Mechanistic-Empirical Pavement Design Guide: Project Level Pavement Management

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Session 1a: PMS to Support the New MEPDG

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Outline

- Background
- Pavement types; levels of analysis
- Inputs
  - Climate/Environment
  - Traffic
  - Materials
  - Reliability and construction Considerations

Outline (cont.)

- Structural analyses-new design
- Distress estimates
- Structural section selection
- Rehabilitation (not discussed)
- Low volume roads (not discussed)
- Calibration considerations

Why M-E Design?

- Better utilize available materials
- Assess changed traffic loading expeditiously
  - New axle and gear configurations
  - New tire designs and increased tire pressures
- Quickly assess behavior of new materials
- Improve reliability of performance prediction
- Assess impacts of construction on pavement performance

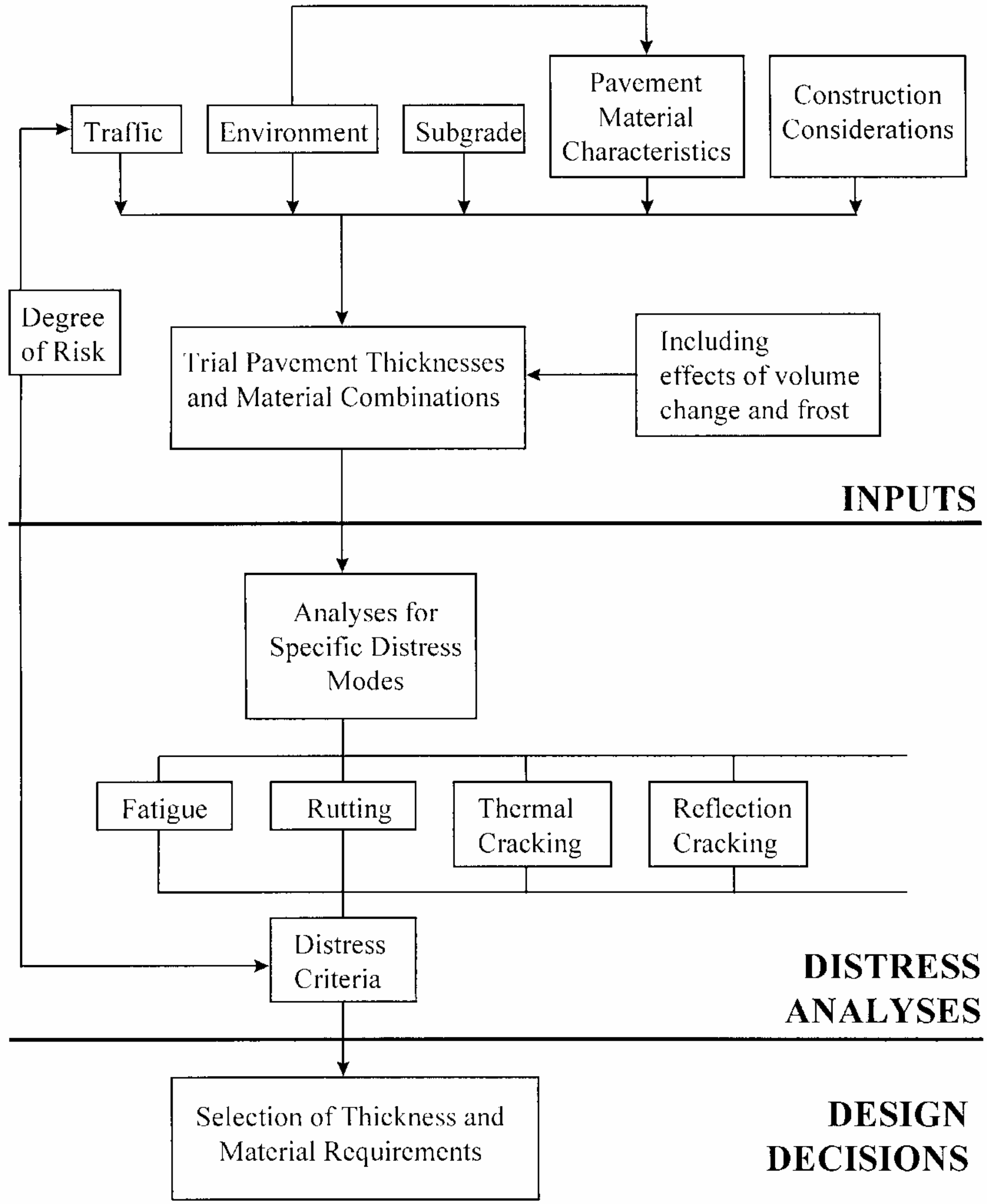
Pavement Types

- Flexible (asphalt) pavements
  - Conventional (HMA, unbound base and subbase)
  - Deep strength and full depth HMA
  - Semi-rigid and inverted (with asphalt or cement treated)
- Rigid (concrete) pavements
  - Jointed plain concrete (JCPC)
  - Continuously reinforced (CRCP)
  - Shoulders (HMA, tied PCC, widened lane)

Design Input Levels

- Level 1
  - Use of site specific materials, environment, and traffic characteristics; material characteristics from laboratory tests
- Level 2
  - Use of less detailed information
- Level 3
  - Use of default values

M-E Pavement Design (flexible pavement example)



Design Inputs

- Climate/Environment
- Traffic
- Materials
- Reliability and Construction Considerations

Climate/Environment

- Water
  - stiffness of untreated subgrade, aggregate subbase (ASB), and base (AB)
  - Stiffness characteristics of pavement materials
  - expansion/heave, fine-grained soils
- Temperature
  - stiffness, permanent deformation and fatigue characteristics of asphalt-bound materials
  - stiffness of untreated materials (freeze/thaw)

Pavement Temperatures

- Use of Integrated Climate Model (ICM)
