

Linear Viscoelastic Behavior of Asphalt Binders At Low Temperatures



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Outline

- Background
- Objective
- Approach
 - How?
 - Why?
- Data Collection and Analysis
- Conclusion



Objective

- To Evaluate The Linear Viscoelastic Behavior Of Asphalt Binders At Low Temperatures



Approach—How?

- Apply Different Stress Levels and Study the Effect on Relaxation Modulus
- Apply Different Strain Levels and Study the Effect on Relaxation Modulus
- Apply Different Strain Rates and Study the Effect On Failure Stress/Strain Rate



Mathematically

- Non-Linear Viscoelastic if:
 - Relaxation Modulus (Stiffness)

$$E(T) = f(t, \sigma \text{ or } \varepsilon)$$

- Linear Viscoelastic if:
 - Relaxation Modulus (Stiffness)

$$E(T) = f(t) \text{ only}$$



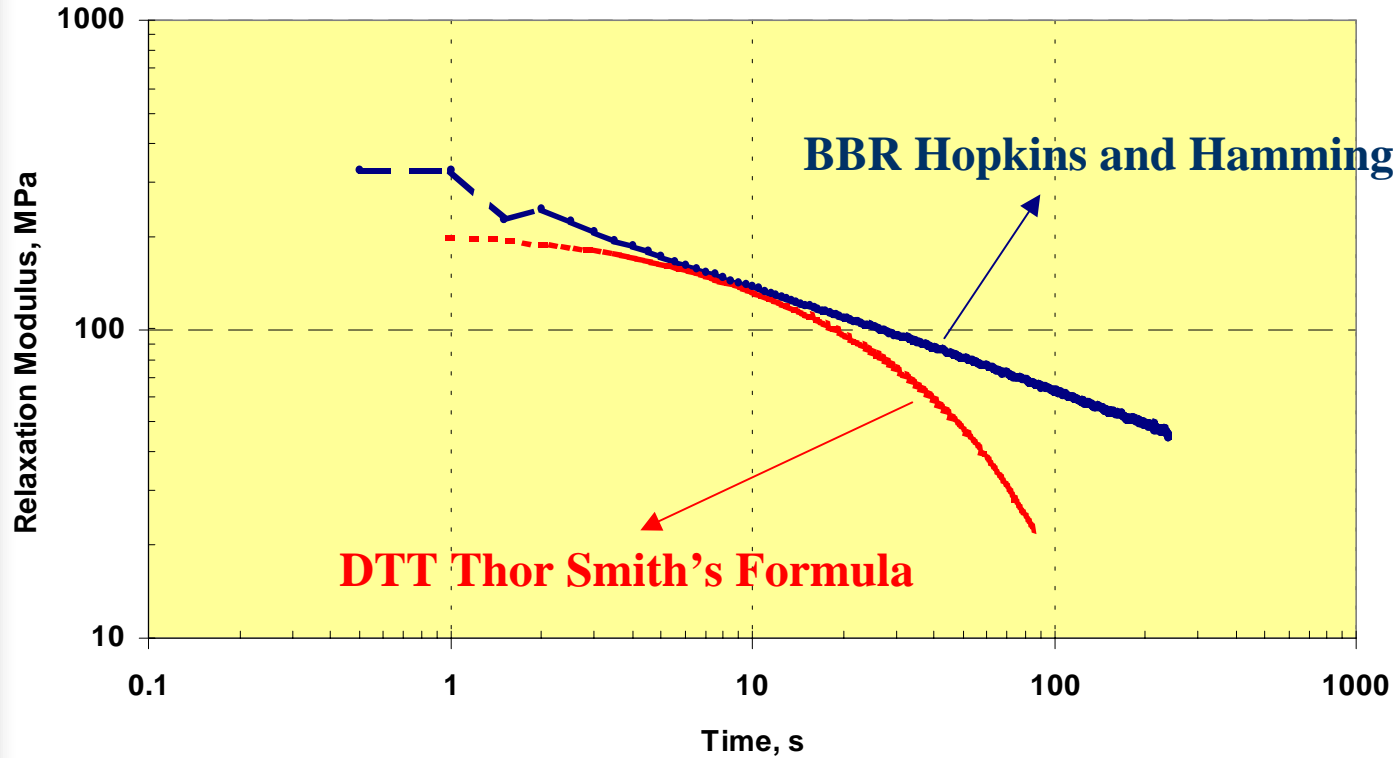
Approach—Why?

- To Explain:

- Why is there a difference between the relaxation modulus calculated using the BBR compliance data and the DTT stress-strain data?
 - As Observed by Marasteanu and Anderson

Problem Statement

PG70-22 Oxd.





Thor Smith's Formula

$$E(t) = F(t) \left[1 + \frac{d \text{Log} F(t)}{d \text{Log}(t)} \right]$$

Where,

$E(t)$ = Relaxation Modulus, MPa

$F(t)$ = Secant Modulus, MPa = Stress/Strain



Hopkins and Hamming

$$\int_0^{\infty} G(t) \cdot J(t - \tau) d\tau = t$$

Numerical Solution Of The Above Convolution Integral



Possible Explanations

- Equipment Differences
- Numerical Errors
- Sample Geometry
- **Non-Linearity**
- Other



Materials and Methods

■ Asphalt Binders

- AI – Five PG 76-22 Binders
- ALF – Styrelf, Novophalt
- LUDO – 581 (BlackMax)
- Lamont – Section 6
- Oxidized PG70-22
- SHRP Core – AAA-1 and AAM-1

■ Test Temperature – PG Low Grade Temp.



Test Methods

■ BBR

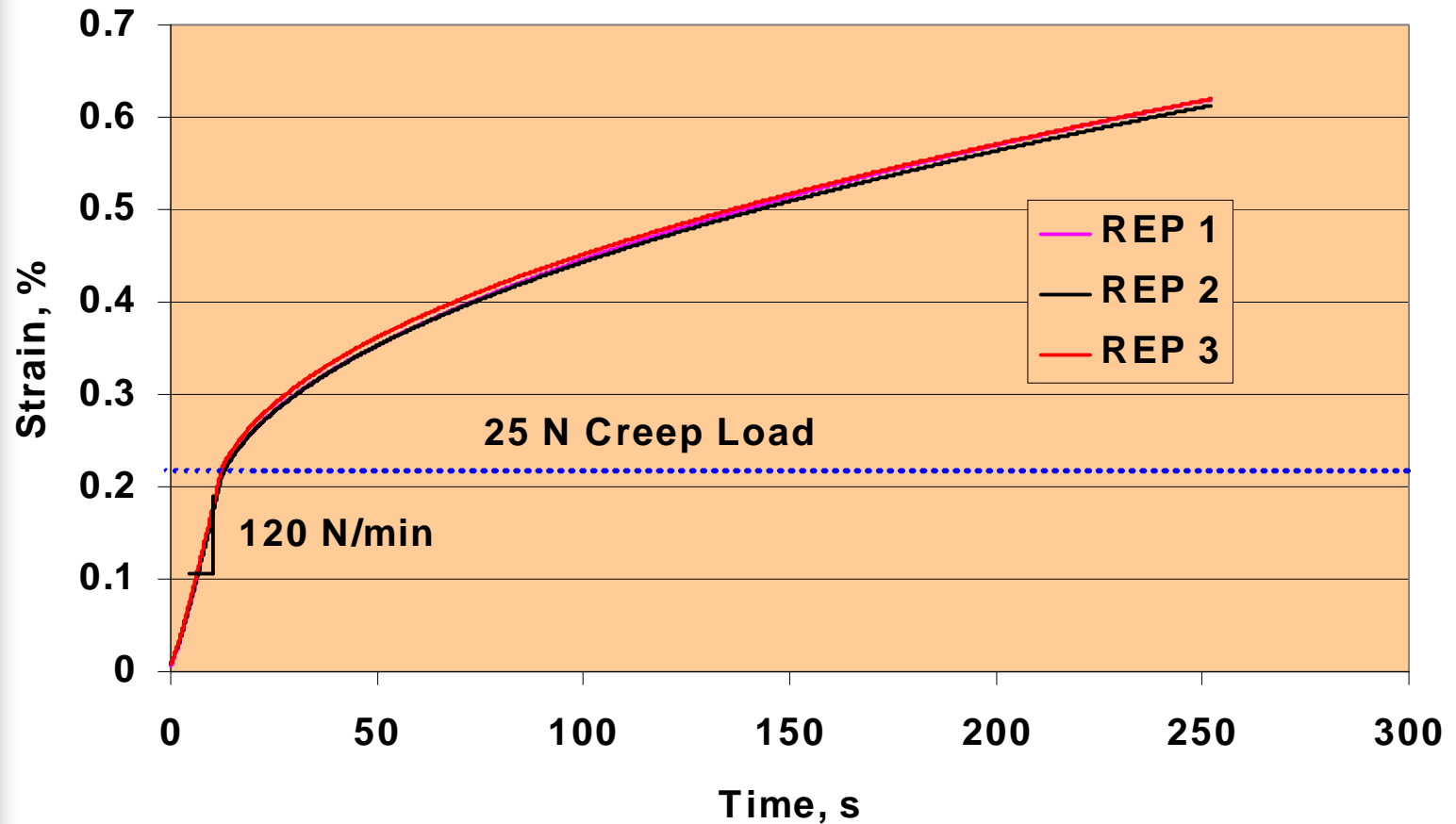
- Creep Compliance Measured
- Relaxation Modulus Computed Using Improved Hopkins and Hamming Method

■ DTT

- Creep Compliance Measured
- Relaxation Modulus Measured
- Failure Data (Stress Strain Curve) Measured
- Relaxation Modulus Computed Using Thor Smith's Formula

