

# Modeling of Hot Mix Asphalt

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Measuring and modeling for  
APT:  
Introduction and objectives



## Outline

- **Mechanistic Approach for Modeling Asphalt Pavements.**
- Material Properties in a Mechanistic Model
- Experimental Methods for Determining Material Properties.
- Role of Accelerated Pavement Testing.
- Future Directions.

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# The Continuum of Development

*Actual current practice?*

*State-of-the-art*



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## Material Properties

- Aggregate shape
- Anisotropy
- Adhesive and Cohesive bond strengths
- Healing
- Binder rheology

## Pavement Structure

- Thickness
- Sub grade type

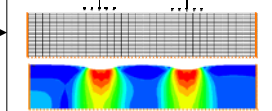
## Environmental Factors

- Temperature
- Humidity differential
- Rainfall

## Loading Conditions

- Type of loading
- Tire pavement interaction

## FEM Modeling



Calibration (minimize shift factor dependency)

Prediction of material distress

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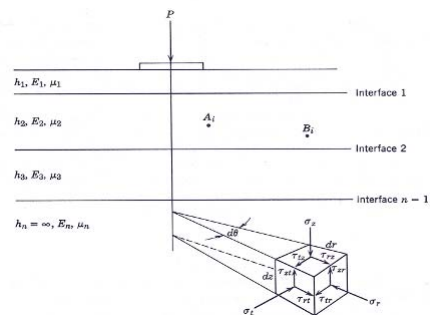
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## Elastic Models

- No failure mechanisms.
- Predicts distresses using empirical “transfer functions”.
- Relates distresses to stiffness.

$$N_f = \beta_3 k_1 \varepsilon_t^{-k_2} E^{-k_3}$$



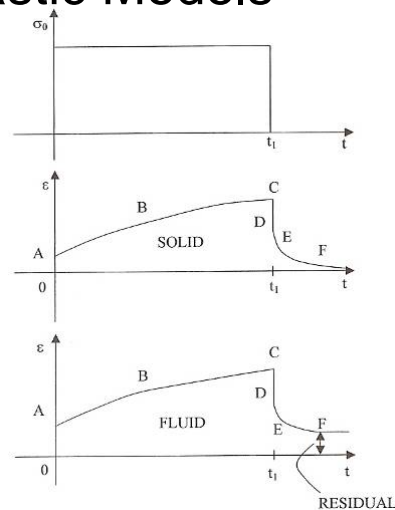
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## Classical Viscoelastic Models

- Temperature and time dependency.
- Can be formulated to provide plastic deformation.
- No failure mechanisms.

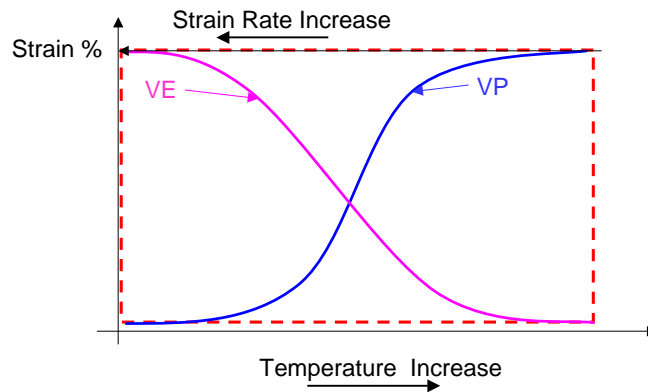


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## Viscoelastic-Viscoplastic Models



- Recoverable and irrecoverable responses.
- Can account for hardening, damage, confinement, and other important mechanisms.

