The Basics of Mechanistic Pavement Design

2002

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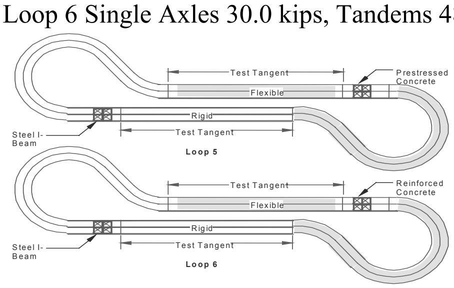
Empirical Approach

- Based on results of experiments or experience
- Scientific basis not established
- AASHTO 86/93 an empirical design method
- Refer to AASHO Road Test

Typical Loop Layout--AASHO Road Test

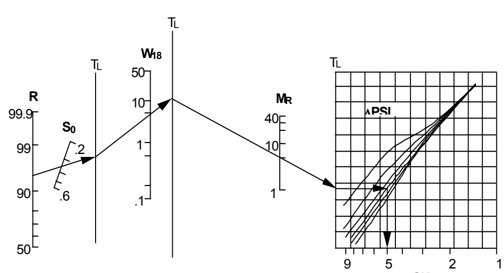
Loop 5 Single Axles 22.4 kips, Tandems 40 kips

Loop 6 Single Axles 30.0 kips, Tandems 48 kips



Empirical Approach
AASHTO Flexible Pavement
Performance Equation

$\mathbf{log_{10}\ W_{18}} =$
$(Z_R)\ (S_0) + (9.36)(\log\ (SN + 1)) - 0.20$
$+\{\log_{10}[\Delta PSI/(4.2-1.5)]/[0.40 + 1.094/(SN + 1)^{5.19}\}$
$+ (2.32)\ (\log_{10}M_R) - 8.07$



Mechanistic-Empirical Approach

- **Mechanistic**: Determine stresses, strains, or deflections at critical locations in a pavement structure.
- **Empirical**: Relates stresses, strains, or deflections to pavement performance. Sometimes referred to as Failure Criteria or Transfer Functions.

Important Advantages

- Relate material properties to design
- More accurate portrayal of traffic effects
- Effects of construction variability and traffic variability can be accounted for
- Pavement layers can be engineered for expected distresses

M-E is important for contractors and agencies.

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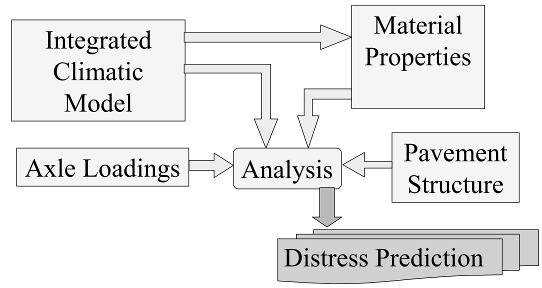
Design Process



Multi Layer Analysis

Elastic Layer & Finite Element Programs have made M-E designs and analysis practical.

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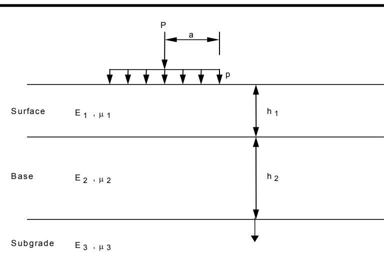
Structural Modeling AC Pavements

- Multi-layer elastic solution
  - Main engine: JULEA
- 2-D Desai finite element analysis
  - For special loading conditions,
  - Non-linear unbound material characterization

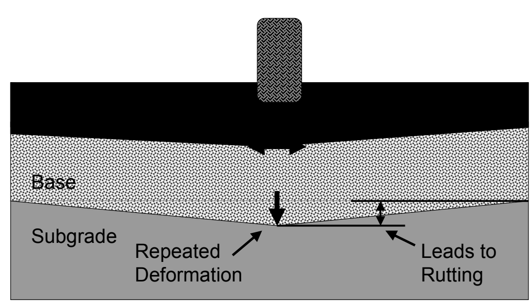


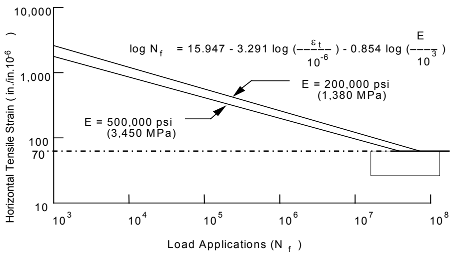
M-E design process requires

•Material properties of each layer (E_i, μ_i)

•Thickness of each layer (h_i) and load (P, a)

Fatigue and Rutting

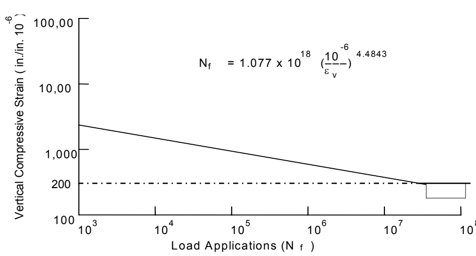




Fatigue Cracking and $N_{fatigue}$

Fatigue Cracking Low Severity

Fatigue Cracking High Severity



Total Pavement Rut Depth and $N_{rutting}$

Rutting

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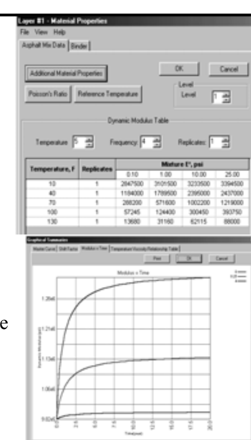
AC Material