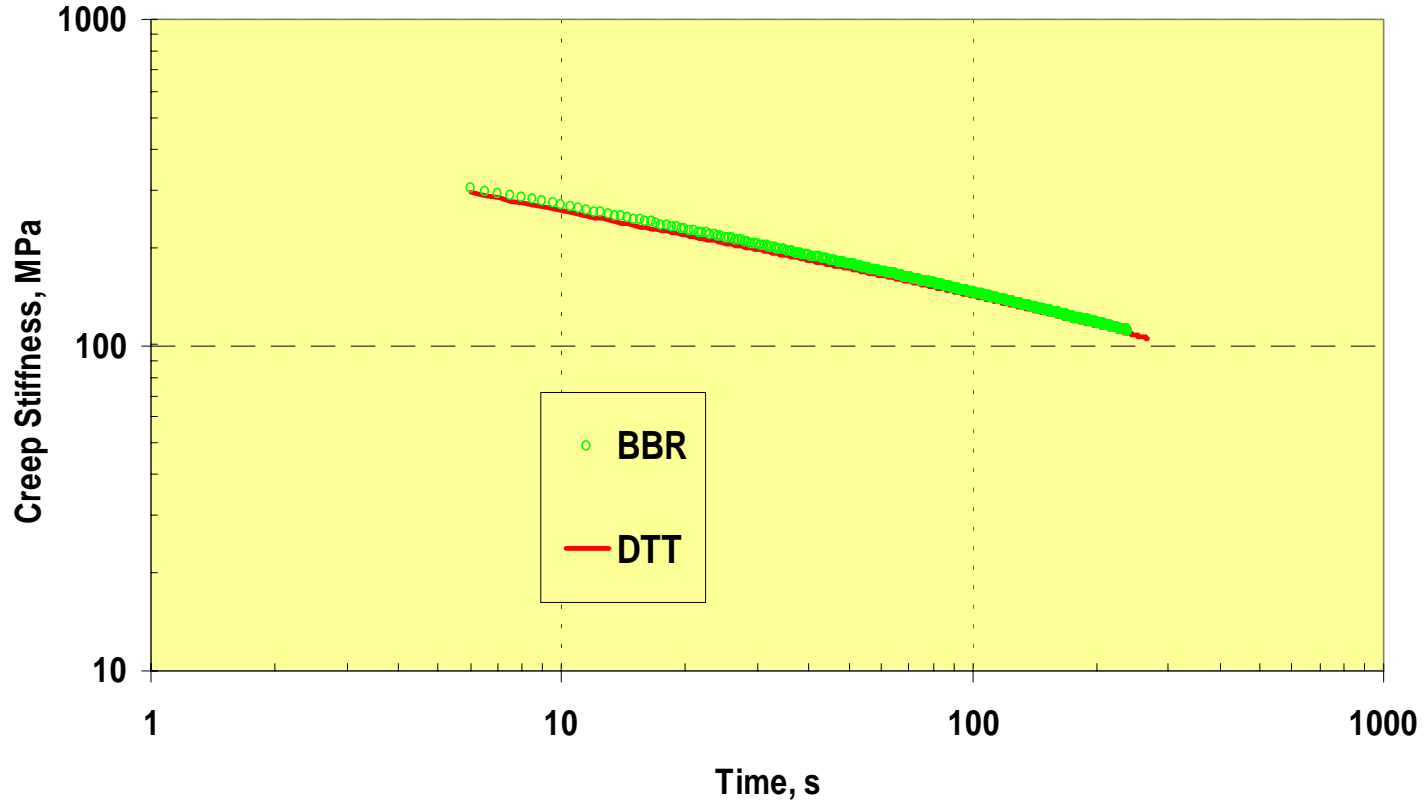
Typical BBR with DTT - Creep

BBR with DTT



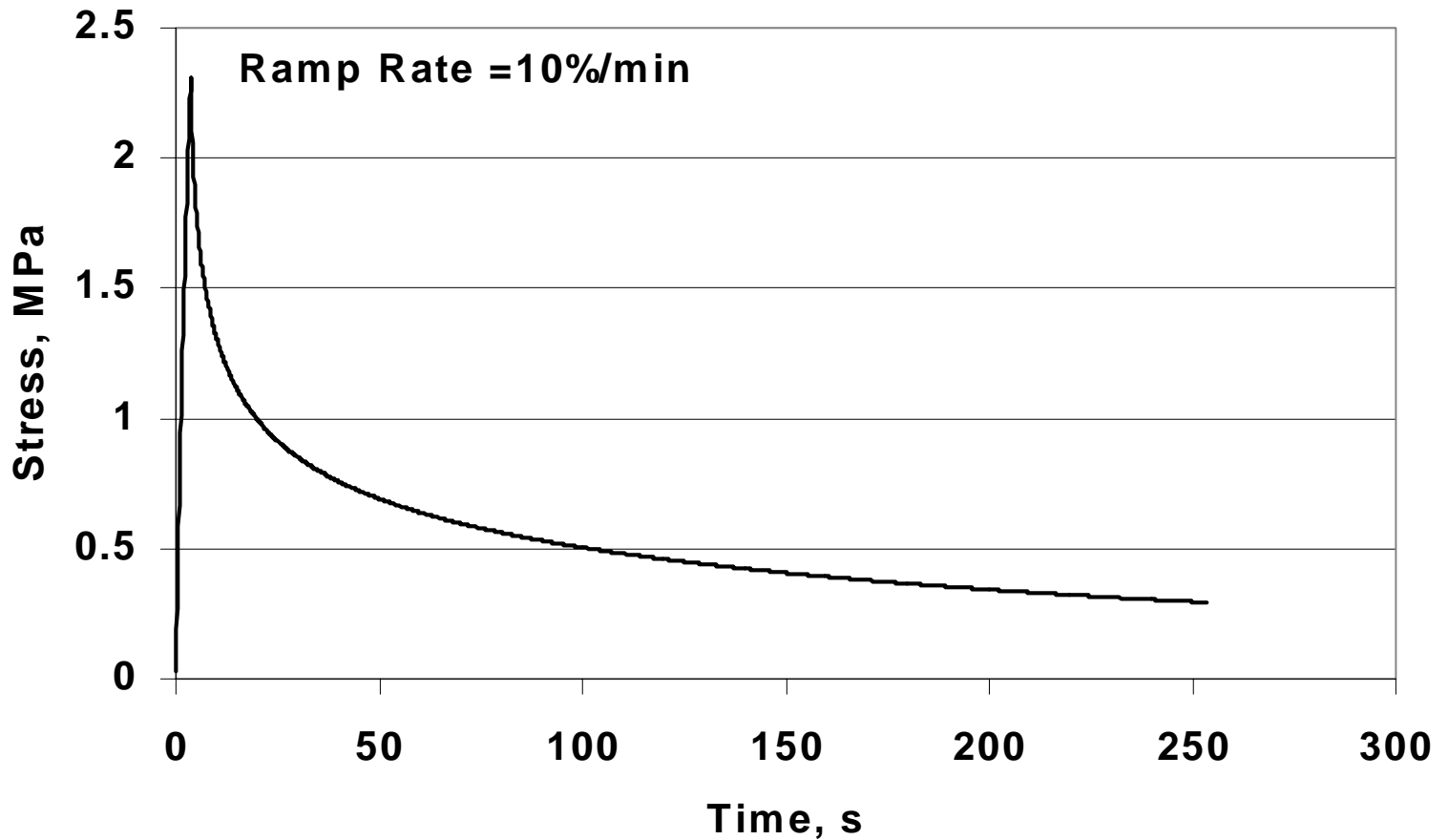
BBR Vs. DTT – Creep Data

AI-095 PG76-22



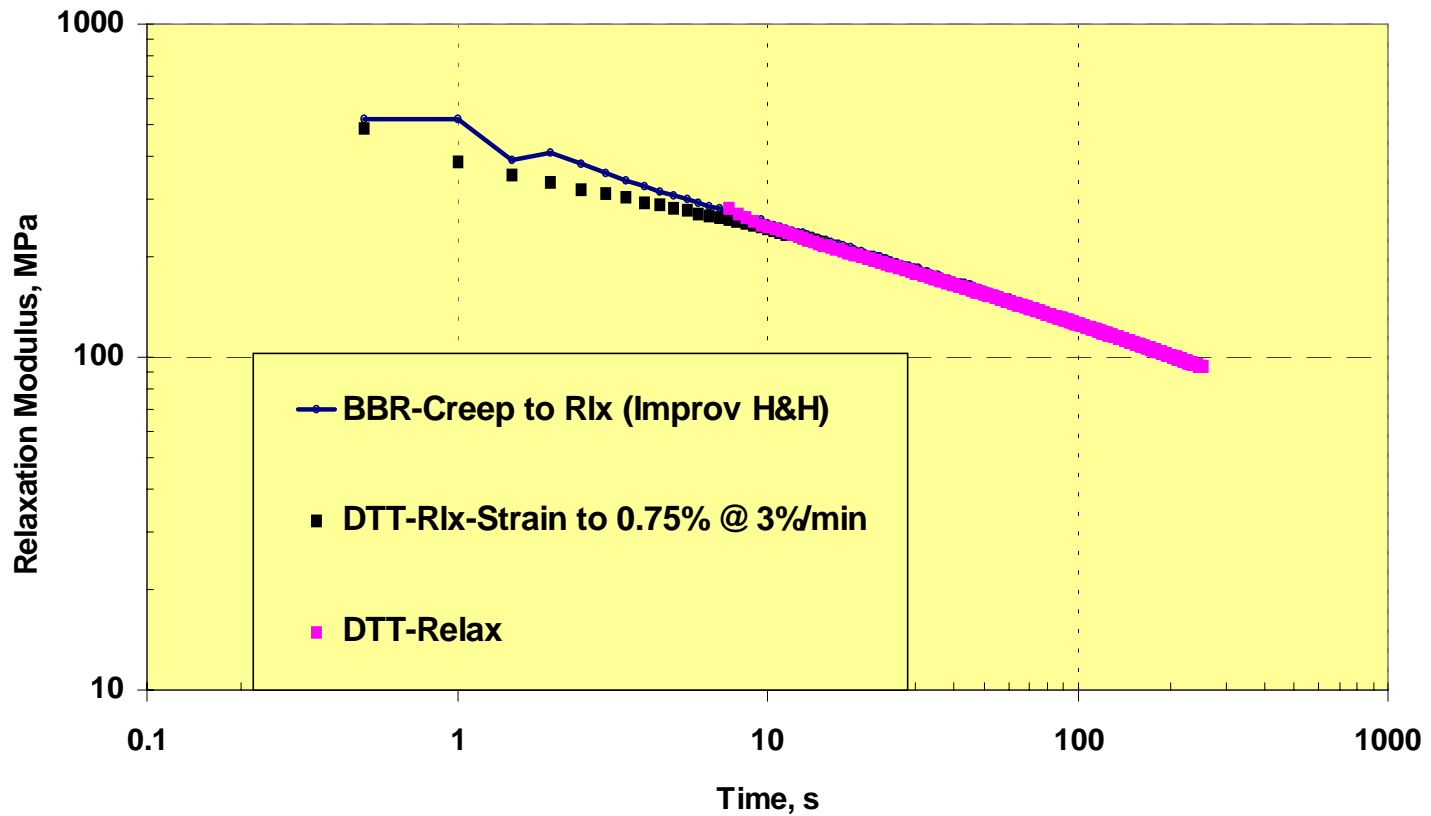
