Module 3-3

PCC PERFORMANCE PREDICTION MODELS

This module describes models for performing design checks on PCC pavements.

It also introduces tools that can be used to analyze designs based on several different types of distress.

Performance Prediction Models

- Predict future distress (e.g., cracking, faulting) of a pavement using key input variables
- Can be used for:
  - Checking suitability of pavement design
  - Forecasting pavement condition for PMS
- Models developed from observations of performance of in-service pavements ("calibrated")

Some models are completely empirical
- Based solely on observed performance of in-service pavements

Others are mechanistic-empirical
- Based on mechanistic principles and calibrated to actual pavement performance

Models are used to analyze pavements and assess their ability to provide adequate performance throughout the design period.

Types of Prediction Models

- Cracking Models
- Joint Faulting
- Pumping
- Joint Spalling
- PSR/ Roughness
- Punchouts (CRCP)

Many different models are discussed
- NCHRP 1-26 (cracking)
- RIPPER (cracking, joint faulting and spalling, PSR/roughness)
- PEARDARP (empirical cracking, joint faulting and spalling, pumping, PSR/roughness)
- COPES (empirical cracking, joint faulting and spalling, pumping, PSR/roughness)
- PCA (fatigue and faulting)
- Others

Critical Distress Levels

- Cracking
  - 10% of slabs or 800 ft/mi (JPCP)
  - 800 ft/mi (JRCP)
- Faulting
  - 0.10 (JPCP)
  - 0.25 (JRCP)
- Spalling
  - 50 joints/mi (JPCP)
  - 25 joints/mi (JRCP)
- PSR: 2.5 to 3.0
- Punchouts in CRCP: 25/mi

These are some typical values for distress limits.

Each agency should select their own criteria.

JRCP allows more faulting per joint and fewer spalled joints per mile because there are fewer joints in JRCP.

If design is inadequate, modify and check again.

Transverse Cracking

- Mechanistic-Empirical Models
  - Based on accumulated fatigue damage concepts
- Empirical Models
  - Based solely on observations of performance of in-service pavements

Mechanistic-empirical models will have calculated stress incorporated as an input.

Empirical models will have design inputs such as thickness and joint spacing.

Accumulated Fatigue Damage

- Repeated applications of less than ultimate loads can cause cracking of the PCC slab
- Critical stress location is the outside slab edge, midway between the transverse joints
- Concept valid for JPCP pavements

JRCP and CRCP are designed to crack; steel is present to hold cracks tight.

Corner loads can also result in fatigue cracking (corner breaks). Usually only a problem if loss of support exists.

Quantifying Fatigue Damage

- Miner's Theory of accumulated fatigue damage:

$$\text{Fatigue Damage} = \sum \frac{n}{N}$$

n = number of actual load applications
N = number of allowable load applications

- Theoretically, if n/N = 1, cracking will occur
- Variability in material properties and loading can result in cracking at values less than or greater than 1

Miner's hypothesis results in a 50 % chance of fatigue failure (i.e. FD =1, 50 % slabs cracked) if safety factors are not used.

FD of less than 1 should therefore be used to provide a higher reliability level.

Everything in the process has variability built in (materials, construction, loading).

- Need to be conservative, but not too conservative ($)

Calculating N

- Various fatigue models available
- Most use relationships between critical stress and concrete modulus of rupture (stress ratio)
- Examples:
  - ► Zero-Maintenance
  - ► NCHRP 1-26
  - ► ERES/COE
  - ► PCA
  - ► ARE
  - ► Vesic
  - ► RISC

Different models provide a wide range of answers for N.

Figure 3-3.2 illustrates the wide distribution and the large scatter in the data.

Example Calculation of N

- Assume: h = 8, k = 200, MR = 675 psi
- Critical Edge Stress (load only) for single-axle load of 20,000 lb = 386 psi
- Using PCA Fatigue Model:

log N = 11.737 - 12.077 (386/675)
N = 67,724 applications of 20-kip single axles

The PCA fatigue model has three equations for calculating N, each for a different stress ratio.

Below an SR of 0.45, N is unlimited.

Fatigue Damage Calculation

- Assume "n" (actual number of 20-kip SAL repetitions) = 3,000,000
- Fatigue damage consumed: 3,000,000/13,765,000 = 22%
- Must also accumulate the damage incurred by other axle load groups
- Should include effect of thermal curling on critical stress
  - ➤ Identify daily distribution of traffic over discrete curling condition

22 % of fatigue life is consumed by the 3,000,000 20-kip SALs.

