Characterizing Nonlinear Viscoelastic Response of Asphaltic Materials

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Background

Computational models of asphalt composites are increasingly being used to:

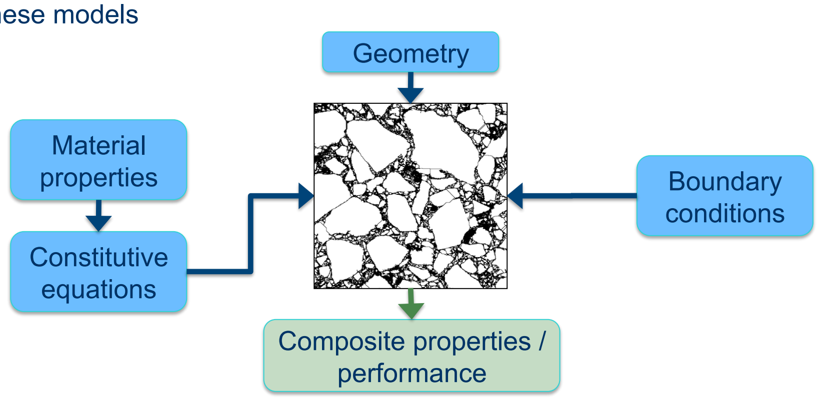
•investigate relationship between constituent and mixture properties

•predict damage evolution in composites

•optimize mix design using virtual testing

Background

While these micromechanical computational models may vary in **length scale** (e.g. mastic, mortar, or mixture) or **technique** (e.g. FEM or DEM), there are some elements that are common to most of these models



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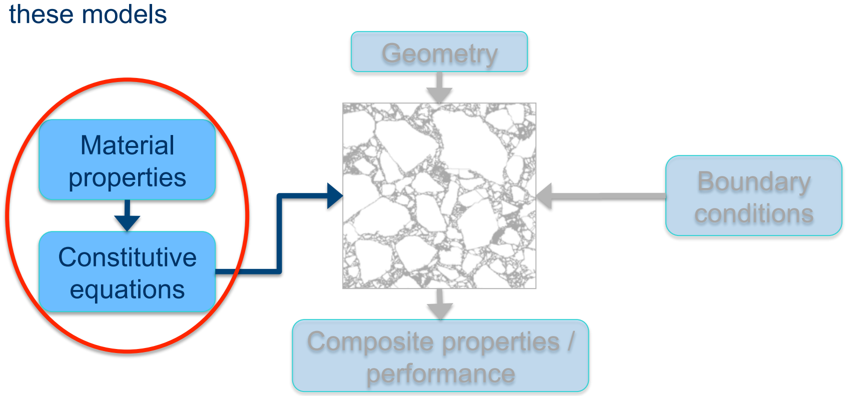

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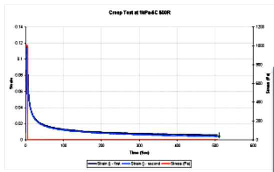
Objectives

Creep-recovery / Time sweep / Amplitude sweep

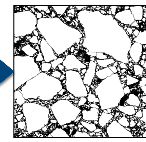


Obtain model parameters

Power Law

Prony Series

Input to computational model



✔ Performance prediction

✔ Material characterization

Typical approach to characterize binder / matrix

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Objectives

Investigate linear and non-linear viscoelastic behavior of binders in typical torsion shear tests with emphasis on:

- sources of non-linear viscoelastic response
- constitutive equations that can be used to model this response

Tests

- Creep and Recovery at different stress levels
- Cyclic Loading (Stress Amplitude Sweep)
- Cyclic Loading (Time Sweep at Different Stress Amplitudes)

Test

Materials

- PG 82-22
- PG 76-22

Tests

- Creep and Recovery at different stress levels:
  - Creep (loading): 5 Sec.
  - Recovery (unloading): 1000 Sec.
  - Stress level: Ranged from 100 Pa - 60 kPa
- Cyclic Loading (Stress Amplitude Sweep):
  - Freq.: 0.1 Hz
  - Amplitude Range: 1kPa – 48 kPa
- Cyclic Loading (Time Sweep at Different Stress Amplitude):
  - Freq.: 0.1 Hz
  - Amplitude Range: 1kPa – 48 kPa

Test

Selecting the stress levels

• Several studies have investigated local stresses within the mixture

• Binder can experience stresses that are approximately 80 to 100 times the far field stresses

• The applied stresses therefore reflect localized stresses when the applied far-field stresses are of the order of 1.5 kPa (30 psi)

