiarize the participant with all of the components of a pavement structure.

To define the major methods or philosophies of pavement design.

To define and discuss the traffic parameters necessary to design pavement structures.

Topics:

1. Pavement Design Definitions
   A. Components of a Pavement System
      1. Subgrade
      2. Base
      3. Surface
      4. Portland Cement Concrete
   B. Design Concepts and Terminology
      1. Empirical
      2. Mechanistic
      3. Mechanistic-Empirical (Kentucky Method)
   C. Traffic Parameters
      1. Average Daily Traffic (ADT)
      2. Percent Trucks
      3. Axle/Wheel Loads
      4. Load Equivalencies
      5. Equivalent Single Axleloads (EASL)
      6. Functional Class

Comments:

A pavement is an engineered structure designed to transmit loads from vehicle tires to the soil or rock subgrade. Pavements are normally of multilayer construction with relatively weaker materials below and progressively stronger ones above. Such an arrangement leads to the economic use of available materials. Flexible pavements usually consist of several layers starting with the unbound base on the subgrade (i.e. dense-graded aggregate), one or more courses of bound base, and finally the riding surface. Rigid pavements usually consist of two layers — the concrete slab and the unbound base layers. Modern pavements will often have a bound drainage layer immediately above the unbound base.
A number of different empirical methods of pavement design have been developed during the last 60 years. Most are based on observations of the performance of existing roads under a variety of traffic conditions. In this country, large test tracks using a variety of pavement structures have been trafficked with specific vehicle types operating with known axle loads. This has given valuable understanding of the relative damaging effect of different axle loads on a variety of pavements constructed to different thicknesses. These experiments have provided the basis for the design procedures used in many parts of the country. These are all empirically based procedures.

Concurrently with the development of empirical design methods, work has been in progress relating to a more fundamental design procedure based on structural theory and the behavior of road material under repeated stress. These procedures are referred to as mechanistic design. At present, the theoretical approach is proving most useful in interpreting and extending the conclusions reached from experimental pavement research. Kentucky’s pavement design method currently follows this latter approach, and is called a mechanistic-empirical procedure.

Traffic information is required by the pavement designer to associate the damaging effects of the applications of an axle of any load applied to the pavement. The term equivalent single axle load is used in pavement design methodologies to describe the relative amount of damage done to the pavement. The most common expression of pavement damage is the 18,000-pound (80 kN) equivalent single axle load. Load equivalency factors (pavement damage factors) are used to describe the relative amount of damage for a specific axle loading and axle configuration in terms of the amount of damage done to the pavement by some number of equivalent 18,000-pound axle loads. It should be noted that relationships between load equivalency factors (pavement damage factors) and load is not a linear relationship. Load equivalency factors are calibrated to specific pavement design procedures. For example, the load equivalency factors for the AASHTO Guide for Design of Pavement Structures are different from the load equivalency factors used with the Kentucky Mechanistic-Empirical Pavement Design Procedure which are different from the load equivalency factors used with the Asphalt Institute Thickness Design Asphalt Pavements For Highways & Streets (MS-1). Also, load equivalency factors used for the design of flexible pavements (asphalt concrete) are different from the load equivalency factors used for rigid pavements (Portland cement concrete) for some pavement design procedures. For example, the load equivalency factors for the AASHTO Guide For Design of Pavement Structures include separate load equivalency factors for flexible pavements and for rigid pavements. Conversely, the mechanistic-empirical pavement design procedures developed in Kentucky have been calibrated on the basis of load equivalency factors used for flexible pavements.
There are four key considerations which influence the accuracy of traffic estimates and which can significantly influence the life cycle of a pavement. These are:

1. The correctness of the load equivalency values used to estimate the relative damage influenced by axle loads of different mass and configurations.

2. The accuracy of traffic volume and weight information used to predict the actual loading projections.

3. The prediction of ESAL’s over the design period.

4. The interaction of age and traffic as it relates to the functional and structural deterioration of the pavement and related changes in pavement serviceability.

Forecasting of ESAL’s is perhaps the most critical aspect of pavement design since it involves forecasting not only the growth in traffic volumes for a particular route but also forecasting the change in the characteristics of vehicles in the traffic stream. For example, during the past twenty years, there has been significant growth in traffic volumes and proportions of trucks in the traffic stream for most major routes. At the same time, the sizes and weights of trucks in the traffic stream have also increased. As a result, many pavements have deteriorated more rapidly than expected because the combination of increased traffic volumes, growth in proportions of trucks, and increases in sizes and weights of trucks.

A computer program to calculate ESAL forecasts is included with this manual. The program will be demonstrated during the course of this study. Further details on ESAL forecasting is included in the Design Guide accompanying this manual.
Principles of Pavement Design

Pavement Design Definitions

Pavement:
- An Engineered Structure Designed to Support Traffic Loads and to Distribute Those Loads to the Roadbed.
Definitions

Subgrade

Top Surface of a Roadbed Upon Which the Pavement Structure and Shoulders are Constructed
Subgrade
- Lowest Member
- Must Support Load
- Considered Top 24”
- Can Be Soil or Rock
- Can Be Modified

Definitions

Base Courses

The layer of specific, selected materials of designed thickness placed on a subgrade to support a surface course.

Pavement Cross Section

Unbound Base Courses
**Unbound Base Materials**

- Immediately Above Subgrade
- Economical Strength
- Provide a Working Platform
- Can Provide Drainage
- Act as a Separation Layer
- Various Gradations

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**Asphalt Base Courses**

- Provide Most of Pavement Strength
- Can Provide Drainage
Asphalt Binder Courses

- Finer Gradation Than Bases
- Coarser Than Surfaces
- Used in Leveling and Wedging

Definitions
Surface Course

The Layers of a Pavement Structure Designed to Accommodate the Traffic Load and Which Resists Skidding, Traffic Abrasion, and the Disintegrating Effects of Climate. Also Called "Wearing Course."
Surface Course

- Top Layer
- Riding Surface
- Thin Lifts
- Finest Gradation

Definitions
Portland Cement Concrete Pavement

A Pavement Structure Which Distributes Loads to the Subgrade
Having as One Course a Portland Cement Slab of Relatively High Bending Resistance

PCC Pavements

- Also Called Rigid or PCC
- A Coarse Aggregate, Fine Aggregate and Portland Cement Mixture
- Usually a Higher Initial Cost But a Lower Maintenance Cost
- Usually Jointed
Definitions

Design Concepts and Terminology

Empirical:
Relying on Experience and/or Observation only without Regard to a System or Theory

Mechanistic:
Based on a Theoretical System such as Layer Elastic Theory or Finite Elements Models
Mechanistic - Empirical

Based on a Theoretical System and Adjusted or Calibrated by Empirical Means (Kentucky Method)

Layer Coefficient

Expresses the Empirical Relationship Between the Structural Number and Layer Thickness, and is a Measure of the Relative Ability of the Material to Function as a Structural Component of the Pavement

Structural Number

An index number derived from an analysis of traffic, roadbed soil conditions, and environment which may be converted to thickness of flexible pavement layers through the use of suitable layer coefficients related to the type of material being used in each layer of the pavement structure.
Definitions

**Average Daily Traffic**

The total volume during a given time period (in whole days) greater than one day and less than one year, divided by the number of days in that period.

**Obtaining ADT**

- Vehicle Classification Recorders (VCR)
- Automatic Traffic Recorders (ATR)
- Tube Counts (Volume Only)
- Visual Counts
- Weigh-in-Motion (WIM)
### Vehicle Types

- 1. Motorcycles
- 2. Cars
- 3. Pickup Trucks
- 4. Buses
- 5. 2-Axle, 6-tire, Single Unit
- 6. 3-Axle, Single Unit
- 7. 4 or More Axles, Single Unit
- 8. 4 or Less Axles, Single Trailer
- 9. 5-Axle, Single Trailer
- 10. 6 or More Axles, Single Trailer
- 11. 5 or Less Axles, Multi-Trailer
- 12. 6-Axle, Multi-Trailer
- 13. 7 or More Axle, Multi-Trailer

### Percent Trucks

The Ratio of the Number of Trucks to the Total Number of Vehicles in the Traffic Stream, Expressed as a Percentage

### Importance of Percent Trucks

- Determines Pavement Loads, Hence Pavement Thickness
- Helps to Determine Highway Capacity
- In a Life-Cycle Cost Analysis, It's Important in Calculating User Delay Cost
Lane Distribution Factor

The percent of total vehicles or one vehicle type (in one direction) in a particular lane of a multi-lane facility

Axle/Wheel Loads

Wheel Load

-Load in Pounds or Kilos on Each Wheel

-Wheel Load / Tire Pressure Equals Tire Contact Area
Axle Load

Equivalent Single Axle Load

(ESAL)

ESAL:
The amount of damage done to a pavement structure by a 4-tired, single axle, carrying 18,000 pounds.
Load Equivalencies

**Load Equivalency Factor (LEF)**

(Also Called Damage Factor)

The Damage Produced by an Expected Axle Load Converted to an Equivalent Number of 18-kip Single Axle Loads

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**Damage Factors for Various Truck Types**

- Type 10
- Type 9
- Type 7
- Type 6

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**Tandem:**
*Two Closely Spaced Axles*

**Tridem:**
*Three Closely Spaced Axles*

**Functional Class**
The classification of highways into different operational systems based on the character of service they provide

Environment:
* Urban
* Rural

Hierarchy:
* Local
* Collector
* Arterial
Kentucky Functional Classes

- 01 - Rural Interstate
- 02 - Rural Principal Arterial
- 06 - Rural Minor Arterial
- 07 - Rural Major Collector
- 08 - Rural Minor Collector
- 09 - Rural Local
- 11 - Urban Interstate
- 12 - Urban Other Freeways/Expressways
- 14 - Urban Other Principal Arterial
- 16 - Urban Minor Arterial
- 17 - Urban Collector
- 19 - Urban Local
Part II: Foundation (Geotechnical) Parameters

Objectives:

To understand the important role the subgrade plays in the life and performance of a pavement structure.

To familiarize the participant with the various methods of measuring subgrade strength.

To discuss the methods of stabilization or modification of weak subgrades.

To discuss the importance of drainage to the performance of a pavement structure.

Topics:

II. Foundation (Geotechnical) Parameters
   A. Measuring Subgrade Strength
      1. CBR Laboratory Testing Methods (AASHTO, ASTM, KY)
      2. In-situ Method
      3. Resilient Modulus Laboratory Testing Procedure
   B. Subgrade Stabilization
      1. Criteria for Stabilization
      2. Methods of Stabilization
   C. Structural Parameters
   D. Pavement Drainage

Comments:

The material property used to characterize the roadbed soil for pavement design is the Kentucky CBR. Details for testing for the Kentucky CBR are presented in the current Edition of the Kentucky Methods (KM 64-501). Generally, the California Bearing Ratio (CBR) was originally developed by the California Division of Highways for evaluation of subgrade quality. The test has been refined, modified, and adapted by others and today is the most common test conducted on soils to define the structural quality of subgrade soils for pavement design. The methods for performing the test are discussed in detail in this section.

Subgrades typically are constructed of soils from roadway excavation or borrow. However, subgrades also may be composed of rock. Rock subgrades may exclude shale, include shale
with other rock types, or be constructed entirely of shale. Rock roadbed is utilized for the top two feet of the roadway when sufficient quantities of suitable rock are available from roadway excavation.

Shales are cemented or non-cemented sedimentary deposits of various chemical composition in which the constituent particles are 0.75 mm in diameter and includes siltstone, claystone, and mudstone. Shales are classified according to Slake Durability Index (SDI) results. Sedimentary shale deposits are frequently interbedded with thin sections of carbonates or arenaceous (sandy) partings which can produce distorted SDI values. Jar slake tests typically are performed to provide additional information about rock disintegration to compare with SDI results. A table is included in the Design Guide that illustrates typical ranges of estimated CBR values for a range of material types. The design CBR also may be estimated on the basis of soil classifications. A table is also included in the Design Guide for estimating design CBR.

The majority of pavements constructed in Kentucky are constructed on fine grained soils. When first compacted, these fine grained soils usually have sizeable bearing strength. If pavements are constructed immediately after compaction of fine grained soils, then major problems typically will not be encountered when placing and compacting layers of paving materials. Problems arise however, when surface and subsurface water penetrates compacted fine grained soils. Water from rainfall, snow melt, and groundwater seepage enters the fine grained soil subgrades, causing swelling, and producing a loss of bearing capacity in the subgrade.

Recent experience in Kentucky has demonstrated the benefits of stabilized subgrades for providing a stable platform for placement of pavement layers and also for extending the life of the pavement structure. Methods for stabilization may be characterized into two broad categories: mechanical stabilization and chemical stabilization. These methods and the warrants for stabilization are discussed in this section. More detailed information on stabilization is given in the Design Guide.

It has been demonstrated in recent years that pavement drainage is a critical factor in a pavement’s performance. Kentucky has been using positive drainage systems on major highways for almost three decades. In general, water in pavements may be treated in one of three ways:

1. Prevent water from entering pavement.
2. Provide a drainage system to remove excess water from the pavement system.
3. Construct the pavement sufficiently strong to resist the combined effects of loadings and moisture.

Kentucky’s guidelines are generally founded on the belief that water will enter the pavement structure. Free water may be removed from the pavement system by daylighting the aggregate base and/or by subsurface piping system. The use of filter materials is required to prevent clogging of the free-draining aggregate base. Where daylighting is not possible or recommended, pipe or strip drains are to be used.
The following are warrants for use of underdrain systems:

1. For annual ESAL accumulations of 250,000 or less, daylighting of the base will be required except in cut sections or other geometries which make daylighting inappropriate. In these areas, a closed drainage network will be provided.

2. For annual ESAL's greater than 250,000, daylighting will not be permitted. A closed drainage network will be provided.

3. Open graded free draining aggregate bases will be required for all pavements in urban areas. A closed drainage system that drains into a storm sewer will be required for all urban pavement sections.
II

Foundation Parameters

Measuring Subgrade Strength

California Bearing Ratio Test (CBR)
- AASHTO
- ASTM
- Kentucky Method
CBR:
Developed by the California Division of Highways in 1929 to Classify the Suitability of Soil for Use as a Subgrade

CBR: Definition
CBR defined as the ratio of the unit load (psi) required to produce a certain depth of penetration with the penetration piston (area of 3.0 sq. in.) into a compacted specimen of soil at some water content and density to the standard unit load required to obtain the same depth of penetration on a standard sample of crushed stone

\[ CBR = \frac{\text{Test unit load}}{\text{Standard unit load}} \times 100 \]

<table>
<thead>
<tr>
<th>Penetration (in.)</th>
<th>Standard Unit Load (psi)</th>
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<tbody>
<tr>
<td>0.1</td>
<td>1,000</td>
</tr>
<tr>
<td>0.2</td>
<td>1,500</td>
</tr>
<tr>
<td>0.3</td>
<td>1,900</td>
</tr>
<tr>
<td>0.4</td>
<td>2,300</td>
</tr>
<tr>
<td>0.5</td>
<td>2,600</td>
</tr>
</tbody>
</table>
Comparison of CBR Testing Procedures

ASTM D1883
AASHTO T 193
KM 64 - 501

CBR Compaction

ASTM
AASHTO

- STANDARD
  - Three Layers
  - 56 Blows / Layer
  - 5.5 lb. Hammer
- MODIFIED
  - Five Layers
  - 56 Blows / Layer
  - 10 lb. Hammer

Kentucky Method
- The compaction plunger is inserted into the mold on the specimen and a pressure of 2,000 psi is applied gradually over a 2-min. interval. When the maximum load is reached, it is held for approximately 1 minute.
**CBR Soaking Time**

<table>
<thead>
<tr>
<th>ASTM AASHTO</th>
<th>Kentucky Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Soak in the water tank for 96 hours.</td>
<td></td>
</tr>
<tr>
<td>• Swell readings taken daily.</td>
<td></td>
</tr>
<tr>
<td>• Swell is complete when two successive 24-hour readings differ by no more than 0.003 in.</td>
<td></td>
</tr>
<tr>
<td>• Minimum swell time must be 72 hours.</td>
<td></td>
</tr>
</tbody>
</table>

**CBR Load Intervals**

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<thead>
<tr>
<th>ASTM AASHTO</th>
<th>Kentucky Method</th>
</tr>
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<tbody>
<tr>
<td>• 0.025</td>
<td>• 0.025</td>
</tr>
<tr>
<td>• 0.050</td>
<td>• 0.059</td>
</tr>
<tr>
<td>• 0.075</td>
<td>• 0.075</td>
</tr>
<tr>
<td>• 0.100</td>
<td>• 0.100</td>
</tr>
<tr>
<td>• 0.150</td>
<td></td>
</tr>
<tr>
<td>• 0.200</td>
<td>• 0.200</td>
</tr>
<tr>
<td>• 0.300</td>
<td>• 0.300</td>
</tr>
<tr>
<td>• 0.400 (Optional)</td>
<td>• 0.400</td>
</tr>
<tr>
<td>• 0.500 (Optional)</td>
<td>• 0.500</td>
</tr>
</tbody>
</table>

**Penetration Values at Which CBR is Calculated**

<table>
<thead>
<tr>
<th>ASTM AASHTO</th>
<th>Kentucky Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>• 0.10</td>
<td></td>
</tr>
<tr>
<td>• If 0.20 is greater rerun test.</td>
<td></td>
</tr>
<tr>
<td>• If 0.20 is greater the second time, use 0.20.</td>
<td></td>
</tr>
<tr>
<td>• The minimum CBR value calculated at the five penetration values of 0.10, 0.20, 0.30, 0.40, 0.50</td>
<td></td>
</tr>
</tbody>
</table>
SUBGRADE COMPACTION

Soil Suction

Negative Pore Pressure

Dry of Optimum

Wet of Optimum

Moisture Content

Sheepfoot Rolling

Density

Optimum Moisture

MOISTURE

DENSITY

COMPACTION CONDITIONS

COMPACTION CONDITIONS

Optimum Moisture
Apparent Cohesion

PROCESS OF SATURATION OF TOP LAYER OF SUBGRADE

Resilient Modulus ($M_r$)

Laboratory Testing Procedure
Resilient Modulus

\[ M_r = \frac{S_d}{E_r} \]

Where:
- \( S_d \) = deviator stress = \( s_1 - s_3 \)
- \( s_1 \) = vertical stress
- \( s_3 \) = horizontal stress
- \( E_r \) = resilient strain

Subgrade Stabilization

- High Moisture Content
- High Clay Content
- Low CBR

Criteria for Stabilization

- \( CBR < 6 \) -- Recommended
- \( CBR > 6 \) -- No
Methods of Stabilization

- Mechanical
- Chemical
- Others

Mechanical Stabilization

- Compaction (Cohesive Soils)
  - Fine-Grained Clays and Silts
  - Strength Increases
  - Density Increases
  - Permeability Decreases
  - Compressibility Decreases
  - Shrinkage Decreases
- Equipment (Cohesive Soils)
  - Sheepfoot Roller
  - Smooth-Wheeled Roller

Mechanical Stabilization

- Compaction (Cohesionless Soils)
  - Clean Sands and Gravels
  - Not Significantly Affected by Compaction
  - Remain Permeable
- Equipment (Cohesionless Soils)
  - Crawler Tractor
Chemical Stabilization

- Lime
- Lime - Fly Ash
- Fly Ash
- Cement
- Asphalt
- Waste by-products (AFBC, Kiln Dust, et.)

Chemical Stabilization

- Lime - Best for Fine-Grained Soils
- Lime - Fly Ash - Medium to Coarse Grained Soils
- Fly Ash - Medium to Coarse Grained Soils

Chemical Stabilization

- Cement - Coarse Grained, All Soils
- Asphalt - (1) Less than 25% Passing 200 Sieve
  (2) P.I. Less than 6
  (3) Sand Equiv. Less than 25
- Waste by-products - Exercise Caution
Other Stabilization Methods

Geogrids
Geotextiles
Removal / Replacement

Subgrade Structural Parameters

Currently Using 0.08 - 0.11 Layer Coefficient for Stabilized Subgrades
Part III. Unbound Materials

Objectives:

To familiarize the designer with the various types of unbound base materials and their uses.

To discuss the various gradations currently in use.

To discuss the characteristics and warrants for the various types of unbound bases.

Topics:

III. Unbound Materials
   A. Dense-Graded Aggregate (DGA)
   B. Crushed Stone Base (CSB)
   C. Drainage Blanket Type I, Aggregate Base
   D. Warrants for Use
   E. Structural Parameters

Comments:

There are currently several types of unbound bases used in Kentucky. Dense-graded aggregate (DGA), as its name implies, is a dense-graded mixture of crushed stone with a considerable amount of fines. These fines generally contribute to the low permeability and high stability characteristics of DGA. DGA was first used to take advantage of this low permeability in trying to prevent water from entering the pavement structure. DGA can also be used as a separating layer to prevent clay and silt-sized particles from fine-grained material (such as soil subgrades) from intruding into more open-graded materials such as drainage blankets.

Crushed stone bases (CSB) were developed in more recent years for use as a fairly high stability product with a more free-draining ability when compared to DGA. Although the two gradations currently overlap, changes currently underway in the CSB gradation will move these two materials further apart. CSB will become a coarser material.

Type I drainage blankets are comprised of #57 stone. This is a very open-graded mixture with very high permeability (10,000 to 20,000 ft./day). Very high permeability is required for lateral flow of water through open-graded bases because of low hydraulic gradients in
pavements and the area of flow is small.

Proper filters must be used with an open-graded base to prevent clogging of the material. The use of an open-graded aggregate base material over untreated subgrades and some treated subgrades requires the use of a filter material to prevent the intrusion of soil into the open graded aggregate base material. An open-graded aggregate base placed directly on a fine-grained subgrade may become clogged with fine materials because of stress-induced intrusion of the subgrade material into the base material and/or the potential for the finer particles to be washed into the voids of the coarse material. Either condition will result in the overall reduction of permeability.

It should be noted that the current gradation for DGA will meet filter requirements for use with many of the fine grained soils in Kentucky. Geotextile fabrics are permitted as an alternate to the use of graded aggregate filter materials. Specific fabric materials must be selected so as to function equivalently with a graded aggregate filter. Theoretically, a very thin, graded aggregate filter (approximately 1 inch) should function satisfactorily. However, for practical purposes it is recommended that the filter layer be 3 inches thick.
III

Unbound Materials

Dense-Graded Aggregate (DGA)

DGA Gradation
DGA FIRST USED

- 1951-1952
- SOUTHLAND DR., LEXINGTON
- ROAD MIXED
- STABILIZED WITH CALCIUM CHLORIDE

DGA NEXT USED

- 1953
- PHIL-PINE GROVE ROAD, CASEY COUNTY
- PLANT MIXED
- NO CALCIUM CHLORIDE
WARRANTS FOR USE OF DGA

- Economical Strength
- Working Platform
- Prevent Water from Entering Stabilized Layers from Below
- Separation Layer
Crushed Stone Base

In use since the early 1990's

Ashland - Alexandria Highway has sections with crushed stone base
Crushed Stone Base

Permeability -

Approx. 100 to 1000 ft./day
Will Not Meet Filter Requirements

Crushed Stone Base

Strength -

High Stability
Comparable to DGA

Warrants for Use of Crushed Stone Bases

More Drainage than DGA

Higher Stability than Drainage Blankets

Type I
**Gradation Comparison of Drainage Blanket, Type I with DGA**

**EARLY USES**
- KY 55, Taylor County
- Louisa Bypass, Lawrence County

**Type I - Permeability**
- 10,000 to 20,000 ft./day

**Type I - Strength**
- **Unconfined** - Somewhat less than DGA
- **Confined** - Comparable to DGA
Warrants for Use of Drainage Blanket Type I

Quick Drainage Response

Disadvantages of Use

Some Problems in Maintaining Shape in Front of Paver

Structural Parameters for Unbound Materials

- Layer Coefficient Usually Assumed to be 0.11 to 0.14
Part IV: Bound Materials

Objectives:

To discuss and identify the various pavement materials that are cemented with an asphalt binder or Portland cement.

To discuss the gradations and warrants for the various types of asphalt bound pavement materials.

To explain the new "Performance Graded" asphalt binders.

To familiarize the participant with the old Marshall and the new Superpave Mix design methods.

Topics:

IV. Bound Materials

A. Asphalt Materials
   1. Drainage Blanket Type II
   2. Base Mixtures
   3. Binder Mixtures
   4. Surface Mixtures
   5. Structural Parameters

B. Asphalt Binder
   1. PG Grading System
   2. Superpave

C. Portland Cement Concrete (PCC)
   1. PCC Treated Drainage Blanket
   2. PCC Pavement
   3. Structural Parameters

D. Warrants for Use

Comments:

This section discusses all of the various types of asphalt bound materials, including the gradations, normal range of percent of asphalt binder material, permissible range of layer thicknesses, and some of the warrants for their use.
Asphalt binders are discussed. The old viscosity graded binders are discussed, including the laboratory tests used to grade the binders. It should be noted that this system of grading binders will shortly be obsolete in Kentucky. The new Performance Graded (PG) binders are discussed in detail. The PG graded asphalts are an integral part of the new Superpave system of mixtures. The laboratory tests used to classify the PG binders are mentioned briefly, as well as how pavement temperature and air temperature are used to help determine the binder grade to use in a particular mixture.

This section also discusses two asphalt mixture design systems — the Marshall mix design method and the new Superpave system. The Marshall method also will be shortly obsolete in Kentucky. The following five steps necessary to perform a Superpave design are discussed in detail.

1. Calculate ESAL’s
2. Select Materials
3. Design Aggregate Structure
4. Design Binder Content
5. Check Moisture Sensitivity

A discussion is also given in this section on Portland cement bound materials. PCC treated drainage blankets are explained and illustrated (although currently none have been used on Kentucky highways). The different types of PCC pavements are discussed and explained. Discussion on the use of PCC pavements and their structural parameters are also given.
IV

Bound Materials

Asphalt Materials

Drainage Blanket Type II
Warrants for Use of Type II Drainage Blanket

- High Stability
- High Strength
- High Permeability
- Integral Part of Pavement Underdrain System
- Layer Thickness 4.0 - 6.0 in.

Base Mixtures
Types of Bases

Class I
Class CI
Class CK

Asphalt Cement Content

3.5 - 6.5 %
Warrants for Use of Base Courses

- Strength
- Reduce Rutting
- Layer Thickness

Class I Base - 2.0 - 4.0 inches
Class CI Base - 3.0 - 4.5 inches
Class CK Base - 3.5 - 6.0 inches
Warrants for Use of Binder courses

High Strength
High Stability
Leveling and Wedging
Can be Used as Thin Base Course
Layer Thickness 1.5 - 2.0 inches
Types of Surface Mixtures

- Class I
  - Class I-0
  - Class I-20/30
  - Class I-40/20
- Class N
  - Class N-30
- Class AK
  - Class AK/A
  - Class AK/B
  - Class AK/S

Warrants for Use of Surface Mixtures

- Class I-0
  - Low Volume
  - Low ESAL's
- Class I-20/30
  - High Volume
  - High ESAL's
  - Some Rutting Potential
- Class I-40/30
  - High Volume
  - High ESAL's
  - Use in Intersections
Warrants for Use of Surface Mixtures

- Class AK
  - Class AK/A
    - Highest Type
    - High Volume, High ESAL’s
    - High Skid Resistance
  - Class AK/B
    - High Type
    - Less Polish Resistant Aggregate Required
    - High Volume, High ESAL’s
  - Class AK/S
    - Lower Volume, Lower ESAL’s
    - No Polish Resistant Aggregate Required

- Class N
  - Class N-30
    - Use When Surface Drainage Important
    - Used In-Lieu of OGFC
    - High Volume, High ESAL’s
    - Some Polish Resistant Aggregate Required

New Specifications for Surface Mixtures

- Type A. 100 percent of the coarse aggregate shall be from the Department’s list of Class A Polish-Resistant Sources. Ensure that 20% of total combined aggregate is polish resistant fine aggregate.
- Type B. Provide one of the following:
  a. 100% of the Coarse Agg. From the Departments list of Class B Polish-Resistant Sources
  b. The Coarse aggregate shall be a minimum of 50% from the Department’s list of Class A Polish-Resistant sources which may however, exclude some limestones, dolomites, and gravels
  - For option a or b, ensure 20% or more of the total combined aggregate is polish resistant fine aggregate.
New Specifications for Surface Mixtures

- Type C. Ensure that 40 percent or more of the total combined aggregate is polish-resistance; unrestricted Class A coarse, fine, or combination.
- Type D. Ensure that 20 percent or more of the total combined aggregate is polish-resistant; unrestricted Class A coarse, fine, or combination.
- Type E. No restriction on aggregate type.

