Block 2: AC Pavements

Modules:
- **AC Design Procedures**
- **AC Pavement Responses**
- **Performance Prediction Models**

This block provides a framework and tools for performing, analyzing, and checking AC pavement designs.

Computers will be used to provide participants with hands-on experience.

Talk about the schedule.

Module 2-1

AC PAVEMENT DESIGN PROCEDURES

Look at objectives of this module on page 2-1.1.

The overall objective of this block is to provide participants with an understanding of the tools for checking designs of AC pavements.

This particular module addresses several different design procedures that can be used to check AC designs.

AC Pavement Design Procedures

- **Asphalt Institute (AI)**
- **AASHTO**
- **National Stone Association (NSA)**
- **Design Catalogs**

There is a separate course for AASHTO design, so it is discussed only briefly here.

Design catalogs are becoming increasingly popular. NY State has a design catalog that is based on the 1986 AASHTO Design Guide. Many European countries have also developed design catalogs.

Asphalt Institute Procedure

- Mechanistic-empirical procedure developed in 1964 from results of several road tests
- In 1981, incorporated the use of multi-layer elastic theory
- Revised in 1991 to include design charts for 3 typical sets of environmental conditions
- DAMA used to determine the number of repetitions to failure

"HWY" (Highway) is a computerized version of the Asphalt Institute procedure.

"DAMA" is an elastic-layered pavement analysis program used in the development of the Asphalt Institute procedure.

DAMA Capabilities

- Traffic volumes can be entered monthly
- Pavement properties can be seasonally adjusted
- Effect of temperature on material properties is considered
- Considers 2 critical strain conditions
  - ➤ Tensile strain at bottom of AC
  - ➤ Compressive strain on top of subgrade

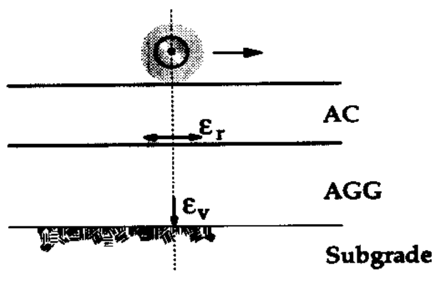
Discuss reasons for each of the features.

Temperature effects:
- When hot, AC softens
- When cold, AC stiffens

"DAMA" attempts to take this into account. The effect of ambient temperatures on the properties of the AC is done internally in the program.

Entering traffic on a monthly basis takes into account seasonal changes in AC and subgrade properties.

Critical Locations



Vertical (compressive) strains on the subgrade are the cause of rutting. The procedure assumes a stable high-quality AC mix is used and rutting does not occur in the AC.

Radial (tensile) stresses lead to fatigue of AC layers or stabilized base layers.

The philosophy of the Asphalt Institute design procedure is to "Design a pavement structure that will be thick enough to prevent excessive horizontal tensile strains and vertical compressive strains."

DAMA Limitations

- Can only analyze up to 5 layers
- Maximum of one granular layer directly above the subgrade
- Can only analyze dual wheel loads

DAMA has several restrictions. Dual wheel load restriction can be overcome by increasing the spacing between wheels.

DAMA was used in the development of the AI's thickness design charts.

User is never actually exposed to DAMA.

Design Inputs

- Traffic
- Roadbed soil strength
- Material properties
- Environmental conditions

Whenever possible, these variables should be based on studies of actual data.

If this information is unavailable, the guidelines provided in MS-1 may be used.

The many input of the DAMA program are transformed into these simple inputs.

Traffic

- Based on LEFs from AASHTO
- Assumes $p_t = 2.5$ and SN = 5.0 for LEFs
- Input is ESALs during design period
- Has "generic" ESAL calculation based on roadway classification and truck volumes

Explain the ESAL concept. Load Equivalency Factor (LEF) equates damage of a given axle to that of an 18-kip axle.

AASHTO has several LEF charts. The Asphalt Institute procedure uses a terminal serviceability of 2.5 and a structural number (SN) of 5.

Generic ESAL calculations should be avoided if possible.