Typical Stress Relaxation - DTT

AAA-1, PAV, -18°C



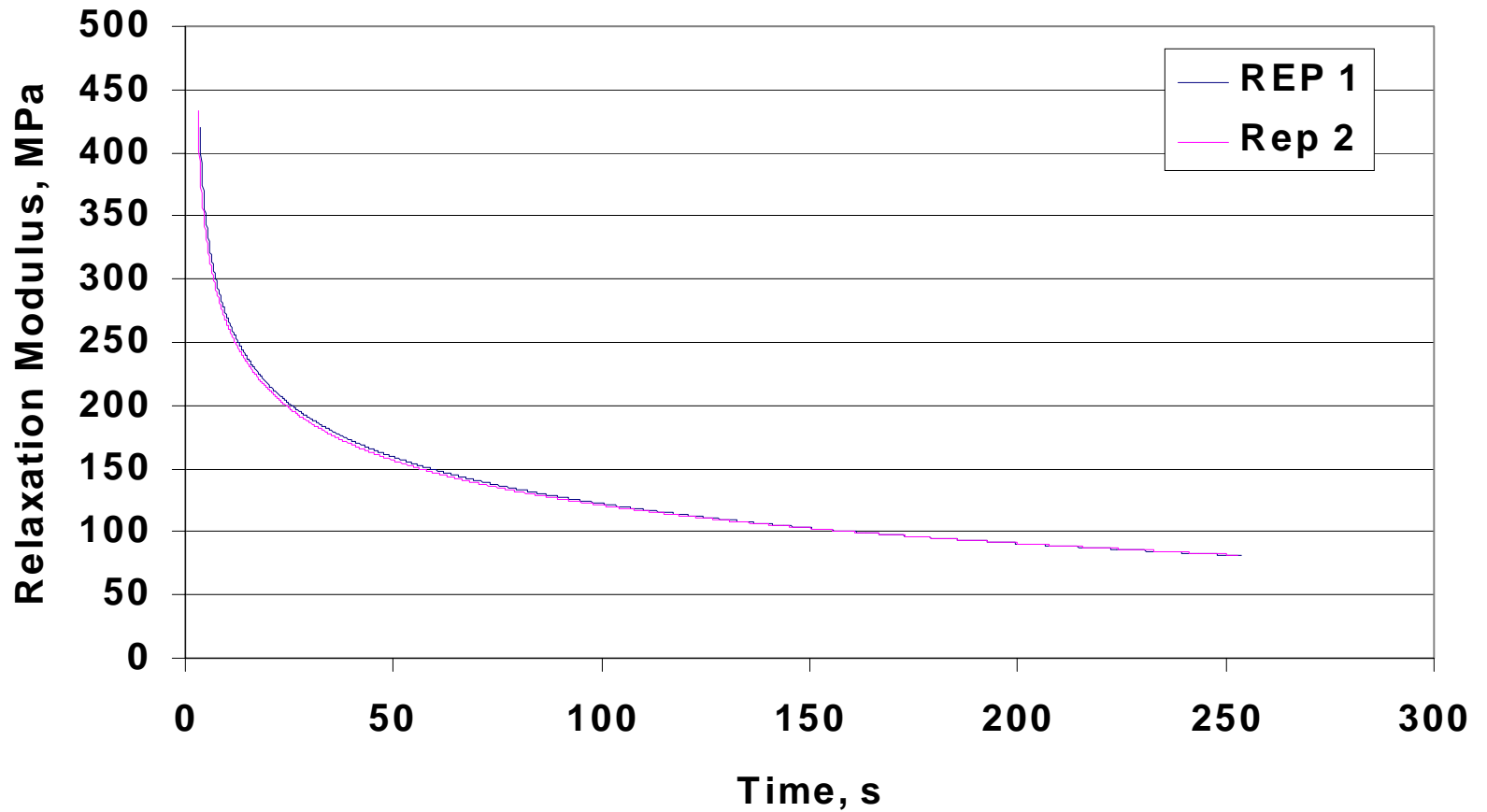
BBR Vs. DTT – Relaxation

AI-095 - PG76-22



Repeatability

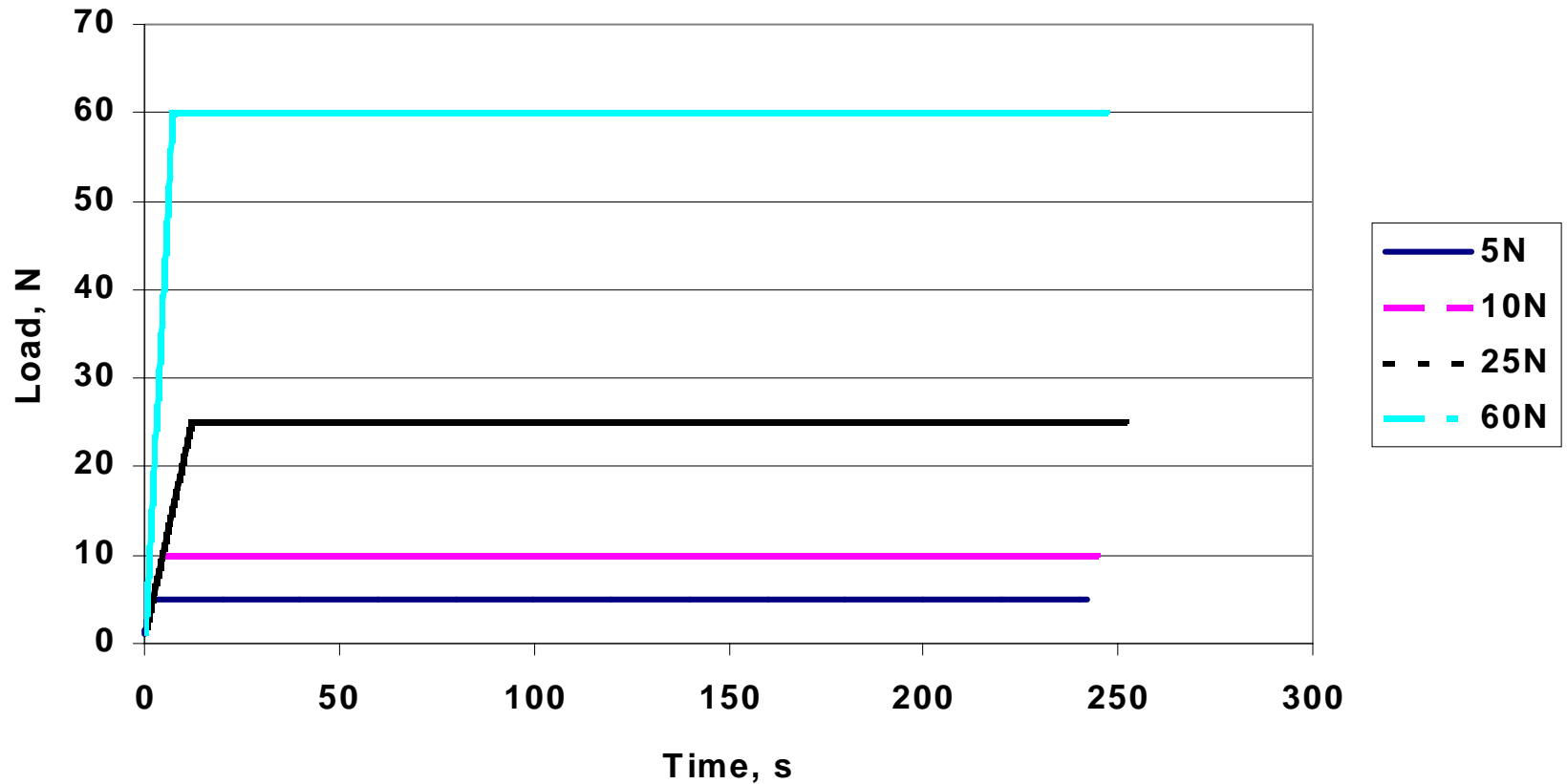
AAM-1, -12°C



Linearity Check – Creep Loads

