Module 4-2

OVERLAY DESIGN PROCEDURES

This module presents procedures for thickness design and design checks for pavement overlays. We'll assume that the participants are familiar with AASHTO overlay design, which covers 7 different overlay types and up to 3 different methods of calculating structural capacity of existing pavement.

Focus in this module is on procedures based on deflection or mechanistic-empirical concepts.

Procedures

- AC Overlays
  - Asphalt Institute
  - Washington State
  - AASHTO
- PCC Overlays
  - PCA
  - AASHTO

The AASHTO procedure is taught in another training course, *AASHTO Pavement Overlay Design*, and is therefore not discussed in this module.

PCC overlays of AC not covered
- Similar to design of PCC pavement on an AC stabilized base.
- Procedures in module 3-2 for new PCC pavement design may be used.

Other procedures are available (see table 4-2.1) and more are under development.

Asphalt Institute Procedure

- AC overlays of both AC and PCC pavements
- Deflection-based procedure
- Component analysis method (similar to AASHTO)

This is a widely used procedure. Deflection-based procedure was based on data analyzed from WASHO, AASHO road tests, TRRL, RTAC.

Also provides the component analysis method of design (similar to AASHTO, so not discussed here).

Separate procedures for design of AC over AC and AC over PCC.

Concepts

- AC Concept - The higher the deflection under load, the shorter the pavement's life
- PCC Concept - Minimize differential deflection at joints and cracks to minimize reflection cracking

AC overlays of AC and PCC are discussed separately.

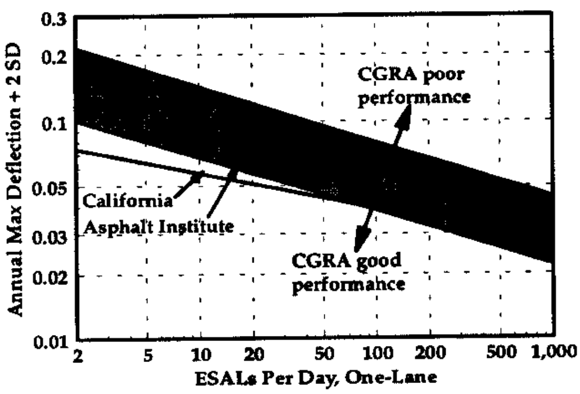
AC over AC

- Higher Deflection = Shorter Life
- The "tolerable" deflection after overlaying is a function of the expected traffic
- Additional overlay thickness reduces the deflection to a tolerable level
- Procedure based on AC surface and a granular base

Deflection was selected over stress or strain because it is typically obtained more easily.

Deflection criteria in procedure were based on performance data from various road tests.

AI procedure does not consider use of stabilized bases.



This is figure 4-2.1 (page 4-2.5), which shows the concept of the relationship between deflection and ESALs based on many studies. Note the following:

- Based on benkelman beam.
- Deflection is critical period value.

Figure 4-2.2 on the same page shows the same relationship in terms of total ESALs.

- This is the design chart in the current AI overlay design manual (MS-17).
- Design deflection is related to cumulative ESALs.
- If deflection after overlay is kept below design value, pavement will carry ESALs shown.

Design Steps

- Obtain deflections
- Calculate mean and standard deviation
- Determine temperature and critical period adjustment factors
- Calculate rebound deflection
- Calculate foundation modulus
- Calculate expected deflection after overlay
- Compare to design traffic and iterate as needed

Procedure is outlined on page 4-2.11. Note that figure 4-2.4 (page 4-2.9) is the solution if modulus is 3.5 GPa (500,000 psi).

The AI has a computer program, HWY, that automates the procedure.

Deflections

- Representative rebound deflection from Benkelman beam
- 13 measurements per km

$$\delta_B = 1.61 * \delta_{FWD}$$

- Design value obtained using:

$$\delta_{rrd} = (\delta + 2\,S) * f * c$$

Equation 4-2.6 (page 4-2.10) converts FWD deflections to equivalent Benkelman Beam deflections. Equation 4-2.3 (page 4-2.6) calculates representative rebound deflection.

f is temperature adjustment factor (needed if measurements not taken at 70 F) (Fig. 4-2.3, p. 4-2.6).

c is critical period adjustment factor (converts deflections measured at noncritical periods).