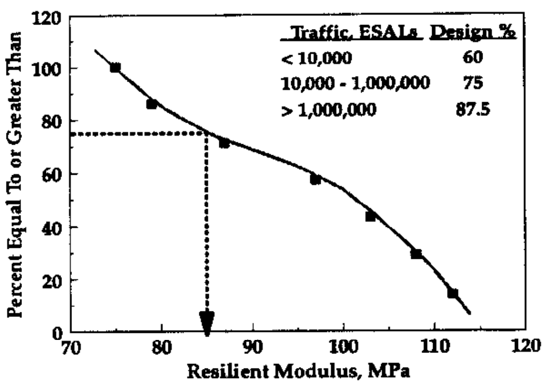
Roadbed Soil Strength, M_R

- Use value when soil is not frozen or during period of thaw
- Recommend extensive testing on actual soils
- Weakest soil controls
- Design project can be subdivided if large variability in soil conditions
- Based on traffic level (reliability)

Table 2-1.1 (page 2-1.5) provides the design subgrade strength based on the traffic level of the pavement.

Random sampling may be required to determine the weakest (controlling) soil type and its boundaries.

If subgrade strengths vary significantly in some areas, the project may be divided into smaller projects with different designs.



This is figure 2-1.2 (page 2-1.5), which illustrates how the design subgrade strength is selected.

Higher traffic levels reduce modulus to provide a more conservative design.

Material Properties

- Materials characterized by modulus of elasticity and Poisson's ratio
- High quality AC used to design charts
- Emulsified Asphalt Mixtures
  - Allowed for base and subbase layers
  - Categorized by type of aggregate
- Untreated Granular Materials
  - Must comply with ASTM D 2940

Allows use of emulsified mixtures for base or surface course layers. However, the charts were not developed specifically for emulsified bases and should be used with caution.

Again, a high-quality AC mix is assumed and rutting is not expected to occur in the surface or base layer, only in the subgrade.

Environmental Effects

- Considered through effects of monthly temperature changes on E^{AC}
- Also considered through changes in monthly support as measured by M_R

See Table 2-1.4 and Figure 2-1.3 on page 2-1.8.

Design charts are provided for three different mean annual air temperatures (MAATs).

Softer asphalt cements should be used in cold regions; stiffer asphalt cements in warm regions.

Effects of moisture and drainage are not considered directly.

Design Procedure

- Design Criteria
  - ➤ Limit fatigue cracking to 20 - 25 % of area
  - ➤ Limit rutting to 12 mm (0.5 in)
- Design Steps
  - ➤ Test roadbed soil
  - ➤ Select materials
  - ➤ Traffic calculations
  - ➤ Determine thickness from design charts

We've looked at the background; now we'll look at how the design is accomplished.

Restrict tensile strain at bottom of AC layer to control fatigue cracking.

Restrict vertical strain at top of subgrade to control rutting.

Allowable Pavement Types

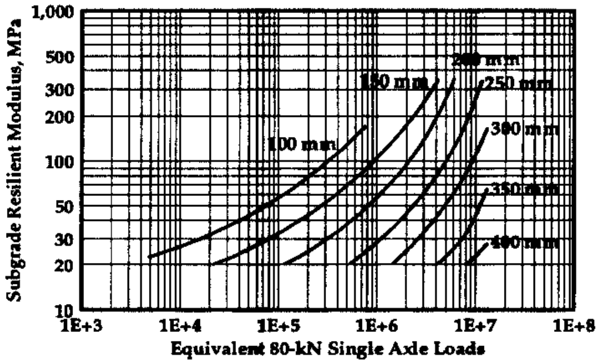
- Full-depth AC
- AC over emulsified asphalt base
- AC over 150- or 300-mm (6- or 12-in) untreated aggregate base

Design charts for several types are shown in Figures 2-1.4 through 2-1.6 (pages 2-1.10 through 2-1.12).

- All are at a MAAT of 15.5°C (60°F).
- Charts also available for 7°C (45°F) and 24°C (75°F).

Designs can be developed for each pavement type and compared through a life-cycle cost analysis.

Sample Design Chart
150 mm Aggregate Base, MAAT = 15.5 °C



Show the participants how to use the design chart.

From traffic data and subgrade modulus, one may determine the required asphalt thickness.