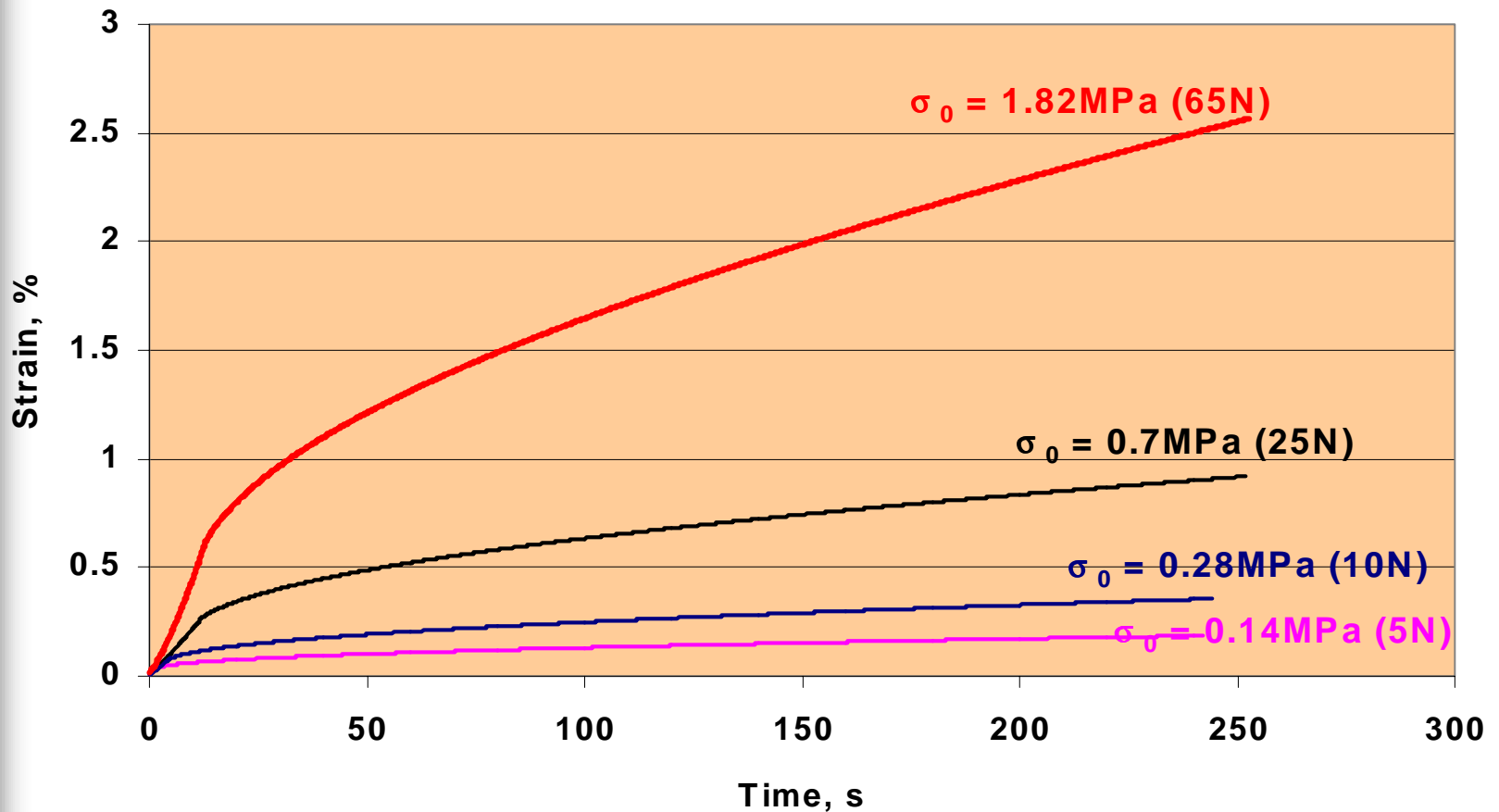
BBR with DTT

Ref: BBR Load = 0.980N



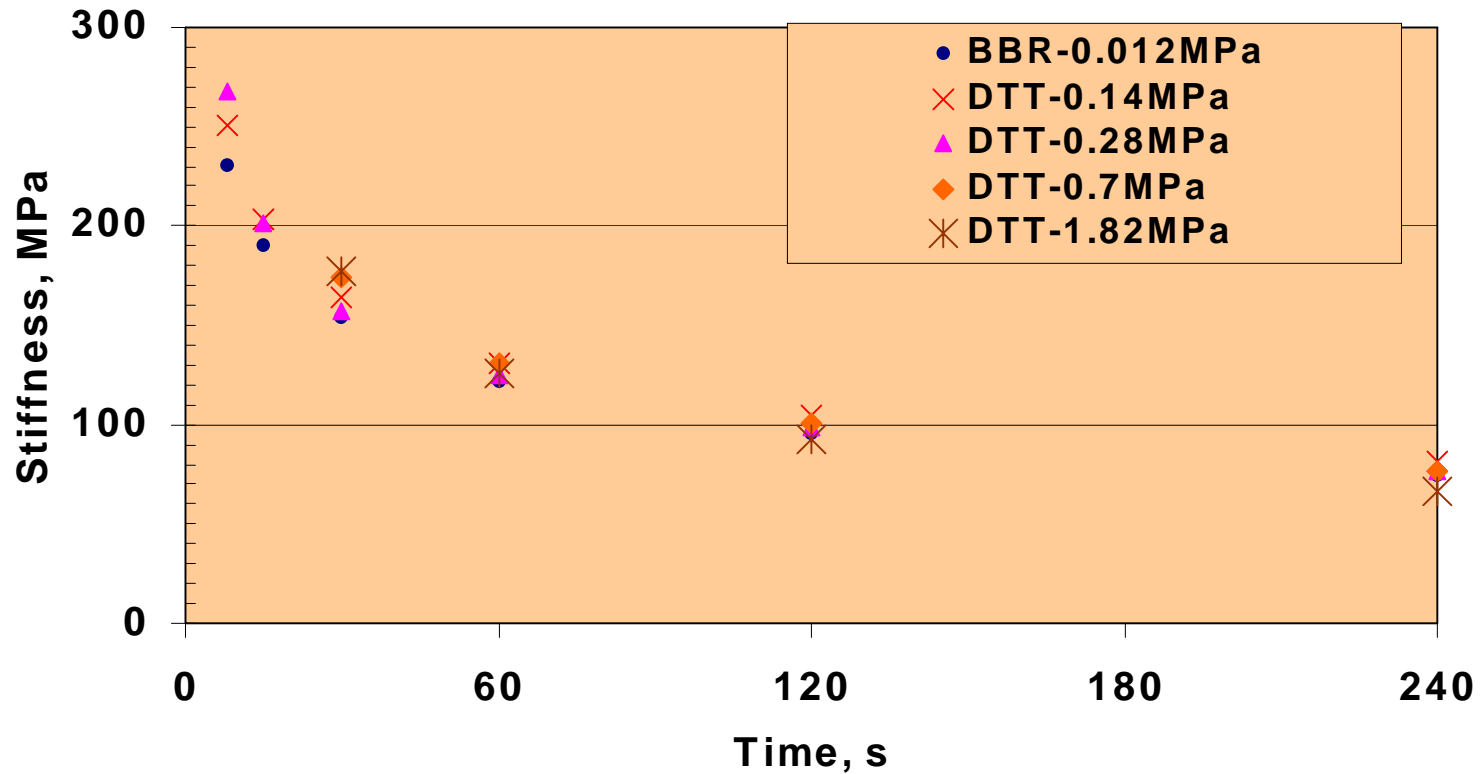
Linearity Check – Creep Loads

Husky Lyodminster 150/200A



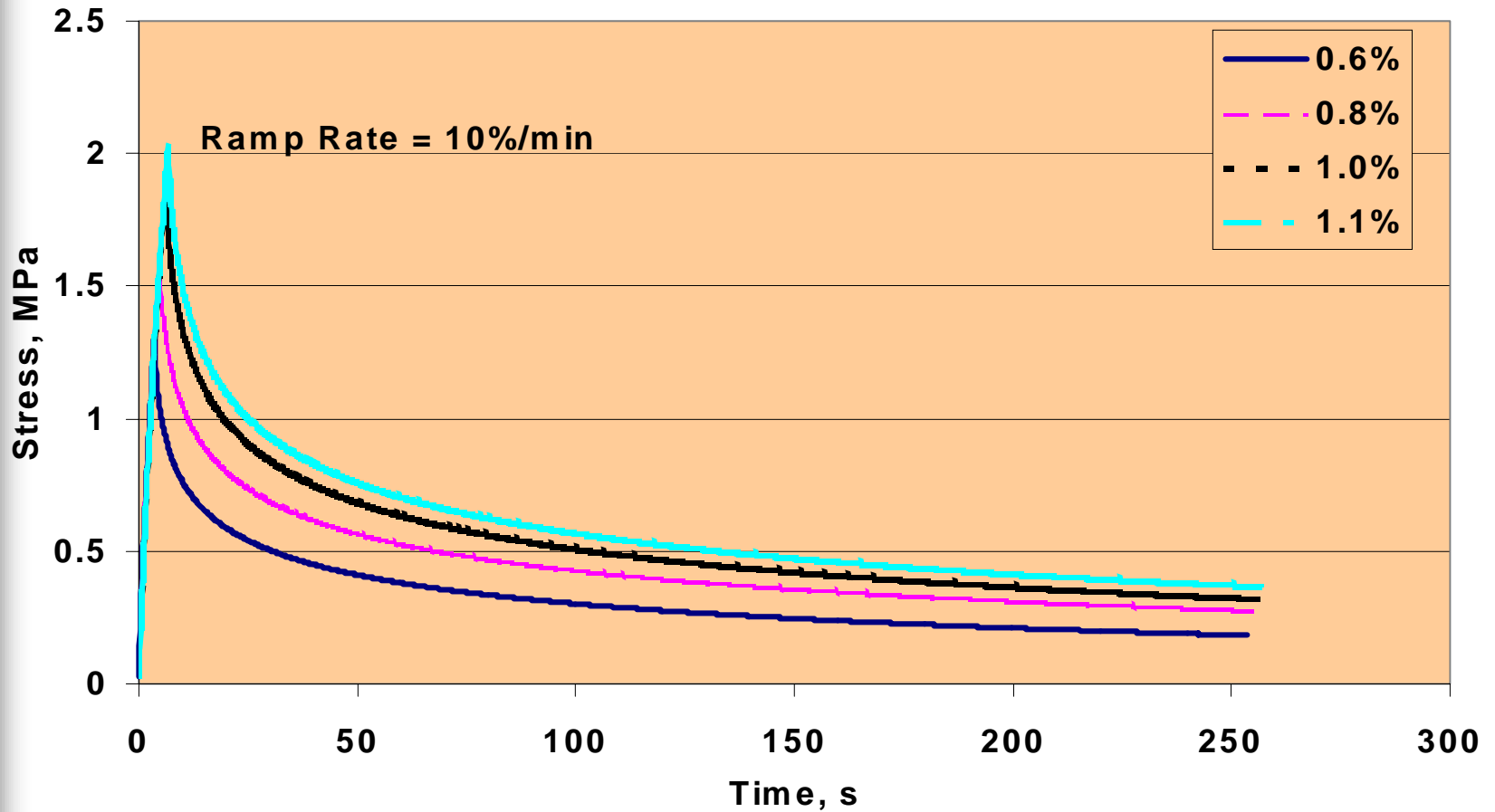