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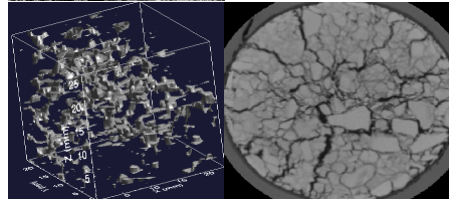
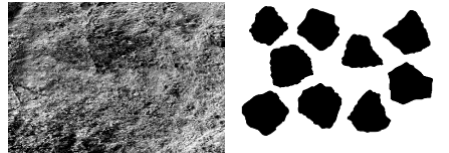
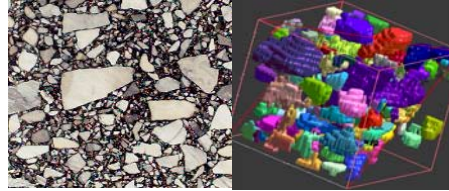
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## Model Material Properties

- Model accounts for:

- Rate.
- Temperature.
- Anisotropy.
- Heterogeneity.
- Dilation/Contraction.
- Confining pressure.
- Damage.
- Stress state.



- Model predicts:

- Permanent deformation.
- Fatigue cracking.
- Low temperature cracking.

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## Nonlinear Viscoelastic Model

- Shapery nonlinear Model:

$$\varepsilon(t) = g_o D_o \bar{\sigma} + g_1 \int_0^t \Delta D(\psi - \psi') \frac{dg_2 \bar{\sigma}}{d\tau} d\tau$$

$$\psi = \int_0^t dt / a_{\bar{\sigma}}[\bar{\sigma}(t')] \quad (a_{\bar{\sigma}} > 0)$$

$$\psi' = \psi(\tau) = \int_0^{\tau} dt' / a_{\bar{\sigma}}[\bar{\sigma}(t')]$$

$\psi$  : is the reduced time (effective time)

- For the case of constant load it reduces to:

$$D_n = \frac{\varepsilon(t)}{\bar{\sigma}} = g_o D_o + g_1 g_2 \Delta D \left( \frac{t}{a_{\bar{\sigma}}} \right)$$