Must be certain that the correct chart is chosen from the series in the Asphalt Institute manual.

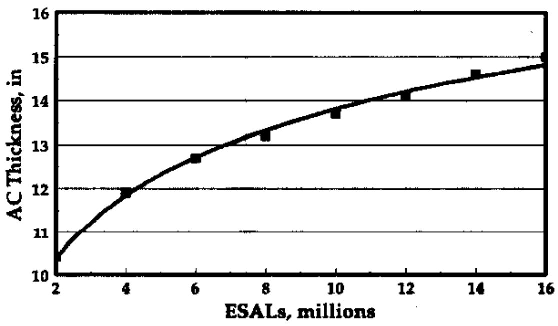
Design Selection

- **Full-depth AC**
  - ➤ **Better resistance to stresses**
  - ➤ **Least total thickness**
  - ➤ **Less sensitive to frost/moisture**
  - ➤ **Expensive**
- **Perform an economic analysis based on several different designs**

Asphalt Institute discusses the advantages of full-depth AC. However, it hasn't always performed this well.

Stage construction should also be considered in the economic analysis, particularly if funds are short and/or future traffic is uncertain.

Sensitivity to Traffic

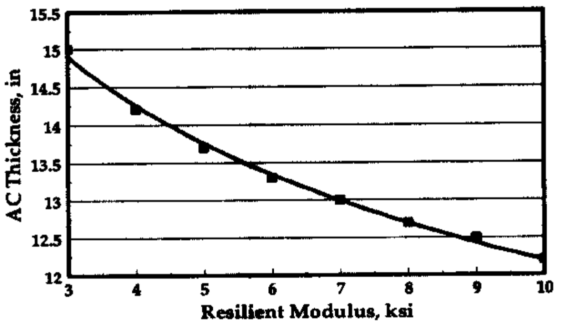


This is figure 2-1.7 (page 2-1.15), which illustrates the effect of traffic on the design thickness for a full-depth AC pavement.

All inputs are held constant except for traffic (ESALs).

An increase in traffic results in an increase in required thickness. It levels off after a certain point.

Sensitivity to Resilient Modulus



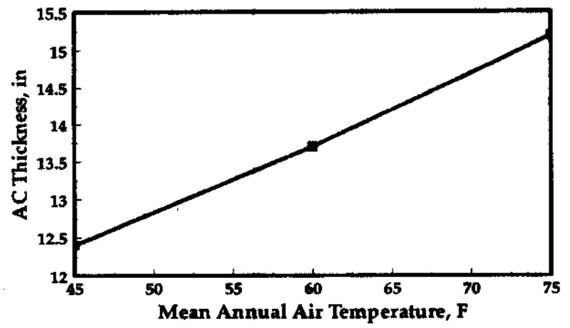
This is figure 2-1.8 (page 2-1.15), which illustrates the effect of the subgrade resilient modulus on full-depth AC thickness.

Effect of roadbed soil resilient modulus on thickness

- M_R = 3000, thickness = 15 inches
- M_R = 10,000, thickness = 12 inches

Conclusion - resilient modulus has a significant effect on design thickness

Sensitivity to MAAT

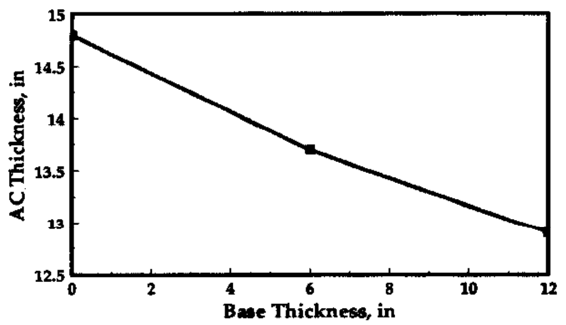


This is figure 2-1.9 (2-1.16), which illustrates the effect of the MAAT on full-depth AC thickness.

Additional thickness is needed in warmer regions to avoid subgrade rutting. If fatigue cracking is the controlling factor, the opposite would be true.

Different grades of AC may also be needed.