Layer Thickness of Asphalt Surface Mixtures

1.25 - 1.5 inches

Layer Coefficients Asphalt Materials

- Surface = 0.40 - 0.44
- Binder = 0.40 - 0.42
- Base = 0.36 - 0.40
- Drainage Blanket Type II = 0.18 - 0.21
Asphalt Binder

Viscosity Graded (AC)
Performance Graded (PG)

Viscosity Grades
(Viscosity in Poise at 140°F)

\[
\begin{align*}
AC-5 &= 500 \\
AC-10 &= 1000 \\
AC-20 &= 2000 \\
AC-40 &= 4000
\end{align*}
\]
**PG Grades**

**PG 64-22**

- **PG** = Performance Grade
- **64** = Design High Pavement Temperature, °C
- **-22** = Design Low Pavement Temperature, °C
Asphalt Mix Design Methods

Marshall Method
Superpave Method

Marshall Method
50 Blows
75 Blows
112 Blows

Testing Marshall Sample
Five Steps in Superpave Mix Design

1. Calculate ESAL’s
2. Select Materials
3. Design Aggregate Structure
4. Design Binder Content
5. Check Moisture Sensitivity

1. Calculate ESAL’s

<300,000
<1,000,000
<3,000,000
<10,000,000
<30,000,000
<100,000,000
≥100,000,000

2. Select Materials

A. Binder Grade
2. Select Materials

B. Coarse Aggregate Angularity

<table>
<thead>
<tr>
<th>Traffic ESAL's x10⁶</th>
<th>Depth from Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 3</td>
<td>&lt; 4.0 in.</td>
</tr>
<tr>
<td>&lt; 1</td>
<td>55%</td>
</tr>
<tr>
<td>&lt; 5</td>
<td>65%</td>
</tr>
<tr>
<td>&lt; 10</td>
<td>75%</td>
</tr>
<tr>
<td>&lt; 30</td>
<td>85/80</td>
</tr>
<tr>
<td>&lt; 100</td>
<td>95/90</td>
</tr>
<tr>
<td>&gt; 100</td>
<td>100/100</td>
</tr>
</tbody>
</table>

2. Select Materials

C. Fine Aggregate Angularity

(AASHTO T-304 Method A)

<table>
<thead>
<tr>
<th>Traffic ESAL's x10⁶</th>
<th>Depth from Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 3</td>
<td>&lt; 4.0 in.</td>
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<tr>
<td>&lt; 1</td>
<td>40%</td>
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<tr>
<td>&lt; 3</td>
<td>40%</td>
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<tr>
<td>&lt; 10</td>
<td>45%</td>
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<td>&lt; 30</td>
<td>45%</td>
</tr>
<tr>
<td>&lt; 100</td>
<td>45%</td>
</tr>
<tr>
<td>&gt; 100</td>
<td>45%</td>
</tr>
</tbody>
</table>

2. Select Materials

C. Fine Aggregate Angularity

(AASHTO T-304 Method A)

![Diagram of test setup](image-url)
2. Select Materials

D. Flat and Elongated Particles
(ASTM D 4791)

<table>
<thead>
<tr>
<th>Traffic ESAL's x10^6</th>
<th>Maximum, Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3</td>
<td>-</td>
</tr>
<tr>
<td>&lt;1</td>
<td>-</td>
</tr>
<tr>
<td>&lt;3</td>
<td>10</td>
</tr>
<tr>
<td>&lt;10</td>
<td>10</td>
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<tr>
<td>&lt;30</td>
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</tr>
<tr>
<td>&lt;100</td>
<td>10</td>
</tr>
<tr>
<td>&gt;100</td>
<td>10</td>
</tr>
</tbody>
</table>

2. Select Materials

D. Flat and Elongated Particles
(ASTM D 4791)

2. Select Materials

E. Sand Equivalent Test
(AASHTO T 176)

<table>
<thead>
<tr>
<th>Traffic ESAL's x10^6</th>
<th>Sand Equivalent Minimum, Percent</th>
</tr>
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<tbody>
<tr>
<td>&lt;3</td>
<td>40</td>
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<tr>
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<td>&lt;10</td>
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<td>&lt;30</td>
<td>45</td>
</tr>
<tr>
<td>&lt;100</td>
<td>50</td>
</tr>
<tr>
<td>&gt;100</td>
<td>50</td>
</tr>
</tbody>
</table>
2. Select Materials

E. Sand Equivalent Test
(AASHTO T 176)

3. Design Aggregate Structure

(Superpave Mixture Gradations)

37.5 mm (1.5")
25.0 mm (1.0")
19.0 mm (0.75")
12.5 mm (0.50")
9.5 mm (0.38")
Mix Design Requirements

1. Air Voids = 4.0%
### Mix Design Requirements

#### 2. VMA Criteria

<table>
<thead>
<tr>
<th>Nominal Max. Aggregate Size</th>
<th>Minimum VMA Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.5 mm (0.38&quot;)</td>
<td>15.0</td>
</tr>
<tr>
<td>12.5 mm (0.50&quot;)</td>
<td>14.0</td>
</tr>
<tr>
<td>19.0 mm (0.75&quot;)</td>
<td>13.0</td>
</tr>
<tr>
<td>25.0 mm (1.0&quot;)</td>
<td>12.0</td>
</tr>
<tr>
<td>37.5 mm (1.5&quot;)</td>
<td>11.0</td>
</tr>
</tbody>
</table>

### Mix Design Requirements

#### 3. VFA Criteria

<table>
<thead>
<tr>
<th>Traffic millions, ESAL's</th>
<th>Design VFA Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;3</td>
<td>75-80</td>
</tr>
<tr>
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<td>65-78</td>
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<td>&lt;3</td>
<td>65-78</td>
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<td>&lt;10</td>
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<td>&lt;30</td>
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<td>&lt;100</td>
<td>65-75</td>
</tr>
<tr>
<td>&gt;100</td>
<td>65-75</td>
</tr>
</tbody>
</table>

### 5. Check Moisture Sensitivity

- A. Compact Samples to 7.0% Air Voids
- B. Vacuum Saturate
- C. Optional Freeze Cycle - Thaw for 24 hrs.
- D. Indirect Tensile Test - On Control Samples and Conditioned Samples
- E. TSR = Conditioned / Control
- F. Superpave Minimum = 80%
Three Levels of Superpave Mix Designs

Level 1: No Performance Information Required, < 1,000,000 ESAL’s
Level 2: Some Performance Information, < 10,000,000 ESAL’s
Level 3: Detailed Performance Information, > 10,000,000 ESAL’s

Portland Cement Concrete

PCP Treated Drainage Blank Type II
Type III Drainage Layer

Gradation Comparison of PCC Drainage Blanket with DGA

PCC Pavements
Types of PCC Pavements

Structural Parameters

Portland Cement Concrete
Typical Use

Elastic Modulus - 3.5 to 5.5 million psi
Flexural Strength - 500 to 750 psi
Modulus of Subgrade Reaction, (k)

High Volume, Urban Locations
Reduced Rehab Cycles
Rutting Susceptible Intersections
Other Engineering Considerations
Part V: Overview of Pavement Design

Objectives:

To give a historical perspective on highway design, including early highways, and early road tests conducted in this country and in Kentucky.

To give the participant a thorough understanding of the major design philosophies or methods currently in use in this country.

To give an overview of the state-of-practice of pavement design in this country.

Topics:

V. Overview of Pavement Design
   A. Historical Context of Pavement Design
      1. First Paved Roads
      2. Early Road Tests
         a. Maryland
         b. WASHO
         c. AASHO
      3. Later Activities
         a. SHRP
         b. Mn/Road
         c. WES Track
      4. Kentucky Activities
         a. Full-Depth Asphalt Test Road — US 60
         b. Aggregate Base — KY 627
         c. Pavement Management Data
         d. Non-Destructive Testing
         e. Special Test Projects
   B. Methods of Design
      1. Empirical (AASHTO 1993 and Previous Guides)
      2. Mechanistic
      3. Mechanistic-Empirical (Kentucky Method)
   C. Current Practices in Pavement Design
      1. Number of States
      2. Number of States Using Other Empirical Procedures
      3. Number of states using Mechanistic-Empirical Procedures
      4. Catalogs of Design
Pavement design has been an evolutionary process throughout history. This section gives a brief review of some of the highlights and advancements in pavement technology and pavement design through time. In this country, much of pavement design information and procedures are based upon early road tests conducted in the last 60 years. Major strides were made in the understanding of pavement behavior, performance, failure and design as a result of these early road tests. The most used pavement design system in this country today (AASHTO) was a direct development of one of these road tests.

Research and large-scale road tests are continuing today. The Strategic Highway Research Program, begun in the late 1980's and continuing through the early 1990's was the most massive highway research program ever attempted in this country. The Superpave mixture design system was one of the major products of that research effort. In addition, massive data bases were developed on design and pavement performance from hundreds of pavement sections scattered throughout the nation. Pavement performance data is still being collected and analyzed from these sites. Other large-scale test roads are currently in operation in the country. The Mn/Road test site in Minnesota is providing valuable performance data on PCC pavements. The WES Track project in Nevada is currently testing numerous design sections of flexible pavements.

The Kentucky Highway Department has maintained an aggressive research program since the early 1940's. Research in the pavements area has always been a high priority of Department. Research projects such as full-depth asphalt pavements, design and testing of aggregate bases, break-and-seat and overlay of PCC pavements, various asphalt mixture designs, pavement performance analysis, and development of Kentucky’s pavement design method have all been a major part of the research effort of the Department.

Since the early 1980's, the Department of Highways has been actively engaged in the development, maintenance, and implementation of a pavement management program. There is currently almost 20 years of pavement performance data available. This information is used in predicting future conditions on various highway networks in the state, and it is also used in helping to develop future rehabilitation and funding needs.

Non-destructive testing has been an important part of the highway program in Kentucky since the early 1960's. Roughness testing for ride quality has been used for several decades in Kentucky. Kentucky now uses second and third generation devices that measure roughness and rutting. Skid testing to determine pavement slipperiness is also regularly used at selected sites. Kentucky began non-destructive structural testing of pavement in the early 1970's with Models 400 and 400B Road Rater. The Road Rater imparts a sinusoidally varying (at a rate of 25 Hz) load to the pavement and the pavement response is measured by a series of geophones. The Division of Operations, Pavement Management Branch currently has a Model 2000 Road Rater. The Kentucky Transportation Center operates a JILS 20 model falling weight deflectometer (FWD) for measuring the structural capacity of a pavement. It differs from the Road Rater by imparting an impulse load to the pavement instead of a sinusoidal load. Much information can be obtained from these devices including the effective structural...
thickness of an in-service pavement that can be used in determining overlay thickness on a rehabilitation project.

This section also discusses in detail the three major methods of pavement design. The AASHTO pavement design equations for rigid and flexible pavements are discussed. Design examples are given. The AASHTO design method was developed from empirical data from the AASHO Road Test of the late 1950's and early 1960's. The system has undergone a number of revisions from the 1972 Design Guide. There have been revisions in 1986 and in 1993. A new AASHTO Design Guide is scheduled to be published in 2002. It will be a radical departure from the earlier guides and will be largely a mechanistic design method calibrated with empirical data.

The theory for a simplified mechanistic design method was first developed in 1885. A major improvement to the method was published in 1943 by Burmister in which his system permitted multiple layers to be in the pavement structure. Mechanistic systems depend solely on theoretical information to develop the pavement thickness design. The Asphalt Institute has a mechanistic design method. Example designs from the Asphalt Institute’s method are given.

Kentucky’s pavement design method is a mechanistic-empirical method. The history of Kentucky’s method is given in detail beginning in 1942 and going through the development of the 1981 thickness design curves. Examples of Kentucky’s method will be given in Section VII of the course.

Finally, the current state of the practice in pavement design is given in the section. The number of states using the various methods are discussed.
Overview of Pavement Design

Historical Context of Pavement Design

Romans First Real Road Builders in Europe

1. In Britain, Romans Built 3000 Miles of Roads in Only 150 Years
2. Two Trenches Dug 5 Meters apart for Drainage, Subgrade Excavated and Backfilled with Granular Material, Paved with Flat Quarry Stone.
3. Military Purposes Only
Early Pavements

1. Medieval Times - In Cities
   - Stone Sett (3 in x 8 in x 9 in)
   - Brick
2. American Cities (1870 to 1890)
   - Ceramic Block
   - 2 to 3 inches thick
   - Built on Natural Sand Bed
   - Leveled Periodically
3. European Cities (1850's)
   - Wood Block

Beginnings of First Modern Paved Roads

1. Asphalt Pavements
   - Paris, 1854
   - Natural Rock Asphalt
   - Crushed to Fine Gradation
   - Lay-Down Temperature - 250 °C
   - Spread with Rakes
   - Compacted with Heavy Iron Rammers
Beginnings of First Modern Paved Roads

2. Concrete Pavements
- Portland Cement - Patented 1824 - Joseph Aspdin
- Portland Cement - Refers to Portland Stone Mined in Dorset England
- Early Experiments in Scotland in 1865

Beginnings of First Modern Paved Roads

2. Concrete Pavements
- Weak Concrete First Used as Base for Stone Sett, Brick
- First Concrete Pavement in US Was Bellefontaine, OH, 1891
- First Serious Concrete Use Was in the U.S. in the first Decade of the 20th Century

Early Road Tests
- Maryland
- WASHO
- AASHO
Maryland Road Test

1. Constructed in 1941
2. Objective: Check Relative Effect of Four Axle Loads
3. Loads Were:
   - 18 kip and 22.4 kip Single Axles
   - 32 kip and 44.8 kip Tandems
4. Length = 1.1 miles
5. Two 12-foot Driving Lanes
6. Thickness: Variable

Maryland Road Test Results

1. Slab Cracking and Slab Settlement Increased with Loading in the Following Order:
   - 18 kip - Single Axle
   - 32 kip - Tandem
   - 22.4 kip - Single Axle
   - 44.8 kip - Tandem
2. Pumping Occurred with Fine-Grained Soils, But Not Granular Soils

Maryland Road Test Results

3. Pumping Caused Large Stress Increases for Corner Loads
4. As Pumping Increased, Slab Deflections Increased Correspondingly
5. Stresses and Deflections Caused by Corner Loads and Edge Loads Were Greatly Influenced by Temperature Curling
WASHO Road Test
1. Constructed in 1952
2. Two Test Loops with 1900-ft Tangents
3. Each Loop Contained:
   - Five 300-ft. Test Sections
   - Four 100-ft. Transition Sections
4. Loads:
   - 18 kip and 22.4 kip Single Axles
   - 32 kip and 40 kip Tandem Axles
5. 119,000 Applications of Each Load

WASHO Road Test
6. Subgrade was A-4 Soil
7. Two 12-foot Driving Lanes
8. Thicknesses:
   \[ h_1 = 0, 4, 8, 12, 16 \text{ inches} \]

WASHO Road Test Results
1. Pavement Damage Increased with Load in the Following Order:
   - 18 kip Single Axle
   - 32 kip Tandem
   - 22.4 kip Single Axle
   - 40 kip Tandem
2. The Behavior of the Pavement with 4-inch HMA was far Better Than the Pavement with 2-inch HMA with Equal Total Thickness
WASHQ Road Test Results

3. Distress in the Outer Wheelpath Was Considerably More Than in the Inner Wheelpath.

4. Paving the Shoulder Was Highly Effective in Reducing Outer Wheelpath Distress.

5. Based on Distress, a Tandem Axle with 1.5 Times a Single Axle Load is equal to the Single Axle. Based on Deflections, Tandem Axle with 1.3 Times Single Axle Load Equals Single Axle.

WASHQ Road Test Results

6. Development of Structural Distress Was Confined to Two Critical Periods:
   - June 11 to July 7, 1953
     - 27% of Distress from 0.7% of Loads
   - Feb. 17 to Apr. 7, 1954
     - 49% of Distress from 13% of Loads

7. Factors Affecting Deflections:
   - Temperature
   - Vehicle Speed (<15 mph)
   - Load
   - Moisture Content of Subgrade (>22%)

WASHQ Road Test Results

<table>
<thead>
<tr>
<th>Thickness</th>
<th>12,500 Single</th>
<th>25,000 Single</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Asp. Ac.</td>
<td>C. Ac.</td>
</tr>
<tr>
<td>2</td>
<td>51.236</td>
<td>46.955</td>
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<td>4</td>
<td>76.160</td>
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<td>8</td>
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</tr>
<tr>
<td>16</td>
<td>1,778.000</td>
<td>5,628.000</td>
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WASHQ FINDINGS

(Thicker Thickness Found Adequate for 119,800 Trips)

10 in. 13 in. 4 in.
Kentucky Participates in WASHO Road Test
WASHO Road Test Results

MINIMUM LABORATORY CBR VALUE

COMBINED THICKNESS-BASE AND PAVEMENT, INCHES

Kentucky Department of Highways

FLEXIBLE PAVEMENT DESIGN CURVES

Materials Research Laboratory

DCT 1954

V-20
AASHO Road Test

OBJECTIVE:
To Determine Relationship
Between Number of
Repetitions of Specified Axle
Loads of Different Magnitudes
and Arrangements and the
Performance of Different
Thicknesses of Flexible
and Rigid Pavements

AASHO Road Test
1. Ottawa Illinois
2. Six Test Loops Constructed
3. Construction Started - August 1956
4. Test Traffic Started - October 1958
5. Traffic Stopped - November 1960
6. Axle Loads Applied - 1,114,000
7. Cost - $27,000,000
8. Tangent Lengths
   Loops 3 through 6 = 6800 ft.
   Loop 1 = 2000 ft.
   Loop 2 = 4400 ft.
AASHO Road Test

Design Sections

Minimum Length of Test Sections = 100 ft.
AASHO Road Test
Loop 1
Lane 1 - No Load
Lane 2 - No Load
Loop 2
Lane 1 - 2000 Single
Lane 2 - 6000 Single
Loop 3
Lane 1 - 12000 Single
Lane 2 - 24000 Tandem

AASHO ROAD TEST RESULTS
Flexible Pavements
1. The Best Bases were in the following Order: Bituminous Treated, Cement Treated, Crushed Stone, Uncrushed Gravel
2. Greatest Damage in Outside Wheelpath
3. Most Rutting Occurred in Pavement (92%) Only 8% in Subgrade
4. Most Surface Cracking Occurred in Cold Weather
5. Greatest Deflections Occurred in Spring
AASHO ROAD TEST RESULTS
Rigid Pavements

1. Of Panel Length, Subbase Thickness, or Slab Thickness, only Slab Thickness had Significant Effect on Strains
2. Faulting Mostly Occurred at Cracks, not Transverse Joints
3. No Cracking Attributed Solely to Environmental Changes (in Traffic Loops)
4. Pumping a Major Cause of Failures (most material ejected along the edge, not joints)

Later Activities

- SHRP
- Mn/Road
- WesTrack

SHRP
(Strategic Highway Research Program)

$150,000,000 Research Program
Financed by Congress under the Federal-aid Highway Program
SHRP
Began in 1987
Concluded in 1993
Additional $108,000,000 for Implementation
FHWA and AASHTO - Manages

SHRP
Four Major Areas of Research
Asphalt
Concrete and Structures
Highway Operations
Pavement Performance

SHRP Products
Asphalt
Superpave System
**SHRP Products**

**Concrete and Structures**

1. NDT Tools to Assess Condition of Concrete Pavements
2. New Strategies to Protect and Rehab Concrete Pavements
3. New Concrete Mix Designs
4. New Ways to Detect, mitigate, and Prevent Alkali-Silica Reactivity
5. New Guidelines for HPC in Pavements

---

**SHRP Products**

**Highway Operations**

1. Pavement Preservation
2. Work Zone Safety
3. Snow and Ice Control

---

**SHRP Products**

**Long-Term Pavement Performance (LTPP)**

Over 2000 Pavement Sections Monitored (20-Year Program)
- General Pavement Sections (GPS) (7 in KY)
- Special Pavement Sections (SPS)
**SHRP Products**

*Long-Term Pavement Performance (LTPP)*

Pavement Monitoring Procedures
Materials Testing Procedures
Equipment Standards
Calibration Procedures
Pavement Performance Models

---

**Mn/Road Project**

* Constructed 1990
  Otsego, MN

---

**Mn/Road Project**

Objectives

1. Evaluate Effects of Heavy Vehicles on Pavements
2. Evaluate Seasonal Changes on Materials
3. Improve Design and Performance of Low-Volume Roads
Mn/Road Project

Two Test Roads
I-94 WB Lanes
Low-Volume Test Road
40 Test Sections
4,572 Sensors
WesTrack

1. Located at Nevada Automotive Test Center Proving Ground

2. Constructed in 1995
WesTrack

Objectives

1. Develop PRS for HMA Construction and determine the impact of Deviation of Material and Construction Properties on Performance

2. Field Verification for SUPERPAVE, Level III

Hot Mix Asphalt Only

26 Test Sections

Test Sections 230 Feet Long

Automated (Driverless) Vehicles

Target of 10 Million ESALS
### Kentucky Activities

#### WesTrack

<table>
<thead>
<tr>
<th>Design Air Void Content (%)</th>
<th>Fine</th>
<th>Fine Plus</th>
<th>Coarse</th>
<th>Design Asphalt Contents (%)</th>
</tr>
</thead>
<tbody>
<tr>
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<td>4.7</td>
<td>5.4</td>
<td>6.1</td>
<td>6.8</td>
</tr>
<tr>
<td>8</td>
<td>1.15</td>
<td>1.14</td>
<td>1.12</td>
<td>1.13</td>
</tr>
<tr>
<td>12</td>
<td>3/10</td>
<td>3/11</td>
<td>3/10</td>
<td>3/10</td>
</tr>
</tbody>
</table>

#### WesTrack

---

---
**Full-Depth Asphalt Test Road US 60**

- Constructed 1971
- Boyd County
- Design CBR = 3
- Thickness = 10"-18"
- Length = 5 miles
- Control Section
  - 6.5" AC
  - 19" DGA

---

**Full-Depth Asphalt - US 60**

Experimental Instrumentation

- Weigh-in-Motion Scales
- Solar Radiation
- Temperature Measurement
- Road Rater Testing
Full-Depth Asphalt - US 60
Findings
Vibratory Rollers were Accepted for General Use
NDT Methods Developed and Refined
Calibrated Kentucky's Full-Depth Thickness Design Curves
Difficult to Get Density on First AC Lift

Aggregate Base Test -- KY 627
KY 627

From Boonesboro to Winchester
Constructed 1975-1976
Ten Test Sections
Three DGA Gradations
Three Design Thicknesses

Comparisons of Base Gradations

Percent Passing

Sieve Size (inch)

KY 627
Conclusion

No Significant Difference in the Performance of Any of the Sections
### Pavement Condition

#### Evaluatoin Form,
**Interstate/Parkway**

**V-69**
## Pavement Condition Evaluation Form

<table>
<thead>
<tr>
<th>District</th>
<th>County</th>
<th>Route</th>
<th>Road Name</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### I. CONDITION SURVEY

<table>
<thead>
<tr>
<th>Extent</th>
<th>Few</th>
<th>Intermediate</th>
<th>Extensive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cracking</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Base Failures (Faulting)</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Raveling (Spalling)</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
</tr>
<tr>
<td>Out of Section</td>
<td>1</td>
<td>1.5</td>
<td>2</td>
</tr>
<tr>
<td>Appearance</td>
<td>Fair</td>
<td>Poor</td>
<td>Very Poor</td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

### II. RIDEABILITY

<table>
<thead>
<tr>
<th>N/E</th>
<th>SW</th>
<th>RU</th>
</tr>
</thead>
</table>

### III. RUTTING

<table>
<thead>
<tr>
<th>N/E</th>
<th>SW</th>
<th>Depth</th>
</tr>
</thead>
</table>

### IV. SKID RESISTANCE

<table>
<thead>
<tr>
<th>SN</th>
</tr>
</thead>
</table>

### V. TRAFFIC VOLUME

<table>
<thead>
<tr>
<th>TRAVEL SPEED</th>
<th>AADT</th>
<th>MPH</th>
</tr>
</thead>
</table>

## Pavement Condition

<table>
<thead>
<tr>
<th>ROADWAY CHARACTERISTICS</th>
<th>RATER ASSESSMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCC</td>
<td>AC</td>
</tr>
<tr>
<td>Curbs &amp; Gutters</td>
<td>Manholes</td>
</tr>
<tr>
<td>Shoulders</td>
<td>High</td>
</tr>
<tr>
<td>Type:</td>
<td>Industrial Haul</td>
</tr>
<tr>
<td>Recent Patching (Percent)</td>
<td></td>
</tr>
</tbody>
</table>

**Preparer:**

**Remarks:**

**Treatment Code:**

**Cost Estimate:**

**Date:**
# Rideability/Serviceability Scale

<table>
<thead>
<tr>
<th>Rating</th>
<th>Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very Good</td>
<td>5.0</td>
</tr>
<tr>
<td>Good</td>
<td>4.0</td>
</tr>
<tr>
<td>Fair</td>
<td>3.0</td>
</tr>
<tr>
<td>Poor</td>
<td>2.0</td>
</tr>
<tr>
<td>Very Poor</td>
<td>1.0</td>
</tr>
<tr>
<td></td>
<td>0.0</td>
</tr>
</tbody>
</table>
# Pavement Condition Criteria

<table>
<thead>
<tr>
<th>ADT</th>
<th>Poor Condition</th>
<th>Fair Condition</th>
<th>Good Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Above 8000</td>
<td>2.8*(0.0) or lower</td>
<td>2.9(0.1) to 3.2(0.4)</td>
<td>3.3(0.5) or higher</td>
</tr>
<tr>
<td>6201-8000</td>
<td>2.7(0.0) or lower</td>
<td>2.8(0.1) to 3.1(0.4)</td>
<td>3.2(0.5) or higher</td>
</tr>
<tr>
<td>4401-6200</td>
<td>2.6(0.0) or lower</td>
<td>2.7(0.1) to 3.1(0.5)</td>
<td>3.2(0.6) or higher</td>
</tr>
<tr>
<td>2701-4400</td>
<td>2.5(0.0) or lower</td>
<td>2.6(0.1) to 3.0(0.5)</td>
<td>3.1(0.6) or higher</td>
</tr>
<tr>
<td>1501-2700</td>
<td>2.4(0.0) or lower</td>
<td>2.5(0.1) to 2.9(0.5)</td>
<td>3.0(0.6) or higher</td>
</tr>
<tr>
<td>1101-1500</td>
<td>2.3(0.0) or lower</td>
<td>2.4(0.1) to 2.9(0.6)</td>
<td>3.0(0.7) or higher</td>
</tr>
<tr>
<td>901-1100</td>
<td>2.2(0.0) or lower</td>
<td>2.3(0.1) to 2.8(0.6)</td>
<td>2.9(0.7) or higher</td>
</tr>
<tr>
<td>701-900</td>
<td>2.1(0.0) or lower</td>
<td>2.2(0.1) to 2.8(0.7)</td>
<td>2.9(0.8) or higher</td>
</tr>
<tr>
<td>601-700</td>
<td>2.0(0.0) or lower</td>
<td>2.1(0.1) to 2.7(0.7)</td>
<td>2.8(0.8) or higher</td>
</tr>
<tr>
<td>501-600</td>
<td>1.9(0.0) or lower</td>
<td>2.0(0.1) to 2.7(0.8)</td>
<td>2.8(0.9) or higher</td>
</tr>
<tr>
<td>401-500</td>
<td>1.8(0.0) or lower</td>
<td>1.9(0.1) to 2.6(0.8)</td>
<td>2.7(0.9) or higher</td>
</tr>
<tr>
<td>301-400</td>
<td>1.7(0.0) or lower</td>
<td>1.8(0.1) to 2.6(0.9)</td>
<td>2.7(1.0) or higher</td>
</tr>
<tr>
<td>201-300</td>
<td>1.6(0.0) or lower</td>
<td>1.7(0.1) to 2.5(0.9)</td>
<td>2.6(1.0) or higher</td>
</tr>
<tr>
<td>1-200</td>
<td>1.5(0.0) or lower</td>
<td>1.6(0.1) to 2.5(1.0)</td>
<td>2.6(1.1) or higher</td>
</tr>
</tbody>
</table>

*Critical RI's*
Non-Destructive Testing

Model 400B Road Rater
Backcalculation of Materials Properties

I-64 Carter County, MP 161.0 - 171.61
Methods of Design

1. Empirical (Concept of AASHTO) Examples

2. Mechanistic Examples

3. Mechanistic-Empirical Examples
AASHTO Design Parameters

- Design Traffic, ESAL's
  - 18 kip axle loads over the performance period
- Serviceability - Initial and Terminal
  - Measure of the Pavement Smoothness or Rideability
  - 0 - 5 scale
- Reliability Level
  - Probability that a Pavement Structure Will Survive the design period traffic
- Overall Standard Deviation
  - Error or Variability Associated with Construction and Design Inputs
- Roadbed Soil Strength (resilient modulus, CBR k-value)

Terminal Serviceability

<table>
<thead>
<tr>
<th>Volume Type</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Volume (&gt;10,000 ADT)</td>
<td>3.0 - 3.5</td>
</tr>
<tr>
<td>Medium Volume (3,000 - 10,000 ADT)</td>
<td>2.5 - 3.0</td>
</tr>
<tr>
<td>Low Volume (&lt;3,000 ADT)</td>
<td>2.0 - 2.5</td>
</tr>
</tbody>
</table>
Reliability Level

<table>
<thead>
<tr>
<th>Functional Classification</th>
<th>Urban</th>
<th>Rural</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interstate and Other Freeways</td>
<td>85.0 - 99.9</td>
<td>80.0 - 99.9</td>
</tr>
<tr>
<td>Principal Arterial</td>
<td>80.0 - 99.9</td>
<td>75.0 - 95.0</td>
</tr>
<tr>
<td>Collectors</td>
<td>80.0 - 95.0</td>
<td>75.0 - 95.0</td>
</tr>
<tr>
<td>Local</td>
<td>50.0 - 80.0</td>
<td>50.0 - 80.0</td>
</tr>
</tbody>
</table>

Overall (Standard) Deviation

- Overall Variability of Design Inputs
- Flexible Pavements
  - 0.45 - 0.49
- Rigid Pavements
  - 0.35 - 0.39

Flexible Pavement Parameters

- Pavement Material Parameters
  - Layer Coefficients
    - AC Surface 0.40 - 0.44
    - AC Base 0.38 - 0.44
    - Granular Base Layers 0.14 - 0.18
    - Treated Base Layers 0.14 - 0.21
Structural Number

- Determined from the AASHTO Equation or Nomograph
- Relates Material Thickness and Structural Value

\[ SN = \sum a_i D_i \]

Where \( a_i \) = material layer coefficient for layer \( i \)
\( D_i \) = material thickness for layer \( i \)

Pavement Drainage

<table>
<thead>
<tr>
<th>Quality of Drainage</th>
<th>Water Removed Within</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>2 hrs</td>
</tr>
<tr>
<td>Good</td>
<td>1 day</td>
</tr>
<tr>
<td>Fair</td>
<td>1 week</td>
</tr>
<tr>
<td>Poor</td>
<td>1 month</td>
</tr>
<tr>
<td>Very Poor</td>
<td>Water Will Not Drain</td>
</tr>
</tbody>
</table>

Drainage Coefficient

<table>
<thead>
<tr>
<th>Quality of Drainage</th>
<th>Less Than 1%</th>
<th>1-5%</th>
<th>5-25%</th>
<th>Greater Than 25%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>1.25-1.20</td>
<td>1.20-1.15</td>
<td>1.15-1.10</td>
<td>1.10</td>
</tr>
<tr>
<td>Good</td>
<td>1.20-1.15</td>
<td>1.15-1.10</td>
<td>1.10-1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>Fair</td>
<td>1.15-1.10</td>
<td>1.10-1.00</td>
<td>1.00-0.90</td>
<td>0.90</td>
</tr>
<tr>
<td>Poor</td>
<td>1.10-1.00</td>
<td>1.00-0.90</td>
<td>0.90-0.80</td>
<td>0.80</td>
</tr>
<tr>
<td>Very Poor</td>
<td>1.00-0.90</td>
<td>0.90-0.80</td>
<td>0.80-0.70</td>
<td>0.70</td>
</tr>
</tbody>
</table>
SN/Elastic Modulus Relationship
Asphalt Concrete

