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The Basics of Mechanistic Pavement Design

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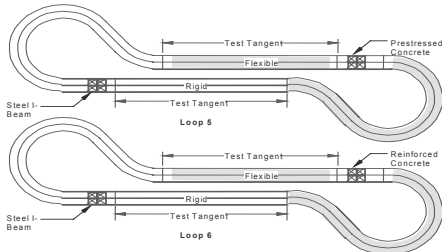
Empirical Approach

- 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

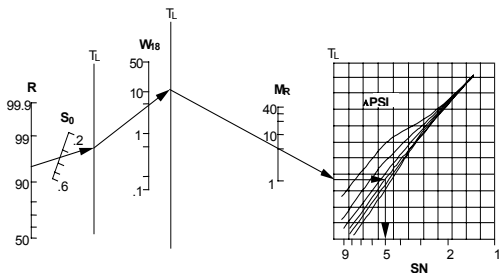
Loop 5 Single Axles 22.4 kips, Tandems 40 kips

Loop 6 Single Axles 30.0 kips, Tandems 48 kips



Empirical Approach AASHTO Flexible Pavement Performance Equation

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



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.

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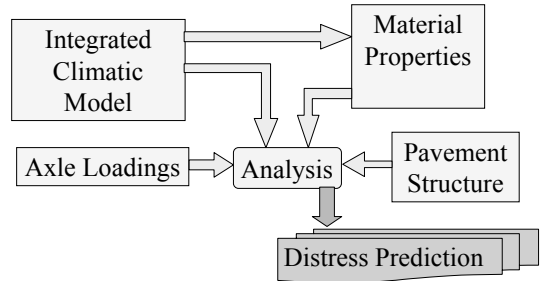
Important Advantages

- 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



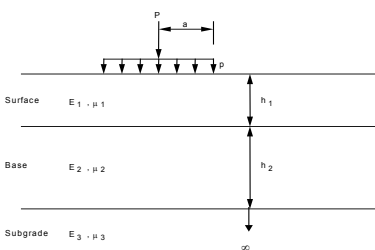
Multi Layer Analysis

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

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Structural Modeling AC Pavements

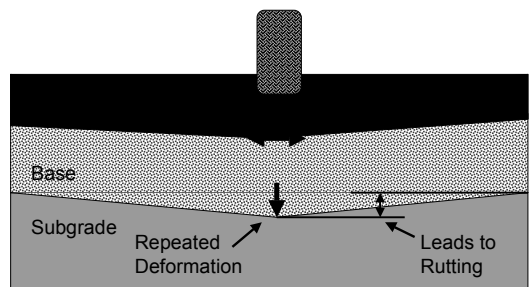
- Multi-layer elastic solution
 - Main engine: JULEA
- 2-D Desai finite element analysis
 - For special loading conditions,
 - Non-linear unbound material characterization



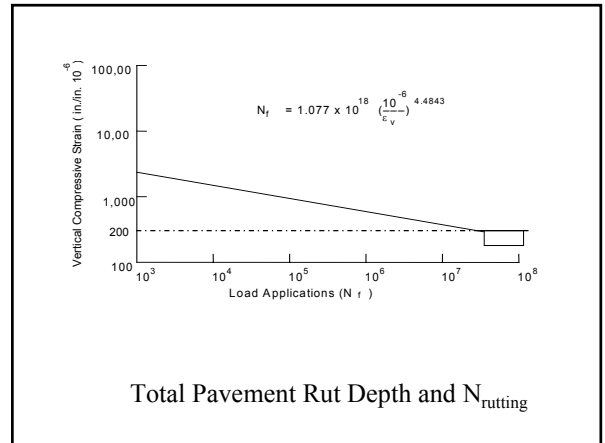
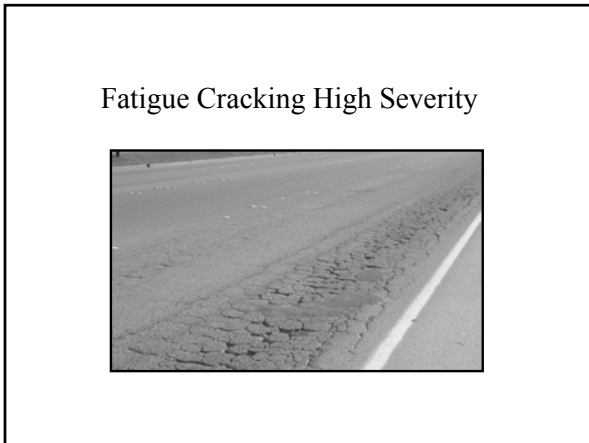
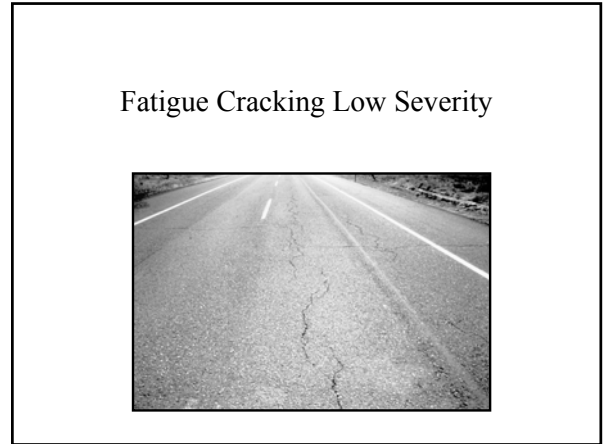
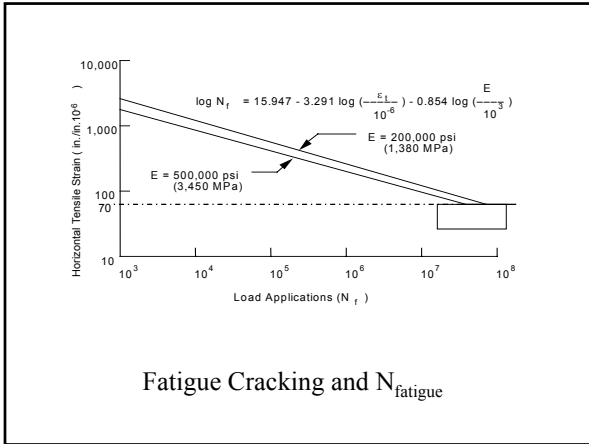
M-E design process requires


