Block 4: Overlay Design

Modules:

- **Principles of Overlay Design**
- **Overlay Design Procedures**

This block presents concepts and procedures for the structural design of overlays and methods of verifying the designs.

Only structural overlays are discussed in this course. The design of functional overlays is governed primarily by existing pavement type and the properties of the overlay material.

Why are overlays placed? How do they perform? What are typical failure modes? What methods are used to analyze overlays?

Module 4-1

PRINCIPLES OF OVERLAY DESIGN

This module discusses the factors affecting overlay performance and how to address these factors in design.

Principles of Overlay Design

- **Design Considerations**
- **Overlay Design Approaches**
- **Structural Evaluation**
- **Traffic Evaluation**
- **Critical Stresses and Strains**
- **Available Analysis Tools**
- **Design Validation**

Constructibility, required service life, available lane closure time, maintenance requirements, and cost are all important factors to consider.

Design checks include subjective, as well as analytical, reviews of the design.

Overlay design involves many factors that do not need to be considered for new design.

Design Considerations

- Feasibility
- Preoverlay Repair
- Reflection Crack Control
- Drainage

These considerations are all important for overlay design; more is involved than just thickness design.

Feasibility - distresses and constraints can influence type of overlay (see table 4-1.1 on page 4-1.4).

Reconstruction may be more cost-effective if amount of preoverlay repair is large and/or vertical clearance is a major problem.

If poor drainage is contributing to the deterioration of the existing pavement, adding an overlay will not correct the problem.

Overlay Design Approaches

- Engineering Judgment Approach
- Structural Deficiency Approach
- Deflection Approach
- Mechanistic Approach

These are the four basic approaches to overlay design.

These approaches differ in the way design factors are considered in determining the required overlay thickness.

Engineering Judgment Approach

- Different thicknesses for each functional classification
- No engineering analysis
- Not recommended

Using engineering judgment is not necessarily a bad approach.

However, it is advisable to use other approaches in combination with engineering judgment. Using this approach in combination with other approaches creates a more sound overall approach.

Structural Evaluation

- Part of field evaluation
- Involves distress surveys, core testing, and nondestructive testing
- Objectives
  - ➤ Determine material properties
  - ➤ Assess structural capacity of existing pavement

A structural evaluation is an essential part of designing overlays in order to determine the in-place properties and to assess the structural capacity of the existing pavement.

An assessment of the requirements for preoverlay repairs, reflection crack control, and drainage improvements is also part of the field evaluation.

FWD testing has become an increasingly popular means of measuring deflections, which are then used to backcalculate material properties.

Deflection Testing

- Falling Weight Deflectometer (FWD)
- Test at regular intervals
- 40 kN (9000 lb) circular load
- Backcalculate material properties

Deflection testing provides a great deal of information regarding the structural capacity of the existing pavement.

Deflections can also be used to determine load transfer efficiency at joints and cracks for PCC pavements.

In-Place Material Properties

- AC
  - ➤ Subgrade resilient modulus
  - ➤ Pavement layer moduli
- PCC
  - ➤ Modulus of subgrade reaction (k)
  - ➤ PCC modulus of elasticity
  - ➤ Load transfer

For analysis and design, we need these properties.

Some of these properties can be obtained through other methods, such as coring and testing.

Deflection testing allows for numerous tests to be conducted in a short period of time without destroying the pavement.

Deflection testing also provides load transfer and loss of support data.

Backcalculation of Layer Moduli

- **Determined iteratively based on measured deflection basin**
- **Procedure**
  - ► **Assume initial moduli values for all layers**
  - ► **Analyze using an elastic layer program**
  - ► **Compare computed and measured deflection basins**
  - ► **Vary the layer moduli and repeat the analysis until acceptable convergence**

The basic procedure is to search for a set of modulus values that gives a close match between the calculated and measured deflection basins.

Available Programs

- WESDEF
- BISDEF
- MODULUS
- EVERCALC

Programs are based on different, existing elastic layer programs. A brief description of each program is provided on page 4-1.3.

None of the methods currently available is guaranteed to give reasonable values for every deflection basin.

Engineering judgment still plays an important role.