Layer Coefficients, AC Treated Base
Layer Coefficient, Cement Treated Base

Layer Coefficient, Granular Base
Estimation of Modulus of Subgrade Reaction

Example:

\[ D_{SB} = 6 \text{ inches} \]
\[ E_{SB} = 20,000 \text{ psi} \]
\[ M_{SH} = 7,000 \text{ psi} \]
Solution: \[ k_w = 400 \text{ psi} \]

Figure 3.3. Chart for Estimating Composite Modulus of Subgrade Reaction, \( k_w \). 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.)
Flexible Pavement Design Chart

**Equation:**

\[
\log_{10} W = \log_{10} W_{10} + 9.36 \cdot \log_{10} (SN+1) - 0.20 \cdot \frac{\log_{10} \left( 4.2 - 1.5 \cdot \frac{\Delta \text{PSI}}{0.40 + \frac{1094}{(SN+1)^{0.19}}} \right)}{1.9 - 1.9 \cdot \frac{\Delta \text{PSI}}{0.40 + \frac{1094}{(SN+1)^{0.19}}} - 8.07}
\]

**Example:**

\[
W_{10} = 5 \times 10^4 \\
R = 95\% \\
S_o = 0.35 \\
M_R = 5000 \text{ psi} \\
\Delta \text{PSI} = 1.9 \\
Solution: SN = 5.0
\]

**Figure 3.1.** Design Chart for Flexible Pavements Based on Using Mean Values for Each Input
Rigid Pavement Design Chart, Part I

Figure 3.7. Design Chart for Rigid Pavement Based on Using Mean Values for Each Input Variable (Segment 1)
Rigid Pavement Design, Part II

Figure 3.7. Continued—Design Chart for Rigid Pavements Based on Using Mean Values for Each Input Variable (Segment 2)
Loss of Support

Figure 3.6. Correction of Effective Modulus of Subgrade Reaction for Potential Loss of Subbase Support (6)
Rigid Pavement Design Parameters

- 28-day Mean PCC Modulus of Rupture (bending)
- 28-day Mean Elastic Modulus of Slab
- Mean Effective Modulus of Subgrade Reaction (k)
  - base, subbase, subgrade
  - \( k \) (psi/in) = \( M_r \)(psi)/19.4
- Loss of Support

Load Transfer Coefficient (J)

<table>
<thead>
<tr>
<th>Shoulders</th>
<th>Asphalt</th>
<th>Tied PCC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Transfer Devices</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Pavement Type</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plain Jointed and Jointed Reinforced</td>
<td>3.2</td>
<td>3.8 - 4.4</td>
</tr>
<tr>
<td>Continuously Reinforced</td>
<td>2.9 - 3.2</td>
<td>N/A</td>
</tr>
</tbody>
</table>
Typical Loss of Support Values

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Loss of Support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement Treated Granular Base</td>
<td>0.0 - 1.0</td>
</tr>
<tr>
<td>(1,000,000 - 2,000,000 psi)</td>
<td></td>
</tr>
<tr>
<td>Cement Aggregate Mixtures</td>
<td>0.0 - 1.0</td>
</tr>
<tr>
<td>(500,000 - 1,000,000 psi)</td>
<td></td>
</tr>
<tr>
<td>Asphalt Treated Base</td>
<td>0.0 - 1.0</td>
</tr>
<tr>
<td>(350,000 - 1,000,000 psi)</td>
<td></td>
</tr>
<tr>
<td>Bituminous Stabilized Mixes</td>
<td>0.0 - 1.0</td>
</tr>
<tr>
<td>(40,000 - 300,000 psi)</td>
<td></td>
</tr>
<tr>
<td>Lime Stabilized</td>
<td>1.0 - 3.0</td>
</tr>
<tr>
<td>(20,000 - 70,000 psi)</td>
<td></td>
</tr>
<tr>
<td>UnBound Granular Materials</td>
<td>1.0 - 3.0</td>
</tr>
<tr>
<td>(15,000 - 45,000)</td>
<td></td>
</tr>
<tr>
<td>Fine Grained or Natural Subgrade Mtls</td>
<td>2.0 - 3.0</td>
</tr>
<tr>
<td>(3,000 - 40,000 psi)</td>
<td></td>
</tr>
</tbody>
</table>

Flexible Pavement Design
Example I, Design Inputs

- Design Traffic -- 18,000,000 ESAL's (12,000 ADT)
- Subgrade CBR -- 7.0
- Initial Serviceability -- 3.75
- Terminal Serviceability -- 2.5
- Reliability -- 95% (Rural Arterial)
- Overall Deviation -- 0.49
- Good Drainage 15% of the time -- 1.00
Flexible Example I

Figure 3.1. Design Chart for Flexible Pavements Based on Using Mean Values for Each Input
Flexible Example I
Design Inputs

- SN = 5.7
- Layer Coefficients
  - AC Surface -- 0.44
  - AC Base -- 0.40
  - Type II Drainage Blanket -- 0.18
  - DGA -- 0.14

Flexible Example I
Thickness Determination

\[
SN = a_S D_S + a_B D_B + a_{DB} D_{DB} + a_{DGA} D_{DGA}
\]

<table>
<thead>
<tr>
<th>Layer</th>
<th>SN</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Surface 1.5&quot; x 0.44</td>
<td>0.66</td>
</tr>
<tr>
<td>AC Base 8.5&quot; x 0.40</td>
<td>3.40</td>
</tr>
<tr>
<td>Type II DB 6&quot; x 0.18</td>
<td>1.08</td>
</tr>
<tr>
<td>DGA 4&quot; x 0.14</td>
<td>0.56</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>5.70</td>
</tr>
</tbody>
</table>
Rigid Pavement Design
Example I

- Design Traffic -- 18,000,000 ESAL's (12,000 ADT)
- Initial Serviceability -- 3.75
- Terminal Serviceability -- 2.5
- Reliability -- 95% (Rural Arterial)
- Overall Deviation -- 0.39
- PCC Modulus of Rupture -- 600 psi
- PCC Elastic Modulus -- 4,000,000 psi
- Subgrade CBR -- 7.0
- Load Transfer Coefficient -- 2.7

Rigid Example I
Modulus of Subgrade Reaction

- Subgrade Resilient Modulus -- 10,500
- Base Resilient Modulus -- 30,000
  - 4" Type II Drainage Blanket
  - 4" Dense Graded Aggregate
- Base Thickness 8"
- Modulus of Subgrade Reaction -- 555
Rigid Example I, Modulus of Subgrade Reaction

Example:

\[ D_{SB} = 6 \text{ inches} \]
\[ E_{SB} = 20,000 \text{ psi} \]
\[ M_{R} = 7,000 \text{ psi} \]

Solution: \( k_{m} = 400 \text{ psi} \)

Figure 3.3. Chart for Estimating Composite Modulus of Subgrade Reaction, \( k_{m} \), 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.)
Rigid Example I

Diagram:

Effective Modulus of Subgrade Reaction, k (pci)

Figure 3.7. Design Chart for Rigid Pavement Based on Using Mean Values for Each Input Variable (Segment 1)
Rigid Example I

Figure 3.7. Continued—Design Chart for Rigid Pavements Based on Using Mean Values for Each Input Variable (Segment 2)

NOTE: Application of reliability in this chart requires the use of mean values for all the input variables.
Rigid Example I
Structural Thickness

- PCC Pavement -- 12.0"
- Type II Drainage Blanket -- 4.0"
- Dense Graded Aggregate -- 4.0"

Computer Software

- AASHTO Darwin 3.0
- ACPA -- PAS-5
- Other
Mechanistic (Single Layer)

1. Developed by Boussinesq - 1885
2. Surface < 4.0" thick
3. Ratio of $E_p / E_s < 1$ (Thin Surface and Thick Base)
4. Load Radius Large Compared to Pavement Thickness
5. Pavement Consists Primarily of One Layer - Mostly Subgrade

Mechanistic (Single Layer)
Conclusions from Using Boussinesq Theory

1. Vertical Stress Decreases with Depth and Radial Distance
2. Maximum Stress Occurs Directly Under the Load
3. Stress Independent of Material Properties (Poisson’s Ratio = 0.5)
4. Stress Distribution is Bell-Shaped on a Horizontal Plane
Mechanistic (Single Layer)

Vertical Stresses

Numbers on curves indicate r/a
Mechanistic (Single Layer)

Tangential Stresses

Radial Stresses
Mechanistic (Single Layer)

\[
\varepsilon_z = \frac{1}{E} \left[ \sigma_z - \mu (\sigma_r + \sigma_t) \right]
\]

\[
\varepsilon_r = \frac{1}{E} \left[ \sigma_r - \mu (\sigma_t + \sigma_z) \right]
\]

\[
\varepsilon_t = \frac{1}{E} \left[ \sigma_t - \mu (\sigma_z + \sigma_r) \right]
\]

Equations to Calculate Strains

Mechanistic (Multi-Layer)

(Layer-Elastic)

1. Multi-Layer Theory - Burmister, 1943
2. Material Properties of Each Layer Are Homogenous (Isotropic)
3. Each Layer Has Finite Thickness Except Bottom Layer
4. Bottom Layer - Infinite Half-Space
5. All Layers Infinite in Horizontal Direction
Mechanistic (Multi-Layer) (Layer-Elastic)
6. Full Friction Developed Between All Layers
7. Surface Shearing Forces (Frictional) Are Not Present
8. Only Two Material Properties per Layer:
   Poisson’s Ratio
   Elastic or Resilient Modulus

Mechanistic (Multi-Layer)

Where:
- $h_n$ = Thickness of Layer $n$.
- $E_n$ = Elastic Modulus of Layer $n$.
- $v_n$ = Poisson’s Ratio of Layer $n$.
- $\sigma_i$ = Stress Component in the $i^{th}$ Direction.
- $\tau_{ij}$ = Shear Stress Component in the $i^{th}$ Direction in the Plane $ij$. 

[Diagram of mechanistic multi-layer model with layered materials and interface conditions]
Mechanistic (Multi-Layer)

Limitations of Layer-Elastic Theory
1. Assumes All Materials Are Linear Over All Stress Ranges - Not True
2. Assumes Material Response Is Non-Viscous (Strain Remains Constant Over the Time Which the Load Is Applied) - Not True
3. Assumes All Deformation is Recoverable - Not True

Deflection at Interface of Two-Layer System

\[
\text{Deflection} = \frac{qaF}{E_2}
\]
Mechanistic (Multi-Layer) Critical Strains

- Compressive strain - rutting.
- Tensile strain - fatigue or alligator cracking.
- Compressive strain - rutting.
- Compressive strain - rutting, depressions.

Typical Flexible Pavement with Granular Base

Mechanistic (Multi-Layer)

Failure Criterion for Fatigue
(Tensile Strain - Bottom of Asphalt)

Asphalt Institute Equation
Shell Equation

Number of Repetitions
Mechanistic (Multi-Layer) Computer Programs

ELSYM5
* Multiple Wheel Loads
* Interface Slip

CHEVRON
* Layer-Elastic Only

BISAR
* Interface Friction Can Be Specified
* Horizontal Loading (Braking)

SDEL
* Stress Dependent Elastic Theory
Asphalt Institute Mechanistic Design Method

Based on Modified CHEVRON Program - DAMA
Asphalt Institute Mechanistic Design Method

Example 1

Untreated Aggregate Base 12.0 in. Thickness

ESAL's = 2 \times 10^6
M_r = 10,000 \text{ psi}
Base Thickness = 12"
Mechanistic-Empirical (Kentucky Method)

Timeline of Pavement Design Progress

Prior to 1949 Kentucky Used Design Curves Developed by California Department of Highways in 1942
Mechanistic-Empirical
(Kentucky Method - 1948)

In 1948 Kentucky Conducted a Field and Laboratory Study. Conducted Performance Survey of 435 Miles of Roads and Sampled 185 Locations

Mechanistic-Empirical
(Kentucky Method - 1948)

Sampled Thicknesses
Determined Performance
Laboratory CBR's
Field CBR's
Mechanistic-Empirical (Kentucky Method - 1948)
Mechanistic-Empirical (Kentucky Method - 1948)

Fig. 22
Mechanistic-Empirical
(Kentucky Method - 1948)

MINIMUM LABORATORY GBR VALUE

CURVE LIMITING EWL (million)

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<th>Curve</th>
<th>Limiting EWL</th>
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<tr>
<td>I</td>
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<tr>
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<td>VI</td>
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Kentucky Department of Highways

Materials Research Laboratory

FLEXIBLE PAVEMENT DESIGN CURVES

OCT 1954

V - 148
In 1957, Kentucky performed a new study of 389 miles of pavements, totaling 57 projects. This was to verify and/or revise the 1948 curves.

Mechanistic-Empirical (Kentucky Method - 1959)

- Design Data
- Traffic Analysis
- Traffic vs. Pavement Life
- Performance Inspections
- Rutting Measurements
- Roughness
- Pavement Deflections
  (Benkelman Beam)
Benkelman Beam
18,000 lb. Single Axle

Benkelman Beam
32,000 lb. Tandem
Fig. 13: Pavement Deflections, 18,000-Lb. Single Axle, Obtained From Both Satisfactory and Unsatisfactory Pavements Plotted According to Traffic Groups Corresponding to Accumulated EWL's.

Fig. 14: Pavement Deflections as Obtained in Fig. 13, Plotted according to the Logarithm of the Mid-Point Value of the Respective EWL Groups.
Fig. 15: Pavement Deflections Representing only Satisfactory Pavements Plotted According to Corresponding Pavement Thicknesses. The curve, as drawn, implies that deflections of equal or lesser magnitude would be within safe limits.

Fig. 16: Plot of Thicknesses and EWL's Interpolated from Figs. 14 and 15 for Corresponding Deflections.
Kentucky Method - 1959 Revision

MINIMUM LABORATORY CBR VALUE

COMBINED THICKNESS - BASE AND PAVEMENT, INCHES

CURVE LIMITING EWL (million)

IA Less than 1/2
I 1 - 2
II 2 - 3
III 3 - 6
IV 6 - 10
V 10 - 20
VI 20 - 40
VII 40 - 80
IX 80 - 160
X 160 - 320

DIVISION OF RESEARCH
JANUARY, 1959

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Kentucky Method - 1959 Revision

MINIMUM LABORATORY CBR VALUE

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</table>

DIVISION OF RESEARCH JANUARY, 1959
Kentucky Method
1959 Revision

Based on 5-kip Wheel Loads

Empirical Data Based on Surface Deflections Only

Reasons for Further Development in 1968

1. AASHO Design System Based on EAL
2. Increased Traffic Volumes and Weights
1968 Revision

1. Extensive Benkelman Beam Measurements Throughout State
2. Tremendous Scatter in Data
3. Partially Due to Effects of Temperature
4. Temperature Corrections Reduced Scatter But Not Enough

1968 Revision

5. Concluded that Surface Deflections Were Not the Key Attribute
7. CHEVRON N-Layer Computer Program Used to Run a Large Array of Problems
Kentucky Method
• Kentucky Method

1968 Revision
Kentucky Method - 1968 Revision

Critical Strains

Subgrade Critical Strain Criteria

V - 164

V - 165
Kentucky Method

1968 Revision

V-166
Kentucky Method
1973 Revision

1. AC Modulus Substituted for
   AC Temperature
2. Unlike 1968 Curves, DGA
   Modulus Allowed to Vary
3. The Idea of Traffic Level Curves
   Abandoned for EAL’s

1973 Revision

\[ E' = F \times CBR \times 1500 \]

1968 Curves
DGA Modulus
Held Constant at
25,000 psi
1973 Revision

DESIGN CURVES
PERCENT OF TOTAL THICKNESS COMPOSED
OF ASPHALTIC CONCRETE + 50%
MODULUS OF ASPHALTIC CONCRETE FOR
FULL-DEPTH DESIGN - 305 ksi

Modulus = 270 ksi
305 ksi
375 ksi

Percent AC Thickness
100 50
75 33
67

REpetitions of 18-Kip AASHTO Axleloads
Kentucky Method 1981 Revision

1. Based on an Asphalt Modulus of 480 ksi
2. Mechanistically Based EAL’s
Kentucky Method
Kentucky Method
1981 Revision

33% AC

REpetitions of an 18 Kip (80 KN) equivalent axleload

Total Thickness, Inches

10^3 10^4 10^5 10^6 10^7 10^8

6 8 10 12 14 16 18 20 22 24 26 28 30 32 34

V - 173
Kentucky Method

1981 Revision

50% AC
Kentucky Method

1981 Revision
Current Practices in Pavement Design

- Number of States Using AASHTO
- Number of States using Other Procedures
- Number of States Using Mechanistic Procedures
- Catalogs of Design

Current Practices in Pavement Design

Flexible
50% Using 86/93 AASHTO
28% Using 72 AASHTO

Rigid
80% Using AASHTO
Current Practices in Pavement Design

Alaska - No Rigid Pavements
California - State Procedure
Hawaii - PCA Method
Iowa - PCA Method
Kentucky - KY Method/AASHTO (86/93)
New Hampshire - State Procedure
New York - State Procedure
Pennsylvania - State Procedure
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<th>Current Practices in Pavement Design</th>
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<tr>
<td>Rigid (Finite Elements)</td>
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<tr>
<td>Flexible (Finite Elements)</td>
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<td>No State - Asphalt Institute</td>
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<table>
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<th>Current Practices in Pavement Design</th>
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<td>New York - State Procedure</td>
</tr>
<tr>
<td>Missouri - AASHTO</td>
</tr>
<tr>
<td>Washington - AASHTO</td>
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</tbody>
</table>
Part VI: Mechanisms of Pavement Failure

Objectives:

To acquaint the participant with the various methods or modes of pavement failures.

To help the participant recognize the causes of the modes of failure.

To discuss and illustrate the results of an improper pavement design.

Topics:

VI. Mechanisms of Pavement Failure
   A. Flexible Pavements
      1. Rutting
      2. Cracking
      3. Base Failures
      4. Rideability
   B. PCC Pavements
      1. Cracking
      2. Joint Failures
      3. Faulting
      4. Base Failures
      5. Scaling
      6. Pumping
      7. Rideability

Comments:

Pavements may fail in a variety of modes. Failures may be the result of poor materials, poor construction techniques, environmental distress, poor drainage, weak subgrades, heavy traffic loads, or any combination of the preceding items.

Pavements that are designed with insufficient thickness will provide a poorer quality and shortened service life, and the effects of all the factors listed above will be magnified. It is important for the designer to be able to interpret pavement distresses and to be able to identify the causes of those distresses. This ability will assist the designer, in the future, when choosing among competing alternate rehabilitation strategies.
VI

Mechanisms of Pavement Failure

Failure Mechanisms

Flexible Pavement

Rutting
VI

Mechanisms of Pavement Failure

Failure Mechanisms

Flexible Pavement
Maxwell Model

\[ \varepsilon = \frac{s}{2G} \left( 1 - \frac{G}{\eta} t \right) \]

Kelvin Model

\[ \varepsilon = \frac{s}{2G} \left[ 1 - \exp\left( -\frac{G}{\eta} t \right) \right] \]
Burgers Model

\[ e = \frac{s}{2G_0} \left( 1 - \frac{G_0}{\eta} \right) + \frac{s}{2G_1} \left[ 1 - \exp\left( -\frac{G_0}{\eta} \right) \right] \]

Time

\[ \sigma = \sigma_0 \cos(\omega t) + i\sigma_0 \sin(\omega t) = \sigma_0 e^{i\omega t} \]

DYNAMIC MODULUS

\[ G^* = G' - iG'' \]

\[ G' (Storage Modulus) \]

\[ G'' (Loss Modulus) \]

\[ G^* \]

\[ \delta \]
Fatigue Cracking
Base Failures (PCC)
Faulting

Fauling

Scaling
Why a Design Catalog?

- Kentucky Pavement Design, Currently a 3-layer System, (AC, DGA, Subgrade)
- AASHTO Design Procedure Allows for a Multi-Layer System
- Design Catalog Developed to Allow for Additional Pavement Layers (Drainage Blanket, etc)

Current Warrants for Use

- Off the National Highway System
- Less Than One Kilometer (0.6mile) Length
- Less Than 5,000,000 Equivalent Single Axle Loads
Updated Warrants for Use

- OFF National Highway System
- No Length Restrictions
- Less Than 20,000,000 ESALS/20 Years in the Design Lane
- Less Than 20% Trucks
- Less Than 15,000 ADT

Design Catalog Development
Catalog Development, Flexible Pavements

- Kentucky’s Mechanistic-Empirical Procedure
- Utilize Standard Parameters
  - Structural Layer Coefficients
    - Asphalt Concrete 0.44
    - Dense Graded Aggregate 0.14
  - 33% AC Design
- Convert to AASHTO Structural Number
- 95% Reliability or Better

Kentucky Mechanistic Empirical Design Procedure

- Design Traffic -- 2,000,000 ESAL’s
- Design Subgrade Strength -- CBR 4
33% Design Chart

2,000,000 ESAL's
Subgrade CBR 4.0

Total Pavement Thickness
23.8 inches
Kentucky Mechanistic Empirical Design Procedure

- Total Pavement Thickness 23.8 Inches (Kentucky 33\% Mechanistic-Empirical Design Procedure)

- Convert to Layer Thickness
  - AC Layer 7.8 inches
  - DGA Layer 16.0 inches

Conversion to AASHTO Structural Number

- Determine AASHTO Structural Number
  - 7.8 inches AC x 0.44 (layer coefficient) = 3.43
  - 16 inches of DGA x 0.14 (layer Coefficient = 2.24)
  - Total SN = 3.43 + 2.24 = 5.67
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Catalog of Structural Numbers

AASHTO SN

ESAL

CBR 1
CBR 2
CBR 3
CBR 4
CBR 5
CBR 6
CBR 7
CBR 8
CBR 9
CBR 10
CBR 11
Catalog Development,
Rigid Pavements

- PCC Thickness Determined Using the Kentucky Rigid Pavement Design Catalog
- PCC Thickness Determined Using the Kentucky Procedure
- PCC Thickness Also Determined Using the 1986/1993 AASHTO Procedure
- Final Design Thickness Chosen Based on a Comparison of These Two Procedures
- Thickness Rounded to Whole Inch Increments

Catalog Development Cont.,
Rigid Pavements

- Catalog Based on 6" of Dense-Graded-Aggregate Over Unstabilized Subgrade
- PCC Pavements Generally not Used Below 1,000,000 ESAL’s
- Other Base Materials May Be Utilized
  - Treated Subgrades
  - Permeable Bases
# Catalog of PCC Pavement Thicknesses

**03/16/99**

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Catalog of PCC Pavement Thicknesses

PCC Thickness (in)

ESAL

CBR 2
CBR 6
CBR 11
Catalog Design Parameters

Catalog Design Procedure

- Determine Subgrade Strength
  - Geotechnical Data
  - Estimate Based on Soil Type
- Determine Design Traffic
  - Division of Multi-Modal Programs
  - Estimate From Traffic Parameters

Catalog Design Procedure, Cont.

- Select Structural Design
  - Shoulder Design
    - < 5,000,000 ESAL's, Designed for 20% of Mainline Traffic If not used for traffic
    - 5,000,000 - 20,000,000, Designed for 20% - 100% of Mainline Traffic, Decision Based on Project Specific Information
- Select Paving Materials
- Conduct Life-Cycle Cost Analysis
  - < 5,000,000 ESAL's, Initial Cost Only
  - 5,000,000 - 20,000,000 ESAL's, Include Fixed Rehabilitation Cycle and User Costs
Subgrade Strength

- Defined by the Kentucky Method CBR Test (KM 64-501)
- Determined by the Division of Materials or Other Approved Testing Laboratory
- Determined from Bag Samples from Roadway Cut and Fill Sections

Subgrade Strength
Design Value Selection

- Lowest Value of Laboratory Test
- For Larger Projects, 20 or More Tests, 90th Percentile is Selected
- Higher Design CBR's May be Recommended for Rock Roadbed or Bank Gravel Subgrades

Estimated CBR Values

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<th>Material</th>
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<tr>
<td>Rock (limestone, durable sandstone)</td>
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<tr>
<td>durable shale, nondurable sandstone</td>
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<tr>
<td>Rock (nondurable shale)</td>
<td>2 to 5</td>
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<tr>
<td>Bank Gravel</td>
<td>6 to 9</td>
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<tr>
<td>Soil and/or other shale mixtures</td>
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Estimated CBR, Based on Soil Classification

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<td>Fine Grained Soils, High Compressibility (PT, OD, CH, MH)</td>
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<td>Fine Grained Soils, Low Compressibility (CL, CL, ML)</td>
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<tr>
<td>Coarse Grained Soils, Sand and Sandy Soils (SC, SM, SU, SP, SW)</td>
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<td>Coarse Grained Soils, Gravel and Gravel Soils (GC, GM, Gу, GP, GW)</td>
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Subgrade Stabilization

- Subgrade CBR Less Than 6
- Chemical Stabilization (Lime or Cement)
  - 5 - 6 percent by dry weight
- Mechanical Stabilization
  - Blending of Soil Aggregate Mixtures
  - Coarse Grained Soils Only

Analysis of Design Traffic
Traffic Characterization

- Equivalent Single Axle Load (ESAL)
- Kentucky ESAL’s Utilized for the Design Catalog
- Critical Aspect of Pavement Design
- Division of Multi-Modal Programs Best Suited to Determine ESAL’s for Pavement Design

Estimation of ESAL’s

ESAL’s may be estimated from the following equation:

\[ \text{ESAL’s} = \text{ADT} \times T \times (\text{ESAL’s/Truck}) \times \text{DL} \times 365 \times L \]

where:

- \( \text{ADT} \) = Average Daily Traffic at the mid-year of the design life, with appropriate growth rate applied
- \( T \) = Percentage of Trucks in the traffic stream.
- \( \text{ESAL’s/Truck} \) = Pavement Damage associated with a typical truck in the traffic stream.
- \( \text{DL} \) = Design Life or Design Period in years.
- \( L \) = Proportion of Traffic in the design lane.

ESAL Estimation Cont.

General Traffic Stream Knowledge

Light Trucks (delivery trucks, very few heavily loaded trucks with few overweight vehicles)

\( \text{ESAL’s/Truck} = 0.70 \) to 1.0

Heavy Trucks (trucks hauling aggregates, grain, steel, coal or concrete with numerous overweight trucks)

\( \text{ESAL’s/Truck} = 4.0 \) to 10
**ESAL Estimation Cont.**

**Detailed Traffic Knowledge**

<table>
<thead>
<tr>
<th>Single Unit Trucks</th>
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<td>1.1 to 1.3</td>
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<td>40,000 pounds</td>
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**ESAL Estimation Cont.**

**Detailed Traffic Knowledge**

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**ESAL Estimation Program**

- Developed To Estimate ESAL's for Selection of SUPERPAVE Mix Designs
- Can Be Used with Caution for Estimation of Pavement Design ESAL's
- Utilizes Division of Multi-Modal Programs Historical Data
Selection of Structural Design

Design Parameters

- Design Subgrade Strength
  - CBR 3
  - Obtained from Geotechnical Branch

- Design Traffic
  - 13,829,000 ESAL’s
  - 14,900 AADT
  - Mainline Pavement
  - Obtained From the Division Multi-Modal Programs
### Catalog of Structural Numbers

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### Catalog of PCC Pavement Thicknesses

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**VII - 34**
Structural Cross Section

- Flexible Pavement Select Structural Number
  - SN = 7.59

- PCC Pavement Select Pavement Thickness
  - PCC Thickness 11"

Flexible Pavement Thickness Determination

- Select Material Thickness
  - Asphalt Surface Course 1.5" ($a_1 = 0.44$)
  - Asphalt Binder Course ($a_2 = 0.42$)
  - Asphalt Base Course ($a_3 = 0.40$)
  - Drainable Base 4"
    - Untreated ($a_{db} = 0.11 - 0.14$)
    - Asphalt Treated ($a_{db} = 0.18 - 0.21$)
  - Aggregate Base 4" ($a_{gba} = 0.14$)

$$ SN = a_S D_S + a_B D_B + a_{DB} D_{DB} + a_{DGA} D_{DGA} $$
Flexible Pavement Thickness Determination, Maximum Asphalt Design

\[ SN = a_5 D_S + a_6 D_B + a_{db} D_{db} + a_{DGA} D_{DGA} \]

<table>
<thead>
<tr>
<th>Layer</th>
<th>SN</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Surface</td>
<td>0.44 \times 1.25&quot;</td>
</tr>
<tr>
<td>AC Base</td>
<td>0.40 \times ?&quot;</td>
</tr>
<tr>
<td>Type II DB</td>
<td>0.18 \times 4.0&quot;</td>
</tr>
<tr>
<td>DGA</td>
<td>0.14 \times 4.0&quot;</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
</tr>
</tbody>
</table>

SN remaining = 7.59 - 1.83 =
AC Base = 5.76/0.40 = 14.40", use 14.5"

---

Flexible Pavement Thickness Determination, Maximum Asphalt Design

**Final Layer Thicknesses**

<table>
<thead>
<tr>
<th>Layer</th>
<th>SN</th>
</tr>
</thead>
<tbody>
<tr>
<td>AC Surface</td>
<td>0.44 \times 1.25&quot;</td>
</tr>
<tr>
<td>AC Base</td>
<td>0.40 \times 14.5&quot;</td>
</tr>
<tr>
<td>Type II DB</td>
<td>0.18 \times 4.0&quot;</td>
</tr>
<tr>
<td>DGA</td>
<td>0.14 \times 4.0&quot;</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
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</table>

Design OK
Flexible Pavement Material Selection, Maximum Asphalt Section

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Lift Thickness (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Asphalt Concrete Surface</td>
<td>1.25 to 1.5</td>
</tr>
<tr>
<td>Asphalt Concrete Binder</td>
<td>1.5 to 2.0</td>
</tr>
<tr>
<td>Asphalt Concrete Base, Class I</td>
<td>2.0 to 4.0</td>
</tr>
<tr>
<td>Asphalt Concrete Base, Class CI</td>
<td>3.0 to 4.5</td>
</tr>
<tr>
<td>Asphalt Concrete Base, Class CK</td>
<td>3.5 to 5.0</td>
</tr>
<tr>
<td>Aggregate Base (DGA or CSB)</td>
<td>4.0 to 6.0</td>
</tr>
<tr>
<td>Untreated Drainage Blanket, Type I</td>
<td>4.0 to 6.0</td>
</tr>
<tr>
<td>AC Treated Drainage Blanket, Type II</td>
<td>4.0 to 6.0</td>
</tr>
<tr>
<td>Chemically Modified Roadbed</td>
<td>8.0 to 12.0</td>
</tr>
</tbody>
</table>

