Module 2-2

AC PAVEMENT RESPONSES

What are responses?
- Can be thought of as reactions to load
- Stresses, strains, deflections

This module discusses AC pavement analysis portion of design checking process.

Module Contents

- Stresses, Strains, and Deflections
- Critical Locations
- Calculating AC Responses
- Designing to Minimize AC Distresses

Responses can be measured or estimated using a variety of different approaches.

These responses can then be used to estimate future distresses.

By minimizing these responses through proper design, performance can be improved.

Why are pavement responses important ?

The magnitude of responses greatly affects the rate at which a pavement deteriorates.

Excessive values may lead to premature failure of pavement.

Repeated applications of non-critical loads also cause distresses.

Sources of Stresses/ Strains

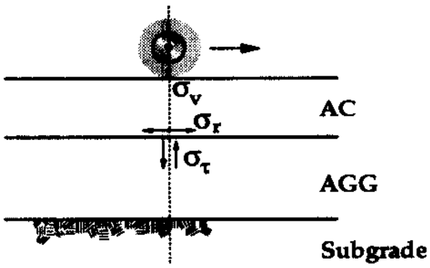
- **Load-Related**
  - ► **Vertical**
  - ► **Shear**
  - ► **Radial**
- **Non-load-Related**
  - ► **Shrinkage**
  - ► **Temperature**

Any applied load that causes a deflection has an applied strain associated with it

Each source of stresses and strains should be considered in the analysis of a pavement.

Failure to consider one of these sources can lead to premature failure of the pavement.

Load Stresses/ Strains

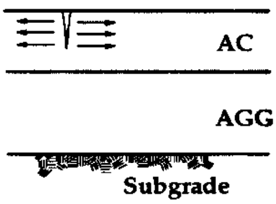


Vertical (compressive) stresses and strains are the cause of rutting.

Shear stresses can cause unstable movements in untreated granular bases (typically seen only on low-volume roads).

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

Environmental Stresses



- **Shrinkage due to increased brittleness and temperature changes**
- **Thermal cracking caused by extreme low temperatures or by thermal fatigue**

Shrinkage stresses, combined with oxidation over time, lead to block cracking.

Thermal cracking occurs two different ways:

- Low-temperature cracking (cold regions).
- Thermal fatigue cracking due to large, repeated daily temperature variations.

Thermal cracking can occur in any region (hot or cold) due to large fluctuations in temperature between day and night.

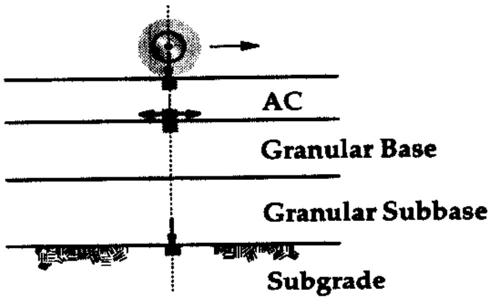
Critical Pavement Responses

- Those that have a significant effect on the pavement's performance (generally leading to pavement deterioration)
- Exist at different locations within a pavement because of varying material properties and ordering of layers within the pavement structure

Critical responses control the performance (life) of the pavement.

Different critical pavement response locations result in different types of distress.

AC Over Granular Base



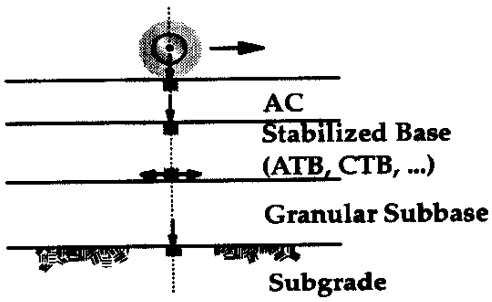
This is figure 2-2.2 (page 2-2.6), which illustrate the critical locations for an AC pavement with an aggregate base. This slide and the next illustrate how responses change with changes in cross-section.

Radial (tensile) (horizontal) stress at bottom of AC layer leads to fatigue cracking.