$D_n$  : Nonlinear Creep Compliance

$g_o$  : Nonlinear instantaneous elastic compliance

$g_1$  : Transient compliance nonlinearity effect parameter

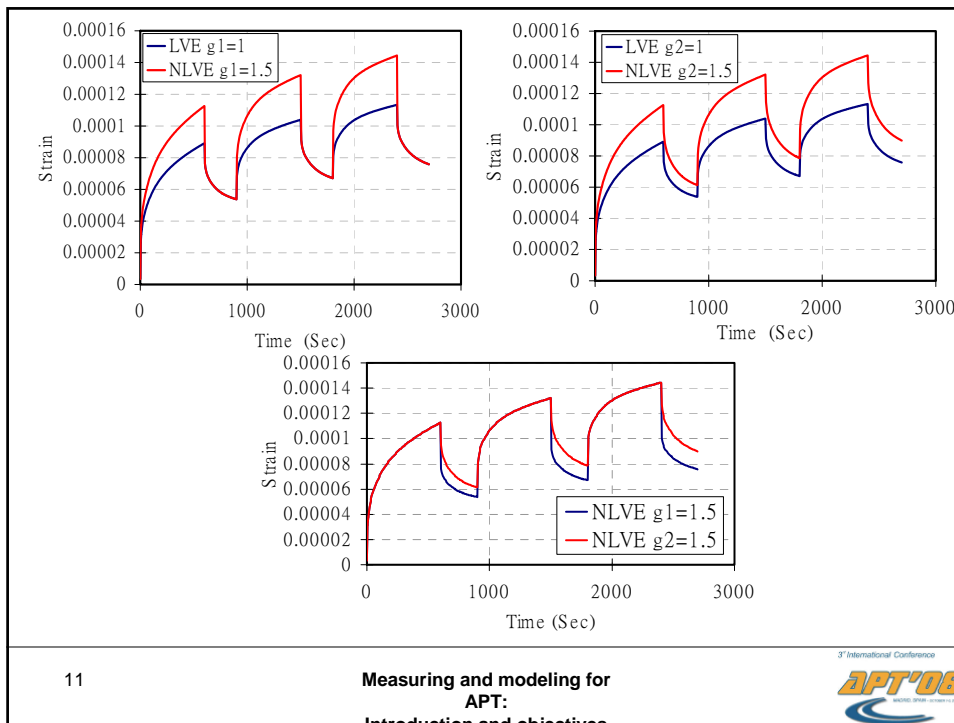
$g_2$  : Load rate effect parameter

$a_{\bar{\sigma}}$  : Time scaling factor

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## Viscoplastic Model

$$\dot{\epsilon}_{ij}^{vp} = \Gamma \cdot \langle \phi(f) \rangle \cdot \frac{\partial g}{\partial \sigma_{ij}}$$

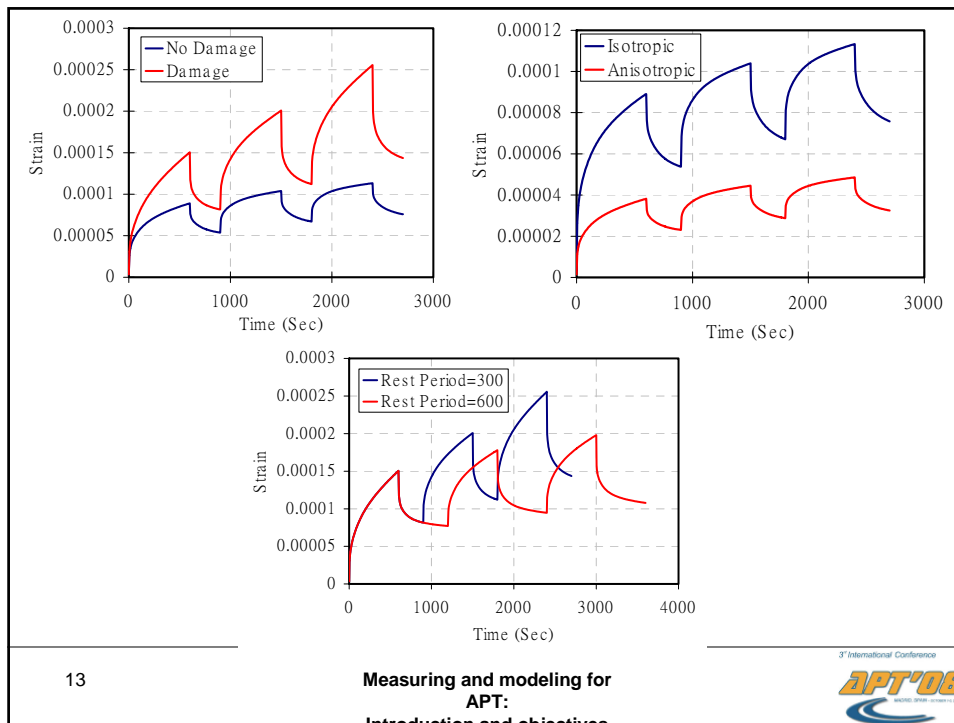
$$f = F(I_1, J_2, J_3, \Delta, \xi) - \kappa$$

$$\langle \phi(f) \rangle = \begin{cases} 0 & f \leq 0 \\ f^N & f > 0 \end{cases}$$

- $I_1$  1<sup>st</sup> invariant of the stress tensor (**confinement**)
- $J_2$  2<sup>nd</sup> invariant of deviatoric stress tensor (**shear stresses**)
- $J_3$  3<sup>rd</sup> Invariant of deviatoric stress tensor (**stress state**)
- $k$  Hardening parameter
- $\Delta$  Anisotropy Parameter
- $\xi$  Damage Parameter

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ASPHALT PAVEMENT TESTING

# Experimental Methods

- Well defined boundary conditions in the test.
- Measuring three dimensional response.
- These conditions do not apply for APT tests!