Target Design

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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<tbody>
<tr>
<td>Surface</td>
<td>1.25&quot;</td>
</tr>
<tr>
<td>Base</td>
<td>14.5&quot;</td>
</tr>
<tr>
<td>Type II DB</td>
<td>4.0&quot;</td>
</tr>
<tr>
<td>DGA</td>
<td>4.0&quot;</td>
</tr>
</tbody>
</table>

PG Binder Selection

- Warrants for Asphalt Binder Selection

- *All Mainline Pavements Designed Using This Guide Will Utilize PG-64-22*

- For Severe Rutting and High Pavement Stresses, Such as Intersections and Truck Lanes, Increase PG Grade
**PG Binder Selection**

**Intersection Pavements**

- **PG 64-22**
  - \(<5\% \) Trucks or
  - \(< 7,500 \) ADT or
  - \(< 5,000,000 \) Design Lane ESALS
- **PG 70-22**
  - \(5 - 10\% \) Trucks or
  - \(7,500 - 15,000 \) ADT or
  - \(5,000,000 - 10,000,000 \) Design Lane ESALS
- **PG 76-22**
  - \(> 10\% \) Trucks or
  - \(> 10,000,000 \) ESALS

---

**Flexible Pavement Final Design, Maximum Asphalt Design**

- **AC Surface**
  - 1.25” (single layer)
- **AC Base**
  - 14.5”
  - Class I, \(4.0 + 4.0 + 3.5 + 3.0 \)
- **Drainage Blanket**
  - 4”
  - AC Treated Type II
- **DGA**
  - 4.0”
- **No Intersections,**
  - AC Binder Grade PG-64-22
Flexible Pavement Thickness Determination, Maximum Aggregate Design

Surface Courses are Assumed to be 1.25”, \( D_{surface} = 1.25" \)

Therefore:

\[
D_{AC} = D_{Surface} + D_{Base} = 1.25 + D_{Base}
\]

For a maximum aggregate design, \( D_{DGA} = 2 \times D_{AC} \)

Therefore:

\[
D_{DGA} = 2 \times (1.25 + D_{Base}) = 2.5 + 2D_{Base}
\]

Where:
- \( D_{DGA} = \) depth of the DGA
- \( D_{Base} = \) depth of the AC Base
- \( D_{AC} = \) total depth of asphalt materials

By substituting for the Depth of DGA (\( D_{DGA} = 2.5 + 2D_{Base} \)), the Equation of SN becomes the following:

\[
S_n = a_5D_s + a_6D_B + a_{db}D_{DB} + a_{dga}(2.5 + 2D_B)
\]

<table>
<thead>
<tr>
<th>Layer</th>
<th>SN</th>
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<tbody>
<tr>
<td>AC Surface</td>
<td>0.44 x 1.25”</td>
</tr>
<tr>
<td>AC Base</td>
<td>0.40 x ( D_B )</td>
</tr>
<tr>
<td>Type II DB</td>
<td>0.18 x 4.0”</td>
</tr>
<tr>
<td>DGA</td>
<td>( 0.14 \times (2.5 + 2D_B) )</td>
</tr>
<tr>
<td>Total</td>
<td></td>
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</tbody>
</table>

Remaining SN = 7.59 - 1.27 = 6.32,

Therefore:

\[
6.32 = 0.40 \times D_B + [0.14 \times (2.5 + 2D_B)]
\]

Solving for \( D_B \) gives 8.8, use 9.0

Therefore:

\[
D_{DGA} = 2.5 + (2 \times 8.8) = 20.1, \text{ use } 20.50
\]
Flexible Pavement Thickness Determination, Maximum Aggregate Design

<table>
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<th>Layer</th>
<th>SN</th>
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<tbody>
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<td>AC Surface 0.44 x 1.25&quot;</td>
<td>0.55</td>
</tr>
<tr>
<td>AC Base 0.40 x 9.0&quot;</td>
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</tr>
<tr>
<td>Type II DB 0.18 x 4.0&quot;</td>
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<tr>
<td>DGA 0.14 x 20.5</td>
<td>2.87</td>
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<td><strong>Total</strong></td>
<td><strong>7.74 &gt; 7.59</strong></td>
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<tr>
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Flexible Pavement Material Selection, Maximum Aggregate Section

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<th>Material Type</th>
<th>Lift Thickness (in)</th>
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<tr>
<td>Asphalt Concrete Surface</td>
<td>1.25 to 1.5</td>
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<tr>
<td>Asphalt Concrete Binder</td>
<td>1.5 to 2.0</td>
</tr>
<tr>
<td>Asphalt Concrete Base, Class I</td>
<td>2.0 to 4.0</td>
</tr>
<tr>
<td>Asphalt Concrete Base, Class CI</td>
<td>3.0 to 4.5</td>
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<tr>
<td>Asphalt Concrete Base, Class CK</td>
<td>4.0 to 6.0</td>
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<tr>
<td>Aggregate Base (DGA or CSB)</td>
<td>4.0 to 6.0</td>
</tr>
<tr>
<td>Untreated Drainage Blanket, Type I</td>
<td>4.0 to 6.0</td>
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<tr>
<td>AC Treated Drainage Blanket, Type II</td>
<td>4.0 to 6.0</td>
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<td>Chemically Modified Roadbed</td>
<td>8.0 to 12.0</td>
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Target Design

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<td>Type II DB</td>
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<tr>
<td>DGA</td>
<td>20.5&quot;</td>
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</table>
Flexible Pavement, Final Design, Maximum Aggregate Design

- AC Surface
  - 1.25" (single layer)
- AC Base
  - 9.0"
  - Class I, (3 + 3 + 3)
- Drainage Blanket
  - 4"
  - AC Treated Type II
- DGA
  - 20.5" (5 + 5 + 5 + 5.5)
- Non Intersections,
  - AC Binder Grade PG-64-22

Rigid Pavement, Material Selection

- PCC Pavement
  - 11.0"
- Drainage Blanket
  - 4.0"
  - AC Treated, Type II
- DGA
  - 4.0"
Life Cycle Cost Analysis

- Maximum AC Design
  - AC -- 16.25"
  - DB -- 4.0"
  - DGA -- 4.0"

- Maximum Aggregate Design
  - AC -- 10.25"
  - DB = 4.0"
  - DGA = 20.5"

- PCC Pavement Design
  - PCC -- 11.0"
  - DB -- 4.0"
  - DGA -- 4.0"
Life Cycle Cost Analysis Parameters

- Analysis Period 40 years
- Standard Rehabilitation Alternatives
  - AC Pavements
    - Year 10, Mill 1.5", 1.5" Overlay
    - Year 20, Mill 1.5", 3.5" Overlay
    - Year 30, Mill 1.5", 1.5" Overlay
  - PCC Pavements
    - Year 15, Clean and Reseal Joints
    - Year 30, Clean and Reseal Joints

Life Cycle Cost Analysis Parameters, Cont.

- User Cost
  - less than 5,000,000 ESAL's
  - 5,000,000 - 10,000,000 ESAL's
  - 10,000,001 - 15,000,000 ESAL's
  - 15,000,001 - 20,000,000 ESAL's
  - No User, Cost Initial Cost
  - $1,000/day
  - $2,000/day
  - $3,000/day

- Length of Construction
  - Initial Construction -- 120 days
  - Rehabilitations -- 30 days

- Material Costs -- Average Unit Bid

- Pavement Salvaged Value Determined as the Cost of Pavement in terms of DGA

- Discount Rates of 2 - 10 Percent
### Material Parameters

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<td>AC Base, CI</td>
<td>110 lbs/sy/in</td>
<td>33.50 $/ton</td>
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<tr>
<td>AC Base, CK</td>
<td>110 lbs/sy/in</td>
<td>13.60 $/ton</td>
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<tr>
<td>Drainage Blanket</td>
<td>100 lbs/sy/in</td>
<td>27.44 $/ton</td>
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<td></td>
<td>16.00 $/ton</td>
<td>Type I</td>
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<tr>
<td>DGA</td>
<td>115 lbs/sy/in</td>
<td>33.50 $/ton</td>
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<td>PCC Pavement</td>
<td>110 lbs/sy/in</td>
<td>33.36 $/ton</td>
<td>8&quot; -- 29.8 $/sy</td>
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<td>9&quot; -- 29 $/sy</td>
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<td>10&quot; -- 27.87 $/sy</td>
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<td>12&quot; -- 40.04 $/sy</td>
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<td>13&quot; -- 39.48 $/sy</td>
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## Life Cycle Cost Comparison

### Maximum Asphalt Design

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<td>130,632</td>
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<td>89,088</td>
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<td>30</td>
<td>297,719</td>
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<td>164,382</td>
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<td>91,792</td>
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<td>51,836</td>
<td>0.10</td>
<td>29,567</td>
<td>0.06</td>
<td>17,062</td>
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<td>40</td>
<td>795,678</td>
<td>0.31</td>
<td>(360,346)</td>
<td>0.10</td>
<td>(195,727)</td>
<td>0.06</td>
<td>(77,356)</td>
<td>0.02</td>
<td>(39,256)</td>
<td>0.01</td>
<td>(17,680)</td>
</tr>
<tr>
<td>PW Total Cost</td>
<td>1,956,997</td>
<td>2,068,456</td>
<td>2,056,662</td>
<td>2,049,920</td>
<td>1,959,012</td>
<td>1,914,803</td>
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<td></td>
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</table>

### Maximum Aggregate Design

<table>
<thead>
<tr>
<th>YEAR</th>
<th>COST</th>
<th>P/W</th>
<th>PW</th>
<th>P/W</th>
<th>PW</th>
<th>P/W</th>
<th>PW</th>
<th>P/W</th>
<th>PW</th>
<th>P/W</th>
<th>PW</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>1,917,652</td>
<td>1.00</td>
<td>1,917,652</td>
<td>1.00</td>
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<td>1,917,652</td>
<td>1.00</td>
<td>1,917,652</td>
<td>1.00</td>
<td>1,917,652</td>
</tr>
<tr>
<td>10</td>
<td>297,719</td>
<td>0.82</td>
<td>244,234</td>
<td>0.68</td>
<td>201,128</td>
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<td>0.46</td>
<td>137,902</td>
<td>0.36</td>
<td>114,784</td>
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<td>20</td>
<td>418,953</td>
<td>0.67</td>
<td>261,943</td>
<td>0.46</td>
<td>191,205</td>
<td>0.31</td>
<td>130,632</td>
<td>0.21</td>
<td>89,088</td>
<td>0.15</td>
<td>62,275</td>
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<tr>
<td>30</td>
<td>297,719</td>
<td>0.55</td>
<td>164,382</td>
<td>0.31</td>
<td>91,792</td>
<td>0.17</td>
<td>51,836</td>
<td>0.10</td>
<td>29,567</td>
<td>0.06</td>
<td>17,062</td>
</tr>
<tr>
<td>40</td>
<td>1,180,222</td>
<td>0.31</td>
<td>(534,511)</td>
<td>0.10</td>
<td>(245,287)</td>
<td>0.06</td>
<td>(114,744)</td>
<td>0.02</td>
<td>(54,327)</td>
<td>0.01</td>
<td>(28,077)</td>
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<tr>
<td>PW Total Cost</td>
<td>1,751,822</td>
<td>2,073,580</td>
<td>2,156,556</td>
<td>2,151,621</td>
<td>2,128,699</td>
<td>2,085,695</td>
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</table>

### PCC Design

<table>
<thead>
<tr>
<th>YEAR</th>
<th>COST</th>
<th>P/W</th>
<th>PW</th>
<th>P/W</th>
<th>PW</th>
<th>P/W</th>
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<td>1.00</td>
<td>1,965,555</td>
<td>1.00</td>
<td>1,965,555</td>
</tr>
<tr>
<td>10</td>
<td>283,056</td>
<td>0.82</td>
<td>240,408</td>
<td>0.68</td>
<td>197,978</td>
<td>0.56</td>
<td>153,641</td>
<td>0.46</td>
<td>112,988</td>
<td>0.39</td>
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<td>133,747</td>
<td>0.31</td>
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<td>0.21</td>
<td>52,870</td>
<td>0.15</td>
<td>43,561</td>
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<td>40</td>
<td>518,329</td>
<td>0.56</td>
<td>(234,744)</td>
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<td>(107,962)</td>
<td>0.10</td>
<td>(50,333)</td>
<td>0.05</td>
<td>(23,059)</td>
<td>0.02</td>
<td>(11,452)</td>
</tr>
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<td>PW Total Cost</td>
<td>2,053,338</td>
<td>2,188,435</td>
<td>2,209,318</td>
<td>2,190,179</td>
<td>2,160,312</td>
<td>2,130,649</td>
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<td></td>
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</tr>
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</table>
## Spreadsheet Procedures

- Selection of Structural Number and PCC Thickness
- Determination of Initial Cost and Life Cycle Cost

---

## Pavement Design Catalogs

<table>
<thead>
<tr>
<th>Design Memo 10-97</th>
<th>New Design Catalog</th>
<th>Interstate Design Catalog</th>
</tr>
</thead>
<tbody>
<tr>
<td>- &lt; 5,000,000 ESALS</td>
<td>- &lt;20,000 ESALS</td>
<td>- 20,000,000 - 100,000,000 ESALS</td>
</tr>
<tr>
<td>- CBR 1 - 11</td>
<td>- &lt; 20% Trucks</td>
<td>- CBR 2 - 11</td>
</tr>
<tr>
<td>- &lt; 1 km in Length</td>
<td>- &lt;15,000 ADT</td>
<td>- Life Cycle Cost Analysis</td>
</tr>
<tr>
<td>- Life Cycle Cost Analysis</td>
<td>- CBR 1 - 11</td>
<td>- Simplified Spreadsheet</td>
</tr>
<tr>
<td>- Initial Cost Only</td>
<td>- Non NHS</td>
<td>- Mean Unit Costs</td>
</tr>
<tr>
<td>- Users</td>
<td>- No Length Restrictions</td>
<td>- Fixed User Delay</td>
</tr>
<tr>
<td>- Design Consultants</td>
<td>- Life Cycle Cost Analysis</td>
<td>- Users</td>
</tr>
<tr>
<td>- District</td>
<td>- Simplified Spreadsheet</td>
<td>- Design Consultants</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- District</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Central Office Staff</td>
</tr>
</tbody>
</table>
Pavement Design Workshop
Kentucky Transportation Cabinet
Division of Highway Design

Design Catalog 1999
- OFF The National Highway System
- < 20,000,000 ESAL's
- < 15,000 ADT
- < 20% Trucks
- No Length Restriction

Design Submittal Procedures
≤5,000,000 ESAL’s & ≤1 mile

- Does Not Need to be Approved by Central Office Design Staff*
- Signatures Needed only by Designer (P.E.) and Project Manager
- Designers will submit designs to C.O. Pavement Staff for archival and distribution purposes

>5,000,000 ESAL’s or >1 mile

- Designs WILL BE Submitted to Central Office Pavement Design for Approval
- Signatures Needed by Designer (P.E.), Project Manager, and T.E.B.M for Pavement Design

*Designs WILL BE Reviewed and Approved for Pavement Type Selection Justification
- C.O. Staff will be allowed 10 working days to review type selection, after which, if no comments are made, design will be presumed approved
Approval Process

- Intended to verify implementation of process and justification for pavement type selection (Asphalt/PCC)
- Initially 100% of Designs will be approved
- Gradually the review and approval will be reduced to some lesser level of review

Distribution Responsibilities

- Project Manager: ≤5,000,000 ESAL's and ≤1 mile
- C.O. Design Staff: >5,000,000 ESAL's or >1 mile

Project Mgr Distribution List

- C.O. Pavement Design
- Location Engineer
- Plan Processing
- Consultant (If Necessary)
C.O. Staff Distribution List

- Location Engineer
- Project Manager
- Plan Processing
- Consultant (If Necessary)

Pavement Design Folder

- Required For All Pavement Designs
- Should Include Two(2) Copies of the Pavement Design

Pavement Folder Contents

- Design Executive Summary
- Pavement Design Schedule
- Design Calculations
- Type Selection Justification
- Geotechnical Information
- Traffic Information
Pavement Folder Contents (cont)

- Typical Sections and Details
- Comparison of Alternatives: Initial and Life Cycle Cost
- Special Notes and Provisions
- Other Documentation

Pavement Folder Cover Sheet

Revised TD 61-29E

- Pavement Design <20,000,000 ESAL's & Off the National Highway System
- Revised Signature Block: 
<table>
<thead>
<tr>
<th>County</th>
<th>Item No.</th>
<th>UPN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Road</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sta. to Sta.</td>
<td>MP to MP</td>
<td>to</td>
</tr>
<tr>
<td>Designed By</td>
<td>Project Length</td>
<td>miles</td>
</tr>
<tr>
<td>Type Selection</td>
<td>ESAL's</td>
<td>Design ESAL's</td>
</tr>
<tr>
<td>AC</td>
<td>&lt;5,000,000</td>
<td></td>
</tr>
<tr>
<td>PCC</td>
<td>&gt;5,000,000</td>
<td></td>
</tr>
</tbody>
</table>

**DOCUMENTATION**

- Design Executive Summary
- Pavement Design Schedule
- Special Notes and Provisions
- Type Selection Justification
- Geotechnical Information
- Traffic Information
- Typical Sections and Details
- Comparison of Alternatives
- Initial Cost
- Life Cycle Cost
- Other Documentation
- List:

**SUBMITTED:**

- P.E.
- Date:

**APPROVED:**

- Project Manager
- Date:

**APPROVED:**

- C.O. Highway Design
- Date:
Important Contacts

• Contact for information and questions regarding ESAL's
• Contact: Rob Bostrom
• (502) 564-7686

Multimodal Programs

• Contact for information and questions regarding asphalt
• Contact: Allen Meyers
• (502) 564-3160

Division of Materials
Geotechnical Branch

- Contact for information and questions regarding subgrade and soil stabilization
- Contact: Bill Broyles
- (502) 564-2374

New Pavement Design Memo

- Should go into effect in July 1999
- Will replace Design Memo 10-97
- All Designs should be submitted directly to the Central Office Pavement Design Branch Staff
PAVEMENT DESIGN GUIDE

For Projects
Off The National Highway System
less than 20,000,000 ESAL'S,
less than 15,000 ADT,
and less than 20% Trucks

DIVISION OF HIGHWAY DESIGN
PAVEMENTS BRANCH

April 1999
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Shoulder Design
Pavement Drainage
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Comparison of Alternate Pavement Designs
Selection of the Best Pavement Design
Life Cycle Cost Analysis

Submittals and Approvals
**Background and Scope**

This guide is intended to be used for new construction projects only. This guide provides a methodology for the structural design of pavements for projects off the National Highway System, less than 20,000,000 ESAL’s, less than 15,000 ADT, and less than 20% trucks. The methodology as presented has roots in both the AASHTO Guide For Design of Pavement Structures and also the Kentucky mechanistic-empirical pavement design systems which are used for structural design of pavements in Kentucky.

The procedure as presented uses an AASHTO structural number concept to define structural requirements of the pavement section. However, the minimum required structural number has been determined on the basis of the Kentucky mechanistic-empirical pavement design procedure. The structural capacity of the subgrade soil has been defined in terms of a California Bearing Ratio (CBR) determined by the current Kentucky Method (Note: The Kentucky Method for CBR Tests is different from the AASHTO and ASTM Methods for CBR Tests). The fatigue requirements of the pavement structure used in this guide are based on Equivalent 18,000 lb Axle Loads (ESAL’s) as determined using load equivalency factors developed for the Kentucky mechanistic-empirical pavement design procedure. (Note: Kentucky load equivalency factors are different from AASHTO load equivalency factors.)

The intent of this “guide” is to provide the roadway designer with a simplified, straightforward methodology for developing the structural design for pavements off the National Highway System, less than 20,000,000 ESAL’s, less than 15,000 ADT, and less than 20% trucks. This guide is intended to be self-sufficient with the exception of (1) forecasts for ESAL’s, (2) recommended design CBR, (3) special notes and special provisions not included in the Standard Specifications or Standard Drawings, and (4) pavement policy guidelines which may be subject to periodic modifications such as guidelines for surface type selection. This guide includes a discussion relating to ESAL’s and the prediction of ESAL’s. Also included is a discussion relating Kentucky CBR with typical soil types and provides general guidelines for estimating a design CBR. A listing of Special Notes and Special Provisions most typically used in pavement design is included in an Appendix of this guide. Applicable policy documents are included in an Appendix.

Also included are discussions defining the responsibilities of the roadway designer for documentation of pavement design computations and related submittals. The guide also includes discussions regarding the role of the Pavements Branch, Division of Highway Design for providing assistance in the implementation of this guide.
Subgrade Strength

The material property used to characterize the roadbed soil for pavement design in this guide is the Kentucky CBR. Details for testing for the Kentucky CBR are presented in the current Edition of the Kentucky Methods (KM 64-501). Generally, the California Bearing Ratio (CBR) was originally developed by the California Division of Highways for evaluation of subgrade quality. The test has been refined, modified, and adapted by others and today is the most common test conducted on soils to define the structural quality of subgrade soils for pavement design.

Briefly, the test consists of (1) compacting a subgrade sample at optimum moisture content, (2) applying a surcharge to the sample to represent the thickness of pavement over the subgrades, (3) soaking the sample to simulate a saturated subgrade condition, and (4) forcing a three square inch plunger into the sample. The amount of force required to obtain a penetration of 0.1 inch is expressed as a percentage of the standard load for crushed road base material 1000 lb to determine the CBR value. The variations in procedures for conducting the CBR test primarily relate to the application of the surcharge and the duration of soaking the sample.

Subgrades typically are constructed of soils from roadway excavation or borrow. However, subgrades also may be composed of rock. Rock subgrades may exclude shale, include shale with other rock types, or be constructed entirely of shale. A Rock roadbed is utilized for the top two feet of the roadway when sufficient quantities of suitable rock are available from roadway excavation.

Typically, CBR tests and soil classification tests will be performed by the Division of Materials, Geotechnical Branch. If the design CBR is determined by the Division of Materials, CBR and soil classification tests will be performed on bag samples of soil obtained from roadway cut sections. A similar set of tests will be performed for CBR and classifications from fill sections whenever the project is expected to be in a borrow situation. Typically, the design CBR for soil subgrades will be recommended as the lowest value from laboratory tests (unless there is an isolated value). For larger projects with twenty or more CBR tests, the design CBR will be selected statistically as the 90th percentile value. Higher design CBR’s may be recommended for projects involving rock roadbed or bank gravel.

Shales are cemented or non-cemented sedimentary deposits of various chemical composition in which the constituent particles are 0.75 mm in diameter and includes siltstone, claystone, and mudstone. Shales are classified according to Slake Durability Index (SDI) results. Sedimentary shale deposits are frequently interbedded with thin sections of carbonates or arenaceous (sandy) partings which can produce distorted SDI values. Jar slake tests typically are performed to provide additional information about rock disintegration to compare with SDI results.
The tables below illustrate typical ranges of Estimated CBR values for a range of material types.

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>ESTIMATED CBR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock (limestone, durable sandstone, durable shale, nondurable sandstone)</td>
<td>7 to 11</td>
</tr>
<tr>
<td>Rock (nondurable shale)</td>
<td>2 to 5</td>
</tr>
<tr>
<td>Bank Gravel</td>
<td>6 to 9</td>
</tr>
<tr>
<td>Soil and/or other shale mixtures</td>
<td>1 to 5</td>
</tr>
</tbody>
</table>

The results of slaking tests are used to classify shales as "durable" or "nondurable. Nondurable shales are subdivided into classes for design purposes only. Classification of shales and typical correlations with Jar Slake Test results are listed in the table below.

<table>
<thead>
<tr>
<th>SHALE CLASSIFICATION</th>
<th>RANGE OF SLAKE DURABILITY</th>
<th>SLAKING CATEGORY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Durable Shale</td>
<td>≥ 95</td>
<td>6</td>
</tr>
<tr>
<td>Nondurable Shales</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Class I</td>
<td>80 to 94</td>
<td>4 or 5</td>
</tr>
<tr>
<td>Class II</td>
<td>50 to 79</td>
<td>3 or 4</td>
</tr>
<tr>
<td>Class III</td>
<td>≤ 49</td>
<td>1 or 2</td>
</tr>
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</table>
The design CBR also may be estimated on the basis of soil classifications. The following table may be used to estimate design CBR.

<table>
<thead>
<tr>
<th>DESCRIPTION</th>
<th>ESTIMATED CBR</th>
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<tbody>
<tr>
<td><strong>FINE GRAINED SOILS</strong></td>
<td></td>
</tr>
<tr>
<td>High Compressibility (Liquid Limit Greater Than 50)</td>
<td></td>
</tr>
<tr>
<td>Penet. Organic Soils (PT)</td>
<td>1</td>
</tr>
<tr>
<td>Fat Organic Clays (OH)</td>
<td>1 to 2</td>
</tr>
<tr>
<td>Fat Clays (CH)</td>
<td>2 to 4</td>
</tr>
<tr>
<td>Micaeous Clays (MH)</td>
<td>2 to 4</td>
</tr>
<tr>
<td>Low Compressibility (Liquid Limit Less Than 50)</td>
<td></td>
</tr>
<tr>
<td>Organic Silts or Lean Organic Clays (OL)</td>
<td>3 to 5</td>
</tr>
<tr>
<td>Lean Clays, Sandy Clays, or Gravelly Clays (CL)</td>
<td>3 to 5</td>
</tr>
<tr>
<td>Silts, Sandy Silts, Gravelly Silts (ML)</td>
<td>3 to 5</td>
</tr>
<tr>
<td><strong>COARSE GRAINED SOILS</strong></td>
<td></td>
</tr>
<tr>
<td>Sand and Sandy Soils</td>
<td></td>
</tr>
<tr>
<td>Clayey Sand, Clayey Gravelly Sand (SC)</td>
<td>5 to 7</td>
</tr>
<tr>
<td>Silty Sand, Silty Gravelly Sand (SM)</td>
<td>5 to 7</td>
</tr>
<tr>
<td>Sand or Gravelly Sand (uniformly graded) (SU)</td>
<td>5 to 7</td>
</tr>
<tr>
<td>Sand or Gravelly Sand (poorly graded) (SP)</td>
<td>5 to 7</td>
</tr>
<tr>
<td>Sand or Gravelly Sand (well graded) (SW)</td>
<td>5 to 7</td>
</tr>
<tr>
<td>Gravel and Gravelly Soils</td>
<td></td>
</tr>
<tr>
<td>Clayey Gravel or clayey sandy gravel(GC)</td>
<td>5 to 7</td>
</tr>
<tr>
<td>Silty Gravel or silty sandy gravel (GM)</td>
<td>5 to 7</td>
</tr>
<tr>
<td>Gravel or Sandy Gravel (uniformly graded) (GU)</td>
<td>5 to 7</td>
</tr>
<tr>
<td>Gravel or Sandy Gravel (poorly graded) (GP)</td>
<td>5 to 7</td>
</tr>
<tr>
<td>Gravel or Sandy Gravel (well graded) (GW)</td>
<td>5 to 7</td>
</tr>
</tbody>
</table>
Subgrade Stabilization

The majority of pavements constructed in Kentucky are constructed on fine grained soils. Approximately 85 percent of the soils consist of clay and silt. When first compacted, these fine grained soils usually have sizeable bearing strength. If pavements are constructed immediately after compaction of fine grained soils, then major problems typically will not be encountered when placing and compacting layers of paving materials. Problems arise however, when surface and subsurface water penetrates compacted fine grained soils. Water from rainfall, snow melt, and groundwater seepage enters the fine grained soil subgrades, causing swelling, and producing a loss of bearing capacity in the subgrade. The most susceptible, adverse period occurs when a fine grained soil subgrade has been exposed to the wetting conditions of winter and early spring. During periods before paving, rutting may develop in the softened subgrade. This may slow or even halt construction traffic. This also may impede compaction of the lifts of the pavement structure, resulting in a weaker pavement structure than initially designed. Therefore, the weakened subgrade not only slows construction but also limits the long-term life of the pavement structure.

Recent experience in Kentucky has demonstrated the benefits of stabilized subgrades for providing a stable platform for placement of pavement layers and also for extending the life of the pavement structure. Methods for stabilization may be characterized into two broad categories: mechanical stabilization and chemical stabilization.

Methods for mechanical stabilization of subgrade soils include the following approaches:

a. controlling subgrade density-moisture,
b. undercutting poor materials and backfilling with granular materials,
c. proof rolling and re-rolling of the subgrade,
d. using granular layers, and
e. using granular layers reinforced with geofabrics.

The above techniques for mechanical stabilization of subgrade soils have been used in Kentucky to varying degrees. Laboratory studies of blending stone aggregate into soil subgrades have shown that mixing stone aggregate with subgrade soils of minimum clay content is effective in improving the bearing capacity of the subgrade soil. Conversely, if the percent finer than 0.002 mm-particle size is greater than 15 percent, there is a reduction in bearing strength. Therefore, mechanical stabilization by adding stone aggregate to the soil may be ineffective in soils with a high clay content. The use of geofabrics, such as geogrids, also have been used in Kentucky. These have been demonstrated to improve the bearing capacity of granular bases and granular or coarse grained subgrade soils. However, the use of geogrids with fine grained soils having high clay contents should be approached with greater caution.

Chemical stabilization of subgrade soils were used sparingly in Kentucky prior to the mid 1980’s. Stabilization prior to the mid 1980’s was with portland cement. Since then, there has been much greater emphasis on the use of the chemical stabilization of subgrades. Commercially available stabilizers have included hydrated lime and cement. Both have been demonstrated as effectively stabilizing subgrade soils as stable paving platforms and are believed to contribute to extending the fatigue life of pavement structures. Portland cement has been
Hydrated lime has been demonstrated to be more effective at stabilizing fine grained soils with high clay content. Other by-product materials such as lime or cement kiln dust have been used experimentally for soil stabilization.

Typically, all subgrade soils having a CBR 6 or less are recommended for stabilization. The stabilized subgrade soil layer typically is treated as both an improved subgrade layer serving as a stable paving platform as well as a structural layer for extending the life of the pavement structure. Typically, blending about 5-6% of hydrated lime or portland cement by dry weight with the subgrade soil will result in a stable paving platform and structurally significant layer of the pavement system.

Analyses of chemically stabilized subgrade soils have indicated very high strengths of the stabilized layers (much greater than a CBR 7). However, the long-term strength gain characteristics still are not completely defined. As such, structural credit for these layers in excess of a CBR 7 are not currently recommended. The layer coefficients associated with these structural parameters to be used in this design guide will be defined elsewhere in this document.