The use of 2 standard deviations ensures a 98 percent reliability that maximum deflection will not exceed the design value.

Foundation Modulus

- Modeled as two-layer elastic system
  - ► Existing pavement and subgrade
  - ► Overlay

$$\delta_{rrd} = \frac{1.5 * p * a}{E_s}$$

Equation 4-2.2 (page 4-2.6) can be used to calculate the existing pavement modulus.

Equation was developed by Boussinesq and uses the measured beam deflections.

Overlay Design

- Conduct deflection testing and determine rebound deflection
- Determine the required overlay thickness from design chart
- Check the design using design equations

The thickness design chart is shown in figure 4-2.4 (page 4-2.9).

The remaining life may also be determined using this approach (see procedure outlined on page 4-2.10).

AC over PCC

- Deflection-based procedure
- Objective - minimize reflection cracking
- Procedure considers
  - Vertical shear stresses from differential deflections at joints and cracks
  - Horizontal tensile stresses from slab movements
- AC overlay is assumed to reduce deflections 0.2 percent per mm

The procedure for AC overlays of existing PCC pavements is also a deflection-based approach, although the steps are different.

Allowable Deflections

- Jointed PCC
  - Allowable differential deflection at joint or crack is 0.05 mm (0.002 in)
  - Allowable mean deflection (average of loaded and unloaded side) is 0.36 mm (0.014 in)
- CRCP
  - Benkelman Beam deflection of 0.28 mm (0.011 in) is maximum recommended

For CRCP, corresponding recommended maximum Dynaflect deflection is 0.015 mm (0.0006 in).

Design Chart

- Table 4-2.3 shows thickness design chart
- Chart incorporates movements and deflections through a series of assumptions
- Requires as inputs
  - ► Slab length
  - ► Temperature differential
- Options
  - ► Use chart thickness
  - ► Reduce slab length (fracture)
  - ► Use crack relief layer

Table 4-2.3 is shown on page 4-2.14.

The temperature differential is the difference between the highest normal daily maximum temperature and lowest normal daily minimum temperature for the hottest and coldest month, based on a 30-year average.

A summary of temperature differentials for various cities in the United States is provided in table 4-2.4 (page 4-2.15).

Design Steps

1. Condition surveys and deflection testing
2. Determine temperature differential
3. Determine overlay thickness from design chart and assess effectiveness of other options
4. Calculate whether deflections after overlay are within allowable range

If deflection limits are exceeded, AI recommends undersealing.

AI also recommends using condition survey or deflection testing to identify distressed areas to repair prior to overlay.

Advantages

- Simple
- Based on sound engineering principles
- Incorporates reliability
- Addresses reflection cracking

The procedure only contains a few inputs.

Easy-to-use charts are available for thickness design.

Computer program (HWY) is also available.

Limitations

- Use of maximum deflection as main parameter
- Does not address rutting
- Does not give enough consideration to structural capacity of PCC pavement
- Slab stabilization may not be sufficient rehabilitation for some pavements

Rutting not addressed; assumes stable mix?

Structural capacity is not directly considered.

Potential for further cracking of an underlying PCC pavement is not given adequate consideration.

Washington State Procedure

- Considers fatigue cracking and rutting
- FWD data used to characterize pavement
- Based on data collected from 16 test sites in Washington over 4 years
- Cores taken to determine diametral resilient modulus
- Uses an elastic layer program to determine the critical pavement responses

It is a mechanistic-empirical design procedure.

One objective was to enhance the ability to estimate in-situ material properties.

EVERPAVE Steps

1. Collect data
   - ➤ Conduct FWD testing and use EVERCALC to determine in-place material properties
   - ➤ Determine seasonal adjustment factors for base and subgrade
   - ➤ Calculate design traffic for each season
2. Assume trial overlay thickness
3. Determine seasonal material properties
4. Analyze pavement structure for each season

Steps are outlined on page 4-2.21 and also shown in figure 4-2.5 (page 4-2.22).