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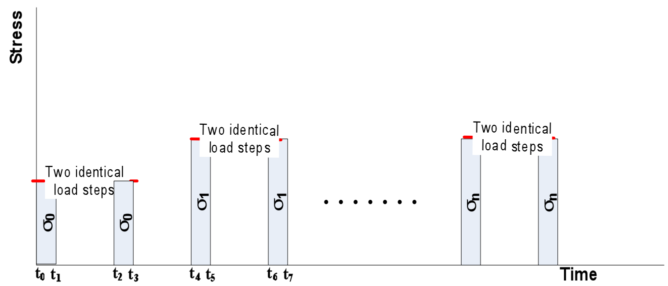
Creep-Recovery



Loading = 5 seconds
Unloading = 1000 seconds

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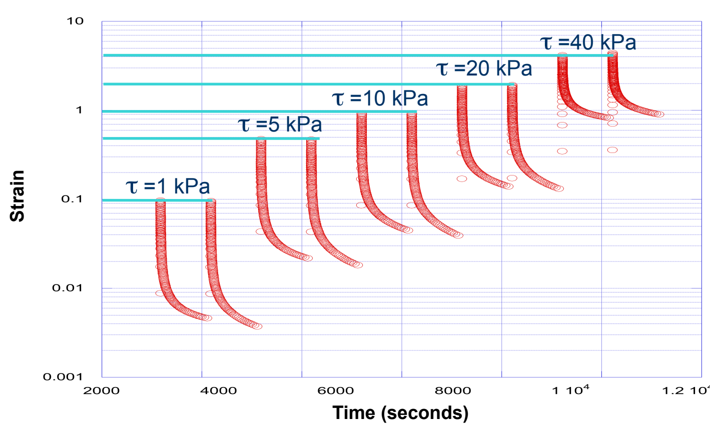
Creep-Recovery



The response was mostly linear even at higher stress levels

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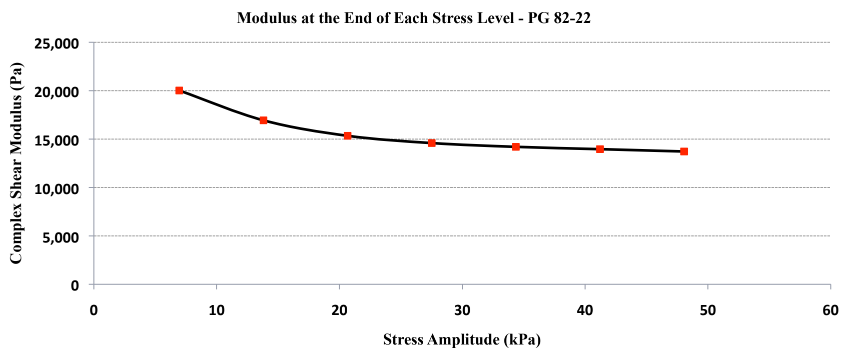
Amplitude Sweep



Two possible sources of non-linearity were investigated

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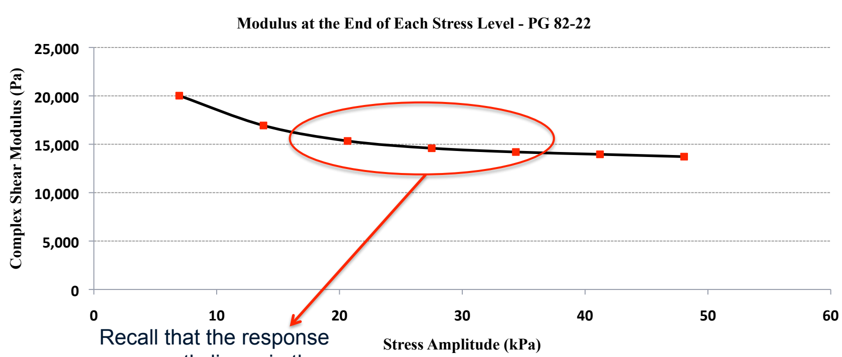
Amplitude Sweep



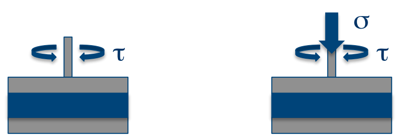
Recall that the response was mostly linear in the creep-recovery test

Two possible sources of non-linearity were investigated

Analysis

Two possible sources of non-linearity were investigated

1. Inherent material non-linearity – Modulus is a function of stress (e.g. $E = fn(\sigma)$ or $G = fn(\tau)$)
2. Interaction non-linearity – Modulus changes due to interaction of shear and normal stresses



Why interaction non-linearity in a shear test?