Analyses of mechanically modified subgrades have indicated varying strengths of stabilized layers dependent upon the characteristics of the soil being modified. Blending aggregate with coarse grained granular soils may increase the strengths of the stabilized layers to strengths similar to that of aggregate bases. However, blending aggregate with fine grained soils with high clay contents may do nothing to increase the bearing capacity of the soil or at best will be minimally effective. The layer coefficients associated with mechanically modified subgrade soils will be defined elsewhere in this guide.
Equivalent Single Axle Loads

Traffic information is required by the pavement designer to associate the damaging effects of the applications of an axle of any load applied to the pavement. The term equivalent single axle load is used in pavement design methodologies to describe the relative amount of damage done to the pavement. The most common expression of pavement damage is the 18,000-pound equivalent single axle load. Load equivalency factors (pavement damage factors) are used to describe the relative amount of damage for a specific axle loading and axle configuration in terms of the amount of damage done to the pavement by some number of equivalent 18,000-pound axle loads. As an illustration, one application of a 12,000-pound single axle load would be expected to do an amount of damage to the pavement equivalent to 0.2 applications of one 18,000-pound single axle load. Stated another way, five applications of a 12,000-pound single axle load will do the same amount of damage to the pavement as one application of an 18,000-pound single axle load. It should be noted that relationships between load equivalency factors (pavement damage factors) and load is not a linear relationship.

Load equivalency factors are calibrated to specific pavement design procedures. For example, the load equivalency factors for the AASHTO Guide for Design of Pavement Structures are different from the load equivalency factors used with the Kentucky Mechanistic-Empirical Pavement Design Procedure which are different from the load equivalency factors used with the Asphalt Institute Thickness Design Asphalt Pavements For Highways & Streets (MS-1). Also, load equivalency factors used for the design of flexible pavements (asphalt concrete) are different from the load equivalency factors used for rigid pavements (portland cement concrete) for some pavement design procedures. For example, the load equivalency factors for the AASHTO Guide For Design of Pavement Structures include separate load equivalency factors for flexible pavements and for rigid pavements. Conversely, the mechanistic-empirical pavement design procedures developed in Kentucky have been calibrated on the basis of load equivalency factors used for flexible pavements.

Equivalent 18,000 pound Single Axle Loads (ESAL’s) for pavement design purposes typically will be provided by the Division of Planning. However, the following discussion is provided as a general description of the parameters associated with the determination of ESAL’s for pavement design purposes. There are various approaches which can be used to convert a mixed stream of different classifications of vehicles, different axle loads, and different axle configurations into an equivalent number of 18,000-pound single axle loads (ESAL’s) and to sum these over the design period.

There are four key considerations which influence the accuracy of traffic estimates and which can significantly influence the life cycle of a pavement. These are:

1. The correctness of the load equivalency values used to estimate the relative damage induced by axle loads of different mass and configurations;
2. The accuracy of traffic volume and weight information used to represent the actual loading projections;
3. The prediction of ESAL’s over the design period; and
4. The interactions of age and traffic as it relates to the functional and structural deterioration of the pavement and related changes in pavement serviceability.

**Historical Data for Forecasting Equivalent Single Axle Loads (ESAL’s)**

Forecasting of ESAL’s is perhaps the most critical aspect of pavement design since it involves forecasting not only the growth in traffic volumes for a particular route but also forecasting the change in the characteristics of vehicles in the traffic stream. For example, during the past twenty years, there has been significant growth in traffic volumes and proportions of trucks in the traffic stream for most major routes. At the same time, the sizes and weights of trucks in the traffic stream have also increased. As a result, many pavements have deteriorated more rapidly than expected because the combination of increased traffic volumes, growth in proportions of trucks, and increases in sizes and weights of trucks. The Division of Transportation Planning maintains historical files of this information and is best suited to apply this information for forecasting of ESAL’s for pavement design purposes. Thus for purposes of this Guide, it is assumed that ESAL’s will be provided.

A procedure has been developed for the forecasting of ESAL’s for selection of SUPERPAVE mix design criteria has been developed by the Kentucky Transportation Center and is outlined in Research Report KTC-99-1, “Development of ESAL Forecasting Procedures for SUPERPAVE Pavement Design”. This procedure has been developed utilizing Microsoft ACCESS and historical data obtained from the Division of Transportation Planning, it provides a means to estimate ESAL’s from known historical data or information provided by the user. This procedure should be used with caution, in that its original intent was the estimation of ESAL’s for SUPERPAVE mix design and *not* for pavement structural design.

There may be those occasional circumstances when ESAL’s are not provided by the Division of Planning. For those limited conditions, the following discussion is provided to allow the designer to estimate ESAL’s for purposes of pavement design:

ESAL’s may be estimated from the following equation:

\[
\text{ESAL’s} = \text{ADT} \times T \times \left(\text{ESAL’s per Truck}\right) \times \text{DL} \times 365 \times L
\]

where: ADT is the average daily traffic at the mid-year of the design life,

\[T\] is the percentage of trucks in the traffic stream,

\[\text{ESAL’s per Truck}\] is the amount of pavement damage associated with one application of a typical truck in the traffic stream,

\[\text{DL}\] is the design life or design period in years, and

\[L\] is the proportion of the traffic in the design lane.
The Division of Transportation Planning maintains historical records of ESAL’s per truck. As the size and weights and styles of trucks change, so do the typical ESAL’s per truck. Following are some general guidelines for ESAL’s per truck which may be used for estimating ESAL’s in the absence of more definitive information from the Division of Planning.

If the Pavement Designer has only General Knowledge of the Traffic Stream

Trucks are predominately Light Trucks (delivery trucks, very few heavily loaded trucks with few overweight vehicles)

\[
\text{ESAL’s per Truck} ---- 0.70 \text{ to } 1.0 \text{ ESAL’s per Truck}
\]

Trucks are predominately Heavy Trucks (trucks hauling aggregates, grain, steel, coal, or concrete with a significant number of overweight vehicles)

\[
\text{ESAL’s per Truck} ---- 4.0 \text{ to } 10 \text{ ESAL’s per Truck}
\]

If the Pavement Designer has more detailed knowledge of the Traffic Stream

An Equivalent Single Axle Load (ESAL) is the measure of the amount of damage done to the pavement by one application of a single axle load (four tires) weighing 18,000 pounds. Thus, the ESAL’s per truck varies dependent upon the number of axles per truck and the specific loadings on each axle or axle group. Following are typical ranges for ESAL’s per truck based on assumed gross vehicle weights (GVW) and assumed distributions of loadings to the various axles or axle groups.

**Single Unit Trucks**

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<tr>
<td>13,000 pounds</td>
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### Semi-Trailer Combination Trucks

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<tr>
<td>Six Axles:</td>
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<td>80,000 pounds</td>
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<td>120,000 pounds</td>
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### Automobiles

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Catalog of Structural Designs

The following CATALOGS OF STRUCTURAL DESIGNS will be used to define the structural requirements for a given pavement section based on the CBR for the subgrade soil/rock and the forecast ESAL’s for the design life. The Kentucky procedure for flexible pavement design is based on layer elastic principles. The required pavement structure layer thicknesses are determined on the basis of critical strains at the bottom of the asphaltic concrete layer and top of the subgrade layer. The results of these analyses have been summarized in the form of graphical illustrations for various percentages of asphalt in the total pavement structure (33% Asphalt, 50% Asphalt, 75% Asphalt, and 100% Asphalt). There also have been computerized solutions for these analyses. However, these analyses still require the designer to apply judgement and experience in the selection of the appropriate percentage of asphalt concrete in the pavement structure. For example, what conditions are more appropriate for a 33% Asphalt design as compared with a 75% Asphalt design. Also, the mechanistic concepts used in the development of the Kentucky system are such that substitution ratios for materials varies from one percent asphalt design to another percent asphalt design. Thus, proper adjustment to a percent asphalt design not already evaluated requires a detailed elastic layer analysis. Detailed elastic layer pavement analyses are not practical for projects such as those covered by this guide.

The AASHTO Guide for Design of Pavement Structures (1993 Edition and earlier editions) is an empirical pavement design procedure. The AASHTO procedure is based on structural layer coefficients which define the structural capacity of the various layers in the pavement structure. The summation of the various layer coefficients multiplied by the thickness of each layer results in a Structural Number (SN) which is an index value defining the structural integrity of the pavement structure. This concept is much less theoretically sophisticated than mechanistic-empirical procedures such as those developed by the Asphalt Institute or the Kentucky procedure. However, the structural number concept is easily used.

The CATALOG OF STRUCTURAL NUMBERS is founded on the Kentucky procedures for design of asphalt pavements. The required pavement structures derived from the Kentucky procedures have been converted to equivalent structural numbers. These structural numbers are the required structural numbers for each specific combination of CBR and ESAL’s as derived from the analyses using the Kentucky procedures. The catalog of structural numbers for flexible pavements is given in Table 1.

The CATALOG OF PCC STRUCTURAL DESIGNS has also been developed based on the AASHTO and Kentucky procedures, thicknesses of portland cement concrete pavement (PCC) for selected levels of ESAL’s and CBR’s wherein the use of PCC pavement has been historically and economically feasible are included in Table 2.
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Table 2. Catalog of Required PCC Thicknesses

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</table>
Pavement Design Computations

The required pavement design for this project is determined on the basis of the required STRUCTURAL NUMBER. The required pavement STRUCTURAL NUMBER is determined from the CATALOG OF STRUCTURAL NUMBERS for the design CBR and design ESAL’s. Required pavement thicknesses are determined using the following equation:

\[ SN = (a_1 \times d_1) + (a_2 \times d_2) + (a_3 \times d_3) + (a_4 \times d_4) + \ldots + (a_n \times d_n) \]

where: \( SN \) is the required STRUCTURAL NUMBER determined from the CATALOG OF STRUCTURAL NUMBERS

\( a_1 \) is the structural layer coefficient for the first layer of the pavement structure, typically the asphalt surface layer for pavement designs in Kentucky. Typical layer coefficients for asphalt concrete surface courses in Kentucky are 0.40 to 0.44. This range of layer coefficients applies for all surface courses used in Kentucky except for Open Graded Friction Courses (OGFC) which are assigned no structural credit for pavement design purposes.

\( d_1 \) is the thickness of the pavement layer corresponding to layer 1.

\( a_2 \) is the layer coefficient for the second layer of the pavement structure, typically the asphalt concrete binder layer or asphalt concrete base layers for pavement designs in Kentucky. Typical layer coefficients for asphalt concrete binder courses in Kentucky are 0.40 to 0.42. Typical layer coefficients for asphalt concrete base courses in Kentucky are 0.36 to 0.40.

\( d_2 \) is the thickness of the pavement layer corresponding to layer 2.

\( a_3 \) is the structural layer coefficient for the aggregate base layer of the pavement structure. Typical layer coefficients for aggregate base layers in Kentucky are 0.11 to 0.14.

\( d_3 \) is the thickness of the pavement layer corresponding to layer 3.

\( a_4 \) is the structural layer coefficient for chemically modified roadbed soils. Typical layer coefficients used for chemically modified roadbeds in the design of pavements in Kentucky are 0.08 to 0.10. These are based on the assumption that chemical modification increases the CBR of the soil to a value greater than a CBR 6.

\( d_4 \) is the thickness of the pavement layer corresponding to layer 4.
Typical values for structural layer coefficients are:

- \( a_1 = 0.44 \) for asphalt surface materials
- \( a_2 = 0.42 \) for asphalt binder materials
- \( a_3 = 0.40 \) for asphalt base materials
- \( a_4 = 0.14 \) for DGA base and Crushed Stone Base
- \( a_5 = 0.08 \) for lime modified roadbed

Structural layer coefficients for other materials typically used in Kentucky are:

- Mechanically modified roadbed: 0.06 to 0.08
- Aggregate drainage blanket: 0.11 to 0.14
- Asphalt treated drainage blanket: 0.18 to 0.21

Shoulder Design

Pavement shoulders should be designed to meet appropriate geometric criteria. Thickness should be determined to insure adequate structural support is provided to meet any anticipated shoulder traffic. Typically shoulders should be designed to accommodate a minimum of 20% of the mainline ESAL's. In situations where earth shoulders would be warranted, it may be necessary to provide an additional 2 feet of full depth pavement to insure adequate edge support.

Pavement Drainage

Adequate drainage should be provided to the pavement structure to insure a successful pavement service life is achieved. Various types of pavement drainage systems have been utilized throughout Kentucky. For pavements designed using this guide the following criteria should be utilized:

<table>
<thead>
<tr>
<th>Design ESAL's</th>
<th>DGA Base</th>
<th>Daylighted Crushed Stone Base (CSB)</th>
<th>Drainage Blanket and Piping System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 1,000,000 ESAL’s</td>
<td>DGA Base</td>
<td>Daylighted Crushed Stone Base (CSB)</td>
<td>Drainage Blanket and Piping System</td>
</tr>
<tr>
<td>1,000,000 - 5,000,000 ESAL’s</td>
<td>DGA Base</td>
<td>Daylighted Crushed Stone Base (CSB)</td>
<td>Drainage Blanket and Piping System</td>
</tr>
<tr>
<td>5,000,001 - 20,000,000 ESAL’s</td>
<td>DGA Base</td>
<td>Daylighted Crushed Stone Base (CSB)</td>
<td>Drainage Blanket and Piping System</td>
</tr>
</tbody>
</table>

Development of Alternate Pavement Designs

The equation for STRUCTURAL NUMBER (SN) indicates that there are an infinite number of combinations of layer thicknesses of the various paving materials that will satisfy the STRUCTURAL NUMBER requirement specified in the CATALOG OF STRUCTURAL NUMBERS. The number of potential solutions is reduced somewhat when considering the practical limitations of placing the various pavement layers. Layer thicknesses of common paving materials in Kentucky are:

- Asphalt Concrete Surface: 1.25 to 1.5 inches per course
- Asphalt Concrete Binder: 1.5 to 2.0 inches per course
- Asphalt Concrete Base, Class I: 2.0 to 4.0 inches per course
- Asphalt Concrete Base, Class CI: 3.0 to 4.5 inches per course
- Asphalt Concrete Base, Class CK: 3.5 to 5.0 inches per course
- Aggregate Base (DGA or CSB): 4.0 to 6.0 inches per course
- Aggregate (Untreated) Drainage Blanket: 4.0 to 6.0 inches per course
- Asphalt Treated Drainage Blanket: 4.0 to 6.0 inches per course
- Chemically Modified Roadbed: 8.0 to 12.0 inches per course
This guide does not include provisions for the utilization of SUPERPAVE asphaltic concrete mixtures. The utilization of SUPERPAVE mixtures will be coordinated between the Division of Design, Division of Materials, and the District Office for projects identified as SUPERPAVE candidates. During the continued implementation of SUPERPAVE, updates to this guide will be provided as necessary to addresses SUPERPAVE requirements.

From a pavement engineering perspective, there are some variations in proportions of paving materials which are better suited to specific engineering applications that others. For example, pavement structures with thick aggregate bases (33% to 50% asphalt concrete) typically would be expected to provide better performance over soil subgrades with the water table close to the surface or where the soils are known to be highly moisture sensitive. Conversely, pavement structures with thick asphalt layers typically will provide better performance over rock roadbed subgrades or chemically modified roadbeds.

Development of alternate pavement designs should typically involve a “maximum aggregate” design, a “maximum asphalt concrete” design, and a Portland cement concrete design for comparative analyses. Other alternate pavement designs should be considered where specific project considerations indicate a need. Each alternate considered should meet or exceed Structural Number requirements identified in the CATALOG OF STRUCTURAL NUMBERS.

Comparison of Alternate Pavement Designs
The positive and negative engineering aspects of each alternate pavement design must be evaluated. Principal considerations include the characteristics of the traffic stream, characteristics of the subgrade, constructibility of the pavement, climatic and other environmental considerations, recycling considerations, and economic considerations. Secondary considerations include performance of similar pavements in the area, adjacent existing pavements, conservation of materials and energy, the availability of local materials or contractor capabilities, traffic safety and maintenance of traffic during construction considerations, incorporation of experimental features, stimulation of competition, and the preferences of local municipalities or the recognition of local industries.

Selection of the Best Pavement Design
Selection of the best pavement design for a given project is a combination of engineering judgement, experience, and economic analyses. Generally, pavement design alternates not satisfying project specific engineering considerations should first be eliminated. Thereafter, the primary and secondary considerations discussed above should be used to eliminate other alternate pavement designs being considered. Economic analyses should be used as the final determination of the best alternate pavement design if all other considerations are equal. For purposes of this GUIDE, economic analyses should be developed on the basis of initial construction costs only for projects having design ESAL's less than 5,000,000. For projects having design ESAL's greater than 5,000,000 and those involving comparisons of asphalt concrete pavement designs as compared to portland cement concrete pavement designs, a life cycle cost analysis should be considered.
Life Cycle Cost Analysis

The Life Cycle Cost Analysis will include the analysis of both initial construction costs and rehabilitation costs at selected intervals over a analysis period of 40 years. In addition, user costs will be considered at various levels based on the design ESAL of the project. Material costs will be determined based on values obtained from the average unit bid summary. The rehabilitation scenarios which are presented may not be the actual rehabilitation schedule for a specific pavement, however they do provide a good estimation of the cost associated with maintaining a pavement structure for 40 years. A spreadsheet is available to assist in conducting the life cycle cost calculations. Specific inputs to this procedure are as follows:

Analysis Period: 40 years

Rehabilitation Scenarios:

Flexible Pavements

Rehabilitation 1, Year 10
Mill 1.5" – 1.5" Overlay

Rehabilitation 2, Year 20
Mill 1.5" – 3.5" Overlay

Rehabilitation 3, Year 30
Mill 1.5" – 1.5" Overlay

Portland Cement Concrete Pavements

Rehabilitation 1, Year 15
Clean and Reseal Joints

Rehabilitation 2, Year 30
Clean and Reseal Joints

User Costs:

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<th>ESAL’s</th>
<th>User Cost</th>
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<td>5,000,000 - 10,000,000 ESAL’s</td>
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<tr>
<td>10,000,001 - 15,000,000 ESAL's</td>
<td>$2,000/day</td>
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<tr>
<td>15,000,001 - 20,000,000 ESAL’s</td>
<td>$3,000/day</td>
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Length of Construction

Initial Construction: 120 days
Rehabilitations: 30 days
Submittals and Approvals

The intent of this expanded pavement design guide is to provide the roadway designer with sufficient information for effective design of pavements off the National Highway System, with less than 20,000,000 ESAL’s, less than 15,000 ADT and less than 20% trucks. The CATALOG OF FLEXIBLE PAVEMENT STRUCTURAL NUMBERS presented earlier in this GUIDE provides required STRUCTURAL NUMBERS (SN’s) for CBR’s 1 to 11 and for a range of ESAL’s from 10,000 to 20,000,000. The CATALOG OF REQUIRED PCC THICKNESSES presented earlier in this GUIDE provides required PCC THICKNESSES for CBR’s 1 to 11 and for a range of ESAL’s from 1,000,000 to 20,000,000.

There will be two sets of criteria for the process of submitting and approving pavement designs done under the guidelines of this guide. These criteria and procedures are as follows:

Less Than or Equal to 5,000,000 ESAL’s & 1 Mile
These designs Do Not need to be approved by Central Office staff. The required approval and signatures are needed only by the Designer (P.E.) and the Project Manager. These designs must be submitted to the Pavement Design Branch of the Division of Highway Design for archival and pavement management purposes. These designs Will Be Reviewed and Approved for pavement type selection justification (Asphalt/PCC). Central Office Staff will be allowed 10 working days to review type selection, after which, either comments or an approved pavement design will be returned to the designer.

The Project Manager will be responsible for distribution of the approved pavement design for these projects. The distribution list includes the Location Engineer, Plan Processing Review, and the consultant, if necessary.

Greater Than 5,000,000 ESAL’s or 1 Mile
These designs Will Be submitted to the Pavement Design Branch of the Division of Highway Design for approval. These designs will require approval and signatures from the Designer (P.E.), the Project Manager, and the T.E.B.M. for Pavement Design. Approval by the Central Office Pavement Staff is intended to verify implementation and justification for pavement type selection. Initially, all of these designs will be approved by the T.E.B.M. for Pavement Design. Gradually, once it is determined that appropriate and consistent application of this design procedure is being followed, the review and approval by the Central Office will be reduced to some lesser level of review.

The Pavement Branch staff in the Division of Highway Design will be responsible for distribution of the approved pavement design for these projects. The distribution list includes the Location Engineer, Plan Processing Review, and the consultant, if necessary.

IMPORTANT: The District designers will be responsible for submitting an updated pavement design with all plans that they submit to the Central Office.
PAVEMENT DESIGN SUBMITTAL FOLDER

All pavement designs will be submitted to the Pavement Branch of the Division of Highway Design in a Pavement Design Folder. The cover sheet for this folder is attached to this document. The cover letter will identify the project information and a summary of the pavement design type selection. The cover letter will also show a checklist of what documentation is included in the pavement design folder. The following items should be included in the pavement design folder:

* Design Executive Summary
* Design Calculations
* Geotechnical Information
* Typical Sections and Details
* Special Notes and Provisions
* Pavement Design Schedule
* Type Selection Justification
* Traffic Information
* Comparison of Alternatives: Initial & Life Cycle
* Other Documentation

Pavement designs prepared by the roadway designer should be documented in a format consistent with the format used for submittal and approval of pavement design documents. Examples of pavement designs are presented in Appendix A. Typically used Special Notes are included in Appendix B. Special Provisions and applicable pavement policy documents are included in Appendix C. The pavement design folder cover sheet and submittal forms are presented in Appendix D. There are also electronic copies of these two forms on the diskette provided as part of the pavement design training course.

The Division of Highway Design Pavement Branch will send out periodic updates of all applicable notes and provisions to all district design personnel.

TECHNICAL ASSISTANCE

Staff from the Division of Highway Design will be available to provide assistance to roadway designers for application and implementation of these guidelines. The Central Office pavement design staff have been assigned as liaisons for support purposes. When pavement designs are submitted to the Central Office they should be directed to their respective district liaison. The following page lists district assignments for the pavement design staff.
Appendix A
Examples
KENTUCKY TRANSPORTATION CABINET
DIVISION OF HIGHWAY DESIGN
PAVEMENT BRANCH

Pavement Design <20,000,000 ESAL's
& off the National Highway System

Sheet 1

County Example 1 Item 1-00 UPN N/A

Road Name Troubled Water Bridge F.P. N/A

Replacement of bridge and approaches.

Traffic 2,200 ,1997 4,700 ,2017 E.S.A.L. 5 x 10^5

Existing: Type Asphalt on DGA Thickness 9/4" on 4"
Length 0.1 Miles. Design Speed 55 M.P.H. Design CBR 3

FOR TYPICAL SECTION SEE ATTACHED SHEET(S)

PAVEMENT

Traffic Lanes

1 DGA BASE 4" DEPTH
120 ASPH BASE CLASS I PG64-22 104" DEPTH (4"+ 4"+2")
154 ASPH SURF CLASS I-20/30 PG64-22 1/4" DEPTH

Shoulders (2' @ 2%)

1 DGA BASE 4" DEPTH
120 ASPH BASE CLASS I PG64-22 104" DEPTH (4"+ 4"+ 2")
149 ASPH SURF CLASS I-0 PG64-22 1/4" DEPTH

(Remaining 6' @ 8%)

NOTE:

Shoulders shall be paved full width within the guardrail limits or 200 feet. The remainder of the project shall be constructed with shoulders as otherwise shown or matching existing.

DESIGNED __________________________ DATE _________ P.E.
APPROVED __________________________ DATE __________ Project Manager
APPROVED __________________________ DATE __________ C.O. Pavement Design

(As Required)
PAVEMENT (Cont.)

Shoulder Paving Within Guardrail Limits

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<tr>
<th>Material</th>
<th>Depth</th>
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<tbody>
<tr>
<td>1 DGA BASE</td>
<td>FULL DEPTH</td>
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<tr>
<td>120 ASPH BASE CLASS I PG64-22</td>
<td>2½&quot; DEPTH</td>
</tr>
<tr>
<td>154 ASPH SURF CLASS I-20/30 PG64-22</td>
<td>1¼&quot; DEPTH</td>
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Asphalt Seal required from outside edge of paved shoulder to a point two feet down existing ditch or fill slope. Two applications of the following:

- **291 EMULSIFIED ASPHALT RS-2** 2.40 LB/SQ YD
- **100 ASPHALT SEAL AGGREGATE** 20 LB/SQ YD (No. 8 or 9M)

PLAN NOTE NO.: 448
EXAMPLE 1

1. SHOULDER SHALL BE WIDENED 2 FEET WHERE GUARDRAIL IS REQUIRED.
2. ASPHALT SEAL.
3. SEE CROSS SECTIONS FOR SLOPES OUTSIDE THE SHOULDER POINT.
4. SHOULDER PAVING WITHIN GUARDRAIL LIMITS.

DETAIL "A"

TYPICAL TANGENT SECTION
TROUBLED WATER BRIDGE
EXAMPLE 1
KENTUCKY TRANSPORTATION CABINET
DIVISION OF HIGHWAY DESIGN
PAVEMENT BRANCH

Pavement Design <20,000,000 ESAL's
& off the National Highway System

Sheet 1

County Example 2 Item 2-00 UPN FSP 010 0060 010-012 057D
Road Name U.S. 60 (13th Street in Ashland) F.P. 00STP 02601 015

Widen and reconstruct U.S. 60 (13th Street) from KY. 168 (Blackburn Ave.) to Oakview Road/Pollard Road

Traffic 14,900 1995 22,100 2015 E.S.A.L. 13,829,000
Existing: Type Asphalt on PCC on DGA Base Thickness 6” on 8” on 2”
Length 0.5 Miles. Design Speed 40 M.P.H. Design CBR 3

FOR TYPICAL SECTION SEE ATTACHED SHEET(S)

PAVEMENT
Traffic Lanes
New Pavement
1 DGA
18 DRAINAGE BLANKET TYPE II-ASPH
120 ASPHALT BASE CLASS I PG64-22
118 ASPH BASE CL I PG70-22
158 ASPH SURF CL I-40/20 PG70-22

Traffic Lanes
Widening
1 DGA
18 DRAINAGE BLANKET TYPE II-ASPH
120 ASPHALT BASE CLASS I PG64-22

Overall
190 LEVELING AND WEDGING PG64-22
118 ASPH BASE CL I PG70-22
158 ASPH SURF CL I-40/20 PG70-22

Shoulders
1810 STANDARD CURB AND GUTTER

Longitudinal Pavement Edge Drains
78 CRUSHED AGGREGATE SIZE NO 2
1000 PERFORATED PIPE-4IN
1010 NON-PERFORATED PIPE-4IN
8100 CONCRETE-CLASS A

(Cont. on Sheet No. 2)

DESIGNED __________ DATE ________ P.E.
APPROVED __________ DATE ________ Project Manager
APPROVED __________ DATE ________ C.O. Pavement Design

(As Required)
NOTES:
(1) All longitudinal pipe drainage systems for the pavement drainage blanket shall be outletted to a Headwall, Median Box Inlet, a Ditch Box, or Curb Box Inlet. Outlets shall be in a fill section whenever possible. Outlet spacing shall not exceed 500ft except grades 1% or less, then the spacing of outlets shall not exceed 250ft. All sags shall have an outlet. The Design Engineer shall spot these on the plans or in the proposal.

PLAN NOTE NO.: 448

SPECIAL NOTE
(2068) WET BOTTOM BOILER SLAG (1-1-99)
(2128) MINERAL ADMIXTURES IN PORTLAND CEMENT CONCRETE (1-1-99)
( ) PAVEMENT SUBSURFACE DRAINAGE OUTLET (3-16-98) Attached
( ) PERFORATED PIPE - 4in FOR AGGREGATE BACKFILLED TRENCH (3-16-98) Attached
Appendix B
Listing of Typically Used Special Notes
---SPECIAL NOTE---

March 18, 1999

SPECIAL NOTE FOR

BITUMINOUS
5X (2104) ASPHALT PAVEMENT REINFORCEMENT (1-1-99)
   ( ) ASPHALT PAVEMENT REINFORCEMENT WITH GEOGRIDS (EXP) (3-16-98) Attached (project specific)
   ( ) POLYPROPYLENE FIBER REINFORCED ASPHALT MIXTURES (EXP) (11-6-92) Attached
   ( ) ASPHALT LEVELING AND SEAL COURSE (3-16-98) Attached
9X (2134) SUPERPAVE MIXTURES (1-1-99)
   ( ) STONE-MATRIX ASPHALT SURFACE (EXP.) (3-3-98) Attached
   ( ) STONE-MATRIX ASPHALT BASE (EXP.) (3-3-98) Attached
9Y (2135) MATERIAL TRANSFER VEHICLE (1-5-99)
   ( ) ASPHALT CONCRETE BASE REPAIR (6-30-98) Attached

PORTLAND CEMENT CONCRETE
9K (2128) MINERAL ADMIXTURES IN PORTLAND CEMENT CONCRETE (1-1-99) Use with any PCC Pavement.
7J ( ) LIGHTWEIGHT AGGREGATE FOR USE IN PORTLAND CEMENT CONCRETE (6-9-92)

ROADBED PREPARATION AND OR REPAIR
2E (2018) ROADBED STABILIZATION AT BRIDGE ENDS (1-1-99)
   ( ) ROADBED REINFORCEMENT (EXP) (6-10-98) Attached
   ( ) MECHANICAL MODIFICATION OF SOIL ROADBED (3-16-98) Attached
   ( ) SOIL SUBGRADE MODIFICATION (3-16-98) Attached

** - Always used with Edge Drains

LONGITUDINAL PAVEMENT DRAINS & BLANKETS
** ( ) PAVEMENT SUBSURFACE DRAINAGE OUTLET (3-16-98) Attached
   ( ) PERFORATED PIPE - 100 mm FOR AGGREGATE BACKFILLED TRENCH (3-16-98) Attached

GENERAL
3M (2068) WET BOTTOM BOILER SLAG (1-1-99) Boyd, Greenup, Lawrence, Lewis
   Note that Blast Furnace Slag may be utilized...
   Est. at 110 lb/sq yd/in. (2.35 kg/sq m/mm)
   ( ) EXCELSIOR BLANKET (9-2-94) Attached
11 (2010) VARIABLE MESSAGE SIGNS (1-1-99)
   ( ) SMARTSONIC CONSTRUCTION ZONE SAFETY SYSTEM (6-30-98) Attached
8K (2129) STABILIZED SOIL SHOULDERS (Approval Pending)

---SPECIAL NOTE---
SPECIAL NOTE FOR PAVEMENT SUBSURFACE DRAINAGE OUTLET

Use approximately one metric ton of Crushed Aggregate Size No. 2 at all Perforated Pipe Headwall Outlets as illustrated in the detail below. Place Crushed Aggregate Size No. 2 to a minimum depth of 100mm as detailed below.