- Material properties of each layer (E_i, μ_i)
- Thickness of each layer (h_i) and load (P, a)

Fatigue and Rutting



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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

Level 11 Material Properties

Alpha Mixture Data [Ende]

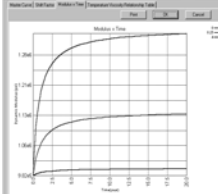
Additional Material Properties [OK] [Cancel]

Pavement Type: Reference Temperature: Level: 2

Dynamic Modulus Table

Temperature, T	Replicates	Frequency	Replicates	Modulus E', psi
50	1	0.10	1.00	100,000
50	1	200,000	200,000	300,000
50	1	1,000,000	1,000,000	2,000,000
70	1	200,000	570,000	1,000,000
100	1	57,000	1,000,000	300,000
130	1	1,000	2,000	400,000

Master Curve [OK] [Cancel]



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Witczak Equation for E*

$$\log E = -1.249937 + 0.29232 \rho_{200} - 0.001767 (\rho_{200})^2 - 0.002841 \rho_{30} - 0.058097 V_v$$

$$-0.802208 \left(\frac{V_{b_{eff}}}{V_{b_{eff}} + V_a} \right) + \frac{3.871977 - 0.0021 \rho_{30} + 0.003958 \rho_{30} - 0.000017 (\rho_{30})^2 + 0.005470 \rho_{34}}{1 + e^{(-0.60333 - 0.313351 \log(f) - 0.393521 \log(\eta))}}$$

- 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

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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)

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Fatigue Analysis

Top-Down Cracking = $f [\epsilon_s(\text{load}) + \epsilon_s(\text{Thermal})]$

Bottom-Up Cracking = $f [\epsilon_s(\text{load})]$

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Permanent Deformation

Sublayer ϵ_p from prediction equation.

$$PD = \sum_{i=1}^{n_{\text{sublayers}}} \epsilon_p^i \times h^i$$

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Permanent Deformation Models

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

$R^2 = 0.73$	where:
$S_c = 0.309$	ϵ_p = total plastic strain
$S_e/S_y = 0.522$	ϵ_r = resilient strain
$N_{\text{tests}} = 3476$	T = temperature
	N = total number of load cycles

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Thermal Cracking

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Design Inputs

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

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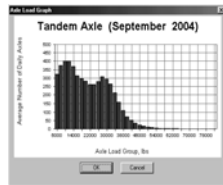
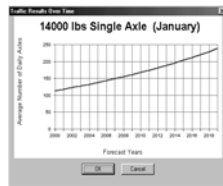
Hierarchical Input Levels

- 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

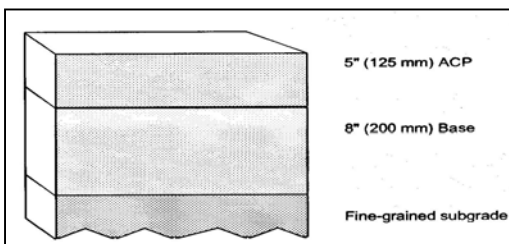


Traffic Loading

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

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

Example Pavement Section

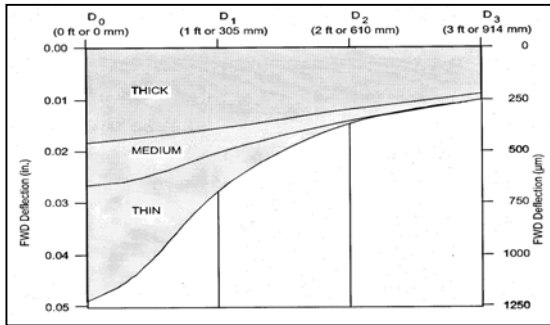


Standard Section with 9000# Load

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

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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