- Level 1 - Dynamic modulus on mixture and binder
- Level 2 – predictive equation to develop the master curve and binder testing
- Level 3 – predictive equation for the mixture and typical binder values
- Output - Master curve, shift factor, mixture aging chart, binder temperature-viscosity relationship



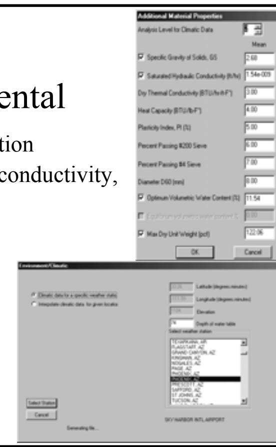
Witczak Equation for E*

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

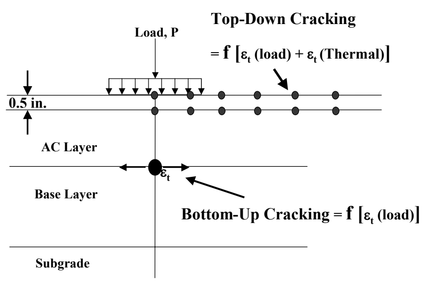
- bitumen viscosity (dynamic shear rheometer)
- loading frequency
- air voids
- effective bitumen content
- cum. % retained on 19-mm sieve
- cum. % retained on 9.5-mm sieve
- cum. % retained on 4.76-mm sieve
- % passing the 0.075-mm sieve

Environmental

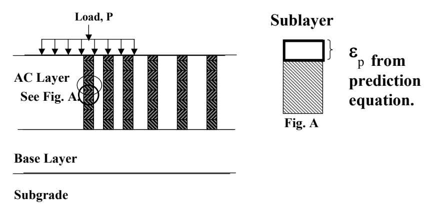
- Weather station or location
- Heat capacity, thermal conductivity, depth of water table
- Output
  - Hourly temperature profile
  - Correction factors to adjust the optimum modulus of unbound layers (moisture and freeze/thaw based)



Fatigue Analysis



Permanent Deformation



$$PD = \sum_{i=1}^{nsublayers} \varepsilon_p^i \times h^i$$

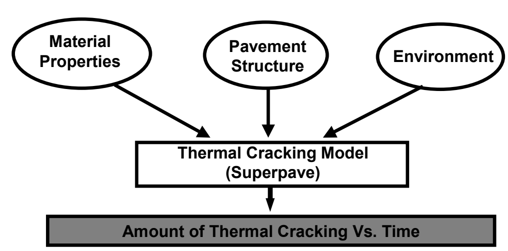
Permanent Deformation Models

$$\log\left(\frac{\varepsilon_p}{\varepsilon_r}\right) = -3.74938 + 0.4262\ \log(N) + 2.02755\log(T)$$

R^2	= 0.73
S_e	= 0.309
S_e/S_y	= 0.522
N_{tests}	= 3476

where:
ε_p = total plastic strain
ε_r = resilient strain
T = temperature
N = total number of load cycles

Thermal Cracking



Design Inputs

- Traffic Loading and the Design Period
- Materials Characterization
- Climate Characterization or Conditions
- Life Cycle Cost Analysis

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Hierarchical Input Levels

- Level 1
  - Advanced materials testing (e*, M_R)
- Level 2
  - Available test procedures with correlation equations
- Level 3
  - Default values

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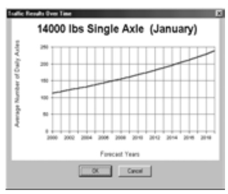
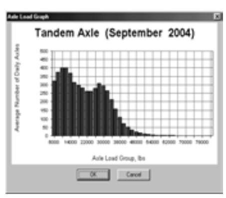
Traffic

- Levels 1 and 2 - Base year load spectra
- Level 3 - ADT, % trucks and road classification
- Outputs
  - Average daily single, tandem, tridem, and quad axles for each month in design period



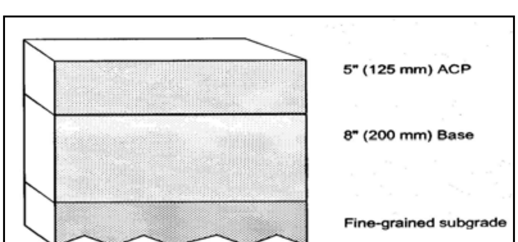


Traffic Loading

- Equivalent Axle Loads (18,000 lb (80kN) single axles)—ESALs or E80s
- Approximate estimate

Fourth Power Law = $[\text{axle wt}/18{,}000]^4$

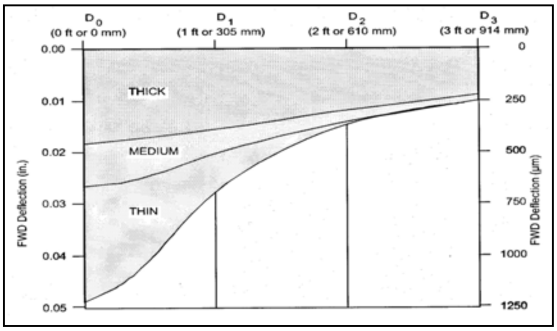
Example Pavement Section



Standard Section with 9000# Load

Case	Standard	Low Tire	High Tire	Moist. Senitive
Surface	0.027”	0.003”	0.028”	0.033”
AC Strain	276	44	352	433
SG Strain	-755	-79	-790	-1,037

Change in Section



Summary

- Mechanistic design is important
- Transfer functions are key to relating pavement responses to performance
- Needs to reflect understanding of materials and structures
- 2002 Guide should be completed by April 30, 2003