Use Dense Graded Aggregate (DGA) removed during placement of the Crushed Aggregate Size No. 2 to dress existing shoulders where DGA is exposed. Waste other materials removed during placement of the Crushed Aggregate Size No. 2 as directed by the Engineer. The Department will make no direct payment for disposal of wasted material.

The Department will consider payment for Crushed Aggregate Size No. 2 as full compensation for all materials, labor, and other incidentals necessary to place Crushed Aggregate Size No. 2 for vegetation control and/or erosion control at pavement edge drain outlets.

See current Standard Drawing RDP-010 for dimensions and other details.

PERFORATED PIPE HEADWALL OUTLET

March 16, 1998

[Diagram of Perforated Pipe Headwall Outlet]
SPECIAL NOTE FOR
Perforated Pipe - 100 mm
For Aggregate Backfilled Trench

Apply section 704, Underdrains, of the current edition of the Standard Specifications except use coarse aggregate for the backfill and partially wrap the aggregate with geotextile fabric as shown in the edge drain details. Apply section 215.03.04 of the current edition of the Standard Specifications except use Type IV fabric secured to the inside face of the trench with steel pins at intervals of 1.5 meters. Place the fabric on the sides and bottom of the trench with suitable equipment without stretching it. Place the filter aggregate in the trench without damaging, displacing or dislodging the fabric. Fold the fabric over the backfilled trench and secure it with steel pins at intervals of 1.5 meters.

March 16, 1998
Appendix C
Listing of Typically Used Special Provisions & Pavement Policy Documents
SPECIAL PROVISION FOR
(1069) No. 69G (99) EMBANKMENT AT BRIDGE END BENT STRUCTURES (1-1-99) Plan note 270, bid#2223
(1076) No. 76D (99) CONCRETE PAVEMENT REPLACEMENT AND REPAIR (1-1-99)
(1079) No. 79B (99) STRESS ABSORBING MEMBRANE INTERLAYER (SAMI) (1-1-99) Use S.P. 70
1.) USE A MINIMUM OF 4" (100mm) AGGREGATE BASE UNLESS SUBGRADE IS AGGREGATE AND CBR IS GREATER THAN 6

2.) LIFT THICKNESSES - 2" TO 4" (50mm-100mm) ASPHALT BASE CLASS I
3" TO 4.5" (75mm-115mm) ASPHALT BASE CLASS CI
4" TO 6" (100mm-150mm) ASPHALT BASE CLASS C
1.5" TO 2" (40mm-50mm) ALL ASPHALT BINDER CLASSES
1.25" (30mm) ASPHALT SURFACE CLASS I (1"-1.5" or 25mm-40mm)
1.5" (40mm) ASPHALT SURFACE CLASS AK/B OR AK/A OR AK/S

3.) AASHTO STRUCTURAL COEFFICIENT - ASPHALT SURFACE - 0.44
ASPHALT BINDER - 0.42
ASPHALT BASE - 0.40 (0.30 for old asphalt)
STABILIZED AGG BASE - 0.20
(Use Break & Seat curves) BREAK & SEAT CONC. - 0.20 (up to 0.35)
CONCRETE OVERLAY - 0.30-0.50 (0.67 new conc.)
DGA/CRUNCHED STONE - 0.14 (use 0.11 for old DGA)
DRAINAGE BLANKET-II - 0.18 to 0.24 (0.14~TYPE - I)
LIME/CEMENT/ROCK ROADBED - 0.11

(From TTN:BR1) WHEN USING TENSAR: DGAnew = 0.8*(DGAold) - 2
NOTE - Put Tensar at midpoint of DGA if Dnew>10" and at bottom of DGA if Dnew<10"
NOTE - TRAFFIC BOUND BASE IS #610's OR #710's MIXED INTO #2 STONE.

4.) RESILIENT MODULUS = 1500*CBR

5.) USE DGA WHEN < 1,000,000 ESALs DURING DESIGN LIFE (OR FOR CURB & GUTTER)
ALWAYS USE DGA WHEN USING A DRAINAGE BLANKET LAYER
USE CSB FOR 1,000,000 TO 5,000,000 ESALs OVER DESIGN LIFE (EXCEPT CURB & GUTTER)

6.) NOTE FOR BRIDGE REPLACEMENTS -
SEE STANDARD DRAWING NO. RBB-001 FOR SHOULDER PAVING AT BRIDGE ENDS. APPLY THE 1:25 PAVED SHOULDER TAPER TO BOTH SHOULDERS AT BOTH ENDS OF THE BRIDGE. IF THE SHOULDERS ARE TO BE PAVED THROUGHOUT THE PROJECT, THEN CONTRARY TO THIS STANDARD DRAWING, THE SHOULDERS WITHIN THIS TAPER AREA MAY BE PAVED THE SAME AS THE REMAINING SHOULDER.

7.) NOTE FOR FULL DEPTH DGA SHOULDERS (NOT 2' SHOULDERS WITH EARTH OUTSIDE PAVEMENT):
   ASPHALT SEAL REQUIRED FROM OUTSIDE EDGE OF PAVED SHOULDER TO A POINT TWO FEET (0.6 METERS) DOWN THE DITCH OR FILL SLOPE. TWO APPLICATIONS OF
   291 Emulsified Asphalt RS-2 2.40 lb/sq yd (1.3 kg/sq m)
   100 Asphalt Seal Aggregate 20 lb/sq yd (size no. 8 or 9m) (10.8 kg/sq m)

8.) CHANGED PLAN NOTES:
275 - CALLS FOR CEMENT STABILIZED ROADBED
276 - CALLS FOR LIME STABILIZATION
447 - OPTION A WARRANTS
448 - OPTION B

9.) 358 ASPHALT CURING SEAL
LIME MODIFIED ROADBED (Special Provision 64C) 2.0 lb/sy (1.1 kg/sq m)
PORTLAND CEMENT MODIFIED ROADBED (Stnd Specs 304) 2.0 lb/sy (1.1 kg/sq m)
OR 0.25 gal/sy
DGA FILTER LAYER FOR DRAINAGE BLANKETS
STABILIZED AGGREGATE BASE (Special Provision 70D) 1.2 lb/sy (0.7 kg/sq m)

10.) 2702 SAND FOR BLOTTER
2 to 3 lb/sy (1.1 - 1.6 kg/sq m) OR 5 lb/sy (2.7 kg/sq m) MAX.

11.) CARRY LOWER COURSES OF PAVEMENT 12" FAST CURB AND GUTTER (whether Asphalt. or DGA)
FOLLOWING IS A LISTING OF BID ITEM CODES, BID ITEM DESCRIPTIONS, POLISH RESISTANT AGGREGATE REQUIREMENTS, AND GUIDELINES FOR IMPLEMENTATION:

<table>
<thead>
<tr>
<th>BID ITEM CODE</th>
<th>BID ITEM DESCRIPTION</th>
<th>POLISH-RESISTANT AGGREGATE REQUIREMENTS</th>
<th>IMPLEMENTATION GUIDELINES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DGA BASE</td>
<td></td>
<td>&lt;50,000 ESALs/yr (1,000,000 ESALs)</td>
</tr>
<tr>
<td>3</td>
<td>CRUSHED STONE BASE</td>
<td></td>
<td>BETWEEN 50,000 and 250,000 ESALs/yr. (1,000,000 to 5,000,000 ESALs TOTAL)</td>
</tr>
<tr>
<td>15</td>
<td>DRAINAGE BLANKET TYPE I-UNTREATED</td>
<td></td>
<td>CONSIDER FROM 50000-250000 ESALs/yr. USE WHEN &gt; 250,000 ESALs/yr.</td>
</tr>
<tr>
<td>18</td>
<td>DRAINAGE BLANKET TYPE II- ASPHALT PG 64-22</td>
<td></td>
<td>CONSIDER FROM 50000-250000 ESALs/yr. USE WHEN &gt; 250,000 ESALs/yr.</td>
</tr>
<tr>
<td>190</td>
<td>ASPHALT MIX LEVEL AND WEDGE PG64-22</td>
<td></td>
<td>* Engineering judgement should be used based on project length</td>
</tr>
<tr>
<td>120</td>
<td>ASPHALT BASE CLASS I PG64-22</td>
<td></td>
<td>ALL MAINLINE AND SHOULDER PAVEMENTS EXCEPT FOR CLASS CK WARRANTS</td>
</tr>
<tr>
<td>118</td>
<td>PG70-22</td>
<td></td>
<td>MAINLINE AND SHOULDER PAVEMENTS EXCLUDING CLASS CK WARRANTS YET RUTTING IS A CONCERN - SAY VERY HIGH ADT OR ON PARKWAYS AND INTERSTATES (OVER CLASS CK BASE)</td>
</tr>
<tr>
<td>119</td>
<td>PG76-22 W/50%ER</td>
<td></td>
<td>ALL INTERSTATES, COAL HAUL ROADS WITH EXTENDED LIMITS, AND ALL OTHER ROUTES WITH MORE THAN 250,000 ESALs PROVIDED TONNAGE EXCEEDS 10,000 TONS (9000 metric tons) BASE</td>
</tr>
<tr>
<td>137</td>
<td>PG64-22</td>
<td></td>
<td>ADT LESS THAN 1,500 (OR AS A WEARING COURSE FOR ADT&lt;1,500 FOR EXTRA RUT RESISTANCE)</td>
</tr>
<tr>
<td>138</td>
<td>PG70-22</td>
<td></td>
<td>ADT 1,500 TO 3,000 &amp; SPEED LESS THAN 45 MPH (70 kph)</td>
</tr>
<tr>
<td>139</td>
<td>PG76-22 W/50%ER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>134</td>
<td>PG 64-22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>135</td>
<td>PG 70-22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>136</td>
<td>PG 76-22 W/50%ER</td>
<td></td>
<td></td>
</tr>
<tr>
<td>128</td>
<td>ASPHALT BINDER CLASS I-0 PG64-22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>126</td>
<td>PG 70-22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>127</td>
<td>PG 76-22 W/50%ER</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### NOTE - A LOWER CLASS SURFACE MAY BE USED IF THE QUANTITY OF SURFACE IS < 500 TONS

<table>
<thead>
<tr>
<th>Asphalt Surface Class</th>
<th>0% Polish Resistant</th>
<th>ADT Less Than 1,500</th>
</tr>
</thead>
<tbody>
<tr>
<td>149 PG 64-22</td>
<td></td>
<td>ADT 1,500 to 3,000 &amp;</td>
</tr>
<tr>
<td>147 PG 70-22</td>
<td></td>
<td>Speed Less Than</td>
</tr>
<tr>
<td>148 PG 76-22 W/50%ER</td>
<td></td>
<td>45 MPH (70 kph)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Asphalt Surface Class</th>
<th>20% Polish Resistant</th>
<th>ADT 1,500 to 3,000 &amp;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Course, Fine, or</td>
<td>Speed 45 MPH (70 KPH) or</td>
</tr>
<tr>
<td></td>
<td>Combination),</td>
<td>Greater</td>
</tr>
<tr>
<td>154 PG 64-22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>160 PG 70-22</td>
<td></td>
<td>MAX 30% Uncrushed Sand Permitted</td>
</tr>
<tr>
<td>161 PG 76-22 W/50%ER</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Asphalt Surface Class</th>
<th>40% Polish Resistant</th>
<th>ADT 6,000 &amp; Greater</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Course, Fine, or</td>
<td>Speed Less Than</td>
</tr>
<tr>
<td></td>
<td>Combination),</td>
<td>50 MPH (80 kph)</td>
</tr>
<tr>
<td>157 PG 64-22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>158 PG 70-22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>159 PG 76-22 W/50%ER</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### AK Surfaces

<table>
<thead>
<tr>
<th>Asphalt Surface Class</th>
<th>100% Polish-Resistant</th>
<th>Interstate Highways</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse Aggregate,</td>
<td>and Parkways with</td>
</tr>
<tr>
<td></td>
<td>20% of Total Combined</td>
<td>ADT 6,000 &amp; Greater</td>
</tr>
<tr>
<td></td>
<td>Fine and Coarse</td>
<td>Speed 50 MPH (80 kph) And Greater</td>
</tr>
<tr>
<td>244 PG 64-22</td>
<td></td>
<td>All Other Roads With ADT &gt; 15,000</td>
</tr>
<tr>
<td>242 PG 70-22</td>
<td></td>
<td>Speed 50 MPH (80 kph) And Greater</td>
</tr>
<tr>
<td>243 PG 76-22 W/50%ER</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Asphalt Surface Class</th>
<th>100% Polish-Resistant</th>
<th>ADT 6,000 to 15,000</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Coarse Aggregate,</td>
<td>Speed 50 MPH (80 kph) And Greater</td>
</tr>
<tr>
<td></td>
<td>20% of Total Combined</td>
<td>Except Interstate Highways</td>
</tr>
<tr>
<td></td>
<td>Fine and Coarse</td>
<td>*** Note - May Use AK/A Instead</td>
</tr>
<tr>
<td>245 PG 64-22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>240 PG 70-22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>241 PG 76-22 W/50%ER</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Asphalt Surface Class</th>
<th>100% Polish-Resistant</th>
<th>Shoulder Mix for Pavements</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fine Aggregate</td>
<td>Utilizing Class AK/B or AK/A Surface Mixes</td>
</tr>
<tr>
<td>246 PG 64-22</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### OPEN-Graded Surface

<table>
<thead>
<tr>
<th>Open-Graded Surface</th>
<th>PG 64-22</th>
</tr>
</thead>
<tbody>
<tr>
<td>267 PG 64-22</td>
<td></td>
</tr>
<tr>
<td>266 PG 70-22</td>
<td></td>
</tr>
<tr>
<td>268 PG 76-22 W/50%ER</td>
<td></td>
</tr>
</tbody>
</table>

### NOTE - SLAG MIXES HAVE THEIR OWN BID CODE
## GUIDELINES FOR SELECTION OF BITUMINOUS SURFACE COURSES

### TRAVEL CATEGORY

<table>
<thead>
<tr>
<th>SPEED (mph)</th>
<th>SURFACE COURSE</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### I. All Interstate Roads, Parkways with ADT greater than 6,000, and all other roads with ADT greater than 15,000

| A. 50 mph or higher | Bituminous Concrete Surface, Class AK/A/A |
| B. Below 50 mph     | Bituminous Concrete Surface, Class I-40/20 |

### II. Roads with ADT between 6,000 and 15,000

| A. 50 mph or higher | Bituminous Concrete Surface, Class AK/A/A or Class AK/B |
| B. Below 50 mph     | Bituminous Concrete Surface, Class I-40/20 |

### III. Roads with ADT between 3,000 and 6,000

- All Speeds: Bituminous Concrete Surface, Class I-20/30

### IV. Roads with ADT between 1,500 and 3,000

| A. 45 mph or higher | Bituminous Concrete Surface, Class I-20/30 (20% polish resistant aggregate required and limit amount of uncrushed sand to maximum of 30%) |
| B. Below 45 mph     | Bituminous Concrete Surface, Class I-0 (No restrictions on aggregate type) |

### V. Roads with ADT below 1,500

- All: Bituminous Concrete Surface, Class I-0 (No restrictions on aggregate type)

### OTHER SURFACES

- Considered on a project to project basis: Open Graded Friction Course, Bituminous Concrete Surface, Class N-30, Bituminous Concrete Binder Class I-O, and Sand Asphalt, Type II.

#### Notes

1. Traffic volumes shown are for two lane roadways. For four lane roads, determine the equivalent two lanes volume for the shoulder or outside lanes from the attached chart.

2. Lower category surfaces may apply when the project quantity of the wearing course is less than 500 tons.

3. Stage construction or special mixtures may be specified for roadways where pavements may develop significant rut depth.

4. Class N-30 surface may be applied for roadways with traffic volumes greater than 1,500 ADT and speeds less than 50 MPH where pavements require extraordinary rutting resistance. Class N-30 mixtures are specifically noted for application at intersections with high truck and turning movements. Class I-O Binder may be used for roads with ADT less than 1,500 at locations which require extraordinary rutting resistance.

5. Higher category surfaces and aggregate may be utilized when warranted by design, materials, or traffic and safety considerations. Exceptions for use of a lower category surface may be made with the approval of the State Highway Engineer in special cases when warranted by design, materials, or traffic consideration.

---

**APPROVED:**

State Highway Engineer

Date: 1-5-95

**APPROVED:**

Federal Highway Administration

Date: JAN 9 1995
WARRANTS FOR ASPHALT BINDER SELECTION

CATEGORY

1. Mainline Pavements With:

   PG 76-22 with 50% Elastic Recovery

   2,500,000 ESAL's per year or greater in design lane,
   or
   30,000 Average Daily Traffic for both directions,
   or
   30 Percent Trucks.

2. Mainline Pavements With:

   PG 70-22

   1,000,000 ESAL's per year or greater in design lane,
   or
   15,000 Average Daily Traffic for both directions,
   or
   20 Percent Trucks.

3. All Other Pavement for Mainline and All Shoulders:

   PG 64-22

4. Locations of Severe Rutting and Demonstrated High Pavement Stresses such as Intersections, and Truck Climbing Lanes:

   *Increase Required PG Grade Binder by one or more grades.

   *For Example:

   If the required PG Grade Binder is PG 64-22 and the pavement conditions are such that there are locations of severe rutting and demonstrated high pavement stresses, increase the performance grade (PG) of the asphalt binder to a PG 70-22 or PG 76-22 dependent upon the extent and severity of the distresses.

5. The use of other methods for modification of asphalt binders and techniques for pavement reinforcement may be considered on a project specific basis. Examples of other applications include the use of fibers, paving fabrics, geogrids, stress absorbing membrane interlayers, etc.

6. A PG 58-22 asphalt binder may be used as the virgin binder in mixes containing Recycled Asphalt Pavement (RAP).

7. PG 76-22 with 50% Elastic Recovery and PG 70-22 Asphalt Cement Binders shall be used only in the top portions of the pavement structure (the top 100 to 125 mm (4 to 5 inches)) for the driving lanes only. A PG 64-22 Asphalt Cement Binder will be used for all other applications excepting for Recycled Asphalt as discussed in Category 6 above or other special considerations identified on a project specific basis.

8. Exceptions for these warrants may be made by the Designer on a project specific basis. The basis for exceptions shall be documented in the project file. This documentation will be used for refinement of these guidelines.

APPROVED:

J. M. Yowell, State Highway Engineer
Date 12/26/96

Paul Toussaint, Division Administrator
Federal Highway Administration
Date 11/6/97
Mr. Jesse Story
Division Administrator
Federal Highway Administration
Frankfort, KY 40601

Dear Mr. Story

Subject: Asphalt Paving Guidelines and Warrants

As a result of our February 19, 1999 Pavement Committee meeting, we have revised our asphalt guidelines and warrants. The revisions are intended to be effective with the January 2000 bid letting. Attached for your review and approval are:

1) Guidelines for Method of Compaction Acceptance of Asphalt Mixtures
2) Guidelines for Superpave Shoulder Mixture
3) Warrants for Asphalt Binder Selection

If you concur with these guidelines, please provide a signature of approval in the designated signature block and return to Mr. Trevor Booker, Division of Construction, 501 High Street, Frankfort, Kentucky 40622.

If there are any questions or if additional information is needed, please advise.

Sincerely,

J. M. Yowell
P.E.
State Highway Engineer

cc: David Smith
Joe Deaton
Marcie Mathews
John Sacksteder
Jim Stone
Gary Sharpe
Dexter Newman
Jim Burchett
Charles Briggs
Dudley Brown
Trevor Booker

EDUCATION PAYS

KENTUCKY TRANSPORTATION CABINET
"PROVIDE A SAFE, EFFICIENT, ENVIRONMENTALLY SOUND, AND FISCALLY RESPONSIBLE TRANSPORTATION SYSTEM WHICH PROMOTES ECONOMIC GROWTH AND ENHANCES THE QUALITY OF LIFE IN KENTUCKY.
"AN EQUAL OPPORTUNITY EMPLOYER M/F/D"
**KENTUCKY DEPARTMENT OF HIGHWAYS**  
**WARRANTS FOR ASPHALT BINDER SELECTION**  
**EFFECTIVE DATE:** JANUARY 1, 2000

<table>
<thead>
<tr>
<th>BINDER PERFORMANCE GRADE (PG)</th>
<th>CATEGORY</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. PG 76-22</td>
<td>Mainline Pavements With:</td>
</tr>
<tr>
<td></td>
<td>2,500,000 ESAL's per year or greater in design lane,</td>
</tr>
<tr>
<td></td>
<td>or</td>
</tr>
<tr>
<td></td>
<td>30,000 Average Daily Traffic for both directions,</td>
</tr>
<tr>
<td></td>
<td>or</td>
</tr>
<tr>
<td></td>
<td>30 Percent Trucks.</td>
</tr>
<tr>
<td>2. PG 70-22</td>
<td>Mainline Pavements With:</td>
</tr>
<tr>
<td></td>
<td>1,000,000 ESAL's per year or greater in design lane,</td>
</tr>
<tr>
<td></td>
<td>or</td>
</tr>
<tr>
<td></td>
<td>15,000 Average Daily Traffic for both directions,</td>
</tr>
<tr>
<td></td>
<td>or</td>
</tr>
<tr>
<td></td>
<td>20 Percent Trucks.</td>
</tr>
<tr>
<td>3. PG 64-22</td>
<td>All Other Pavement for Mainline and All Shoulders.</td>
</tr>
<tr>
<td>4. Increase Required PG Binder by One or More Grades*</td>
<td>Locations of Severe Rutting and Demonstrated High Pavement Stresses Such as Intersections and Truck-Climbing Lanes.</td>
</tr>
</tbody>
</table>

* For Example: If the required PG Binder is PG 64-22 and the pavement conditions are such that there are locations of severe rutting and demonstrated high pavement stresses, increase the PG of the asphalt binder to a PG 70-22 or PG 76-22, depending on the extent and severity of the distresses.

5. The use of other methods for modification of asphalt binders and techniques for pavement reinforcement may be considered on a project-specific basis. Examples of other applications include the use of fibers, paving fabrics, geogrids, stress-absorbing membrane interlayers, etc.

6. A PG 58-22 Asphalt Binder may be used as the virgin binder in mixes containing Recycled Asphalt Pavement (RAP).

7. PG 76-22 and PG 70-22 Asphalt Binders shall be used only in the top portions of the pavement structure (the top 4 to 5 inches) for the driving lanes only. A PG 64-22 Asphalt Binder will be used for all other applications except for RAP as discussed in Category 6 above or other special considerations identified on a project-specific basis.

8. Exceptions for these warrants may be made by the Designer on a project-specific basis. The basis for exceptions shall be documented in the project file. This documentation will be used for refinement of these guidelines.

**APPROVED:**

Jesse Story, Division Administrator  
Federal Highway Administration  
Date
KENTUCKY DEPARTMENT OF HIGHWAYS
GUIDELINES FOR METHOD OF COMPACTION ACCEPTANCE
OF ASPHALT MIXTURES

EFFECTIVE DATE: JANUARY 1, 2000

When the plan quantity is 1,000 tons or greater of one mixture type, apply compaction Option A of Section 402 of the Standard Specifications to all of the following:

1. New construction projects.
2. Interstate and Parkway projects.
3. Mixtures containing PG 70-22, PG 76-22, or other specialty modifiers.
4. Resurfacing projects with mixtures requiring Type A - Type D polish-resistant aggregate.

Use compaction Option A, of Section 402 of the Standard Specifications, for all individual mixtures placed on driving lanes at one inch or greater thickness on the above-listed applications. For group jobs, any single pavement/subsection must be 1,000 tons or greater before Option A applies.

Accept other mixtures and quantities of less than 1,000 tons, including those for shoulders, leveling and wedging, and thin scratch courses (those less than one inch thick), by compaction Option B of Section 402 of the Standard Specifications. For resurfacing mixtures requiring Type E polish-resistant aggregate, apply Option B density requirements.

The Department may apply compaction requirements to other mixtures, or quantities, when deemed necessary because of specialty applications or other considerations. The Division of Highway Design, the Division of Highway Operations, or the Division of Materials will recommend special applications to the State Highway Engineer for approval.

The Department will include a statement in the project proposal indicating whether compaction Option A or Option B applies.

APPROVED

Jesse Story, P. E.
Kentucky Division Administrator, FHWA
GUIDELINES FOR ESAL CLASS SELECTION FOR SUPERPAVE SHOULDER MIXTURES

When selecting the ESAL Class for Superpave asphalt mixtures for shoulder applications, the Department will use one Class lower than that specified for the corresponding mainline Superpave mixture. When the mainline Superpave mixture is a Class 1 mix, the Department will use Class 1 for the corresponding Superpave shoulder mixture also.

The Department may apply a different ESAL Class to a particular Superpave shoulder mixture when deemed necessary because of specialty applications or other considerations.

GUIDELINES FOR SELECTING SUPERPAVE SURFACE MIXTURE SIZE AND LIFT THICKNESS

When selecting a Superpave asphalt surface (wearing course) mixture, the Department will specify:

1. A 0.38-inch nominal-maximum size Superpave mixture, at a 1.0-inch lift thickness, for ESAL Classes 1 and 2; and

2. A 0.5-inch nominal-maximum size Superpave mixture, at a 1.5-inch lift thickness, for ESAL Classes 3 and 4.

The Department may select a different size of, or lift thickness for, a particular Superpave mixture when deemed necessary because of specialty applications or other considerations.

APPROVED

J. M. Yowell, P. E.  
State Highway Engineer  

Date: 5-1-99

APPROVED

Jesse Story, P. E.  
Kentucky Division Administrator, FHWA  

Date:  
Appendix D
Pavement Design Submittal Forms
## KENTUCKY TRANSPORTATION CABINET
### PAVEMENT DESIGN FOLDER

<table>
<thead>
<tr>
<th>County</th>
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**Designed By**

**Type Selection**

- **AC**
  - $\leq 5,000,000$
- **PCC**
  - $>5,000,000$

### DOCUMENTATION

- Design Executive Summary
- Pavement Design Schedule
- Special Notes and Provisions
- Type Selection Justification
- Geotechnical Information
- Traffic Information
- Typical Sections and Details
- Comparison of Alternatives
  - Initial Cost
  - Life Cycle Cost

**Other Documentation List:**

**SUBMITTED:**

**APPROVED:**

**APPROVED:**

P.E.  
Date: __________

Project Manager  
Date: __________

C.O. Highway Design  
Date: __________
## Kentucky Transportation Cabinet
**Division of Highway Design**
**Pavement Branch**

**Pavement Design <20,000,000 ESAL's & off the National Highway System**

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---

For typical section see attached sheet(s)

---

**Pavement**

**Traffic Lanes**

**Shoulders**

---

**Designed**

**Approved**

**Approved**

(As Required)
Appendix E
Example Pavement Design Submittal Folder
<table>
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<tr>
<th>County</th>
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<th>Item No.</th>
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SUBMITTED: __________________________ P.E. Date: ______________

APPROVED: __________________________ Project Manager Date: ______________

APPROVED: __________________________ C.O. Highway Design Date: ______________
KENTUCKY TRANSPORTATION CABINET
DIVISION OF HIGHWAY DESIGN
PAVEMENT BRANCH

Pavement Design <20,000,000 ESAL's & off the National Highway System

Sheet 1

County Harlan Item 11-133.00 UPN FD04 048 0038 001-005
Road Name Harlan-Evarts (KY 38) F.P. ---

Reconstruction from Clovertown East to Brookside.

Traffic 7,500 ,1996 13,200 ,2019 E.S.A.L. 2,594,000
Existing: Type ------ Thickness ------
Length 3.64 Miles. Design Speed 45 M.P.H. Design CBR 9*

FOR TYPICAL SECTION SEE ATTACHED SHEET(S)

PAVEMENT

Traffic Lanes
1 DGA BASE 6.5" DEPTH
120 ASPHALT BASE CLASS I PG64-22 8" DEPTH (4" + 4")
157 ASPH SURF CL I-40/20 PG64-22 1.25" DEPTH

Shoulders
1 DGA BASE FULL DEPTH
120 ASPHALT BASE CLASS I PG64-22 4" DEPTH
149 ASPH SURFACE CL I-O PG64-22 1.25" DEPTH

Asphalt Seal required from outside edge of paved shoulder to a point 2 feet down the ditch or fill slope. Two applications of the following:

291 EMULSIFIED ASPHALT RS-2 2.40 lb/sq yd
100 ASPHALT SEAL AGGREGATE 20 lb/sq yd

NOTE:
Increase bottom 6.5" of DGA 10% by weight for Rock Roadbed construction, including shoulders.