Linearity Check – Creep Stiffness

ALF Styrelf PAV



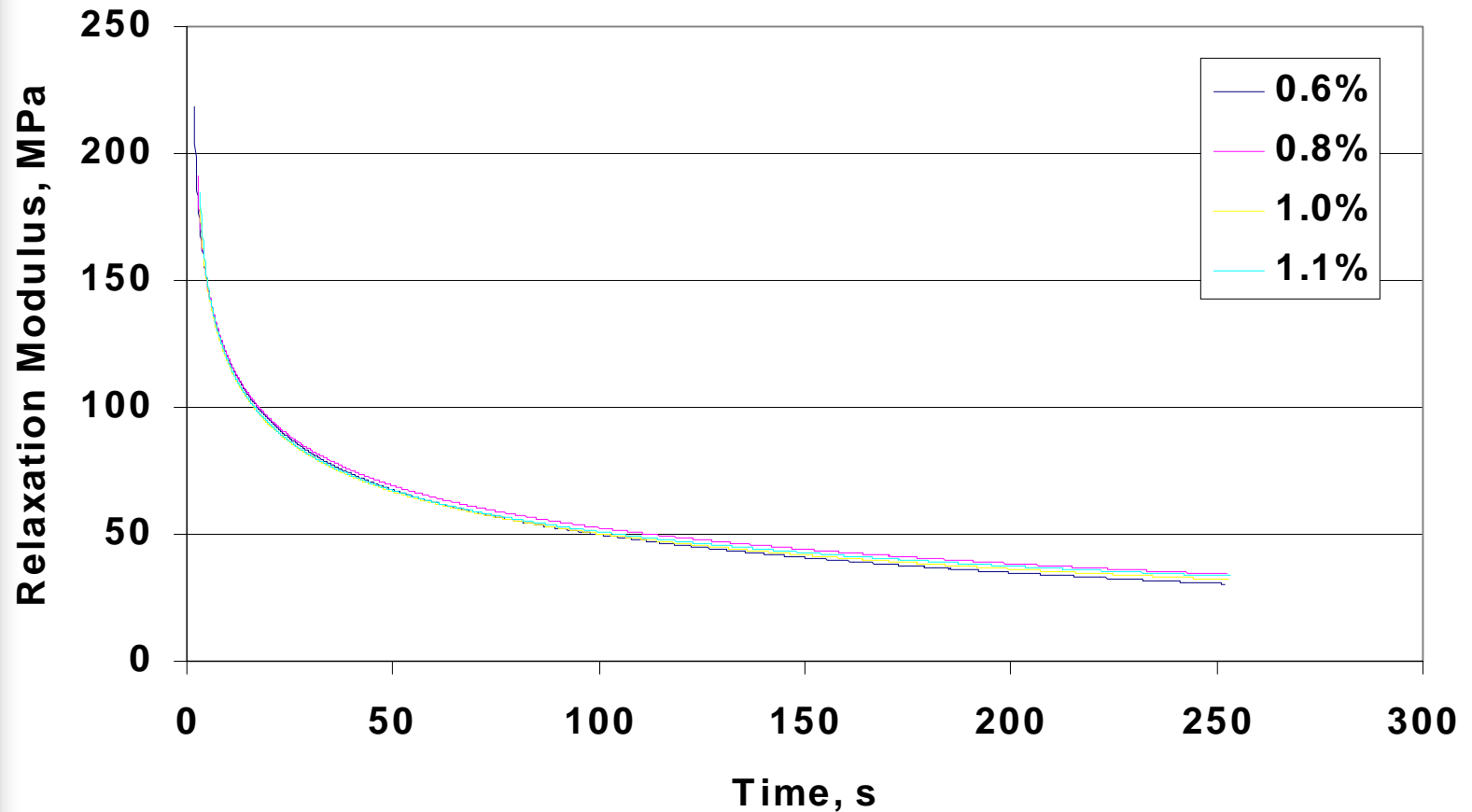
Linearity Check – Relaxation Strains

AAM-1 At -6°C



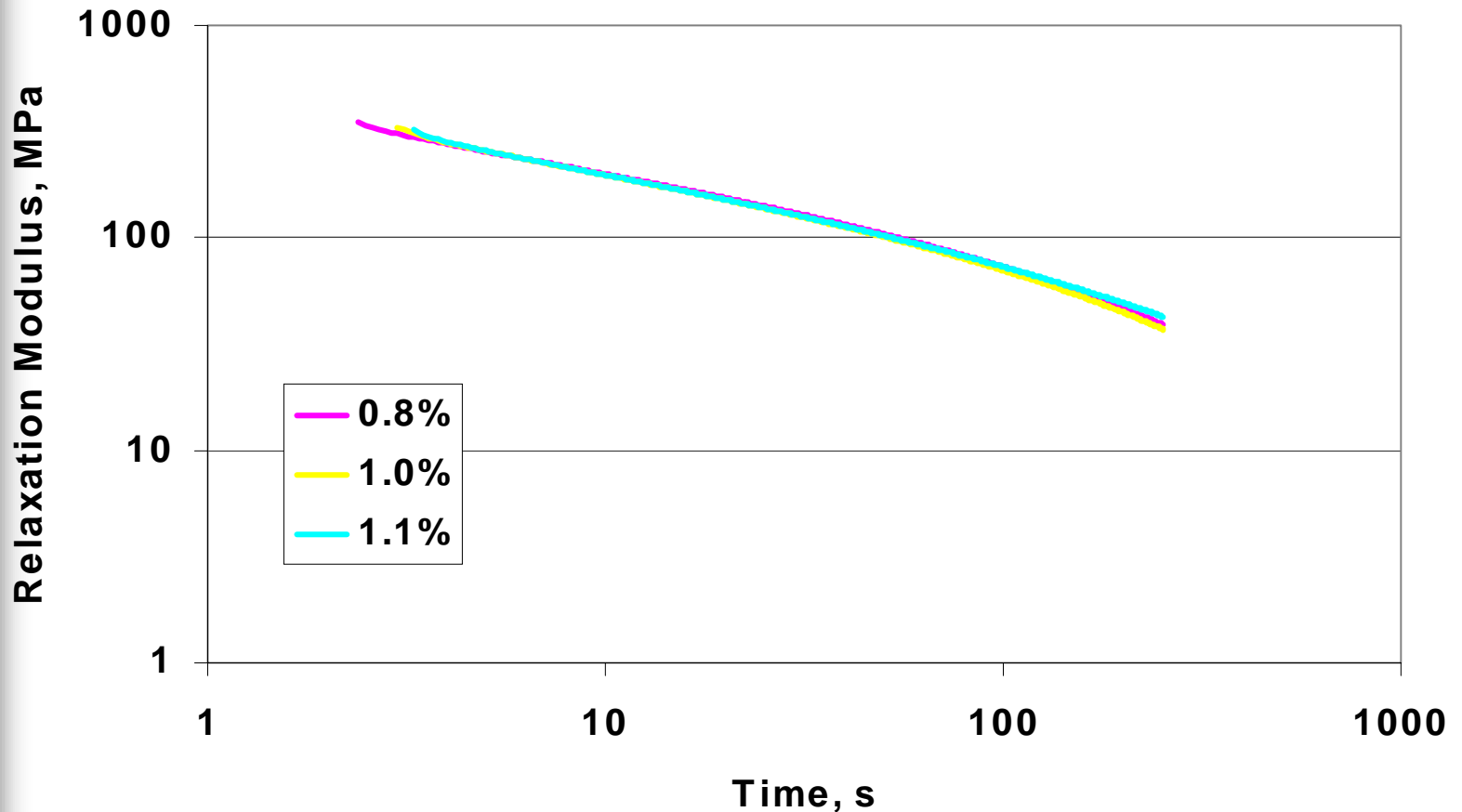
Linearity Check-Relaxation....