  - for calculation of pavement temperatures
- ICM inputs:
  - air temperatures, cloud cover, wind speed
  - site latitude
  - time of day
  - pavement components, layer thicknesses
  - material thermal characteristics: thermal conductivity and specific heat capacity
  - surface reflectance

Environment (other considerations)

- ICM also used to estimate:
  - moisture contents in untreated materials
- ICM estimates:
  - best for pavement temperatures
  - less accurate for moisture contents (work still underway in this area; NCHRP 9-23 study likely to provide improvements)

Traffic

- Primarily Trucks and Buses
  - axle loads
  - axle type: single, tandem, tridem
  - wheel type: single, dual
  - tire type: regular, super (wide-based) single
  - tire pressures
    - regular (radial): 100-110 psi
    - super single: 110-120 psi

Materials

- Asphalt concrete
- Portland cement concrete
- Treated bases/subbases
  - Asphalt treated: asphalt cement (ACB), emulsions (ETB)
  - Cement treated (CTB)
  - Lime treated (LTB)
- Untreated aggregate base/subbase (AB,ASB)
- Subgrade soils: untreated or treated (e.g. lime for expansive soil)

Material Properties-Structural Analysis

- Stiffness modulus
  - Elastic modulus used to represent materials response, E = $\boldsymbol{\sigma/\varepsilon}$
  - Other terms used: dynamic modulus (E*), resilient modulus (M_r), creep modulus (E_c)
- Poisson's ratio, υ
  - Ratio of lateral strain to axial strain
  - Range for materials used for pavement design/analysis: 0.15 to ~0.5

Asphalt Concrete

- Stiffness modulus (S_{mix}) function of:
  - time of loading, *t*
  - Temperature, *T*
  - mix properties: asphalt content (V_{asp}) and air void content (V_{air}):

$$S_{mix} \sim V_{asp}/(V_{asp} + V_{air})$$

  - binder stiffness
  - aggregate grading (dense vs. open)

Asphalt Concrete Stiffness

- Measurement
  - Axial
    - dynamic (sinusoidal): complex modulus, E*
  - Diametral
    - haversine (pulse) loading: stiffness, $S_{mix,}$; creep, stiffness, E_c
  - Flexure
    - dynamic (sinusoidal): complex modulus, E*
    - haversine (pulse) loading: stiffness, S_{mix}