Radial stresses not critical in lower layers if they are not bound (i.e. no stabilized base).

Vertical stresses lead to permanent deformation (especially in lower layers).

AC Over Stabilized Base



This is figure 2-2.3 (page 2-2.6), which illustrates the critical locations for an AC pavement over a stabilized base.

Radial stress shifts to bottom of stabilized base layer.

Other stresses do not change.

Calculating AC Pavement Responses

- Single-Layer Systems } Elastic Layer
- Multi-Layer Systems } Elastic Layer
- Finite Element Methods

Several analytical methods have been developed to estimate pavement responses.

First was Boussinesq (1885).

Over 100 years since, but we still don't have all the answers.

Required Information

- Traffic Information
- Environmental Information
- Material Properties
- Design/ Construction Information

List shown on pages 2-2.7 and 2-2.8.

Need traffic and load information, particularly for trucks.

Must also determine material properties in order to estimate responses from vehicle loads.

Environmental conditions can have a significant impact in some parts of the country.

Boussinesq Theory (Single Layer)

- First to examine pavement's response to load
- Assumptions: homogeneous, isotropic, elastic material subjected to a point load

$$\sigma_z = k\frac{P}{z^2} \qquad k = f(r, z)$$

Theory was first developed in 1885.

Results were based on several assumptions, which limits the use of the equations.

- Single layer on subgrade
- Homogenous
- Isotropic
- Elastic
- Point load

Equation is seldom used today, but provides the basis for several currently used analysis methods.

Boussinesq's Conclusions

- Vertical stress decreases with depth and radial distance from load
- Maximum stress occurs directly under the load
- Stress is independent of material properties
- Stress is bell-shaped at a horizontal plane at depth z

Boussinesq came to these conclusions. Although they are commonly known today, they were considered state-of-the-art at the time.

These conclusions were used as the basis for several additional analysis tools.

Multi-Layer Systems

- More realistic means of modeling AC pavements
- Calculating responses is more difficult
- Readily accomplished through the use of computers

More complex than single-layer analysis, but more accurately represents the pavement system.

Many computer programs are available for solving these complex solutions.

Assumptions

- Material properties within layers are homogeneous
- Each layer except the subgrade has a finite thickness
- Each layer is isotropic
- Each layer can be characterized by the modulus of elasticity and Poisson's ratio

Homogenous - properties are the same throughout the layer.

Isotropic - properties at a specific point are the same in every direction or orientation.

Poisson's ratio = lateral strain/axial strain

Violations

- AC only responds linearly at low stress states
- AC is a visco-elastic material
- All deformation is not recoverable (has a plastic and an elastic component)
- Even with these limitations, predicted AC responses are reasonably similar to actual responses

See Figure 2-2.5 on page 2-2.19.

AC does not fully recover from higher stresses. Therefore, we experience rutting.

Available Software

- BISAR (Shell)
  - ► Linear elastic theory
  - ► Varying interface friction parameter
  - ► Horizontal loadings (braking)
- CHEVRON (Chevron)
  - ► Linear elastic theory
- WESLEA (U.S. Corps of Engineers)
  - ► Linear elastic theory
  - ► Analyzes up to 5 layers

Each program has its own unique attributes and limitations associated with it.

Elastic-layered program are based on Burmister's theory.

Available Software (Cont)

- KENLAYER (Huang)
  - ► Linear elastic, nonlinear elastic, visco-elastic
  - ► Allows multiple wheel loads
  - ► Layer interface slip
  - ► Can analyze up to 19 layers
- ELSYM5
  - ► Elastic layer
  - ► Allows multiple wheel loads
  - ► Layer interface slip
  - ► Can analyze up to 5 layers

Other programs are also available.

All should give roughly the same results.

ELSYM5

- **Elastic layer data**
  - ► **Thickness**
  - ► **Modulus of elasticity**
  - ► **Poisson's ratio**
- **Load data (2 out of 3)**
  - ► **Total load**
  - ► **Tire pressure**
  - ► **Load radius**
- **Evaluation locations**
- **Outputs**
  - ► **Stresses**
  - ► **Strains**
  - ► **Deflections**

Vertical deflections and radial tensile strains are particularly important outputs, as is vertical strain on subgrade.