AAM-1, -6°C



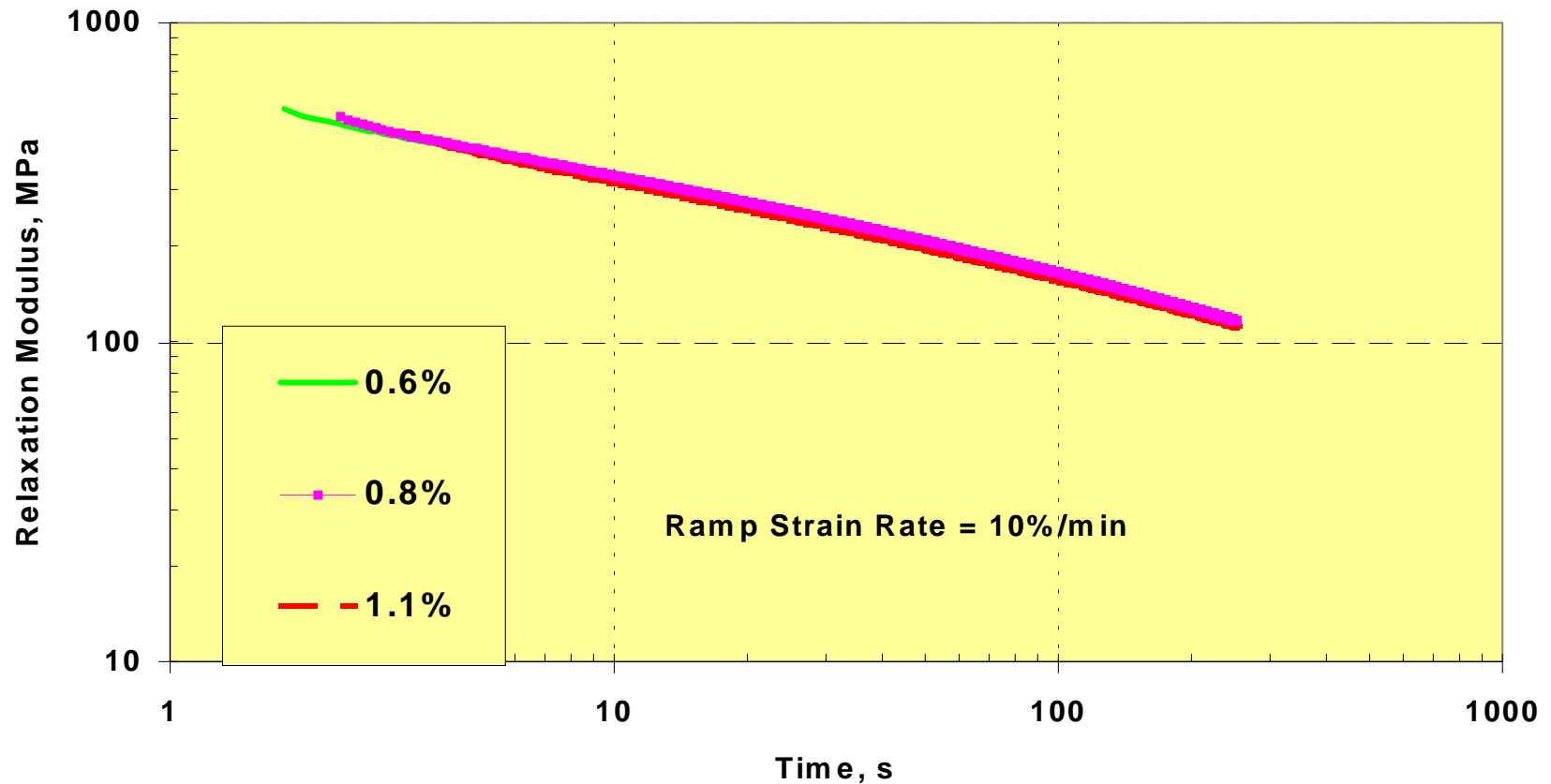
Linearity Check – Relaxation

AAA-1, -18°C

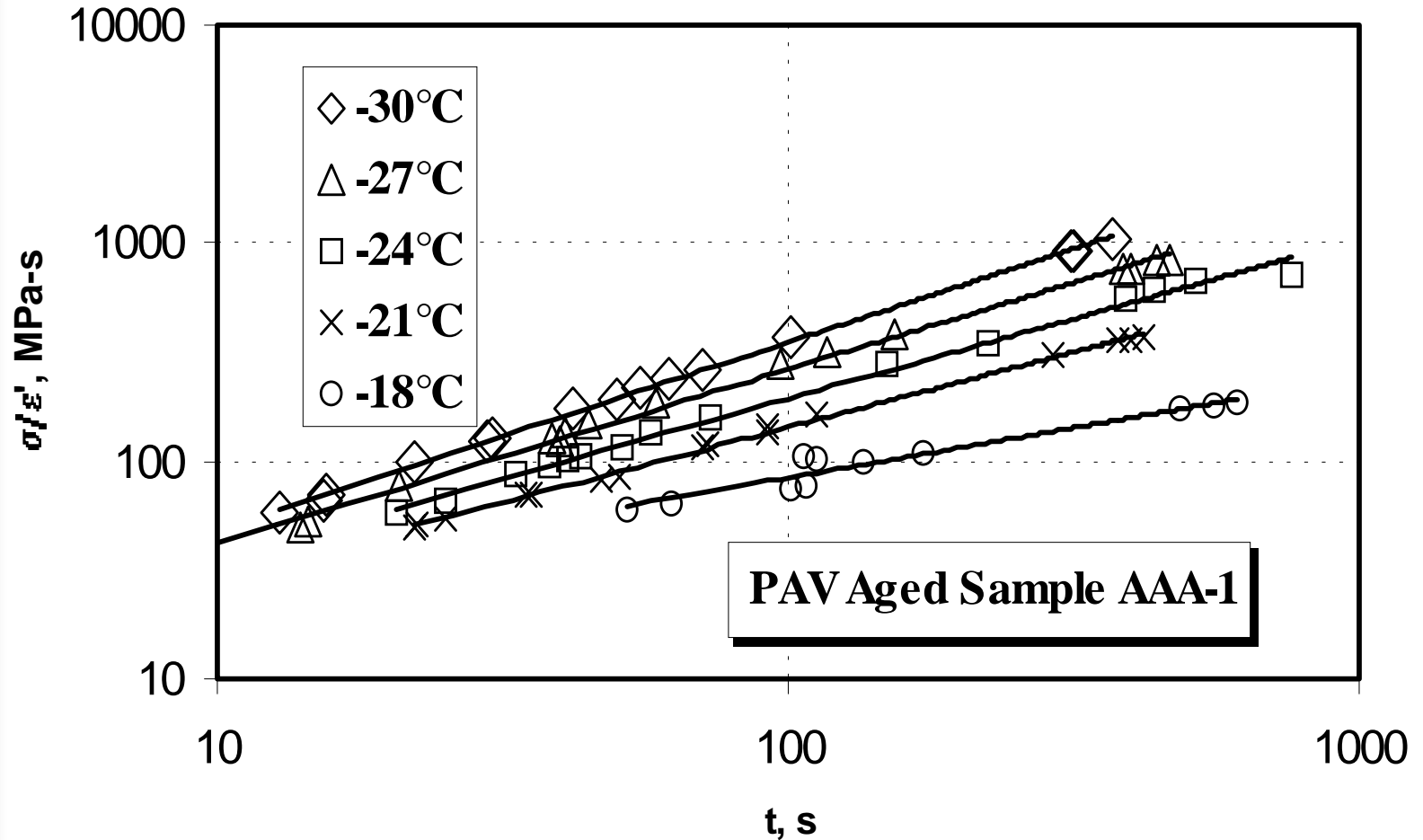


Linearity Check - Relaxation

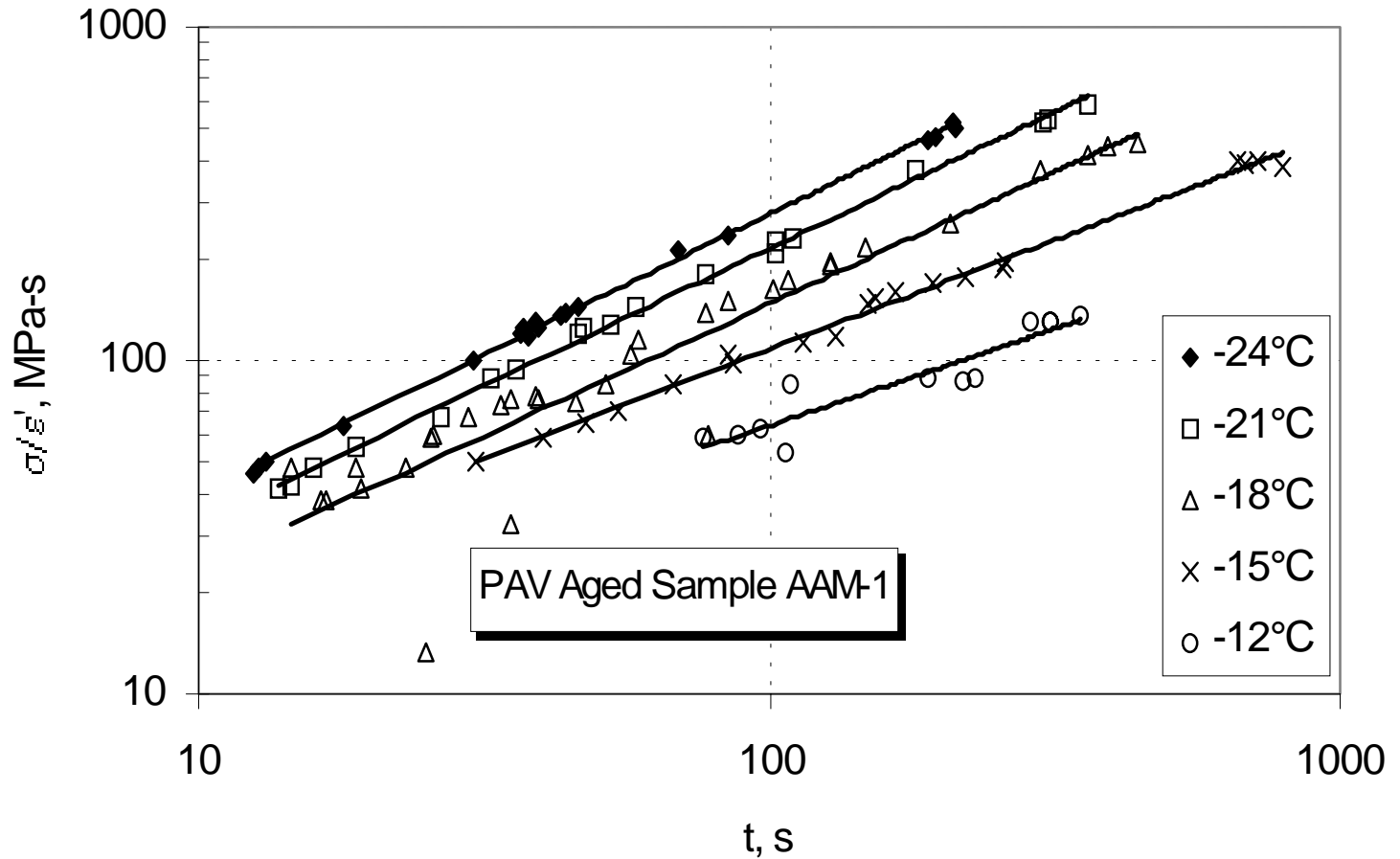
581At -30°C



Linearity Check- Failure

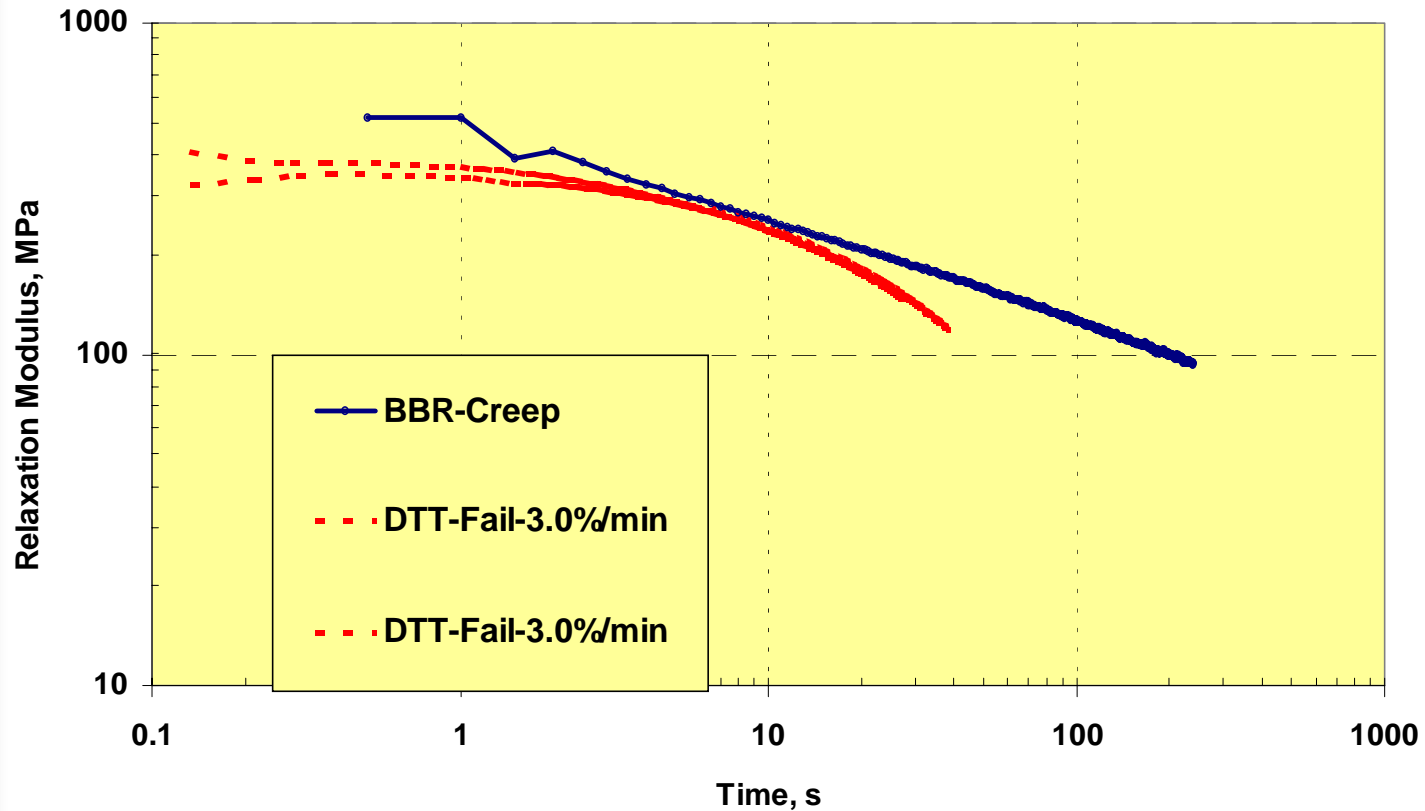


Linearity Check - Failure



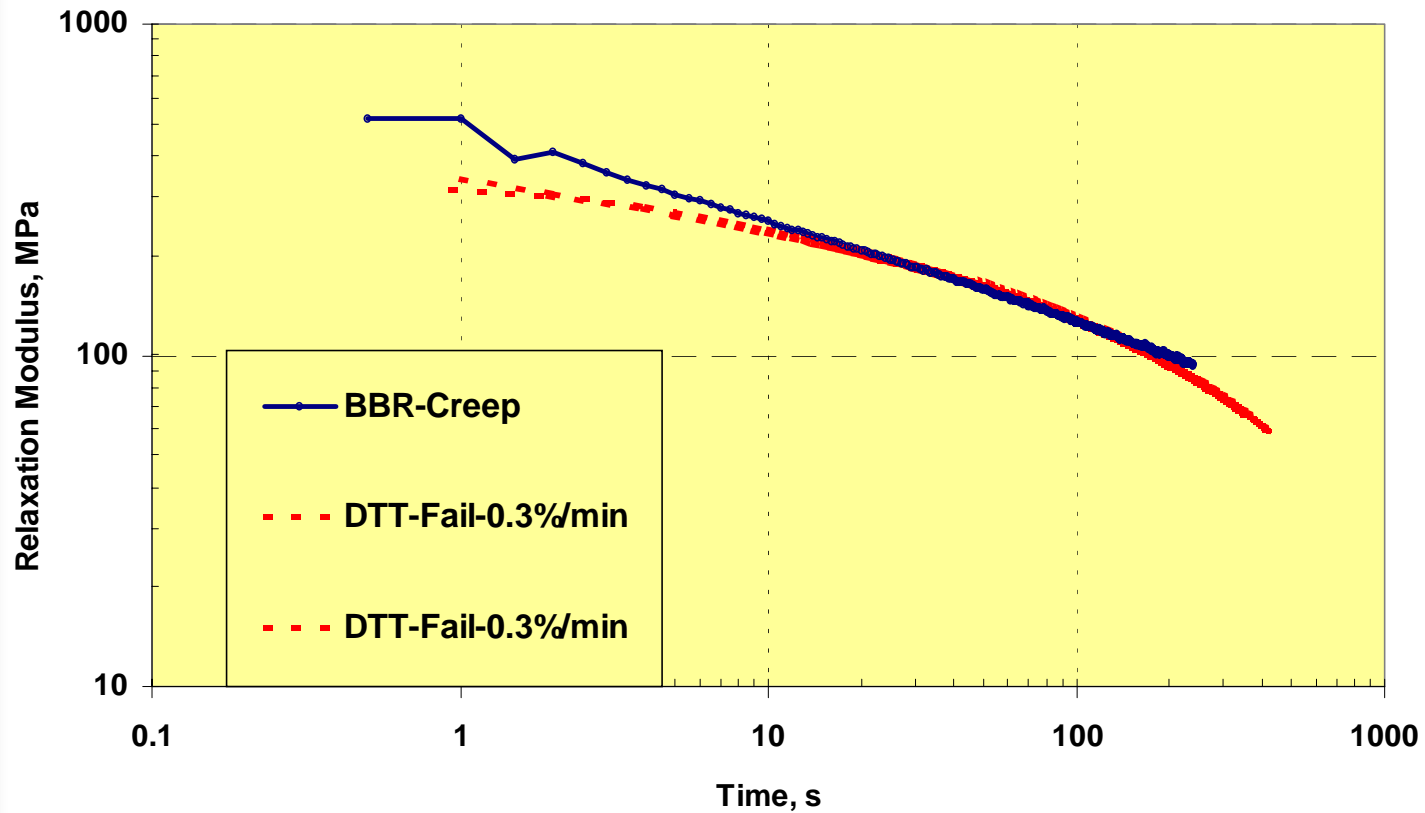
BBR Vs. DTT – Failure Data

