



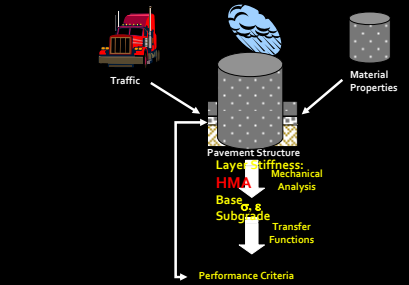
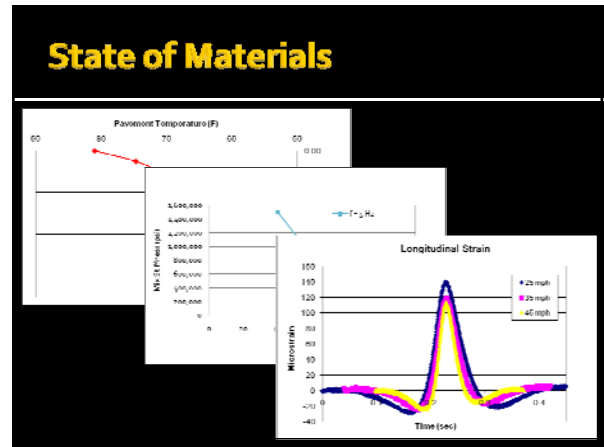
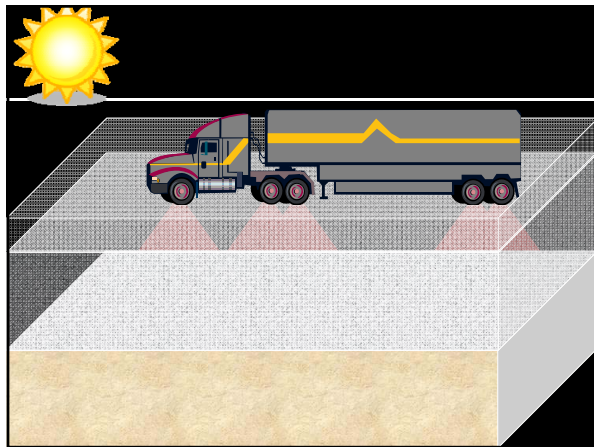
A Practical Look at E*

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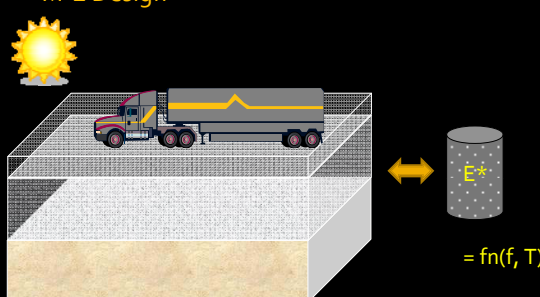
Importance of E*

- M-E Design

Importance of E*

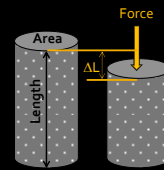
- M-E Design



$E^* = fn(f, T)$

E* Defined

- Purely Elastic Material:



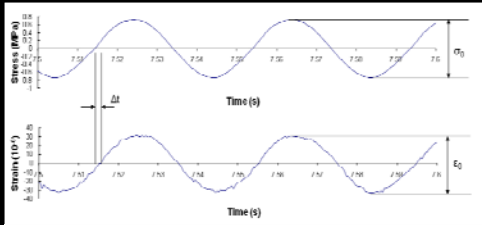
Stress: $\sigma = \frac{\text{Force}}{\text{Area}}$

Strain: $\epsilon = \frac{\text{Deformation}(\Delta L)}{\text{Unloaded Dimension}}$

Modulus: $E = \frac{\sigma}{\epsilon}$

E* Defined

- Visco-Elastic Material (HMA):



Modulus: $E^* = \frac{\sigma_0}{\epsilon_0}$ Phase angle: $\phi = 2\pi f \Delta t$

How?

- Models
 - Van der Poel Model (1954)
 - Shell Nomograph (1977)
 - NCHRP 1-37A (1999)
 - $E^* = \text{fn}(p_{200r}, P_{4r}, P_{38r}, P_{34r}, V_{ar}, V_{beffr}, f, \eta)$
 - Hirsch Model (2003)
 - $E^* = \text{fn}(VFA, VMA, G^*)$
 - NCHRP 1-40D (2005)
 - $E^* = \text{fn}(p_{200r}, P_{4r}, P_{38r}, P_{34r}, V_{ar}, V_{beffr}, G^*)$

How?