An important attribute from torsion shear tests is the normal stress developed in the specimen during the test

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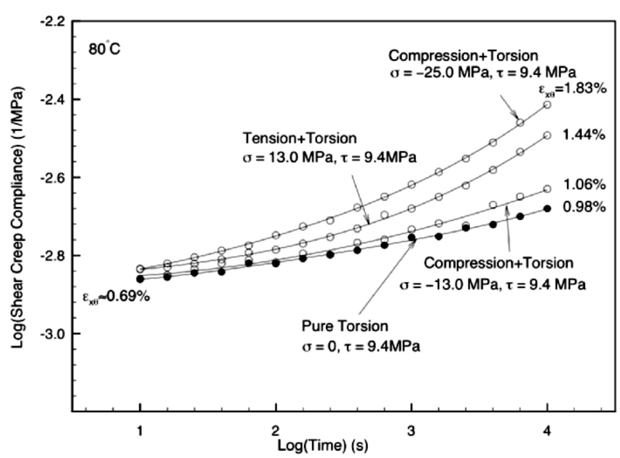
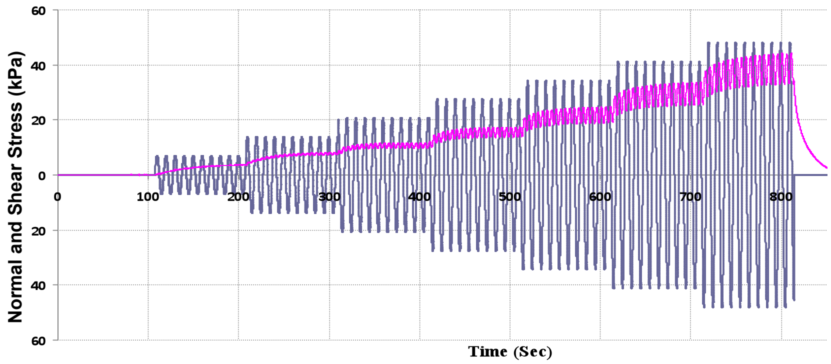
Analysis

Interaction non-linearity



Ref: Knauss et al.

Analysis



Normal force developed in a typical amplitude sweep test

The normal force is due to the constrained geometry and the tendency of the material to expand due to (i) high strains and (ii) inherent tendency to dilate

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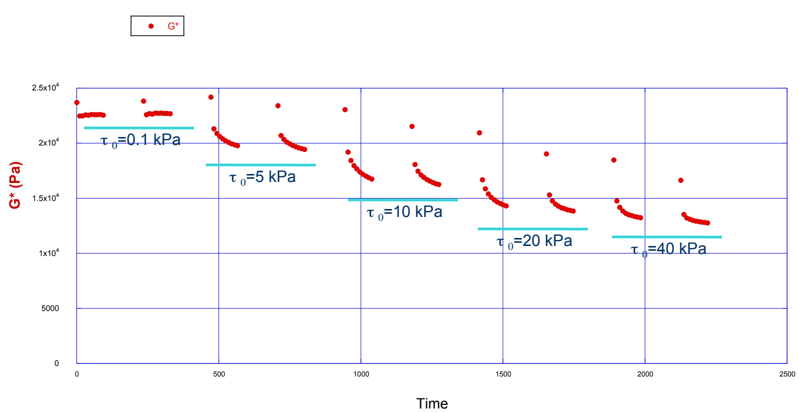
Analysis



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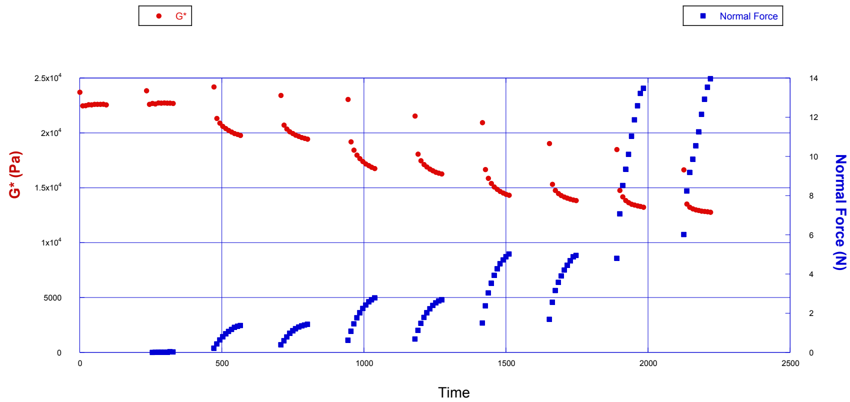
Analysis