- Estimates
    - New Design Guide (Witczak)

Granular Materials (AB, ASB)

- Stiffness Modulus function of:
  - water content
  - dry density
  - stress state; e.g., $M_r = f(\sigma_1, \sigma_2, \sigma_3)$ or $f(\theta)$
    where: $\theta = (\sigma_1 + \sigma_2 + \sigma_3)$
- Measurement
  - triaxial test
- Estimates
  - from R value
  - Shell: $E_g = K \times E_{sub}$;
    where: K = f (base/subbase thickness)

Fine-grained Soils (Subgrades)

- Stiffness Modulus function of:
  - water content
  - dry density
  - Stress state; $M_r = f(\sigma_1 - \sigma_3)$
- Measurement
  - triaxial test
- Estimate
  - Shell; $E_{sub} = 1500 \times CBR$ (psi)
  - from R value; $E_{sub} = (1155 + 555R)$ (psi)

Structural Analysis- New Design

- Pavement representation
  – Multilayer elastic system, flexible
  – Plate on dense liquid (Westergaard), rigid
- Multilayer Elastic System
  – Representation used at this time for flexible pavement analysis
  – E and ν required for each layer
  – circular loaded areas, uniform contact pressure
  – full friction between layer interfaces

Structural Analysis

- **Inputs**
  - layer thicknesses
  - E and n values for each layer
    - for AC layer(s) time of loading and temperature govern E value used
    - seasonal variations in E values for untreated aggregates and fine-grained soils
  - axle configuration and tire spacing
  - tire loads and pressures
- **Outputs**
  - Stress, σ; strain, ε; and deflection, δ

Distress Analyses and Ride Quality (flexible pavement)

- Cracking
  - AC: fatigue
    - bottom up
    - top down
- Permanent deformation (rutting)
- Low temperature cracking
- Smoothness (IRI)

Distress and Ride Criteria (rigid pavement)

- Rigid pavements (e.g. jointed, plain concrete)
  - Fatigue cracking (transverse)
  - Faulting
- Smoothness
  - IRI
- Other rigid pavement types
  - CRCP (in design guide)

(N.B. PCC pavement deign not discussed in the presentation)