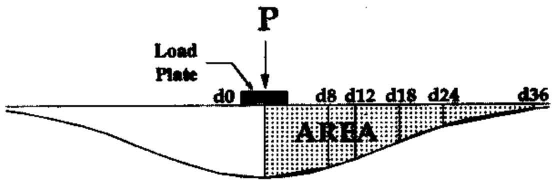
PCC Backcalculation

- **Compare measured deflections to those predicted by plate theory**
- **AREA characterizes the deflected shape of the slab**

$$\text{AREA} = 6\left[1 + 2\left(\frac{d_{12}}{d_0}\right) + 2\left(\frac{d_{24}}{d_0}\right) + \left(\frac{d_{36}}{d_0}\right)\right]$$

Determine values of Ec and k that, when used in the equations given by plate theory, will produce the measured values.

The deflections are represented by a single, normalized parameter (AREA).



This is figure 4-1.3 (page 4-1.15), which illustrates the AREA concept.

Once the AREA is determined, a series of equations are solved to determine the material properties. Charts have also been developed to simplify the process.

In addition, computer programs are available that automate the backcalculation process.

PCC Modulus of Rupture

- Core Testing

$$MR = 1.02\ ST + 210$$

- Backcalculate from modulus of elasticity

$$MR = 43.5\frac{E}{10^6} + 488.5$$

- Beam Testing

The modulus of rupture is an important property for PCC pavement design.

One or more of these methods may be used. The methods may provide slightly different values.

What value do you use if all three methods provide different results?

Structural Capacity of Existing Pavement

- Important to accurately assess the effective capacity of the existing pavement
- Three basic approaches
  - Visual survey
  - Nondestructive testing (NDT)
  - Fatigue analysis

If capacity is overestimated, the resulting design will be too thin.

If the capacity is underestimated, the resulting design will be unnecessarily thick.

The NDT approach is used most commonly for the design of AC overlays of existing AC pavements.

The visual survey and fatigue analysis methods are used for both AC and PCC overlays.

Visual Survey

- Distress and drainage surveys
- Coring and laboratory testing
- Used in both AASHTO and mechanistic design procedures.

A visual survey of the pavement is an essential part of mechanistic overlay design. One cannot accurately assess the structural capacity of the pavement by analytical means alone.

The amount of fatigue-related cracking (generally, transverse cracking) on the pavement can be used to assess the amount of fatigue damage (see equation 4-1.18 on page 4-1.19).

Nondestructive Testing

- Conduct deflection testing to collect data used to backcalculate the pavement layer stiffness
- Determine the effective structural capacity based on the backcalculated stiffness

NDT is used in AASHTO, deflection-based, and mechanistic design procedures for determining the effective capacity of existing AC pavements.

The required overlay thickness can be determined directly from design charts based on measured deflections and expected future traffic. The Asphalt Institute procedure is a good example of this type of procedure.

Fatigue Analysis

- Mechanistic design procedures use the fatigue life concept
- Overlay designed to limit fatigue damage below an acceptable level

$$FD_r = FD_a - \frac{N_p}{N_a}$$

Fatigue analysis performed to estimate accumulated fatigue damage.

Remaining fatigue life is used to determine the capacity of the existing pavement.

Used in AASHTO and mechanistic design procedures to estimate remaining life of pavement.

Traffic Evaluation

- Most procedures use 80-kN (18-kip) ESALs
- Can develop LEFs for specific model
- Must use LEFs for appropriate pavement type

Rigid ESALs = 1.5 * Flexible ESALs

Most procedures use the number 80-kN (18-kip) ESAL applications to represent traffic. The ESAL concept is based on data from the AASHO Road Test and is empirical in nature.

The use of actual projected traffic load spectra is preferred and is more accurate. However, it may be too difficult to calibrate performance models using load spectra.

Table 4-1.4 (page 4-1.21) presents the appropriate LEFs to use for each overlay type.

Available Tools

- Analysis Tools
  - Elastic layer programs
  - Finite element methods
  - Closed-form equations
  - Regression equations
- Overlay Design Programs
  - DARWin
  - HWY
  - EVERCALC, EVERPAVE

Analysis tools are used for determining critical stresses and strains in overlays.

Design programs:

- DARWin - computerized version of AASHTO Design Guide procedures
- HWY - computerized version of the Asphalt Institute design procedure
- EVERCALC, EVERPAVE - mechanistic AC overlay design procedure (Washington State)

These procedure will be discussed in detail in the next module.

Critical Responses

- Can occur in original pavement or in overlay
- Different for each overlay type
- Generally based on controlling fatigue damage and/ or rutting

Pavement responses - stresses, strains, deflections.

The critical responses are those that control the performance of pavement overlays.

Why are critical responses different for each overlay type?

- Each pavement responds differently to loads and the environment, depending on the type of pavement and its properties.