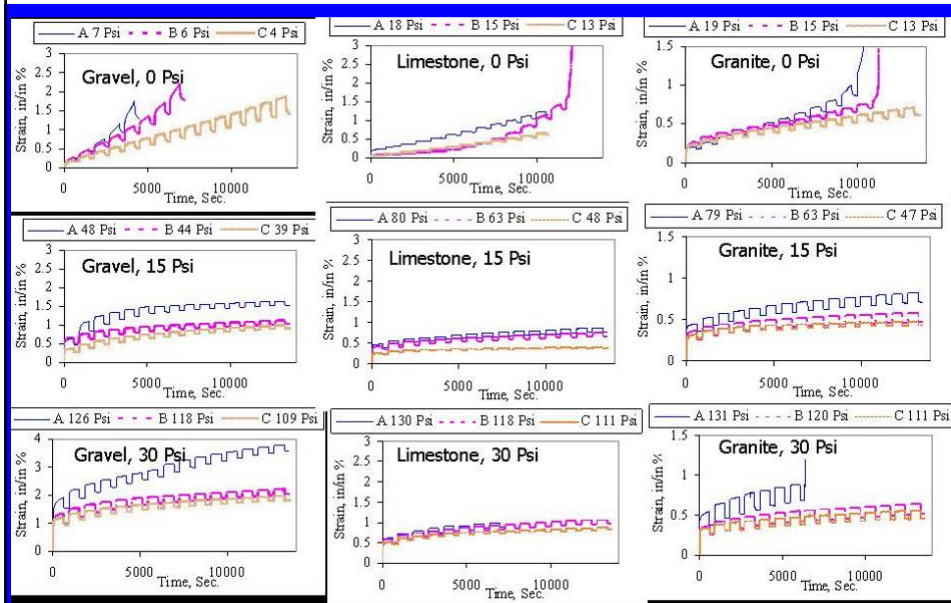


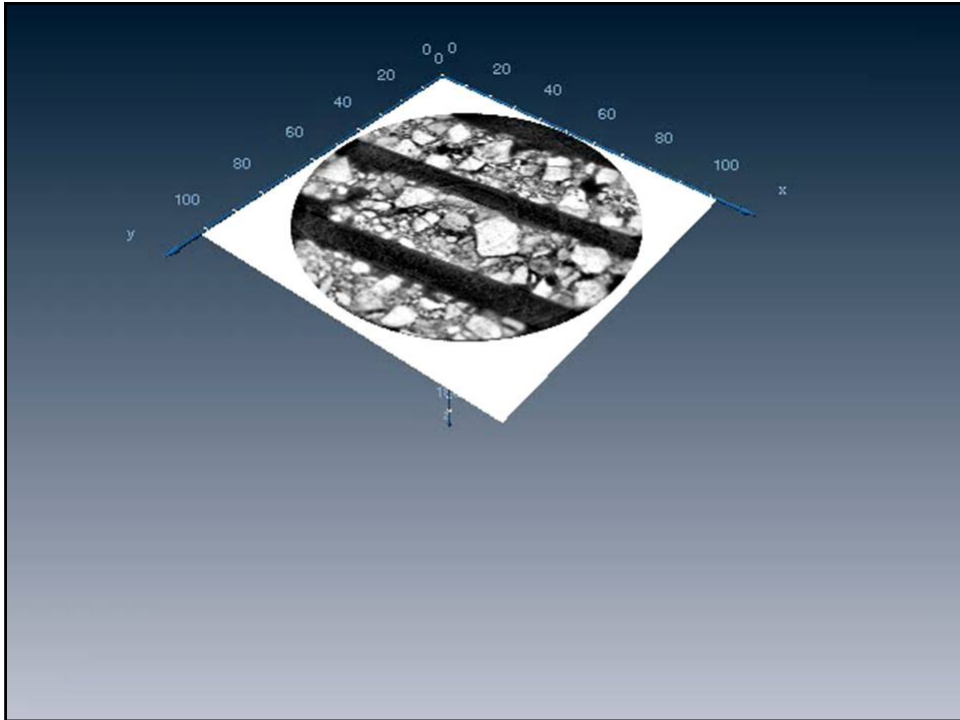
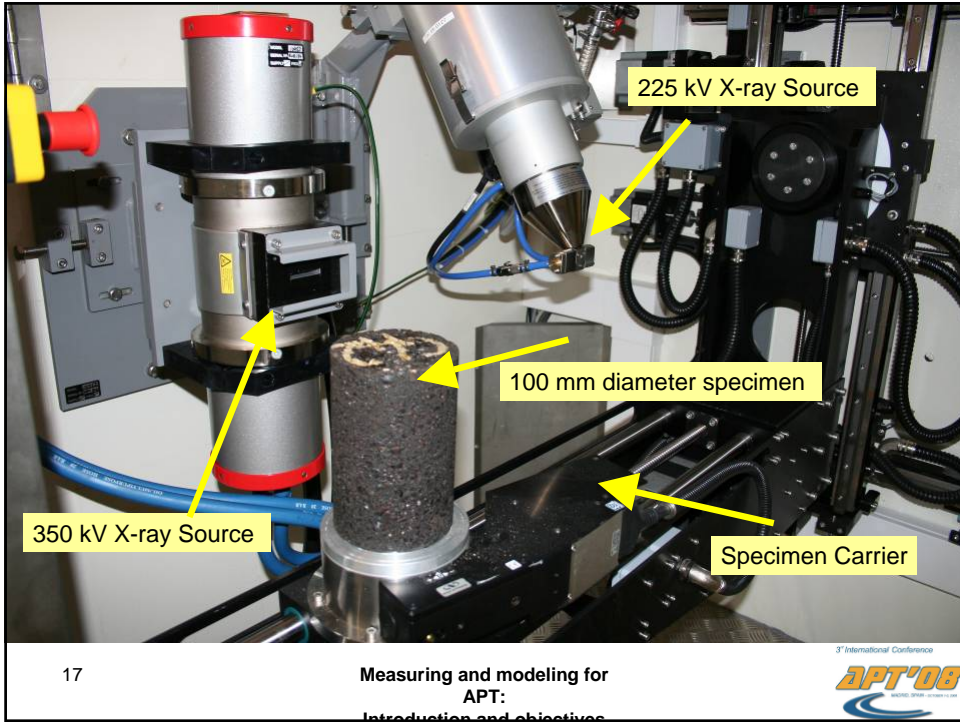