- Laboratory
 - AMPT (a.k.a. SPT)



E* in the Lab

- Min. of 2 specimens
- Target Air Voids = 7% (± 0.5)
 - AASHTO T 269
- Aging
 - AASHTO R30
 - Short-term
 - Long-term

E* in the Lab

- AASHTO Spec.
 - AASHTO PP 60-09
 - Specimen Prep using SGC
 - 100 mm in diameter
 - 150 mm in height
 - End flatness ≤ 0.5 mm
 - End perpendicularity ≤ 1.0 mm



Sample Prep



Sample Prep



Testing

Sample Conditioning

| Specimen Temp (°C) | Time from Room Temp 25°C (hrs) | Time from Previous Test Temp (hrs) |
|--------------------|--------------------------------|------------------------------------|
| -10 | Overnight | Overnight |
| 4 | Overnight | 4 or Overnight |
| 21 | 1 | 3 |
| 37 | 2 | 2 |
| 54 | 3 | 1 |

- Starting at lowest temp
 - Beginning with highest frequency

Testing

- ASTM Specification
 - ASTM D3497-79 (2003)
 - T = 41, 77, 104 °F
 - f = 1, 4, 16 Hz
- AASHTO Specifications
 - AASHTO TP 62-07
 - T = 14, 40, 70, 100, 130 °F (-10, 4.4, 21.1, 37.8, 54 °C)
 - f = 0.1, 0.5, 1.0, 5, 10, 25 Hz

Testing

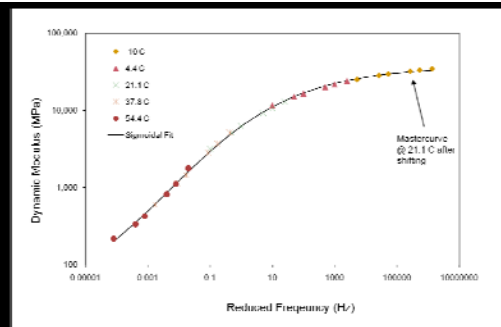
- AASHTO spec. (cont'd)
 - AASHTO TP 79-09
 - For AMPT
 - AASHTO PP 61-09
 - Recommendations on T and f for binder grades

| PG 58-XX and softer | | PG 64-XX and PG 70-XX | | PG 76-XX and stiffer | |
|---------------------|---------------------|-----------------------|---------------------|----------------------|---------------------|
| Temp (°C) | f (Hz) | Temp (°C) | f (Hz) | Temp (°C) | f (Hz) |
| 4 | 10, 1, 0.1 | 4 | 10, 1, 0.1 | 4 | 10, 1, 0.1 |
| 20 | 10, 1, 0.1 | 20 | 10, 1, 0.1 | 20 | 10, 1, 0.1 |
| 35 | 10, 1, 0.1 and 0.01 | 40 | 10, 1, 0.1 and 0.01 | 45 | 10, 1, 0.1 and 0.01 |

Results

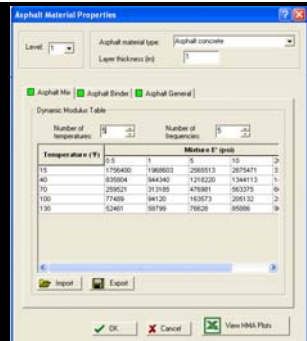
- Check Data Quality
 - Tolerances – AASHTO TP 62-07
 - Updated statistics /guidance – AASHTO TP 79-09
- Develop Master Curve
 - AASHTO TP 61-09
 - Hirsch Model
 - Microsoft Excel – solver function

Results



Use in Design

- MEPDG
 - Master Curve
 - Level 1
 - Lab Data
 - Level 2, 3
 - NCHRP 1-37A model
 - viscosity
 - NCHRP 1-40D model
 - G*



Use in Design

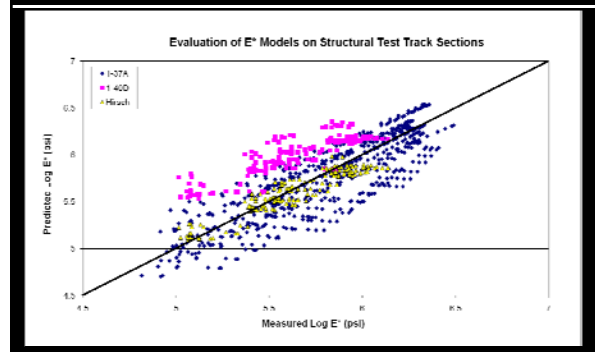
- MEPDG Level 1

| Temp (°F) | Mixture E* and δ | | | | Binder G* δ, 1-59 Hz |
|-----------|------------------|------|-------|-------|-------------------------|
| | 0.1 Hz | 1 Hz | 10 Hz | 25 Hz | |
| 10 | X | X | X | X | |
| 40 | X | X | X | X | X |
| 55 | | | | | X |
| 70 | X | X | X | X | X |
| 85 | | | | | X |
| 100 | X | X | X | X | X |
| 115 | | | | | X |
| 130 | X | X | X | X | X |

Use in Design

- No AMPT?
 - FHWA Pooled Fund Project
 - \$60-75k
 - Utilize Models
 - Hirsch
 - NCHRP 1-37A
 - NCHRP 1-40D
 - Requires G*

Model Comparison



Summary

- E* necessary for M-E Design
- Obtained in Lab
 - AASHTO TP 62-07 and TP 79-09
 - Meets requirements for MEPDG Level 1
 - FHWA Pooled Fund Project
- Obtained thru Models
 - MEPDG Levels 2 and 3: 1-37A/ 1-40D
 - Hirsch Model most accurate

Questions?