Sensitivity to Aggregate Base Thickness



This is figure 2-1.10 (page 2-1.16), which illustrates the effect of aggregate base thickness on the AC thickness.

AI procedure considers only three base thicknesses.

An increase in base thickness of 152 mm (6 inches) results in roughly a 25 mm (1 inch) decrease in AC surface thickness.

Advantages

- Mechanistic-based procedure
- Considers both fatigue cracking and rutting
- Simple - only requires 3 inputs

Looks at stresses and strains in both pavement and subgrade.

Considers two modes of failure.

Design charts simplify procedure.

Computer program HWY is also available.

Limitations

- Environmental effects not directly considered
- Relies on empirical inputs
- Assumes layers are linear elastic
- Constrained in the types of pavements available

Still involves some empirical inputs such as load equivalency factors from AASHTO.

Assumes AC is linearly elastic, when in reality it is visco-elastic.

Has a very unfavorable tradeoff between AC and granular materials (about 1:6).

Explain the example problem beginning on page 2-1.17 and then jump into the workshop problem.

AASHTO Design Procedure

- Empirical design procedure
- Based on results from AASHO Road Test
- First released in 1961
- Revised in 1972
- Major revisions in 1986 (no new changes to AC procedure in 1993)

This procedure is only covered briefly in this course. Another full course is devoted to this procedure alone.

Based on results of AASHO Road Test conducted in the late 1950s and early 1960s in Ottawa, Illinois.

1993 version has updated overlay design and low-volume road design.

AASHO Road Test Conditions

- AC surface: 25 to 150 mm (1 to 6 in)
- Base: crushed stone, gravel, CTB, ATB
- Subbase: densely-graded sand-gravel
- Northern Illinois climate
- Traffic: 1,114,000 load applications, maximum of 7 million ESALs

Inference space was not as large as it could have been.

These are limits at the AASHO Road Test and thus of the AASHTO procedure derived from the Road Test.

Design Inputs

- Performance Period
- Traffic (ESALs)
- Reliability
- Standard Deviation
- Serviceability
- Effective Subgrade Resilient Modulus
- Layer Coefficients
- Drainage Modifying Factors

The design inputs in the 1986 and 1993 Design Guides are identical.

Look at the sensitivity plots in figures 2-1.18 to 2-1.22 (pages 2-1.34 to 2-1.36).

The most sensitive inputs are :

- Traffic
- Reliability level
- Subgrade resilient modulus

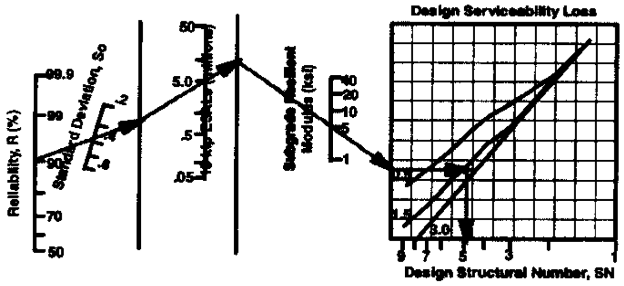
AC Structural Design Model

$$\text{Log } W = Z_R * S_o + 9.36 \log(SN+1) - 0.20 + \frac{\log\left[\frac{4.2 - p_t}{4.2 - 1.5}\right]}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 * \log(M_R) - 8.07$$

Model developed from the results of the AASHO Road Test.

The model was first released in 1961 and has been through several extensions and modifications.

Modified in 1986 to incorporate design reliability, drainage, environmental effects, and use of resilient modulus.



Nomograph may be used to easily solve the design equation.

Work through an example with the nomograph (Figure 2-1.15, page 2-1.28).

Computer program (DARWin) is also now available.

Structural Number Equation

$$SN = a_1D_1 + a_2D_2m_2 + a_3D_3m_3 \ldots a_nD_nm_n$$

a_i = Layer Coefficient of Layer i
D_i = Thickness of Layer i
m_i = Drainage Coefficient of Layer i

No unique solution

The output from the equation or the nomograph is the design structural number, SN.

This is not what we build. This value needs to be converted to thicknesses of each layer.

Need to form a combination of structural coefficients, thicknesses, and drainage coefficients for various layers to achieve the required SN.