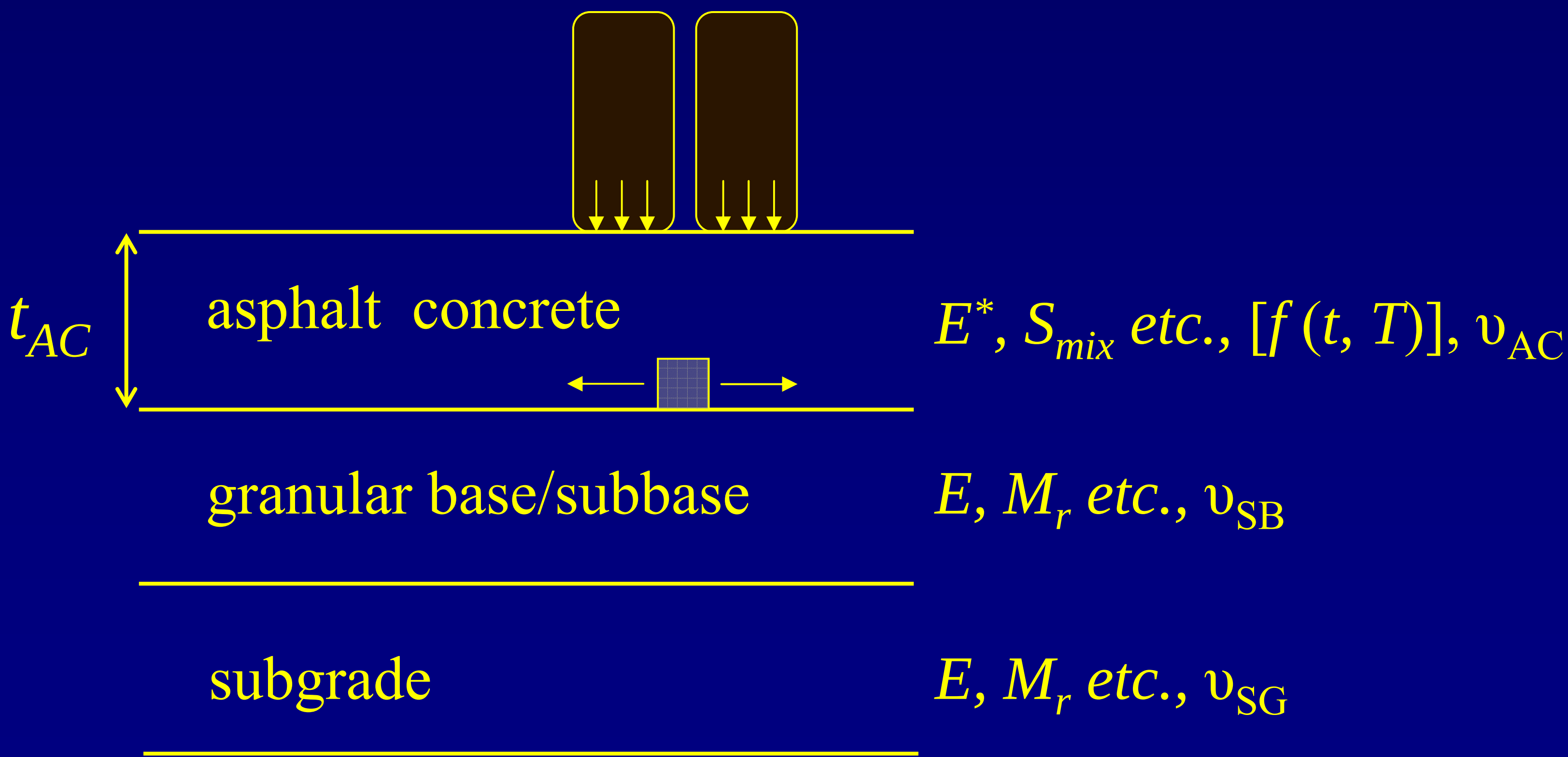
Fatigue Relationship – Asphalt Concrete

- **MEPDG based on NCHRP 1-10B and Asphalt relationships:**

$$N = C\ k\ (1/e_t)^n\ (1/E_{AC})^m$$

Pavement Analysis/Design, Fatigue cracking