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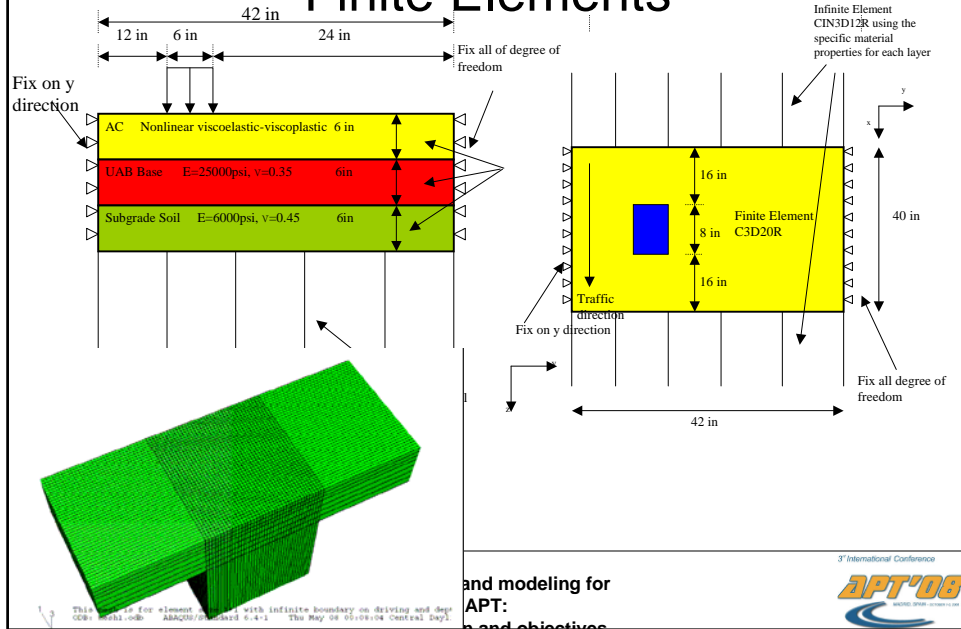