The procedure can be done manually or with the use of a computer program that automates the procedure.

Seasonal adjustments are very important.

EVERPAVE Steps (Cont)

5. Calculate N_f and N_r

$$N_f = 14.82 - 3.29 (\log e_t) - 0.854 \log \frac{E_{AC}}{1000}$$

$$N_r = 1.077 \times 10^{18} (\varepsilon_v)^{-4.4843}$$

6. Determine the damage ratios for each season for rutting and fatigue
7. Sum damage ratios and redo if either is greater than 1.0

Procedure gives a design reliability of 50 % when average values are used for all input values.

EVERPAVE Summary

- Advantages
  - Incorporates mechanistic concepts
  - Conceptually sound
- Limitations
  - Does not consider past damage
  - Has number of inputs that require local calibration in order to make performance models "work"

Although it doesn't consider past damage directly, designers can indirectly look at past damage.

PCA Procedure

- Bonded and unbonded PCC overlays
- Design charts based on JSLAB
- Basic principle - provide an overlay that is structurally equivalent to a new pavement

The procedure is based on the results from JSLAB, a finite element program for analyzing PCC pavements.

Unbonded Overlays

- Design charts for 3 different cases:
  - ► Case 1: Large amount of midslab and corner cracking and poor load transfer
  - ► Case 2: Small amount of midslab and corner cracking, reasonably good load transfer, and localized repairs
  - ► Case 3: Small amount of midslab cracking, good load transfer, and LOS corrected by undersealing

Design charts are shown in figures 4-2.6 through 4-2.8 (pages 4-2.26 and 4-2.27).

The three cases are provided because of the significant effect that the condition of the existing pavement can have on the stresses in the overlay.

Unbonded Overlay Procedure

1. Determine existing pavement condition
2. Perform repairs or subsealing as needed
3. Calculate thickness of new pavement required to carry future traffic
4. Use appropriate design chart to obtain overlay thickness

- Minimum thickness = 152 mm (6 in)
- Thickness can be reduced for tied shoulders
- k = 27 to 81 kPa/ mm (100 to 300 pci)

New full-depth slab thickness and existing pavement thickness are used to determine the required overlay thickness.

Bonded Overlays

- Constructed to act monolithically with existing pavement
- Design stress is ratio of critical stress to modulus of rupture
- Typically 51 to 127 mm (2 to 5 in) thick
- Recommends comprehensive evaluation of existing pavement

The overlay is constructed to act monolithically with the existing slab. Bonding of the two PCC layers is critical for this type of overlay.

The PCA procedure does not take into account past fatigue damage.

Bonded Overlay Procedure

- Similar to unbonded overlay procedure with one additional step
- Convert total thickness to required overlay thickness

$$t_o = t_t - t_e$$

- If MR < 425 psi, do not use bonded overlay
- If MR > 575 psi, use required thickness minus existing thickness

The design chart for bonded overlays is shown in figure 4-2.9 (page 4-2.29).

Minimum recommended bonded overlay thickness is 50 mm (2 in).

Maximum recommended bonded overlay thickness is 100 mm (5 in).

PCA Summary

- Advantages
  - Simple
  - Based on mechanistic analysis
- Limitations
  - Design charts do not consider curling or warping stresses
  - Limited range of material inputs

Same procedure as new design used to determine required full-depth pavement thickness.

Curling stresses are especially critical in unbonded PCC overlays.

Short joint spacings may moderate curling stresses.

Summary

- Several mechanistic-empirical design procedures available for overlay design
- All stress the importance of evaluating the condition of the existing pavement as thoroughly as possible
- The use of different procedures for overlay design is recommended

Several different procedures and tools were illustrated in an effort to give participants the tools to check overlay designs using various techniques. Hopefully, eliminating the weaknesses of each procedure.

QUESTIONS?