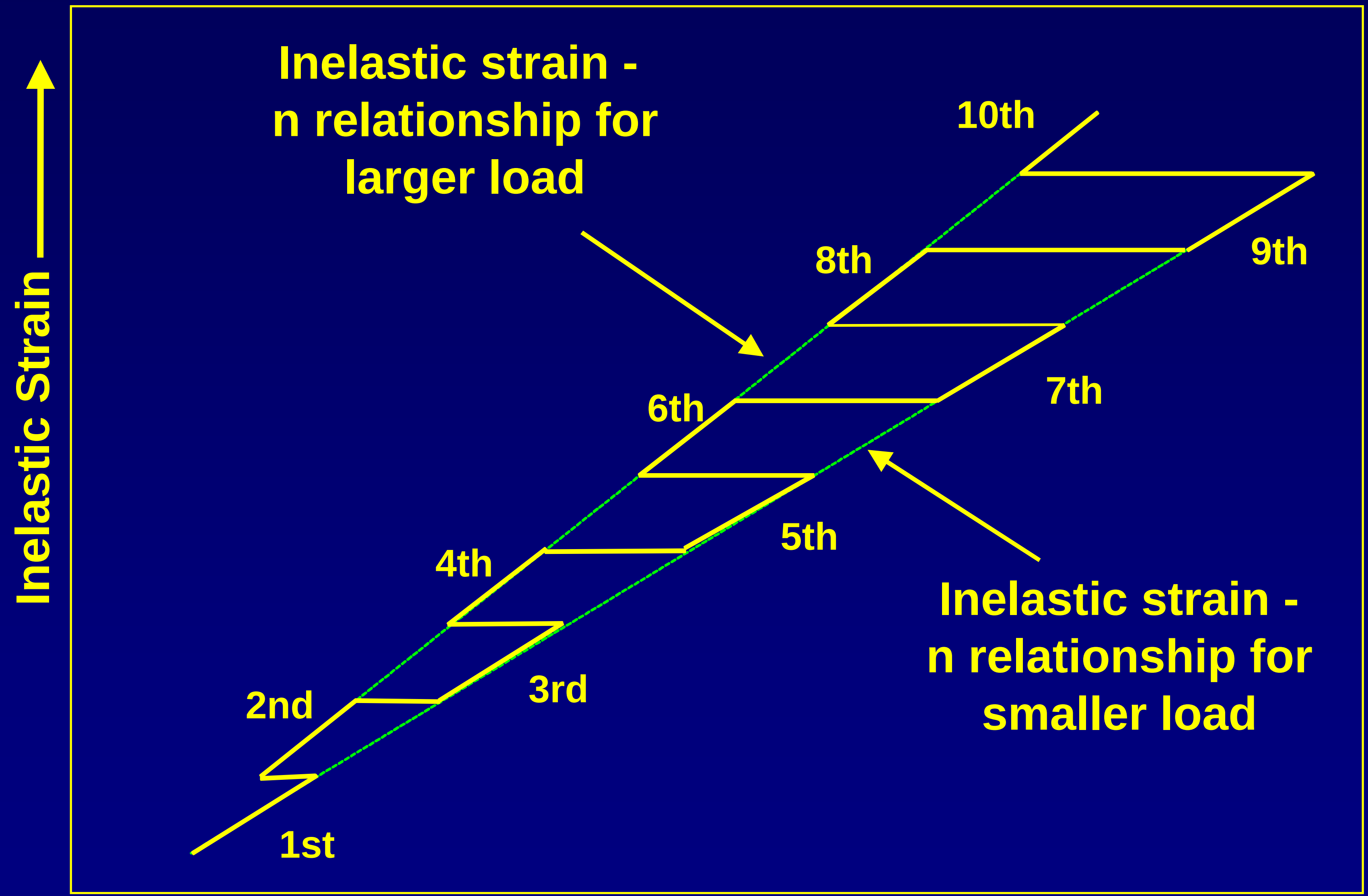
- Usually, bottom-up cracking
- Use of multilayer elastic analysis



Permanent Deformation, AC Layer(s)

- **Prediction**
  - Layered strain procedure
- **Cumulative Damage**
  - Time hardening