The presence of high normal stresses implies the true shear stresses in the specimen have to be corrected before any analysis

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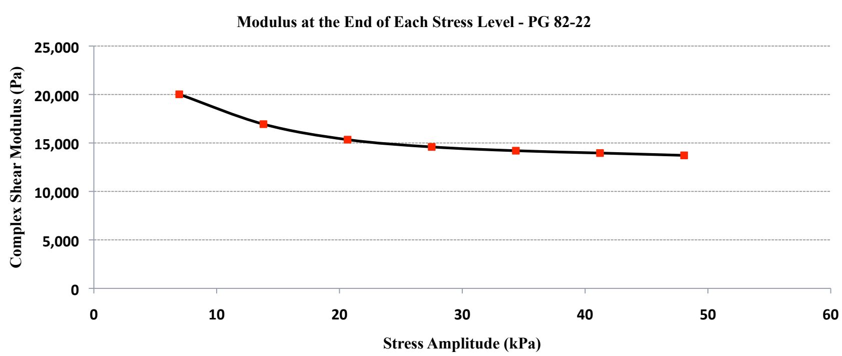
Analysis



G vs. stress amplitude*

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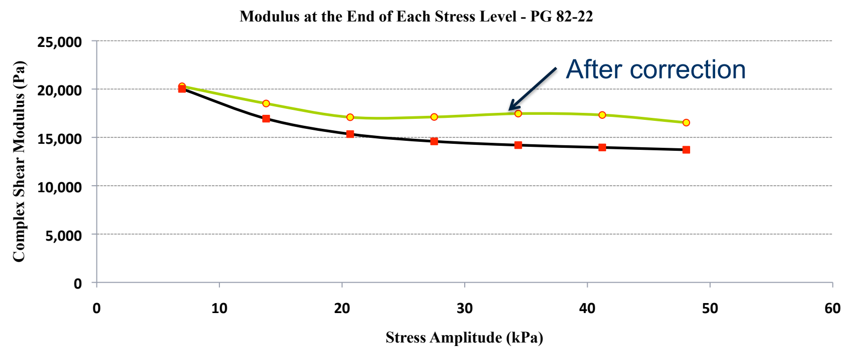
Analysis



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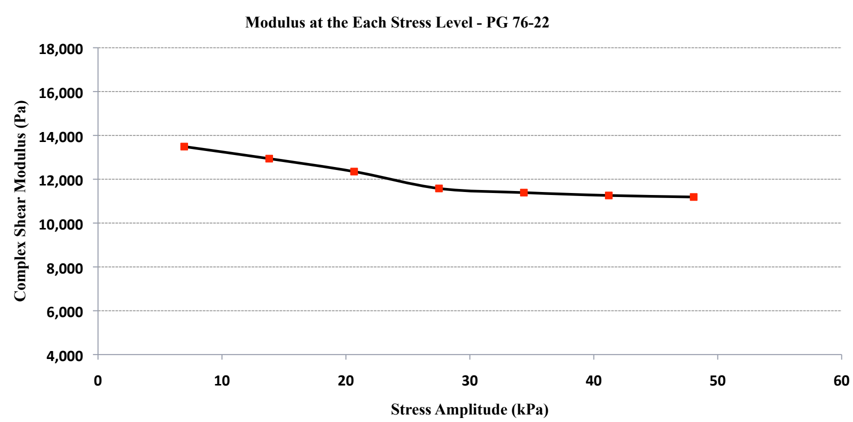
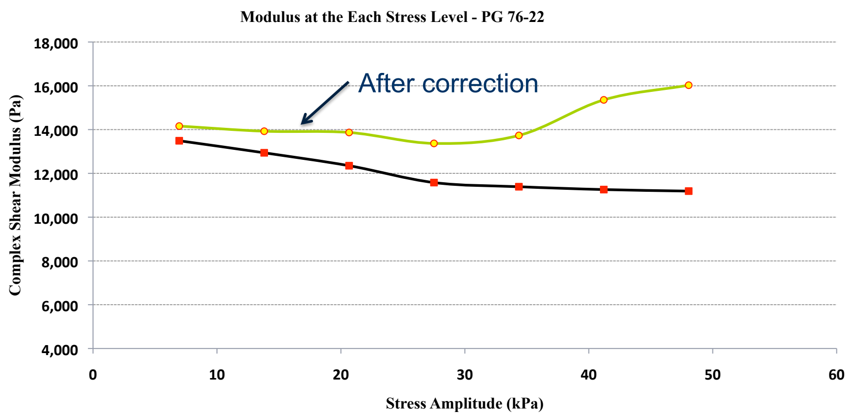


