Perpetual Pavement Design

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Goal of Perpetual Pavement Design

• Design the structure such that there are no deep structural distresses
  – Bottom up fatigue cracking
  – Structural rutting

• All distresses can be quickly remedied from surface

• Result in a structure with ‘Perpetual’ or ‘Long Life’
Surface Distresses Only

Top Down Cracking

Non-Structural Rutting
How do you compute pavement response?

- Flexible pavements consist of multiple layers
- Using physical principles, we can calculate stresses beneath loads

\[ P, H_1, E_1, \mu_1, H_2, E_2, \mu_2, E_n, \mu_n \]
Linear Elastic System Assumptions

• Many constitutive models available
• Linear Elastic Most Common
• Assumptions
  – Homogeneity
  – Finite thickness
  – Infinite in horizontal direction
  – Isotropic
  – Full friction between layers
  – No surface shear forces
Two-Layer Systems

- Analytical solution derived by Burmister (1940’s)
- Importance of stiffness ratio ($E_1/E_2$)

Vertical Stress, $\sigma_z/p$

Layer 1

Layer 2

$E_1/E_2 = 100$

$E_1/E_2 = 1.0$
Two Layer System – Shear Stress

Horizontal Shear Stress, $\tau_{rz}/p$

Layer 1

Layer 2

$E_1/E_2 = 1.0$

$E_1/E_2 = 50$
Two-Layer System – Tensile Stresses

\[ \sigma_x \]

Depth, z

Layer 1

Layer 2

Tension

Compression
Three Layer Systems

- Much more complicated system!
- Initially solved for a limited set of parameters due to computational limitations
  - $\mu = 0.5$
- Limited number of locations

$$H_1, E_1, \mu_1$$

$$H_2, E_2, \mu_2$$

$$E_n, \mu_n$$
Materials
Figure 1. How an Elastic Material Behaves.
Figure 1. Definitions of $E$ and $\mu$.

$\varepsilon_l = \Delta l / l$

$E = \sigma / \varepsilon$

$\varepsilon_t = \Delta D / D$

$\mu = \varepsilon_l / \varepsilon_t$
Dynamic Modulus Test
Witczak Equation for $E^*$

$$
\log E = -1.249937 + 0.29232 \rho_{200} - 0.001767 (\rho_{200})^2 - 0.002841 \rho_4 - 0.058097 V_a \\
-0.802208 \left( \frac{V_{beff}}{V_{beff} + V_a} \right) + \frac{3.871977 - 0.0021 \rho_4 + 0.003958 \rho_{38} - 0.000017 (\rho_{38})^2 + 0.005470 \rho_{34}}{1 + e^{-0.6033'3 - 0.313351 \log(f) - 0.393532 \log(\eta)}}
$$

- bitumen viscosity (dynamic shear rheometer)
- loading frequency
- air voids
- effective bitumen content
- cum. % retained on 19-mm sieve
- cum. % retained on 9.5-mm sieve
- cum. % retained on 4.76-mm sieve
- % passing the 0.075-mm sieve
Soil Modulus Testing
Dynamic Cone Penetration

Mass

Rod

Reference
Effect of Moisture Content

![Graph showing the effect of moisture content on modulus. The x-axis represents Moisture Content (%), ranging from 0 to 20. The y-axis represents Modulus (ksi), ranging from 0 to 100. The graph illustrates a downward trend as moisture content increases.]
Backcalculation

E = f(Load, Pressure, Deflection, Distance)
AASHO Road Test Trucks

FIGURE 3  AASHO Road Test truck traffic.
Single Tire

Dual Tire

Tandem

Tridem
Tire has a total load $P$, spread over a circular area with a radius of $a$, resulting in a contact pressure of $p$.

Figure 2. Layered Elastic Model Representation of a Pavement.
Thickness vs. Tensile Strain

HMA Tensile Strain

HMA Thickness

Layer 1
HMA
$E_1$

Tensile Strain ($\varepsilon_t$)

$h_1$
Modulus vs. Tensile Strain

Layer 1 HMA

HMA Modulus vs. Tensile Strain

HMA Tensile Strain

Tensile Strain ($\varepsilon_t$)

$h_1$

Layer 1 HMA
$E_1$
Thickness vs. Compressive Strain

Subgrade Compressive Strain vs. HMA Thickness

$h_1$, $h_2$, $E_1$, $E_2$, $E_3$, Compressive Strain ($\varepsilon_v$)
Traditional M-E Design

Log $\varepsilon$

Log $N$
Perpetual Pavement Design

No Damage Accumulation

Log ε

Threshold Strain

Log N

No Damage Accumulation
Normal Fatigue Testing Results Versus Endurance Limit Testing
Transfer Functions

\[ N_F = K_1 \left( \frac{10^6}{\varepsilon_t} \right)^{K_2} \]

\[ K_1 = 2.83 \times 10^{-6} \]

\[ K_2 = 3.20596 \]

\[ N_R = K_3 \left( \frac{1}{\varepsilon_v} \right)^{K_4} \]

\[ K_3 = 5.5 \times 10^1 \]

\[ K_4 = 3.929 \]
Miner’s Hypothesis

• Provides the ability to sum damage for a specific distress type
• \( D = \sum \frac{n_i}{N_i} \leq 1.0 \)

where \( n_i = \) actual number of loads during condition \( i \)
\( N_i = \) allowable number of loads during condition \( i \)
Normal Range for Fatigue Testing

Region of Damage Accumulation

No Damage Accumulation

Endurance Limit
Probabilistic Design – Monte Carlo Simulation

- Axle Weight
- Material Properties
- Thickness

Monte Carlo Random Sampling → Mechanistic Model → Pavement Response

% Below Threshold
% Above Threshold
% Below Threshold

- Design should have high % below threshold

How much ‘damage’ does this area correspond to?
‘Damage Computation’

• For responses exceeding threshold, compute N using transfer function
  – User defined

• Calculate damage accumulation rate
  – Damage / MESAL
Estimated Long Life

- Convert damage rate into an estimated life
  - Use traffic volume and growth
  - Calculate when damage = 0.1
- Use for Low Vol. Roads (t ~30 yrs.)

Low Volume Traffic

- 10 - 20/wk
- 3 - 5/wk
- 10 - 20/wk
PerRoad 2.4

- Sponsored by APA
- Developed at Auburn University / NCAT
- M-E Perpetual Pavement Design and Analysis Tool
- Help File is the Users Manual
- Press F1 at Any Time for Help File