Compound Loading - Time Hardening

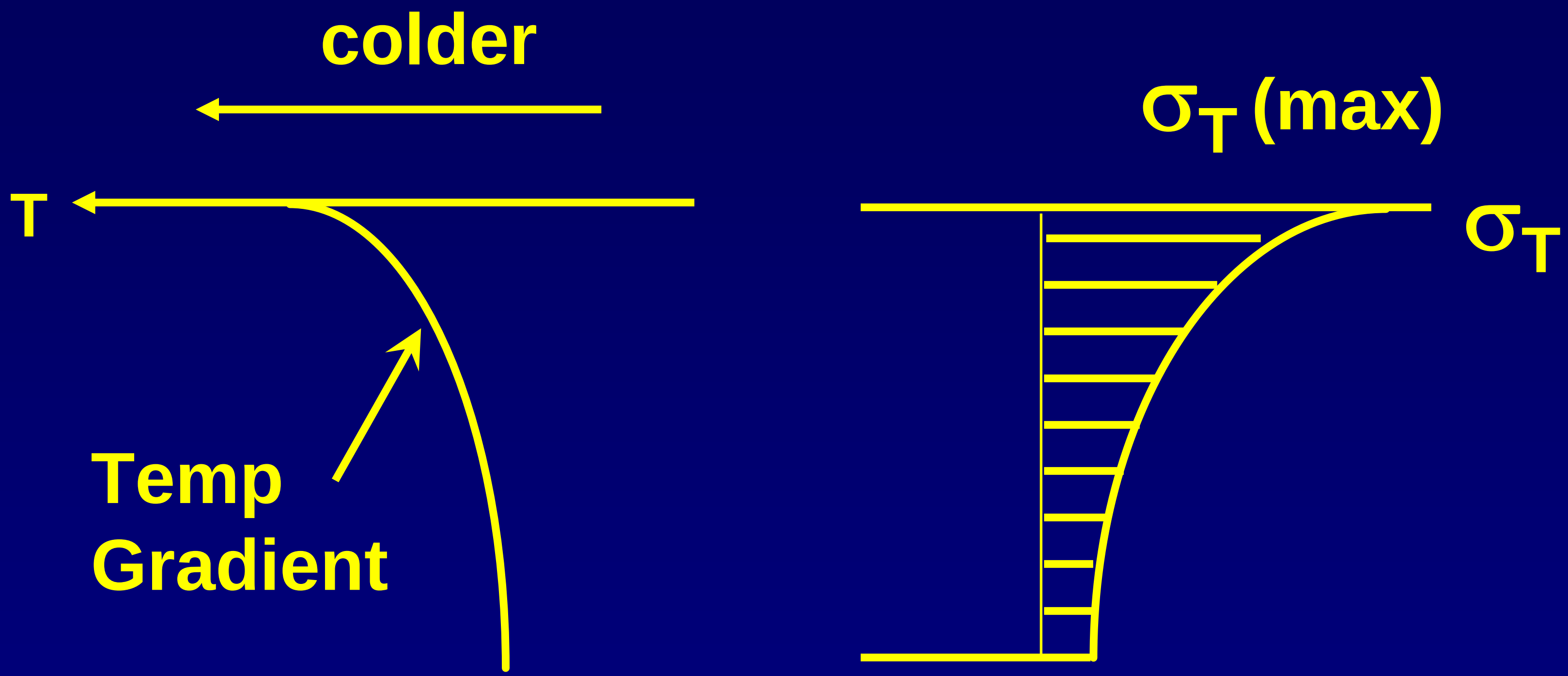


Number of Load Applications

Low Temp Cracking - Mechanism

- volumetric contraction as the temp decreases
- unrestrained - shortens
- restrained - internal stresses, cracking
- crack propagates with additional thermal cycles

Mechanism



If σ_T (max) is > tensile strength of asphalt concrete, cracking occurs.

Low-Temp Cracking

- cracking transverse to direction of traffic
- typical crack spacing:
  - 3 to 300 ft

Low Temp Cracking

- Prediction – New Design Guide
  - Based on SHRP developed procedure
- Lab. Testing
  - Dynamic moduli at low temperatures and longer times of loading (obtained from master curve)
  - Indirect tension tests, low *T*

Smoothness
(flexible pavement)

$IRI = IRI_o$ + a(site factor)

+ b(fatigue cracking)

+ c(low temperature cracking)

+ d(rut depth)

Construction Considerations

- Minimum layer thicknesses
  - Granular base/subbase; 6 in. min.
  - CTB; 4in. min. (preferably 6 in. min.)
  - AC; 3 x max. aggregate size min. lift thickness
- Compaction requirements
  - Granular layers
    - e.g., upper 6-12 in. at least 100% Modified AASHTO dry density
  - Subgrade
    - e.g. upper 24 in. 95% Modified AASHTO dry density

Need for Local Calibration and Validation

- Calibration and validation of the MEPDG by the developers based on results of the Long Term Pavement Performance (LTPP) Program.
- The correction factors which are included in the performance equations for both the rigid and flexible design methodologies must thus be modified to reflect local conditions for individual states

Need for Local Calibration and Validation

- This process includes considerations of local conditions and practices:
  - Environment
  - Traffic
  - Materials
  - Construction practices
  - Maintenance and rehabilitation practices

Need for Local Calibration and Validation

- This necessity for local calibration was emphasized by the developers of the MEPDG in the NCHRP 1-37A Report; e.g., Section 3.3.6.1 for flexible pavements and 3.4.9.1 for rigid pavements.
- The presentations to follow will provide guides for this to be accomplished.