G vs. stress amplitude*

Analysis



G vs. stress amplitude*

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Constitutive equation

We need to incorporate the following:

1. The dilatation or first normal stress when the matrix is subjected to shear stresses

   There are models available for this, e.g. Rivlin's model and its variations that describe first normal stress as a function of shear strain rate and shear stress

2. The non-linearity accounting for interaction between the normal and shear stresses

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Constitutive equation

Schapery's non-linear model is well suited for this case

$$\varepsilon(t,\sigma) = D_0\sigma(t)H(t) + g_1\int_{0^-}^{t}\tilde{D}(t-\tau)\left\{\frac{d[\sigma(\tau)H(\tau)]}{d\tau}\right\}d\tau$$

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Constitutive equation

Schapery's non-linear model is well suited for this case

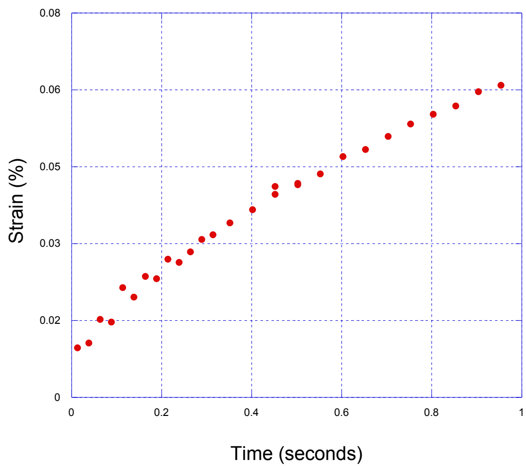
$$\varepsilon(t,\sigma) = \underline{g_0}D_0\sigma(t)H(t) + \underline{g_1}\int_{0^-}^{t}\tilde{D}(\underline{\psi-\psi'})\left\{\frac{d[\underline{g_2}\cdot\sigma(\tau)H(\tau)]}{d\tau}\right\}d\tau$$

g_i's are material parameters that are dependent on the **octahedral shear stress**

Pure dependence on octahedral shear stress and path independence is currently being verified

Constitutive equation

Calibration



Step 1
Linear viscoelastic properties from creep test (power law)

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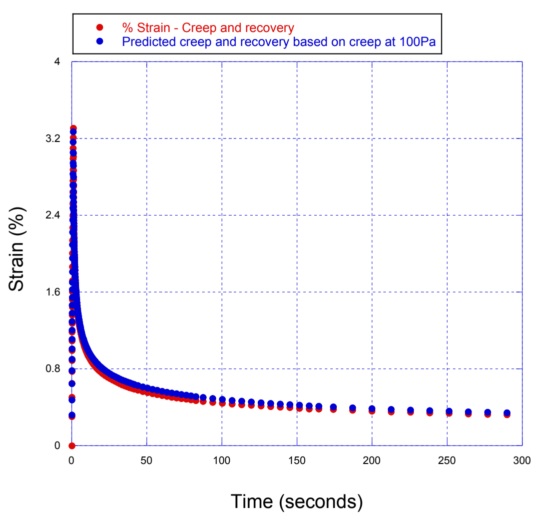
Constitutive equation

Calibration



Step 2
Linearity was verified by using superposition and comparing results to creep-recovery at higher stress levels

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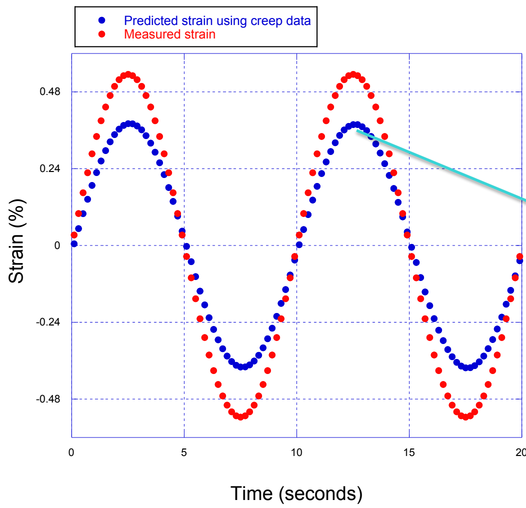
Constitutive equation