PLAN NOTE NO.: 242; 444; 447

DESIGNED ___________________________ DATE _________ P.E.
APPROVED __________________________ DATE _________ Project Manager
APPROVED __________________________ DATE _________ C.O. Pavement Design

(As Required)
PAVEMENT DETAIL (HARLAN - EVARTS ROAD)

1. SHOULDER SHALL BE WIDENED 2 FEET WHERE GUARDRAIL IS TO BE INSTALLED.

PAVEMENT DESIGN DETAIL

HARLAN - EVARTS ROAD (KY 38)

FD04 048 0038 001-005 065 D
### Pavement Design Catalog

**Version 1.0**

**April-99**

#### Structural Design Inputs

- **Design CBR**
- **Design ESAIC's** 2.564,000
- **Design Life (years)** 20
- **Input User Defined Thicknesses (ynets)** yes
- **Analysis Period (years)** 40
- **Stabilized Subgrade Thickness (in)** 0
- **Sub. Stabilization Width (One Direction)** 0

| Material Type Selection list may be edited in the Selection Input Worksheet. |

#### PCC Pavement Design From Design Catalog

- **Required Number** 4.42
- **Required PCC Pavement Thickness** 8.00

#### Maximum Asphalt Design

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Hoskinston

VICINITY MAP

LOCATION & VICINITY MAP

KY 38 (Harlan - Evarts Road)
FD04 048 0038 001-005
Item No. 11-133.00
HARLAN COUNTY, KY.
**Design Executive Summary**

**County:** Harlan  
**Item No.:** 11-133.00  
**Federal Project No.:**  
**UPN:** FD04 048 0038 001-005 065D

**Project Description:** HARLAN-EVARTS ROAD (KY38)  
Reconstruction from Clovertown East to Brookside

**Roadway Classification:**  
- **Local:**  
- **Collector:** X  
- **Arterial:**  
- **Interstate:**  
- **Rural:** X  
- **Urban:**

**ADT (current):** 7500  
**ADT (2019):** 13200  
**DHV (2019):** 1400

**Posted Speed Limit:**  
- 55 (rural)  
- 35 (urban)

**Selected Design Speed:** 70 Km/hr

- X Concurrence in a reduced design speed to be obtained from Director of Design
- Exception to design speed criteria will have to be obtained from FHWA

### Design Criteria

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1. **4.2m, 1:4 - rock cuts**  
2. **1:2 Min - 1:4 or flatter desirable**
Access Control Type: Permit

Environmental Action: Not req'd  
Approval Date: ____________________

Existing Pavement Depths: ____________________

Attachments:
1. Provide map showing project location
2. Discussion of all considered alternates, including Do Nothing, and a brief description of maintenance of traffic schemes
3. 8 1/2” x 11” Typical Section

Submitted By: Daniel Sevitt  
District Preconstruction Engineer  
May 19, 1997

Recommended By:  
Location Engineer  
May 27, 1997

Approved By:  
Acting T.E.M. for Location  
7/8/97

Comments:
Alternate 1B is the recommended alternate

GEOMETRIC APPROVAL GRANTED BY:

David Kratt  
7/10/97

Director, Division of Design
Harlan County, Item No. 11-133.00
Harlan - Evarts Road (KY 38)
FD04 048 0038 001-005 065D

COMMENTS

KY 38 in the area of the subject project is posted for a 55 mph speed limit. The Design Team has selected a 70 km/hr design speed for the subject project (reconstruction of KY 38). Projects to reconstruct KY 38 from the end of the subject project at Brookside to Evarts have been completed within the past 8 years. The projects reconstructed the existing road to a 40 mph design speed in spots and just resurfaced other areas leaving sections of roadway that do not meet any design speed. The 70 km/hr design speed was selected for this project because it allows the use of a 175 meter radius for horizontal curves. A 90 km/hr design speed has a minimum radius of 305 meters. Using this radius places the new roadway further into the mountain, increasing the excavation and the thus the construction cost from 12 million dollars (70 km/hr) to 19 million dollars for a 90 km/hr design speed.
Typical SuperElevated Section

NOTES:
1. Widen 0.6m where Guardrails are required.
2. Bituminous Seal

NOTE:
SUPERELEVATED SHOULDERS - CONSTRUCT TO STANDARD SUPERELEVATION, EXCEPT NOT FLATTER THAN THE SLOPE INDICATED FOR NORMAL SECTION.
Harlan County  
(KY 38) Harlan - Evarts Road  
FD04 048 0038 001-005 065 D  
Item No. 11-133.00

ALTERNATES

The project begins at east end of the Corps of Engineers roadway improvement for the tunnel project and extends a distance of approximately 5.8 kilometers to the west end of the bridge over Clover Fork at Brookside.

Five alternates were studied along with a “Do-Nothing Alternate”.

Alternate 1B is the recommended alternate.

Three Alternates (1, 2 & 3) were presented at the preliminary line and grade inspection. Alternate 1 generally followed the existing roadway. Alternates 2 and 3 provided for improved horizontal alignment and were generally located further from Clover Fork. The cost estimates were $12,600,000, $19,100,000, and $16,800,000 respectively.

The Do-Nothing Alternate would retain the existing roadway which does not meet the needs of the traffic.

Alternate 1A was proposed for discussion at the Preliminary Line and Grade Inspection because of the difficulty of maintaining traffic at Coxton during construction. This Alternate would primarily use Alternate 1 except moving the alignment south to the west of Coxton and north of Clover Fork at Coxton adding two river crossings. It was determined that the alignment north of Coxton would be in the floodway. It would be difficult if not impossible to obtain approval for this alternate.

Alternate 1B was then proposed to move the alignment back to the south side of Clover Fork at Coxton and provide a temporary detour to the north of Clover Fork using the existing crossing and providing a temporary crossing. The estimated cost is $10,700,000.

MAINTENANCE OF TRAFFIC

Maintain traffic on existing roadway except at Coxton where a temporary detour will be provided. Construct new roadway outside limits of existing roadway. Construct temporary connections to connect full and partial sections of the new roadway and divert traffic to these locations using one lane and the shoulder to maintain traffic where necessary. Complete construction of the remaining left and right halves of the new roadway. Construct the approaches to the bridges, railroad and beginning of project. Traffic may restricted to one lane at approach construction during working hours. Shift traffic crossover points allow completion of roadway at these points and complete construction
Harlan County  
(KY 38) Harlan - Evarts Road  
FD04 048 0038 001-005 065 D  
Item No. 11-133.00  

Alternate 1B  

ASSessment of WATER-RELATED IMPACTS  

1. There may be wetlands on this project subject to Environmental Analysis by the Department.  

2. The proposed alignment of the relocated Harlan-Evarts Road (KY 38) crosses a drain at Station 4+640 +/- . The existing 914 x 914 mm (3'x3') reinforced concrete box culvert at 0 degree skew is being replaced with a 1200 mm (48") pipe culvert at the same skew. The proposed pipe fits the existing channel on the inlet end. The proposed pipe provides for a 40 meter channel change (the proposed roadway fills the existing channel) and moves the outlet 35 m southeast.  

3. The proposed alignment of the relocated Harlan-Evarts Road (KY 38) crosses a drain at approximate Station 4+840 +/- . The existing 1219 x 1219 (4'x4') mm reinforced concrete box culvert at 0 degree skew is being replaced with a 1350 mm (54") pipe at the same skew. The pipe fits the existing channel on the inlet end. The proposed pipe provides for the filling of 30 m of existing channel under the proposed roadway and provides for the minimization of any water-related impact at this crossing.  

4. The proposed alignment of the relocated Harlan-Evarts Road (KY 38) crosses a drain at approximate Station 5+240 +/- . The existing 5 m reinforced concrete bridge at 0 degree skew is being replaced with a 1800 x 1200 mm (6'x4') reinforced concrete box culvert at 30 degree skew. The culvert fits the existing channel on both ends. The proposed culvert provides for the filling of 35 m of existing channel at the KY 38 crossing of the existing drain and provides for the minimization of any water-related impact at this crossing.  

5. The proposed alignment of the relocated Harlan-Evarts Road (KY 38) crosses a drain at approximate Station 6+560 +/- . The existing 1372 mm (54") reinforced concrete pipe at 15 degree skew is being replaced with a 2400 x 1800 mm (8'x6") reinforced concrete box culvert at the same skew. The culvert fits the existing channel. The proposed culvert provides for an avoidance of any channel change at the KY 38 crossing of the existing drain and provides for the minimization of any water-related impact at this crossing.  

Note: Proposed pipe and culvert sizes shown hereon are preliminary estimated sizes.
INTRA-DEPARTMENTAL MEMO

TO: John B. Sacksteder, Director
    Division of Highway Design

ATTN: Daryl Greer

FROM: Bruce S. Siria, Director
    Division of Transportation Planning

DATE: November 11, 1996

SUBJECT: Harlan County Traffic Forecast
    KY 38 from KY 3454 to Cloverfork Bridge
    Item No. 11-133.00

In response to your October 16, 1996 request for traffic forecasts on the subject project, we are providing current year ADTs, construction year (1999) ADTs, design year (2019) ADTs, truck percentages, and estimated equivalent axleload accumulations on the attached map and worksheet.

If you have any questions, please call Rob Bostrom of this Division.

BSS:KL
Attachments
c: Gary Sharpe
    Daniel Jewell, D-11
BEG: 0.25 mi. West of KY 3454 (Turner Hill Rd.) at the Corps reconstructed KY 38 (MP 1.118)
END: Cloverfork Bridge at Brookside (MP 4.733)
LENGTH: 3.62 mi.

<table>
<thead>
<tr>
<th>YEAR</th>
<th>FORECAST</th>
</tr>
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<tbody>
<tr>
<td>1996 ADT</td>
<td>7,500</td>
</tr>
<tr>
<td>1999 ADT</td>
<td>8,100</td>
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<tr>
<td>2019 ADT</td>
<td>13,200</td>
</tr>
<tr>
<td>2019 OHV</td>
<td>1,400</td>
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<tr>
<td>2019 OT (ADT)</td>
<td>9</td>
</tr>
<tr>
<td>2019 OT (OHV)</td>
<td>6</td>
</tr>
<tr>
<td>20 Yr EALs</td>
<td>2,594,000</td>
</tr>
</tbody>
</table>
### Forecast of Equivalent Axle Load Accumulations - Design

**County:** Harlan

**Route ID:**
- **Road Name:** KY 38
- **Project Nos.:** FD04
- **Project Limits:** KY 3454 to Brookside

**Ref. Stations:**
- 1995 Vol. Count & Stn 758
- PTR Rpt, Stn 758
- 1995 Aggregated ESALs, FC 7
- 1995 Coal Haul Report

<table>
<thead>
<tr>
<th>Functional Class</th>
<th>Rural</th>
<th>Urban</th>
</tr>
</thead>
<tbody>
<tr>
<td>01 Interstate</td>
<td>------</td>
<td>11 Interstate</td>
</tr>
<tr>
<td>02 Principal Arterial</td>
<td>12 Othr Fre'w's &amp; X-Wys</td>
<td></td>
</tr>
<tr>
<td>06 Minor Arterial</td>
<td>14 Othr Pr ncpl Arterial</td>
<td></td>
</tr>
<tr>
<td>07 Major Collector</td>
<td>X</td>
<td>16 Minor Arterial</td>
</tr>
<tr>
<td>08 Minor Collector</td>
<td>17 Collector</td>
<td></td>
</tr>
<tr>
<td>09 Local</td>
<td>19 Local</td>
<td></td>
</tr>
</tbody>
</table>

**Dates:**
- **Construction Year:** 1999
- **Design Period:** 20
- **Year at Mid-term:** 2009

**Traffic Parameters:**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Construction Year Forecast</th>
<th>Annual Change</th>
<th>Years to Mid-term</th>
<th>Mid-term Increment</th>
<th>Design Year Forecast</th>
<th>Mid-term Forecast</th>
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<tbody>
<tr>
<td>Volume (AADT)</td>
<td>8,069</td>
<td>1.0250 x</td>
<td>10.00</td>
<td>2,260 +</td>
<td>8,069 =</td>
<td>10,329</td>
</tr>
<tr>
<td>Percent Trucks (XT)</td>
<td>7.5</td>
<td>1.0071 x</td>
<td>10.00</td>
<td>.551 +</td>
<td>7,500 =</td>
<td>8.1</td>
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<tr>
<td>Percent Trucks Hauling Coal (XCT)</td>
<td>1.6</td>
<td>.9735 x</td>
<td>10.00</td>
<td>.389 +</td>
<td>1.6 =</td>
<td>1.3</td>
</tr>
</tbody>
</table>

**Non-Coal Trucks:**
- Axles/Truck (A/NCT): 2.881 x 1.0014 x 10.00 = .040 + 2.881 = 2.921
- EALs/Axle (EAL/NCA): .244 x 1.0000 x 10.00 = .000 + .244 = .244

**Coal Trucks:**
- Axles/Truck (A/CT): 4.577 x 1.0000 x 10.00 = .000 + 4.577 = 4.577
- EALs/Axle (EAL/CA): 1.625 x 1.0000 x 10.00 = .000 + 1.625 = 1.625

**Daily EALs at Mid-Term:**

4-Tired Vehicles:
- AADT 10,329 x .919 x 0.005 = 47.486
- Non-Coal Trucks: 10,329 x .079 x 2.921 x .244 = 585.302
- Coal Trucks: 10,329 x .001 x 4.577 x 1.625 = 77.946

**Total Mid-term daily EALs:** 710.734

**Design EALs:**
- Mid-term Daily EALs 710.734 x 365 x 20 x 0.5000 = 2,594,000
- Design EAL in Critical Lane

**No. of Lanes:** 2

Form TF96_950
An abbreviated geotechnical engineering report has been completed for the subject project. The drilling and sampling was obtained by Rhodes, Incorporated. The testing was performed by the Geotechnical Branch. The purpose of the investigation was to define the soil and subsurface conditions. Reduced size geotechnical notes sheet, cut stability and embankment stability sheets are attached. The CADD input for the cut and embankment stability sheets is being sent to T.H.E. Engineers via E-Mail for incorporation into the roadway plans.

Stability analyses were performed at station 6+400 which indicated no problems to be expected for the embankments. The drawing is attached showing the result of these analyses.

A Select Rock Quantity Estimate was submitted by the design consultant. Based on these estimates, a sufficient amount of durable sandstone from roadway excavation will be available on this project for all embankment construction and to perform all the following applicable notes requiring this material.

Our recommendations are listed below:

1). All soils, whether from roadway or borrow, may require manipulation to obtain proper moisture content prior to compaction. Direct payment shall not be permitted for rehandling, hauling, stockpiling, and/or manipulating soils.
2). In accordance with Section 207 of the current Standard Specifications, the moisture content of embankment material shall not vary from the optimum moisture content as determined by KM 64-511 by more than +2 percent or less than -4 percent. This moisture content requirement shall have equal weight with the density requirement when determining the acceptability of embankment construction. Refer to the Family of Curves for moisture/density correlations.

3). Excavation of surfaces ditches and channel changes adjacent to embankment areas shall be performed prior to the placement of the adjacent embankments. The material excavated for the channel changes and surface ditches is suitable for embankment construction if dried to proper moisture content in accordance with Section 207 of the current Standard Specifications.

4). The contractor is responsible for conducting any operations necessary (such as construction of temporary drainage ditches, etc.) to excavate the cut areas to the required typical section. These operations shall be incidental to the roadway price.

5). The contractor shall conduct grading operations in such a manner that durable sandstone from roadway excavation shall be stockpiled separately or otherwise manipulated so that ample quantities are available for those areas requiring said material. No direct payment will be allowed for such necessary manipulating as stockpiling, hauling and/or handling the material.

6). All embankment construction shall be sandstone from roadway excavation.

7). All Earth Cores shall be constructed with non-erodible material only, meeting the requirements of the current edition of Special Provision 69.

8). Soil horizons and slopes on the project may be subject to erosion. Necessary procedures in accordance with Sections 212 and 213 of the Standard Specifications for Road and Bridge Construction, current edition, shall be followed on construction to control the erosion and water pollution.

9). Any saturated, unstable material encountered in existing creek beds and/or drainage swales within embankment foundation limits shall be drained.

10). Foundation embankment benches shall be placed in accordance with Standard Drawing RGX-010 at the locations listed below and/or as directed by the Engineer.

6+430 to 6+450, left side

11). The project should be designed for a 0.6 meter rock roadbed utilizing durable sandstone from roadway excavation, using a CBR design value of 9.0.
12). The recommended rock swell factor is estimated to be ten (10) percent for material excavated below the rock disintegration zone (RDZ).

cc: Kentucky Transportation Center
Division of Design (Roadway Plan Review Section)
√ TEBM for Pavement Design
Division of Construction
TEBM for Construction (District 11) 2 copies
TEBM for Preconstruction (District 11)
T.H.E. Engineers

Attachment
Development of ESAL Forecasting Procedures for Superpave Pavement Design

by

Brad W. Rister
Research Engineer

and

David L. Allen
Chief Research Engineer

Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, Kentucky

in cooperation with
Transportation Cabinet
Commonwealth of Kentucky

and

Federal Highway Administration
U.S. Department of Transportation

The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the University of Kentucky, the Kentucky Transportation Cabinet, nor the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. The inclusion of manufacturer names and trade names are for identification purposes and are not to be considered as endorsements.

March, 1999
### Abstract

This report documents the analysis methods used to develop the Equivalent Single Axle Load (ESAL) forecasting program for Superpave projects. In addition, this report discusses the procedures used in the ESAL forecasting program to forecast ESALs in the design lane for pavement resurfacing/overlay projects which are consistent with the Superpave process of asphaltic mixture design.
EXECUTIVE SUMMARY

This report documents the analysis methods used to develop the Equivalent Single Axle Load (ESAL) forecasting program for Superpave projects. In addition, this report discusses the procedures used in the ESAL forecasting program to forecast ESALs in the design lane for pavement resurfacing/overlay projects which are consistent with the Superpave process of asphaltic mixture design.
ACKNOWLEDGMENTS

The comments and suggestions by Mr. Rob Bostrom, employees of Multimodal Programs, and employees of the Division of Planning helped in the successful development of the "ESAL Forecasting Program." We thank all these people for their contributions.
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1.0 INTRODUCTION

In 1985, a procedure was developed by the Kentucky Transportation Center (report UKTRP 85-30) to estimate Equivalent Single Axle Loads (ESALs) for the purposes of flexible pavement design. Maximum use was made of historical data and well-accepted procedures were used in developing the prediction model. This model was based on a series of computer programs that summarized truck-weight and classification data such that traffic characteristics could be estimated from a matrix of data classified by geographic area, Federal highway system, volume, and extent of coal haulage. In addition, an equation was developed to calculate average daily ESALs using the following seven traffic parameters as independent variables; annual average daily traffic volume (AADT), percent trucks in the traffic stream (%T), number of coal hauling trucks in the traffic stream (CT), average number of axles per coal truck (A/CT), average number of axles per non-coal truck (A/T), average number of equivalent axleloads per coal-truck axle (ESAL/CA), and average number of equivalent axleloads per non-coal truck axle (ESAL/A). The equation to calculate average daily ESALs can be viewed in equation 1 below.

\[ (\text{AADT} \times (1 - \%T) \times 0.005) + ((\text{AADT} \times \%T) \times \text{CT} \times \text{A/CT} \times \text{ESAL/A}) + (\text{CT} \times \text{A/CT} \times \text{ESAL/CA}) \]

The prediction model developed in UKTRP 85-30 is still used by the Cabinet’s traffic forecasting function. However, the advent of Superpave as the Cabinet’s asphalt pavement mix has been the impetus for this study since all Superpave mixes require an ESAL value. Therefore, it was necessary to develop a simplified model to be used for Superpave projects. The model developed uses the same traffic parameters used by the Cabinet’s traffic forecasting function, but makes several simplifying assumptions to arrive at a forecasted ESAL value. These assumptions consist of applying growth rates to the present independent variables (AADT, %T, A/T, ESAL/A, A/CT, and ESAL/CA) based on the functional class growth rates provided in the Aggregated 1997 ESAL table (Appendix A.). Note, a default growth rate of 2 percent is used for the AADT growth rate for all functional classes in this model. The functional class growth rates are applied to the present independent variables using the compound interest equation at the median forecast year, i.e. present \( \%T \times (1 + \text{growth rate})^{(\text{number of forecasted years}/2)} \). After the application of all growth rates, the new independent variables are substituted into equation 1 to calculate a total median year daily ESAL value. Next, ESALs are forecasted in the design lane for Superpave projects, by taking the product of the total median year daily ESAL calculation and multiplying it by (365 days * number of forecasted years * a lane distribution factor) (equation 2). Note, it is not recommended to use this procedure of forecasting ESALs for the Superpave Mix Design except for a “ballpark” estimate.

\[ (\text{Total median daily ESALs}) \times 365 \times (\text{N}) \times (\text{Lanedist}) \]

\( N \) = number of forecasted years
Lanedist = lane distribution factors are based on report UKTRP 85-30, modifications have been made for 6 and 8 lane roads (Table 1).

<table>
<thead>
<tr>
<th>Lane layout</th>
<th>Lane distribution factor or equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 lane, 1 way</td>
<td>1</td>
</tr>
<tr>
<td>2 or 3 lanes, 2 way</td>
<td>5</td>
</tr>
<tr>
<td>4 lanes, 1 way</td>
<td>35</td>
</tr>
<tr>
<td>4 or 5 lane, 2 way</td>
<td>0.497*(1.84+1.42*(%trucks))<em>(AADT)</em>(10^-6)</td>
</tr>
<tr>
<td>5 lane, 1 way</td>
<td>3</td>
</tr>
<tr>
<td>6 lane, 1 way</td>
<td>325</td>
</tr>
<tr>
<td>&gt; 6 lane, 1 way</td>
<td>(1/# of lanes)−0.1</td>
</tr>
<tr>
<td>6 lane, 2 way</td>
<td>325</td>
</tr>
<tr>
<td>&gt; 6 lane, 2 way</td>
<td>25</td>
</tr>
</tbody>
</table>

2.0 ANALYSIS METHOD

This program was designed to give the user two different functions for forecasting ESALs in the design lane for Superpave projects. The first function will allow the user to forecast ESALs in the design lane using collected traffic data, collected by the Division of Planning. In order to forecast ESALs in the design lane using collected traffic data the user will perform a search on the data base by typing in the county name, route prefix, route number, route suffix, beginning milepoint, ending milepoint, and the number of forecasted years. The second function of the program will allow the user to forecast ESALs in the design lane, using user defined data input. Both procedures for forecasting ESALs in the design lane will be discussed in detail in the, “Procedures for using the ESAL Forecasting program” in section 4.0 of this report.

In order to forecast ESALs using collected traffic data, five databases of traffic information provided by the Division of Planning were combined into one master database using Microsoft Excel. The five databases consisted of: Volume.dbf; Class97b.txt; Sta_tonsC.xls; the lane file (Countsta.xls) from the Highway Inventory System (HIS) database; and the Aggregated 1997 ESAL table with three-year averages with smoothed growth rates. A brief description of each database, a sample of the databases, and where they can be located for future reference is listed in Appendix A.

“Volume.dbf” was used as the base file for the master database to which the other four databases were attached. The “Volume.dbf” file provided county number, station number, route prefix, route number, route suffix, beginning milepoint, ending milepoint, and an estimated annual average daily traffic volume (AADT) for 23,237 stations located in the 120 counties in Kentucky. The second database used was “Class97b.txt” which matched up to “Volume.dbf” by county and station number. “Class97b.txt” contained actual multiple year AADT counts, percent trucks, axles per trucks, percent coal trucks, and axles per coal truck for various station numbers. For each station number, the latest actual data for (percent trucks, axles per trucks, percent coal trucks, and axles per coal truck) was matched to the “Volume.dbf” file. The third database used was “Sta_tonsC.xls” which matched up to “Volume.dbf” by county and station number. This database contained annual coal tonnage hauled on coal hauling routes in Kentucky. The
annual coal tonnage hauled was divided by (365 days * 40 tons per truck) to obtain the number of coal trucks per day. This calculated number of coal trucks per day was compared to the number of coal trucks per day found in the “Class97b.txt” database in which the higher of the two values was used in the master database. The fourth database used was the lane file “Countsta.xls” obtained from the HIS database housed at the Division of Planning. This database matched to “Volume.dbf” file by county and station number and provided the number of lanes and functional classification for each station number in the master database. The last database used was the 1997 aggregated ESAL table with three-year averages with smoothed growth rates. This database was used in two ways. First, in the insistence that the “Class97b.txt” database did not provide data on percent trucks, axles per truck, or axles per coal truck to be attached to the “Volume.dbf” database--values for these categories were based on matching the functional classification. Second, the equivalent single axle loads per axle for both trucks and coal trucks (ESAL/A, ESAL/CA) were used based on the matching functional classification of the two databases.

After completing the master database in Microsoft Excel, it was then imported into Microsoft Access 97. The completed master database can be viewed in the ESAL Forecasting program by holding down the shift key on the keyboard as the program is loading. The data file name is combine 22. However, precaution should be taken as to not alter the original data. The column headings used in the master database are as follows: county number, station number, route prefix, route number, route suffix, starting milepoint, ending milepoint, ADT, percent trucks, axles per truck, ESAL/axle, functional classification, number of lanes, number of coal trucks, axles per coal truck, ESAL/coal axle, lane adjustment factor, an indication if percent trucks is actual or estimated data, an indication if axles per truck are actual or estimated, an indication if the number of coal trucks is actual or estimated, and a RSE_UNIQUE code so that this database can be used with Arc View software.

This program can be updated, on a yearly base, by importing an identical database as described above into the program. Data formatting should parallel that of the combine 22 master database, which can be viewed in the design view of the combine 22 database. To update the query, the new database would replace the combine 22 database in the calculate ESAL’s query. To update or change growth rates for the Aggregated 1997 ESALs table, simply go to the 3-year average table and update. To change lane distribution factors go to the lane table and update. To change the AADT growth rate go to the AADT growth rate table and update.

3.0 PROCEDURES FOR ACCESSING THE “ESAL FORECASTING” PROGRAM

To access the ESAL forecasting program, there are a few hardware and software requirements. The requirements are listed below as well as on the inside jacket of the CD case.
Hardware/Software:
1.) i486 or Pentium processor.
2.) Windows 95, 98 or Windows NT.
3.) If using the CD version from the CD reader the CD-ROM drive must be 10x or higher. If the CD-ROM drive is less than a 10x it is recommended that the ESAL forecasting program be copied to the hard-drive.
4.) The hard drive will need a total of 100-MB, and approximately 6 MB of hard disk space to store the program.
5.) A minimum of 16 MB of RAM is required.
6.) Screen resolution set at either 800x600 or 1024x768.
7.) Microsoft Access 97.

Instructions to access the ESAL forecasting program from the CD are listed below and on the inside jacket of the CD case.

1.) Insert ESAL forecasting program CD into CD-ROM drive.
2.) From start menu go to programs.
3.) Click on Windows Explorer
4.) Select the CD-ROM drive containing the ESAL forecasting program CD.
5.) If your computer satisfies numbers 3 & 5 above in the Hardware/Software requirements then double click on the ESAL forecasting program. If your computer does not satisfy numbers 3 & 5 above then copy the ESAL forecasting program to the hard drive.
6.) After opening the program a pop up screen displays “Database is a read-only” click O.K.
7.) In introduction screen (Figure 1) of program click button to enter into program.

Instructions to install the ESAL forecasting program from the 3.5” diskettes to the hard-drive are listed below and on the front label of the diskettes. Note: in order to copy the ESAL forecasting program to your hard drive the program must be unzipped. The diskettes have a self-extracting program loaded on them called PKUNZIP version 2.60. This program is a SHAREWARE product, and is being used as an evaluation copy.

1.) In Windows, go to “My Computer”.
2.) Insert ESAL Forecasting diskette number 1 into the A drive, and double click on the A drive icon.
3.) Double click on ESAL Forecasting Program.exe, and follow the on-screen instructions.
4.) After both diskettes have been read; define a directory where the ESAL Forecasting program will be extracted to.
5.) After choosing the proper directory, click "Extract" button. If the user has not already created the directory to extract the program to, click Yes to create directory.
6.) Follow the on-screen instructions and insert diskettes.
7.) The program will be extracted when the (A) drive directory is displayed.
8.) Go to the directory where the ESAL forecasting program has been stored.
9.) Double click on the ESAL Forecasting program.
10.) In introduction screen (Figure 1) of program click button to enter into program.

This program forecasts Equivalent Single Axle Loads (ESALs) in the design lane for Superpave projects

The collected traffic data used in this program is from the Kentucky Transportation Cabinet, Division of Planning.
4.0 PROCEDURES FOR USING THE “ESAL FORECASTING” PROGRAM

The next section will outline the procedures for using the ESAL forecasting program to forecast ESALs in the design lane for pavement resurfacing/overlay projects which are consistent with the Superpave process asphaltic mixture design. When opening the program, the first screen that will appear is the Introduction Screen (labeled Start in the database) (Figure 1). After arriving at this screen, the user will need to click on the box “Click: to open program”. This will take the user to Screen One (Figure 2).

Figure 2: Screen One

**Screen One** displays the organization chart or layout of the ESAL forecasting program. At the bottom of Screen One, the statement “Click raised buttons to proceed” indicates that the user can go to multiple sections of the program from Screen One by clicking on any of the raised buttons. The buttons consist of; Start Screen which takes the user back to the Introduction Screen, Screen Two—standard data input, Screen Four—detailed data input, or any of the Help screens. Note: after entering Screen Three the user has the option of going to Screen Four, and the Help screens can be accessed inside any of the other screens.

**Screen Two** is the standard data input screen (Figure 3). The purpose of this screen is to forecast ESALs in the design lane using the master database. First, the user
will need to identify the search criteria for searching the master database. The search criteria are the seven yellow boxes located on Screen Two; county name, route prefix, route number, route suffix, beginning milepoint, ending milepoint, and number of forecast years. Second, after identifying the search parameters the user will click on the button labeled “Click: to find matching records”. This will take the user to Screen Three (Figure 4).

![Screen Two](image)

Enter county name:

Enter route prefix:

Enter route number:

Enter route suffix:

Enter beginning milepoint:

Enter ending milepoint:

Enter number of years:

Figure 3: Screen Two

The details for filling in the seven yellow boxes found on Screen Two are listed below and on the Help screen for Screen Two in the Program.

1. Enter county name: in this box the user will type in one of the 120 county names in Kentucky. In addition, there is a drop down box that will allow the user to pick from a list of county names in Kentucky if desired.
2. Enter route prefix: in this box the user will type in the route prefix. There is a list of route prefixes for all of the Parkways in Kentucky located on the right side of Screen-Two.
3. Enter route number: in this box the user will type in the route number. There is a list of route numbers for all of the Parkways in Kentucky located on the right side of Screen-Two.
4. Enter route suffix: in this box the user will type in a route suffix if applicable. Applicable route suffixes for this box are located in the drop down menu. If a route suffix is not applicable to the route the user is evaluating, then the user must leave the default value of “Na” in this box. The following is a list of route suffixes that appear in the drop menu: A,
5. Enter beginning milepoint: in this box the user will type in the beginning
milepoint of the section of roadway to be evaluated. Note that the
beginning milepoint must be less than the ending milepoint.
6. Enter ending milepoint: in this box the user will type in the ending
milepoint of the section of roadway to be evaluated. Note that the ending
milepoint must be greater than the beginning milepoint.
7. Enter number of years: in this box the user will type in an integer value
from 1 to 50 to represent the number of years the user would like to
forecast the design ESALs in the critical lane.
8. Click to find matching records: by clicking this button the program will
query the database for the records that match the criteria input in numbers
1-7 above, and send the user to Screen-Three. Screen-Three will allow
the user to view all of the matching records, print preview all of the
matching records, and go to Screen-Four to calculate ESALs, if the data
shown in Screen-Three is inadequate or if no matching records were
found for the criteria.

Screen Three is the standard data output screen (Figure 4). This screen shows the
results of the search criteria defined in Screen Two. As an example, Figure 4 shows
actual output that was obtained from a search on I-75 in Fayette County.
To look at all of the matching results, the user can use the small arrow buttons located at the bottom left hand corner of the Screen Three to scroll through the matching records. Note: the scroll arrows are not shown in Figure 4 in this report. The user is also given the opportunity to print preview all of the matching forecasts that met their search criteria on Screen Three by clicking “Print preview” button. An example of the print preview page is located in Appendix B. Once in the print preview page, the user can print the forecasted ESALs to any printer that is connected to the personal computer, or publish the print preview page in Microsoft Word or Excel.