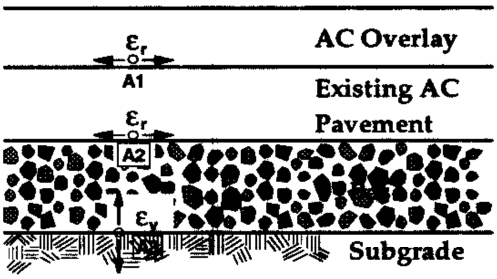
Critical Responses (Cont)

- **AC Overlay of AC Pavement**
  - **Tensile strain at bottom of overlay**
  - **Tensile strain at bottom of original pavement**
  - **Vertical stress on top of subgrade**
- **AC Overlay of PCC Pavement**
  - **Tensile strain at bottom of overlay**
  - **Tensile stress at bottom of PCC slab**

Figure 4-1.4 (page 4-1.24) demonstrates the location of critical stresses in AC overlays.

Reflection cracking is usually the major concern for AC overlays. Many techniques have been developed for controlling reflection cracking; some have been more successful than others. However, no technique can completely eliminate the occurrence of reflection cracking, they can only hope to delay its occurrence.

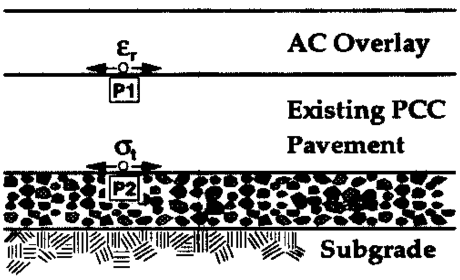
AC Overlay of AC



The three critical responses are:

- Tensile strain at bottom of overlay
- Tensile strain at bottom of original pavement
- Vertical stress at top of subgrade

AC Overlay of PCC



Critical responses:

- Tensile strain at bottom of AC overlay
- Tensile stress at bottom of PCC slab

Reflection cracking is of primary concern for this type of overlay.

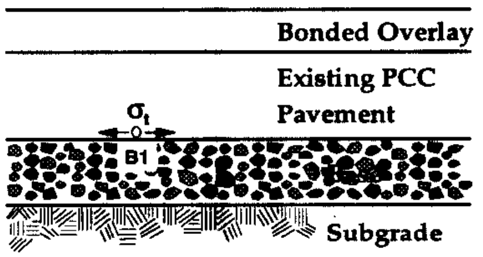
Critical Responses (Cont)

- Bonded PCC Overlay
  - Tensile stress at bottom of original PCC slab
- Unbonded PCC Overlay
  - Tensile stress at bottom of PCC overlay
- PCC Overlay of AC Pavement
  - Tensile stress at bottom of PCC overlay

Figure 4-1.5 (page 4-1.25) illustrates the critical stresses for PCC overlays.

For PCC overlay of AC pavements, the critical stress will be at a crack or joint in the existing pavement (difficult to model).

Bonded PCC Overlay

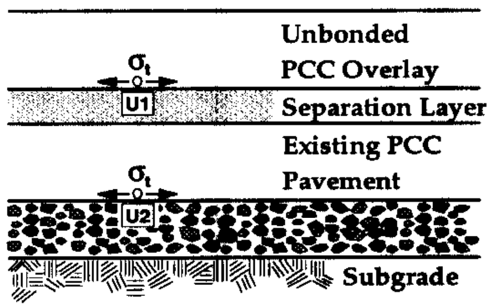


The critical response is the tensile stress at the bottom of the existing PCC pavement.

This type of overlay is designed to act monolithically with existing PCC pavement. Achieving and maintaining the bond between the two PCC layers is critical.

Hence, tensile stress at bottom of existing pavement is critical.

Unbonded PCC Overlay



The critical response is the tensile stress at bottom of overlay.

Also, examine tensile stress at bottom of original pavement.

The separation layer commonly consists of 25 to 50 mm (1 to 2 in) of AC.

Design Validation

- Sensitivity analysis
- Comparison of design procedures
- Mechanistic validation

Sensitivity analyses can be a valuable tool for determining the effect of different parameters.

Comparison of designs and mechanistic validation are the basis of this course, both of which can be used to check designs.

This approach can combine strengths of various procedures while reducing their limitations.

Summary

- Critical responses depend on overlay type
- Critical failure modes
  - Fatigue Cracking
  - Rutting
  - Reflection Cracking
- Analysis and design tools

Principles of overlay design have been presented.

Other failure modes (such as faulting) are not usually a major concern for overlays because better (more uniform) support is provided.

QUESTIONS?