AI-095 - PG76-22

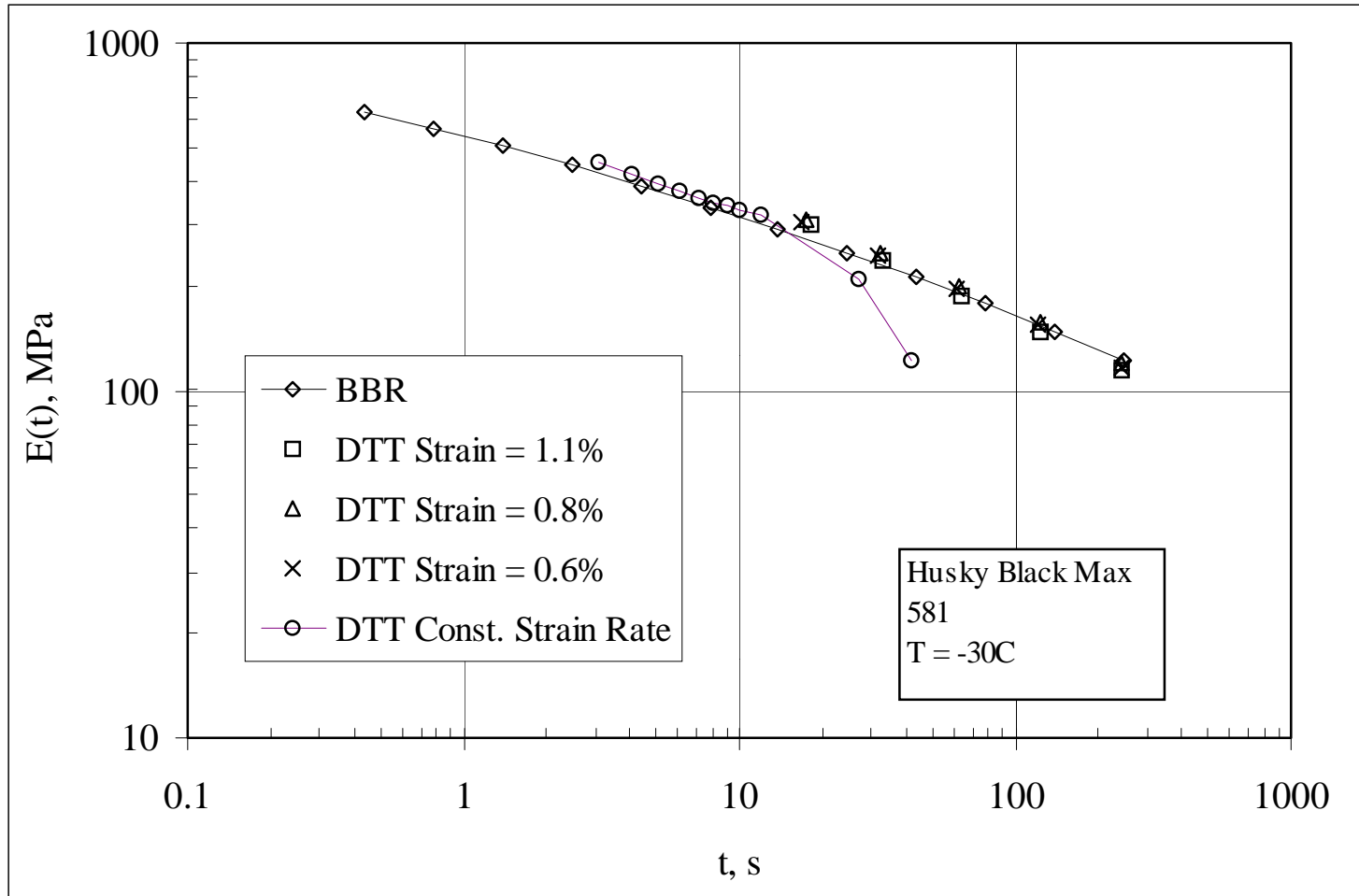


BBR Vs. DTT – Failure Data

AI-095 - PG76-22

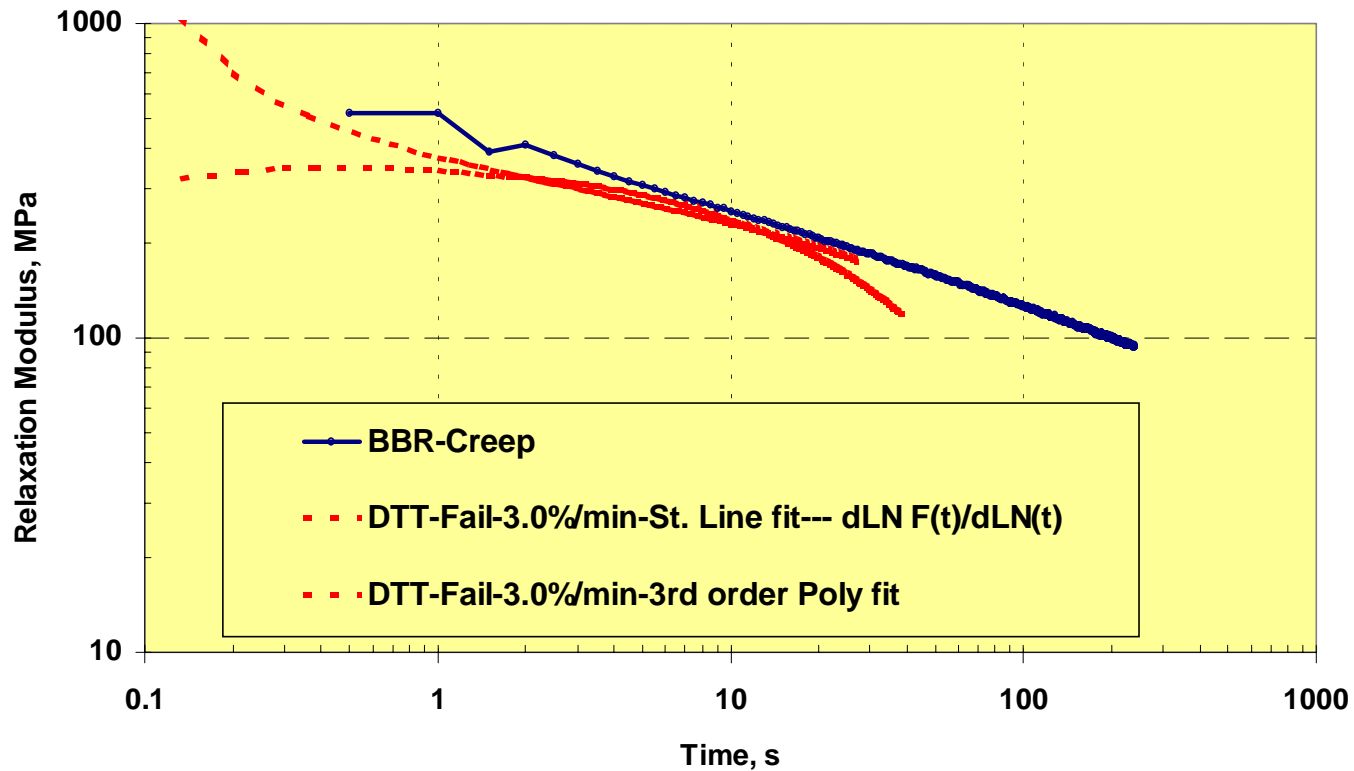


All Combined-Summary



Other Variables

AI-095 - PG76-22





Thor Smith's Formula

$$E(t) = F(t) \left[1 + \frac{d\text{Log}F(t)}{d\text{Log}(t)} \right]$$

Where,

$E(t)$ = Relaxation Modulus, MPa