# Repeated Creep-Recovery Tests

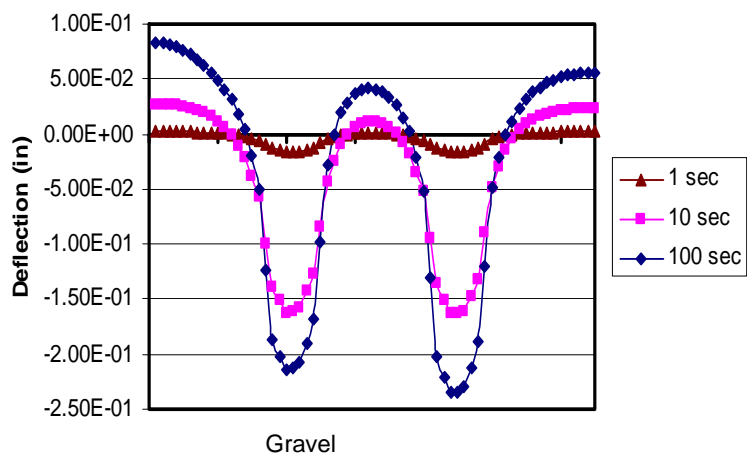




# Viscoelastic-Viscoplastic Model in Finite Elements

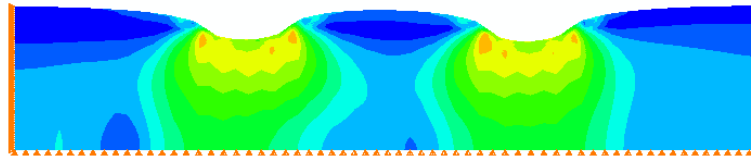


# Viscoelastic-Viscoplastic Model Results

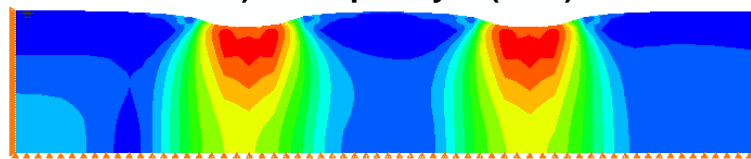


## Viscoelastic-Viscoplastic Model Results

S, Mises  
(Ave. Crit.: 75%)  
+7.985e+01  
+7.321e+01  
+6.657e+01  
+5.993e+01  
+5.330e+01  
+4.666e+01  
+4.002e+01  
+3.338e+01  
+2.674e+01  
+2.010e+01  
+1.346e+01  
+6.826e+00



a) Isotropic layer ( $\Delta = 0$ )



b) Anisotropic layer ( $\Delta = 30$  percent)

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## Role of APT

- Boundary conditions in APT are complex and cannot be used to determine mechanistic model's parameters.
- APT results can be used to verify models predictions by comparing model response to pavement response (strain, deflections, distresses).
- The APT-verified model should be calibrated against field data because of differences between APT and actual pavement conditions.

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## Future Directions

- Challenges for mechanistic models:
  - Extensive experimental program (rate, temp., confinement, stress path..).
  - Long computational time to account for repeated loading. Most available models apply a few cycles.
  - Material variability.
  - Material heterogeneity.

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## Future Directions

- Opportunities:
  - Use APT to develop a database or catalog of material properties and model parameters.
    - Test variety of mixtures
    - Develop correlations between model's parameters and material properties.
    - Use these correlations in determining model's parameters and void future testing for parameters.
  - Use APT to account for realistic loading conditions in verifying mechanistic models using APT. This is a middle step before complete verification using field sections.

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