Example Problem

- **ELSYM5 Example**
- **Workshop Problem**

Look at the example problem beginning on page 2-2.25.

Two loads may result in maximum responses located between the loads instead of directly under the loads. Thus, a variety of horizontal positions may need to be evaluated.

The ELSYM5 workshop problem can be done now or at the end of the module. Now is often a good time while it is still fresh in their minds. Instructor's should run through a quick demo of how to use the program.

Finite Element Analysis

- **Each layer is divided into small elements**
- **Considers the elastic response of the pavement system**
- **Stress state in each element is calculated**
- **Adjacent elements are dependent upon each other**
- **ILLI-PAVE and MICH-PAVE are two available finite elements programs**

Complex method of analyzing the elastic response of a pavement system.

Finite element programs are powerful tools that must be utilized with extreme caution.

Requires development of a finite element "mesh."

If mesh is inaccurate, erroneous results will be produced.

ILLI-PAVE

- Considers non-linear stress-dependent material models and failure criteria
- Analysis algorithms developed
  - ► AC over granular layers
  - ► Full-depth AC

Simplified analysis algorithms developed to predict ILLI-PAVE solutions for typical flexible pavements.

These equations are relatively easy to solve.

Equations are base on a 40-kN (9-kip) load and 550 kPa (80 psi) tire pressure.

Equations were developed using the SPSS stepwise regression program and the results from many ILLI-PAVE runs.

ILLI-PAVE Algorithms

- Radial strain at bottom of AC
- Subgrade deviator stress
- Subgrade stress ratio
- Subgrade vertical strain
- Surface deflection
- Subgrade deflection

Responses are then related to performance through transfer functions

Equations were developed to predict these responses.

Analysis Summary

- Loads/ environment create stresses, strains, and deflections in pavement
- The magnitude, frequency, and duration of these responses determine the type and extent of pavement distress
- The closer σ_{app} to σ_y , the more damage is done (i.e., lower stress allows more repetitions)

Magnitude of responses can be determined from elastic layer theory (e.g., ELSYM5).

Frequency - more than one stress/strain repetition.

Duration - speed at which load is applied.

Different responses will occur at different speeds.

Most programs use static loads.

Sensitivity Analysis

- Analyze effect of design inputs on pavement responses
- Sensitive factors:
  - ► Tire load/ pressure
  - ► Layer thickness and stiffness
  - ► Subgrade support

See page 2-2.38 for sensitivity analysis results.

Tire pressure has a large effect on responses.

Stiffness of roadbed soil has a large effect on responses.

Poisson's ratio has little or no effect on responses for this particular case, although it can affect responses in other situations.

Stabilizing the base course shifts critical stresses to that layer.

Designing to Minimize Stresses

- Minimize ε_v and avoid permanent deformation in layers
- Minimize σ_r in layers subject to fatigue behavior
- Also need to restrain soil swelling pressures and provide adequate frost protection

Must provide an adequate wearing surface at the same time.

Studying responses with these analytical tools helps to improve designs.

Minimizing Stresses in Surface

- Increase stiffness
  - ► Layer has higher modulus
  - ► Layer assumes greater stress
  - ► If thickness is not increased, increase in stress could outweigh increase in stiffness
- Reducing modulus or increasing thickness are best ways of reducing stresses in upper layer

Reducing the modulus can reduce stress in that layer, but can also increase the stress in other layers.

Minimizing Stresses in Subgrade

- Stresses decrease rapidly with increasing depth, so increase total thickness
- Increase stiffness of upper layers, particularly the layer above the subgrade

Increase total thickness to reduce stress in subgrade.

Summary

- Pavement responses are stresses, strains, and deflections due to load
- Critical responses lead to deterioration
- Several tools are available to estimate these responses
- Designs can be changed to reduce the critical responses

Critical location depends on applied load, thickness of layers, and properties of layers.

QUESTIONS?