Calibration



Step 3
Superposition was used with the power law parameters to compare response under dynamic loading

Predicted dynamic response using creep recovery parameters

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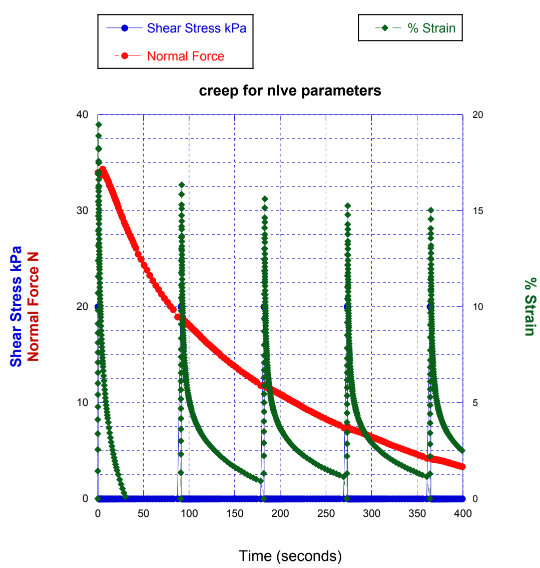
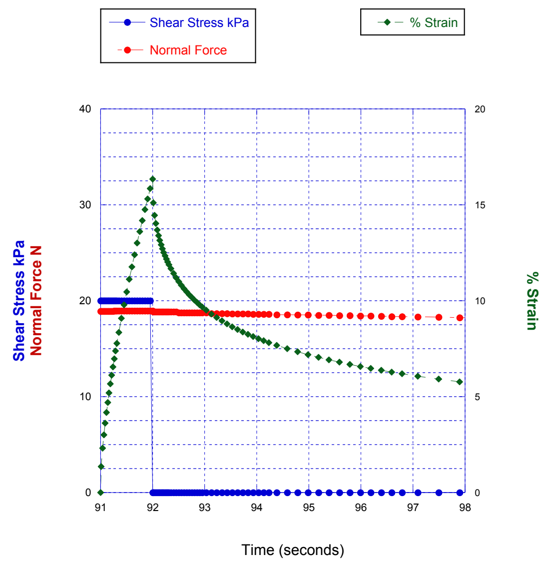
Constitutive equation



Step 4
Non-linear parameters were obtained using creep-recovery response at different levels of interaction

Constitutive equation



Step 4
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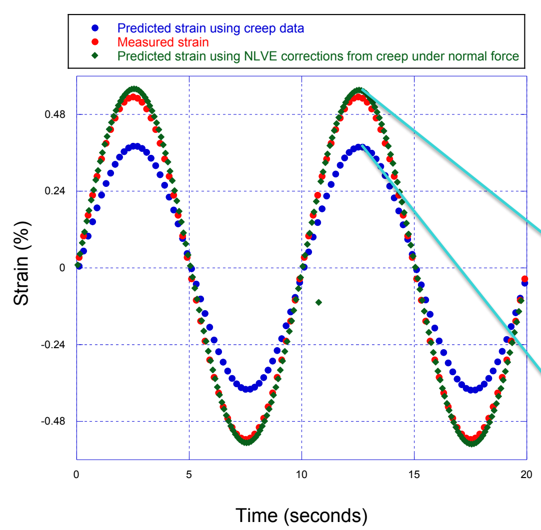
Constitutive equation

(Partial) Validation



Step 5
Non-linear parameters were used along with power constants and modified superposition to predict response under dynamic loading

Predicted dynamic response using creep recovery + NLVE parameters

Predicted dynamic response using creep recovery parameters

Conclusions

Constrained geometry in torsion shear testing can result in very high **normal stresses due to high strain and dilatation**

Dilatation is well recognized in asphalt mixtures, but it also exists in asphalt binders (as well as mastic and mortars)

A combination of normal and shear stress results **in interaction nonlinearity** which may increase or decrease stiffness of the binder and give the **impression of damage** (loss in modulus) – *this may be considered while interpreting test results*

Constitutive models are available to account for dilatation and interaction non-linearity (e.g Scahpery's NLVE model) – *this may be important to improve accuracy of computational models*

Thanks!