Mechanistic-Empirical Cracking Models

- Ripper Model

$$P = \frac{1}{0.01 + 0.03\,[\,20^{-\log(n/N)}\,]}$$

- NCHRP 1-26 Model

$$P = \frac{1}{0.01 + 0.0713\,[\,2.5949^{-\log FD}\,]}$$

See Figure 3-3.4 (page 3-3.10).

Note how % slabs cracked shoots up near log (n/N) of 0 (i.e. FD = 1).

Empirical Transverse Cracking Models

- PEARDARP
  - ➤ JPCP
- COPES
  - ➤ JPCP
  - ➤ JRCP

PEARDARP
- Modified version of Zero-Maintenance model
- Modified to include effects of base type

COPES
- Separate models for JPCP and JRCP
- Both provide total amount of cracking (longitudinal and transverse)

Joint Faulting Models

- PEARDARP
- COPES (JPCP/ JRCP)
- PFAULT (Doweled/ Nondoweled)
- RIPPER (Doweled/ Nondoweled)
- PCA (Doweled/ Nondoweled)

PEARDARP and COPES are empirical.

PFAULT, RIPPER, and PCA are more mechanistic.
- Different models for doweled and nondoweled pavements

Slab Pumping Models

- PEARDARP
- COPES (JPCP/ JRCP)

PEARDARP
- Mechanistic-empirical model based on AASHO Road Test data
- Predicts amount of material required to underseal voids

COPES
- Separate models for JPCP and JRCP
- Answer is in the form of a "pumping index" where 0 = no pumping and 3 = high-severity pumping

Joint Spalling Models

- PEARDARP
- COPES (JPCP/ JRCP)
- RIPPER (JPCP/ JRCP)

These models attempt to predict the development of transverse joint spalling as a function of design and climatic factors.

PSR/ Roughness Models

- AASHO/ PEARDARP
- COPES (JPCP/ JRCP)
- RIPPER (JPCP/ JRCP)

These models attempt to relate physical distress to serviceability (user response).

Punchout Models (CRCP)

- Illinois
- South Carolina
- Texas

Punchouts are the critical structural failure mode of CRCP.

Models were developed from field data to predict the number of failures per mile.

Design Example

- Initial Pavement Design
  - 9 in JPCP
  - 20 ft Joints
  - No Dowel Bars
  - No Drains
  - ATB (k = 200)
  - Cold Climate
  - Fine-Grained Subgrade
  - ESALs = 10 million
  - MR = 700 psi
  - AC Shoulder
- Evaluate adequacy of design

Change one or more design criterion if distress exceeds the limit (see table 3-3.3, page 3-3.40).

Repeat process until all distresses meet the acceptance criteria.

Example is shown in Table 3-3.4 (page 3-3.41).

First Iteration

- Predicted Performance (using RIPPER models):
  - ► Faulting = 0.14 in
  - ► Cracking = 88 percent
  - ► Spalling = 20 joints/mi
  - ► PSR = 3.2

Design not adequate; faulting and cracking unacceptable

Design is inadequate.

Need to decide which variable(s) to modify.

Table 3-3.3 on page 3-3.40 lists possible solutions for improving designs.

Second Iteration

- Modify initial design
  - ► Reduce joint spacing to 15 ft
  - ► Add permeable base with edge drains
  - ► Add PCC shoulders
- Predicted Performance, Design 2:
  - ► Faulting = 0.09 in
  - ► Cracking = 25 percent
  - ► Spalling = 20 joints/mi
  - ► PSR = 3.7

Design inadequate for cracking

Design is still inadequate.

Make further modifications.

Third Iteration

- Design Modifications:
  - ► Add 1.25 in dowel bars
  - ► Increase slab thickness to 10 in
- Predicted Performance, Design 3:
  - ► Faulting = 0.03 in
  - ► Cracking = 0.1 percent
  - ► Spalling = 20 joints/mi
  - ► PSR = 4.1

Revised design is adequate

Design is currently adequate and meets all performance criteria.

Is the design too conservative?

How will this pavement perform?

May wish to do further trials.

Summary

- PCC Performance Prediction Models
  - ➢ Cracking
  - ➢ Faulting
  - ➢ Spalling
  - ➢ PSR/ Roughness
- Used to evaluate adequacy of design.
- Also may be used in PMS for forecasting rehabilitation needs
- Should be calibrated to observed performance of in-service pavements

Models can be very useful tools for predicting various distresses in pavements.

Large empirical content of models makes local calibration important.

QUESTIONS?