The concept is illustrated in figure 2-1.16 (page 2-1.30).

Advantages

- Straightforward and easy to use
- Ample guidance on most inputs
- Considers environmental effects
- Can use wide range of traffic levels and materials

Widely used by DOT's throughout the country.

Guidance on most inputs is provided in the AASHTO Guide and its appendices.

Nomographs are available.

Computer program DARWin allows quick computations and is capable of performing sensitivity analyses.

Limitations

- Based on limited materials and one subgrade
- LEFs based on specific conditions at AASHO Road Test
- 2-year performance period
- Construction variability typically higher than Road Test
- Limited guidance on some inputs

The most significant limitations are attributed to the limited materials and conditions present at the AASHO Road Test.

Data has been extrapolated beyond its inference space, bringing up some question as to its validity.

National Stone Association (NSA) Procedure

- Originally developed in 1972
- Current version developed in 1985
- Based on procedure originally developed by Corps of Engineers
- Empirical procedure
- Uses modified CBR test for subgrade strength

The NSA was established in 1985 with the merger of National Crushed Stone Association (NCSA) and the National Limestone Institute (NLI).

The NSA is a national trade association providing service to users and specifiers of crushed stone through technical publications, related research, and national membership and activity.

Assumptions

- Upgrade subgrade to CBR of 5
- Use high quality crushed stone with broken faces
- Design principle is to provide adequate thickness of quality material to prevent repetitive shear deformation within any layer

Upgrading methods include in-place stabilization with cement or lime, or addition of a coarse, crushed stone product.

Design Inputs

- California Bearing Ratio (CBR)
  - 85 % value for high-volume roads
  - 60 % value for low-volume roads
- Traffic (ESALs)
  - Convert to ESALs using LEFs
  - Convert to Design Index (DI)

CBR may be estimated from other test methods:
- R-value
- Texas Triaxial Classification System
- Soil classifications

The traffic data is converted to a design index category using table 2-1.11 (page 2-1.41).

Thickness Design

- Use traffic data to determine a "Design Index" number
- "Design Index" and CBR used to determine total thickness of structure
- Minimum AC thickness specified
- Lower quality granular materials can be substituted at a 2:1 ratio
- Correct for adverse climate

Design thickness chart is shown in Table 2-1.12 (page 2-1.44).

All designs are a combination of a minimum AC surface thickness on a quality crushed stone base.

In extreme climatic conditions, design must be modified to account for reduced subgrade support during frost-thawing period.

Note the low AC thicknesses that are required, most design procedures would produce much thicker AC thicknesses, especially on higher-volume roads.

Advantages

- Easy to understand and use
- Only requires 2 inputs
- Adjusts for adverse climatic conditions

The procedure can account for climatic effects from freeze-thaw.

Limitations

- Does not consider many important variables
  - ➤ Material strength
  - ➤ Drainage
- CBR is static test
- Does not consider stabilized layers
- Minimum AC thicknesses may not be sufficient for high-volume roads

The simplicity of the procedure is also one of its weaknesses. The procedure fails to consider many important inputs.

CBR is a static test, and does not simulate actual moving wheel loads.

In addition, the procedure places great emphasis on the use of gravel and little on the use of AC.

Design Catalogs

- Increasingly used by agencies for pavement design
- Typically only have a few inputs
- Constrained if don't have specific conditions
- Consider figure 2-1.25 (page 2-1.47)
  - ➤ What are constraints?
  - ➤ What is a design for 10 million ESALs?

Although inputs are few, others are built into the design.

Catalogs are valid only for the specific conditions they are patterned after. Different design charts are available for different conditions.

For figure 2-1.25, the constraints are E = 2800 MPa and CBR = 2.

Germany and NY State have used AASHTO procedure to develop design catalogs.

Summary

- Design procedures can be used to check designs developed from other procedures
  - ➤ Asphalt Institute
  - ➤ AASHTO
  - ➤ National Stone Association
  - ➤ Design Catalogs
- All procedures have assumptions, strengths, and limitations

All procedures have limitations built into them. The purpose of checking designs using alternate procedures is to try to eliminate these limitations.

QUESTIONS?