The following describes what is displayed on Screen Three. The descriptions can also be found on the Help screen for Screen Three in the program.

Note: Screen Three displays the records that match the criteria that were entered on Screen Two. If there were no matching records for the specified criteria then the user can go back to Screen Two to perform a new search or go to Screen Four to calculate ESALs with user defined data.

Disclaimer: This procedure of forecasting ESALs uses default information (example functional class defaults and growth rate default assumptions) to produce ESALs for Superpave Mix Design. It is not recommended for use in producing ESALs for Pavement Design except for a “ballpark” estimate.

1. Highway details: displayed in the highway details box are the items such as: county number, station number, route prefix, route number, route suffix, beginning milepoint, ending milepoint, number of lanes, and lane distribution factor for the records that match the search criteria.

Lane distribution factors are based on Kentucky Transportation Research report UKTRP-85-30. Modifications have been made for 6 and 8 lane roads (Table 2).

Table 2: Lane distribution factors or equations

<table>
<thead>
<tr>
<th>Lane layout</th>
<th>Lane distribution factors or equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 lane, 1 way</td>
<td>1</td>
</tr>
<tr>
<td>2 or 3 lanes, 2 way</td>
<td>4</td>
</tr>
<tr>
<td>4 lanes, 1 way</td>
<td>35</td>
</tr>
<tr>
<td>4 or 5 lane, 2 way</td>
<td>0.497 - (1.84 + 1.42 * (%trucks)) * (AADT) * (10^-6)</td>
</tr>
<tr>
<td>5 lane, 1 way</td>
<td>3</td>
</tr>
<tr>
<td>6 lane, 1 way</td>
<td>325</td>
</tr>
<tr>
<td>&gt; 6 lane, 1 way</td>
<td>(1 / # of lanes) + 0.1</td>
</tr>
<tr>
<td>6 lane, 2 way</td>
<td>325</td>
</tr>
<tr>
<td>&gt; 6 lane, 2 way</td>
<td>25</td>
</tr>
</tbody>
</table>

2. ESAL calculating information: displayed in the ESAL calculating information box are values such as: AADT, functional class, percent trucks, axles/truck, ESAL/axle, number of coal trucks per day, axles/coal truck, ESAL/coal truck axle. The Division of Planning collected the base data that produced this information. The Division of Multimodal Programs is responsible for the base data being converted to traffic forecasting information. Any questions about the input information should be addressed to the Division of Multimodal Programs at (1-502-564-7686).

3. The factors for percent trucks, axles per truck, number of coal trucks/day, and axles per coal trucks are defined with either a “A” for actual collected data, “E” for estimated data based on the functional class using the three-year averages from the aggregated 1997 ESALs developed by the Kentucky Transportation Center, or “J” for insufficient data. Forecasted
ESALs in coal hauling regions should be checked with the Division of Multimodal Programs for the accuracy of the number of coal trucks per day.

4. The equation to calculate total median daily ESALs is

\[
(AADT \times (1-%T)^{0.005} + ((AADT \times %T) \times \frac{A}{T}) \times (ESAL/A) + (CT \times A/CT \times ESAL/CA)
\]

where growth rates have already been applied to (AADT, %T, A/T, ESAL/A, A/CT, and ESAL/CA) based on the Functional Classification growth rates provided in the Aggregated 1997 ESALs table. Note: in order to get median year daily ESALs, the growth rates are calculated at the median year using the compound interest equation i.e.: %T \times ((1+\text{growth rate})^{(N/2)}). The growth rate for AADT was assumed to be 2 percent for all functional classes. The Aggregated 1997 ESALs table with growth rates can be viewed below.

**Table 3: Functional class growth rates.**

<table>
<thead>
<tr>
<th>Functional Class</th>
<th>AADT</th>
<th>%T</th>
<th>A/T</th>
<th>ESAL/A</th>
<th>A/CT</th>
<th>ESAL/CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0.092</td>
<td>1</td>
<td>0</td>
<td>1.989</td>
</tr>
<tr>
<td>26</td>
<td>2</td>
<td>1</td>
<td>0.535</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>7.89</td>
<td>2</td>
<td>1</td>
<td>0.983</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>2</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>18.14</td>
<td>2</td>
<td>1</td>
<td>0.388</td>
<td>0.566</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15.17-19</td>
<td>2</td>
<td>1</td>
<td>0.946</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The equation to forecast design ESALs in the Critical Lane is

\[
\text{(Total median daily ESALs) \times 365 \times (N) \times \text{(Lanedist)}}
\]

AADT = Annual average daily traffic

%T = Percent trucks

CT = Number of coal trucks per day

A/T = Axles per truck

ESAL/A = Equivalent single axle loads per truck axle

A/CT = Axles per coal truck

ESAL/CA = Equivalent single axle load per coal truck axle

N = Number of forecast years

Lanedist = Lane distribution factor

5. Mainline or ramp indicates where the data was collected.

6. "Insufficient data, either no lanes or no AADT", message indicates that the values needed to forecast ESALs are not complete.

7. Print preview allows the user to view the matching records on the computer screen. Once in the print preview, click the printer icon to print out the report, or click close to go back to Screen-Three.

8. To scroll through all of the matching records, use the right and left arrows located in the bottom left hand corner of Screen-Three.

Screen Four is the detailed data input screen (Figure 5). The purpose of this screen, and with the addition of Screen Five (Figure 6), is to forecast ESALs in the design lane based on user defined data. This function of the program can be used if the information obtained from a forecast on Screen Three proves to be inadequate, if no information is available from the master database to forecast ESALs in Screen Three, or for a widening project where the lane information provided from the master database would be inadequate.
Detailed data input: calculate ESALs based on functional class, and lane distribution.

Yellow boxes mean that the user must input a value:

**Functional Classes**

1. Rural Interstate
2. Rural Principal Arterial
3. Rural Minor Arterial
4. Rural Major Collector
5. Rural Collector
6. Rural Local
7. Urban Interstate
8. Urban Freeway or Expressway
9. Urban Principal Arterial
10. Urban Minor Arterial
11. Urban Collector
12. Urban Local

**Lane Distribution Factor Reference #**

<table>
<thead>
<tr>
<th>Lane Distribution Factor Reference #</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>11 - 1 lane, 1 way</td>
<td>11</td>
</tr>
<tr>
<td>12 - 2 or 3 lane, 2 way</td>
<td>2</td>
</tr>
<tr>
<td>13 - 4 lane, 1 way</td>
<td>4</td>
</tr>
<tr>
<td>14 - 4 or 5 lane, 2 way</td>
<td>5</td>
</tr>
<tr>
<td>15 - 5 lane, 1 way</td>
<td>6</td>
</tr>
<tr>
<td>61 - 6 lane, 1 way</td>
<td>61</td>
</tr>
<tr>
<td>62 - 6 lane, 2 way</td>
<td>62</td>
</tr>
<tr>
<td>63A - &gt; 6 lane, 1 way</td>
<td>63</td>
</tr>
<tr>
<td>62A - &gt; 6 lane, 2 way</td>
<td>62</td>
</tr>
</tbody>
</table>

Figure 5: Screen Four

The details of using Screen Four are listed both below and in the Help screen for Screen Four in the program.

1. **Enter functional classification:** the user must enter a numeric value in this yellow box. The different functional classes are located on the right side of Screen-Four. There is a drop-down box located in the yellow box to allow the user to pick the functional class from a list.

2. **Enter lane distribution factor reference #:** the user must enter a value from the lane distribution factor reference # list located on the right side of the screen. The values correspond to the type of lane layout the user is evaluating. A value must be entered into the yellow box. There is a drop-down box located in the yellow box to allow the user to pick the lane distribution factor reference # from a list.

3. **Click to calculate ESALs:** after both one & two above have been completed, click this button to go to Screen-Five to complete the ESAL calculating process with user defined data.
Screen Five is the continuing screen to forecast ESALs using user-defined data (Figure 6). The values entered on both Screen Four and Screen Five will be used to forecast ESALs on Screen Five.

ADT: 

Years: 

Lane configuration: 

ENTER a value for each of the following if applicable:

<table>
<thead>
<tr>
<th># of coal trucks per day</th>
<th>0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual coal tonnage</td>
<td>0.0</td>
</tr>
</tbody>
</table>

Data from 1997 aggregate ESALs: 3-year Averages with smoothed growth rates

- Functional classification: 
- Percent trucks: 
- Axles per truck: 
- ESALs per axle: 
- Axles per coal truck: 
- ESALs per coal axle: 
- Total median daily ESALs: 
- Lane distribution factor: 

Design ESALs for Critical Lane: 

Calculate your own ESALs with your own values:

- Percent trucks: (including coal trucks) %
- Axles per truck: 
- ESALs per axle: 
- Axles per coal truck: 
- ESALs per coal axle: 
- Total median daily ESALs: 
- Lane distribution factor: 

NOTE: only enter coal information in one box; leave the other box defaulted to zero. If there are no coal trucks on the studied route, leave both values equal to zero.

Figure 6: Screen Five

The details of using Screen Five are listed both below and in the Help screen for Screen Five in the program.

1. Enter ADT: in this box an ADT value as specified in the adjacent box “Enter one way ADT”, or “Enter two way ADT” must be entered.
2. Enter number of years: in this box a numeric value greater than zero must be entered to forecast ESALs.
3. Enter a value for one of the following if applicable: if the user is calculating ESALs in a coal-hauling region, there are two different ways to input the number of coal-trucks per day. The user can enter the number of coal trucks per day or the annual coal tonnage. If annual coal tonnage is entered, the number of coal trucks per day is derived by dividing annual coal tonnage by (365 days * 40 tons). NOTE: only enter coal information in one box; leave the other box defaulted to zero. If there are no coal trucks on the studied route, leave both values equal to zero. Questions pertaining to annual coal tonnage on a particular route should be addressed to the Division of Multimodal Programs at (1-502-564-7686).
4. If lane configuration is (> 6 lane, 1 way) then enter number of lanes in box. If lane configuration is not (> 6 lane, 1 way) leave the default value of 1 in the box. This box should always have the default value 1 in it, unless the user has picked the (> 6 lane, 1 way) configuration on Screen-Four. If the user has picked the (> 6 lane, 1 way) configuration then the user must input the number of lanes in the yellow box.

5. ESALs can be calculated for two different scenarios on Screen-Five. The user can use the values from the 1997 aggregated ESALs 3-year average values based on functional class, or the user can calculate ESALs with user defined data. NOTE: if the user calculates ESALs with user defined data, all yellow boxes (percent trucks, axles per truck, ESALs per axle, axles per coal truck, ESALs per coal axle) must have a value entered.

6. Lane distribution factors are determined by the lane distribution factor reference # the user entered on Screen-Four. Lane distribution factors are based on Kentucky Transportation Research report UKTRP-85-30. Modifications have been made for 6 and 8 lane roads (Table 3).

Table 4: Lane distribution factors or equations

<table>
<thead>
<tr>
<th>Lane layout</th>
<th>Lane distribution factors or equations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 lane, 1 way</td>
<td>1</td>
</tr>
<tr>
<td>2 or 3 lanes, 2 way</td>
<td>5</td>
</tr>
<tr>
<td>4 lanes, 1 way</td>
<td>.35</td>
</tr>
<tr>
<td>4 or 5 lane, 2 way</td>
<td>.497*(1.84+1.42*(%trucks))*(ADT)*10^-6</td>
</tr>
<tr>
<td>5 lane, 1 way</td>
<td>3</td>
</tr>
<tr>
<td>6 lane, 1 way</td>
<td>.325</td>
</tr>
<tr>
<td>&gt; 6 lane, 1 way</td>
<td>(1/# of lanes)-0.1</td>
</tr>
<tr>
<td>&gt; 6 lane, 2 way</td>
<td>.325</td>
</tr>
</tbody>
</table>

7. The equation used to calculate total median daily ESALs is

\[(ADT* (1-%T)* .005) + ((ADT*%T)-CT)*(A/T)*(ESAL/A) + (CT*A/CT*ESAL/CA)\]

where growth rates have already been applied to (ADT, %T, A/T, ESAL/A, A/CT, and ESAL/CA) based on the Functional Classification growth rates provided in the Aggregated 1997 ESALs table. Note: in order to get median year daily ESALs, the growth rates are calculated at the median year using the compound interest equation i.e.: %T*[(1+growth rate)^N/2]. The growth rate for ADT was assumed to be 2 percent for all functional classes. The Aggregated 1997 ESALs table with growth rates can be viewed below.

Table 5: Functional class growth rates

<table>
<thead>
<tr>
<th>Functional Class</th>
<th>ADT</th>
<th>%T</th>
<th>A/T</th>
<th>ESAL/A</th>
<th>A/CT</th>
<th>ESAL/CA</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>1</td>
<td>0.092</td>
<td>1</td>
<td>0</td>
<td>1.989</td>
</tr>
<tr>
<td>2.6</td>
<td>2</td>
<td>1</td>
<td>0.535</td>
<td>1</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>7.5</td>
<td>2</td>
<td>1</td>
<td>0.983</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1.989</td>
</tr>
<tr>
<td>12.5</td>
<td>2</td>
<td>1</td>
<td>0.388</td>
<td>0.558</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>2</td>
<td>1</td>
<td>0.946</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The equation to forecast design ESALs in the Critical Lane is

\[(Total\ median\ daily\ ESALs)*565*(N)*(Lanedist)\]

\[
ADT = \text{Average daily traffic} \\
%T = \text{Percent trucks}
\]
CT = Number of coal trucks per day
A/T = Axles per truck
ESAL/A = Equivalent standard axle loads per truck axle
A/CT = Axles per coal truck
ESAL/CA = Equivalent standard axle load per coal truck axle
N = Number of forecast years
Lanedist = Lane distribution factor

8. Type in Reference Location: this box is optional. It allows the user to type in the location of calculated ESALs so a reference name will be included on the printed output.

5.0 ACCESSING THE REPORT FROM CD

An electronic copy of this report is located on the CD version of the ESAL Forecasting Program. In order to view the report, ADOBE ACROBAT READER software must be installed on the user’s computer. ADOBE ACROBAT READER is a free shareware program that can be distributed with word-processed documents that are saved in PDF format. Most computers have ADOBE ACROBAT READER already installed if the user views reports published on the Internet. If the user has ADOBE ACROBAT READER software already installed on their computer, then simply double click on the ESAL-Report.PDF file when viewing the directories on the CD to view the report.

If the user does not have ADOBE ACROBAT READER installed on their hard-drive the user can install ADOBE ACROBAT READER version 3.02 by double clicking on the directory “AR302.exe” on the CD, or going to the ADOBE ACROBAT READER website at http://www.adobe.com/prodindex/acrobat/readstep.html. After installing the software, the user will then go back to the ESAL Forecasting Program CD and double click on the ESAL-Report directory.

6.0 CONCLUSIONS AND RECOMMENDATIONS

It is encouraged that the user consult with the Division of Multimodal programs (1-502-564-7678) when using the ESAL forecasting program to forecast ESALs in the design lane for pavement resurfacing/overlay projects. The information used in the ESAL forecasting program uses default information to produce ESALs for Superpave Mix Design. It is not recommended for use in producing ESALs for Pavement Design except for a “ballpark” estimate.

In the event that this program will become a tool in future ESAL forecasting, it is recommended that the collected traffic data utilized in this program be standardized, and updated annually. Also, consideration should be given to editing the forecasting equation. Applying growth rates only to the median year does not fully estimate the total ESAL value in the design lane for the full design life of the Superpave project. A suggested measure would be to integrate the equation as follows (present independent variable* \( \int_{0}^{x} a^x dx = a^y / \ln a \)) where \( a = (1 + \text{growth rate}) \) and \( x = \text{years} \). By integrating the application of the growth rates, a more accurate total ESAL value would be obtained, thus allowing for a more accurate ESAL forecast.
APPENDIX A
(database files)

Volume.dbf

Volume.dbf file came from the Division of Planning’s “historic.dbf” file that is stored on the mainframe Traffic Volume Summary file. The data contact person is Greg Witt from the Division of Planning (1-502-564-7183). The ADT value used from this database is located in column VOL1. The last number in the four-digit number in the VOL1 column is a power of ten number. For example the number 6581, is $658 \times 10^1 = 6580$, and 1302 is $130 \times 10^2 = 13,000$. When receiving this file, the last number in the VOL1 column will need to be separated from the first three. In Excel, highlight the VOL1 column, then go to the data command. In the data command list pick fixed width, then separate the first three numbers from the fourth. In the adjacent column write an equation that will multiply the first three numbers by the fourth raised to the tenth power. This will give the ADT value for this record. Copy the equation down for all ADT values.

For the files from the other database to match to this “Volume.dbf” database, the county number must be combined with the station number. To do this, make a separate column adjacent the station number. Write an equation using the concatenate function to combine both county number and station number into one. NOTE: the station number has three values. It can be three numbers or a mixture of numbers and text values.

### Volume.dbf

<table>
<thead>
<tr>
<th>CONUMBER</th>
<th>STATION</th>
<th>RTPREFIX</th>
<th>RTNUMBER</th>
<th>RTSUFFIX</th>
<th>STARTMPT</th>
<th>ENDINGMPT</th>
<th>VOL1</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A57</td>
<td>KY</td>
<td>55</td>
<td></td>
<td>9.335</td>
<td>10.059</td>
<td>6581</td>
</tr>
<tr>
<td>1</td>
<td>A47</td>
<td>KY</td>
<td>55</td>
<td></td>
<td>10.059</td>
<td>10.316</td>
<td>1302</td>
</tr>
<tr>
<td>1</td>
<td>A46</td>
<td>KY</td>
<td>55</td>
<td></td>
<td>10.316</td>
<td>10.47</td>
<td>1272</td>
</tr>
<tr>
<td>1</td>
<td>A43</td>
<td>KY</td>
<td>55</td>
<td></td>
<td>10.47</td>
<td>10.614</td>
<td>2002</td>
</tr>
<tr>
<td>1</td>
<td>A41</td>
<td>KY</td>
<td>55</td>
<td></td>
<td>10.614</td>
<td>10.72</td>
<td>2452</td>
</tr>
<tr>
<td>1</td>
<td>A58</td>
<td>KY</td>
<td>55</td>
<td></td>
<td>10.72</td>
<td>10.84</td>
<td>1912</td>
</tr>
<tr>
<td>1</td>
<td>A26</td>
<td>KY</td>
<td>55</td>
<td></td>
<td>10.84</td>
<td>11.17</td>
<td>1962</td>
</tr>
<tr>
<td>1</td>
<td>A13</td>
<td>KY</td>
<td>55</td>
<td></td>
<td>11.17</td>
<td>11.19</td>
<td>2592</td>
</tr>
</tbody>
</table>

Class97b.txt

Class97b.txt was a text file that was originally called “Class97.prm”. This file comes from the processed classification summary data developed by the Traffic & Safety Section at the Kentucky Transportation Center. The data contact person is Greg Witt from the Division of Planning (1-502-564-7183). In this file the county number must be combined with the station number. However, the station number does not have three values in all cases. The length (len) function combined with an (IF) statement must be used in Excel to add a leading zero or zeros to any station number that does not have three values. The length function would be used to tell how many values were present in each cell in the station number column. The (IF) statement would be used after the length function. If the station number length equaled 1, then add two zeros, if the station number length equaled 2, then add one zero, and if the station number equaled 3 then put
the station number as it exists in the cell. Then copy this equation down for all station numbers.

Next, the latest year data was saved in each identical county number/station number combination. This gave the most up-to-date information for each station number. This saved data was copied to a blank sheet in the "Volume.dbf" file where an (Vlookup) equation was used to match identical station numbers between both files. The (Vlookup) equation was used to match the percent truck "TR", axles per truck "A_T", percent coal trucks "CTR", and axles per coal truck "A_CT" values to the "Volume.dbf". If there was not a match between station numbers, a "N/A" value was placed in the cell. To eliminate the "N/A" value the (ISERROR) function was used to put a zero in for all cells that had the "N/A" value.

Class97b.txt

<table>
<thead>
<tr>
<th>CoNumber</th>
<th>Station#</th>
<th>Rt.Prefix</th>
<th>Rt.#</th>
<th>Milepoint</th>
<th>ADT</th>
<th>TR</th>
<th>CTR</th>
<th>A_T</th>
<th>A_CT</th>
<th>FC</th>
<th>AF</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A54</td>
<td>0</td>
<td>0</td>
<td>745</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1986</td>
</tr>
<tr>
<td>1</td>
<td>8</td>
<td>KY 55</td>
<td>11</td>
<td>5961</td>
<td>0.015</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>9</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>A07</td>
<td>KY 55</td>
<td>11</td>
<td>3925</td>
<td>0.113</td>
<td>0</td>
<td>3.257</td>
<td>0</td>
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<td>0.932</td>
<td>96</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>A07</td>
<td>KY 55</td>
<td>11</td>
<td>7716</td>
<td>0.078</td>
<td>0</td>
<td>2.492</td>
<td>0</td>
<td>6</td>
<td>0.981</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>A07</td>
<td>KY 55</td>
<td>11</td>
<td>7716</td>
<td>0.093</td>
<td>0</td>
<td>2.667</td>
<td>0</td>
<td>6</td>
<td>0.97</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>A07</td>
<td>KY 55</td>
<td>11</td>
<td>7716</td>
<td>0.088</td>
<td>0</td>
<td>3.104</td>
<td>0</td>
<td>6</td>
<td>0.954</td>
<td>83</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>A07</td>
<td>KY 55</td>
<td>11</td>
<td>7716</td>
<td>0.064</td>
<td>0</td>
<td>2.905</td>
<td>0</td>
<td>6</td>
<td>0.972</td>
<td>86</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>A07</td>
<td>KY 55</td>
<td>11</td>
<td>5961</td>
<td>0.078</td>
<td>0</td>
<td>2.492</td>
<td>0</td>
<td>6</td>
<td>0.981</td>
<td>79</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>A07</td>
<td>KY 55</td>
<td>11</td>
<td>3925</td>
<td>0.093</td>
<td>0</td>
<td>2.667</td>
<td>0</td>
<td>6</td>
<td>0.97</td>
<td>80</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>A07</td>
<td>KY 55</td>
<td>11</td>
<td>7716</td>
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<td>3.104</td>
<td>0</td>
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<td>0.954</td>
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<td>A07</td>
<td>KY 55</td>
<td>11</td>
<td>7716</td>
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<td>KY 55</td>
<td>11</td>
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<td>0.044</td>
<td>0</td>
<td>3.835</td>
<td>0</td>
<td>6</td>
<td>0.961</td>
<td>92</td>
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<td>A13</td>
<td>KY 55</td>
<td>11</td>
<td>10.5</td>
<td>0.044</td>
<td>0</td>
<td>3.835</td>
<td>0</td>
<td>6</td>
<td>0.961</td>
<td>92</td>
<td></td>
</tr>
</tbody>
</table>

StationsC.xls

StationsC.xls was an Excel file that came from the "Coalseg.lst database. The "Coalseg.lst", file comes from the Division of Planning's coal haul team. This coal haul team converted the "Coalseg.lst" to a format that included station numbers along with the annual tons hauled.

To determine how many coal trucks were hauling daily through these station numbers, the yearly tonnage was divided by 365 days * 40 tons per truck. The combined county number/station number was compared to the station numbers of the "Volume.dbf" file. In the 'Volume.dbf' file, the number of coal trucks provided from the "Class97b.txt" file and the "StationsC.xls" were compared. The value that gave the largest number of coal trucks per day was used.

StationsC.xls

<table>
<thead>
<tr>
<th>County #</th>
<th>Station #</th>
<th>Route pre</th>
<th>Route #</th>
<th>Beg mile</th>
<th>End mile</th>
<th>tons</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1288</td>
<td>CU</td>
<td>9008</td>
<td>48.9</td>
<td>57.791</td>
<td>16931</td>
</tr>
<tr>
<td>1</td>
<td>1A47</td>
<td>KY</td>
<td>55</td>
<td>10.1</td>
<td>10.316</td>
<td>16931</td>
</tr>
<tr>
<td>1</td>
<td>1A46</td>
<td>KY</td>
<td>55</td>
<td>10.316</td>
<td>10.47</td>
<td>16931</td>
</tr>
</tbody>
</table>
Countsta.xls

Countsta.xls was an Excel file that came directly from the Division of Planning’s Highway Information System (HIS) database. The data contact person is Greg Witt from the Division of Planning (1-502-564-7183). This file matched to the “Volume.dbf” by the combination of county and station number. The (Vlookup) function was used to bring in the functional class information (FC) and the number of lanes.

Countsta.xls

<table>
<thead>
<tr>
<th>County #</th>
<th>route</th>
<th>Route #</th>
<th>start. Mp</th>
<th>End mp</th>
<th>station #</th>
<th>F.C.</th>
<th># of lanes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CR</td>
<td>1026</td>
<td>0</td>
<td>2.722</td>
<td>1053</td>
<td>9</td>
<td>2</td>
</tr>
<tr>
<td>1</td>
<td>CR</td>
<td>1041</td>
<td>0</td>
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<td>9</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>CR</td>
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<td>0.849</td>
<td>1122</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>CR</td>
<td>1045</td>
<td>0</td>
<td>0.44</td>
<td>1121</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>CR</td>
<td>1046</td>
<td>0</td>
<td>1.477</td>
<td>1096</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>CR</td>
<td>1046</td>
<td>1.477</td>
<td>1.887</td>
<td>1074</td>
<td>9</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>CR</td>
<td>1046</td>
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<td>2.3</td>
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<tr>
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</tbody>
</table>

Aggregated 1997 ESALs – Three-year averages using smoothed growth rates

Aggregated 1997 ESALs – The three-year averages using the smoothed growth rates table comes from the Traffic and Safety Section at the Kentucky Transportation Center. The data contact person is Dave Cain (1-606-257-4513). The table is generated each June with the latest year traffic data.

The data for percent trucks (%T), axles per truck (A/T), and axles per coal truck (A/CT) are matched based on functional class to the records in the “Volume.dbf” file if the values for these categories are zero. The values for EALs/A and EALs/CA are matched between the two files by functional classification.

After the master database is completed the (ISERROR) function is run on all cells to take out any “N/A” values since Microsoft Access will not recognize “N/A” values. In the event that a blank space is found in the database, a zero value is entered because Microsoft Access cannot recognize blank spaces. Also, four columns are created to determine if the percent trucks, number of coal trucks per day, axles per truck, and axles per coal truck are actual or estimated data.

Aggregated 1997 ESALs – Three-year averages using smoothed growth rates

<table>
<thead>
<tr>
<th>Agg. Class</th>
<th>FCs</th>
<th>T%</th>
<th>GR</th>
<th>A/T</th>
<th>GR</th>
<th>EALs/A</th>
<th>GR</th>
<th>A/CT</th>
<th>GR</th>
<th>EALs/CA</th>
<th>GR</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1</td>
<td>28.653</td>
<td>1.000</td>
<td>4.493</td>
<td>0.092</td>
<td>0.217</td>
<td>1.000</td>
<td>4.778</td>
<td>0.000</td>
<td>0.880</td>
<td>1.989</td>
</tr>
<tr>
<td>II</td>
<td>2.6</td>
<td>11.635</td>
<td>1.000</td>
<td>3.490</td>
<td>0.535</td>
<td>0.251</td>
<td>1.000</td>
<td>4.956</td>
<td>0.000</td>
<td>2.639</td>
<td>2.000</td>
</tr>
<tr>
<td>III</td>
<td>7.89</td>
<td>7.770</td>
<td>1.000</td>
<td>2.936</td>
<td>0.983</td>
<td>0.219</td>
<td>0.000</td>
<td>4.595</td>
<td>0.000</td>
<td>1.235</td>
<td>0.000</td>
</tr>
<tr>
<td>IV</td>
<td>11</td>
<td>13.406</td>
<td>1.000</td>
<td>4.076</td>
<td>1.000</td>
<td>0.183</td>
<td>0.000</td>
<td>4.778</td>
<td>0.000</td>
<td>0.880</td>
<td>0.000</td>
</tr>
<tr>
<td>V</td>
<td>12.14</td>
<td>6.262</td>
<td>1.000</td>
<td>3.042</td>
<td>0.398</td>
<td>0.209</td>
<td>0.556</td>
<td>4.590</td>
<td>0.000</td>
<td>1.048</td>
<td>0.000</td>
</tr>
<tr>
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<td>5.238</td>
<td>1.000</td>
<td>2.772</td>
<td>0.946</td>
<td>0.171</td>
<td>0.000</td>
<td>4.083</td>
<td>0.000</td>
<td>0.594</td>
<td>0.000</td>
</tr>
</tbody>
</table>
### APPENDIX B
(sample output)

**Forecasted ESALs**

<table>
<thead>
<tr>
<th>County#</th>
<th>Station</th>
<th>Rt.Prefix</th>
<th>Rt.#</th>
<th>Rt.Suffix</th>
<th>Milepoints</th>
<th>ADT</th>
<th>%T</th>
<th>Data type</th>
<th>A/T Data type</th>
<th>ESAL/A</th>
<th>FC</th>
<th>Lanes</th>
<th>Daily # of coal trucks</th>
<th>Data type</th>
<th>A/CT</th>
<th>Data type</th>
<th>ESAL/C</th>
<th>Lane dist.</th>
<th>Years</th>
<th>Forecasted ESALs</th>
</tr>
</thead>
<tbody>
<tr>
<td>34</td>
<td>34P90</td>
<td>1</td>
<td>75</td>
<td>na</td>
<td>98.516</td>
<td>34000</td>
<td>17.70</td>
<td>A</td>
<td>4.530</td>
<td>A</td>
<td>0.217</td>
<td>1</td>
<td>4</td>
<td>E</td>
<td>4.778</td>
<td>E</td>
<td>0.88</td>
<td>0.384</td>
<td>20</td>
<td>40,156,077</td>
</tr>
<tr>
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<td>35700</td>
<td>28.30</td>
<td>A</td>
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<td>0.217</td>
<td>1</td>
<td>4</td>
<td>101</td>
<td>A</td>
<td>4.906</td>
<td>A</td>
<td>0.88</td>
<td>0.417</td>
<td>20</td>
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<td>75</td>
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<td>50600</td>
<td>13.41</td>
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<td>4.076</td>
<td>E</td>
<td>0.183</td>
<td>11</td>
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<td>7</td>
<td>E</td>
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<td>20.90</td>
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<td>A</td>
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<td>0.325</td>
<td>20</td>
</tr>
</tbody>
</table>

**Data type**
- A = actual data
- E = estimated data
- I = insufficient data