$F(t)$ = Secant Modulus, MPa = Stress/Strain

Correct Method to Convert

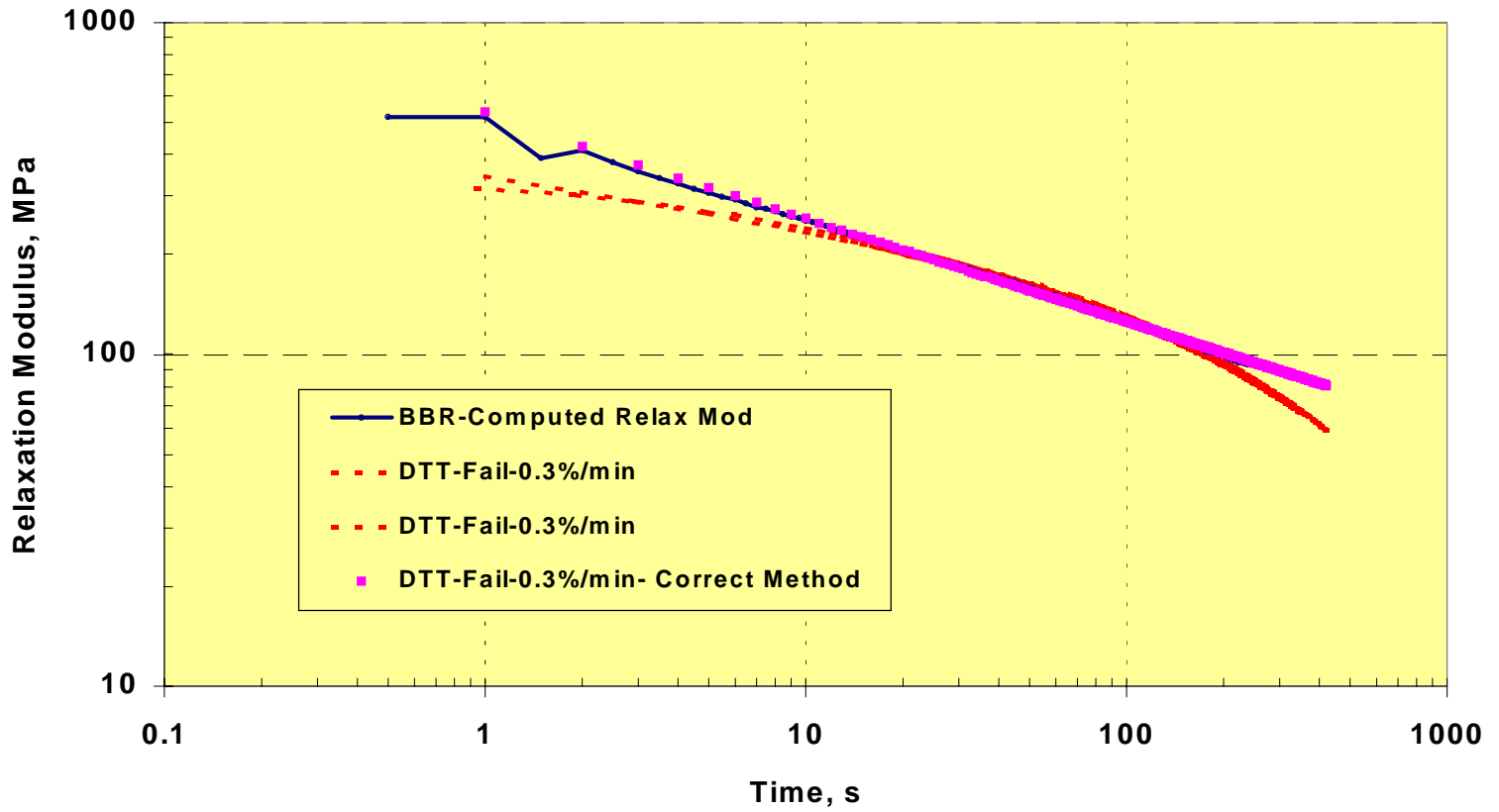
- Take the derivative of the stress-strain curve
 - Fit a Power Law to the True Stress vs True Strain Curve

$$E(t) = \frac{d\sigma}{d\varepsilon}$$

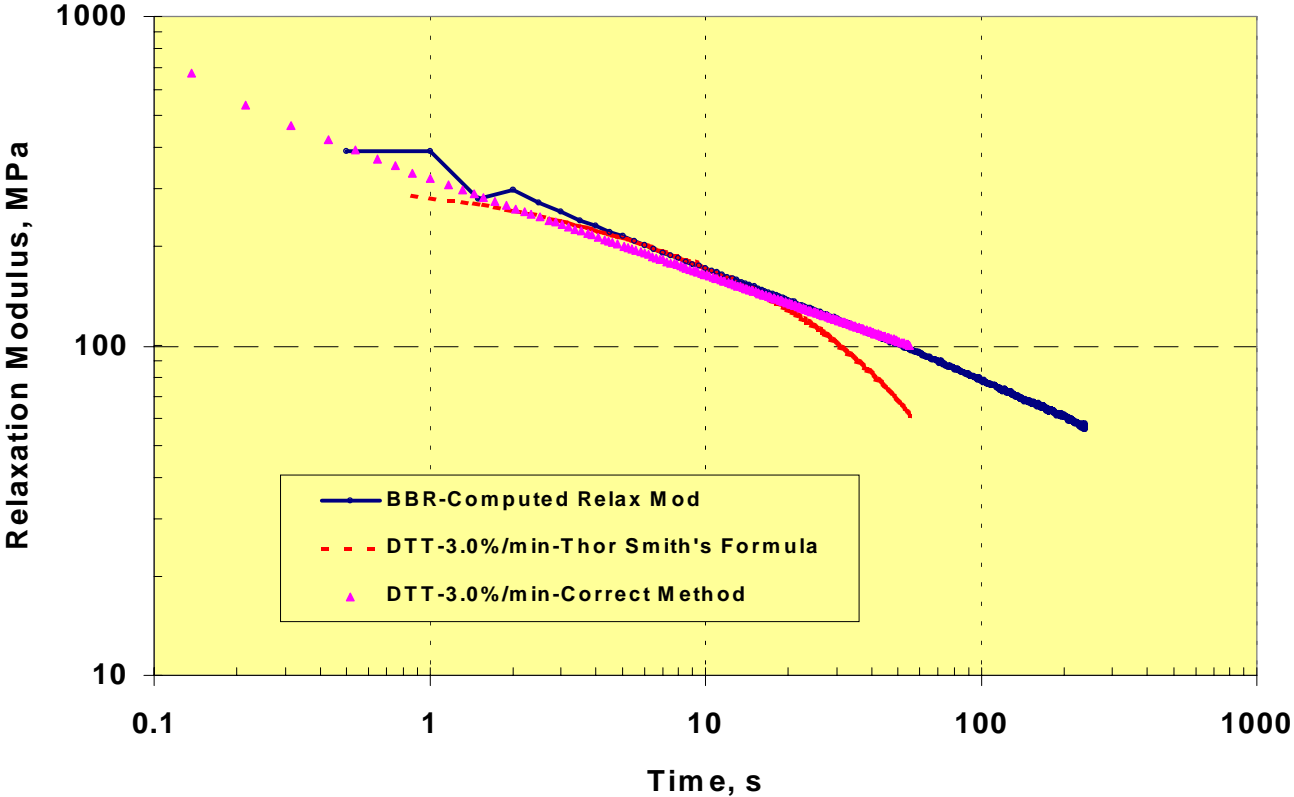
$$\sigma = K(\varepsilon)^n$$

$$\frac{d\sigma}{d\varepsilon} = K \cdot n \cdot (\varepsilon)^{n-1}$$

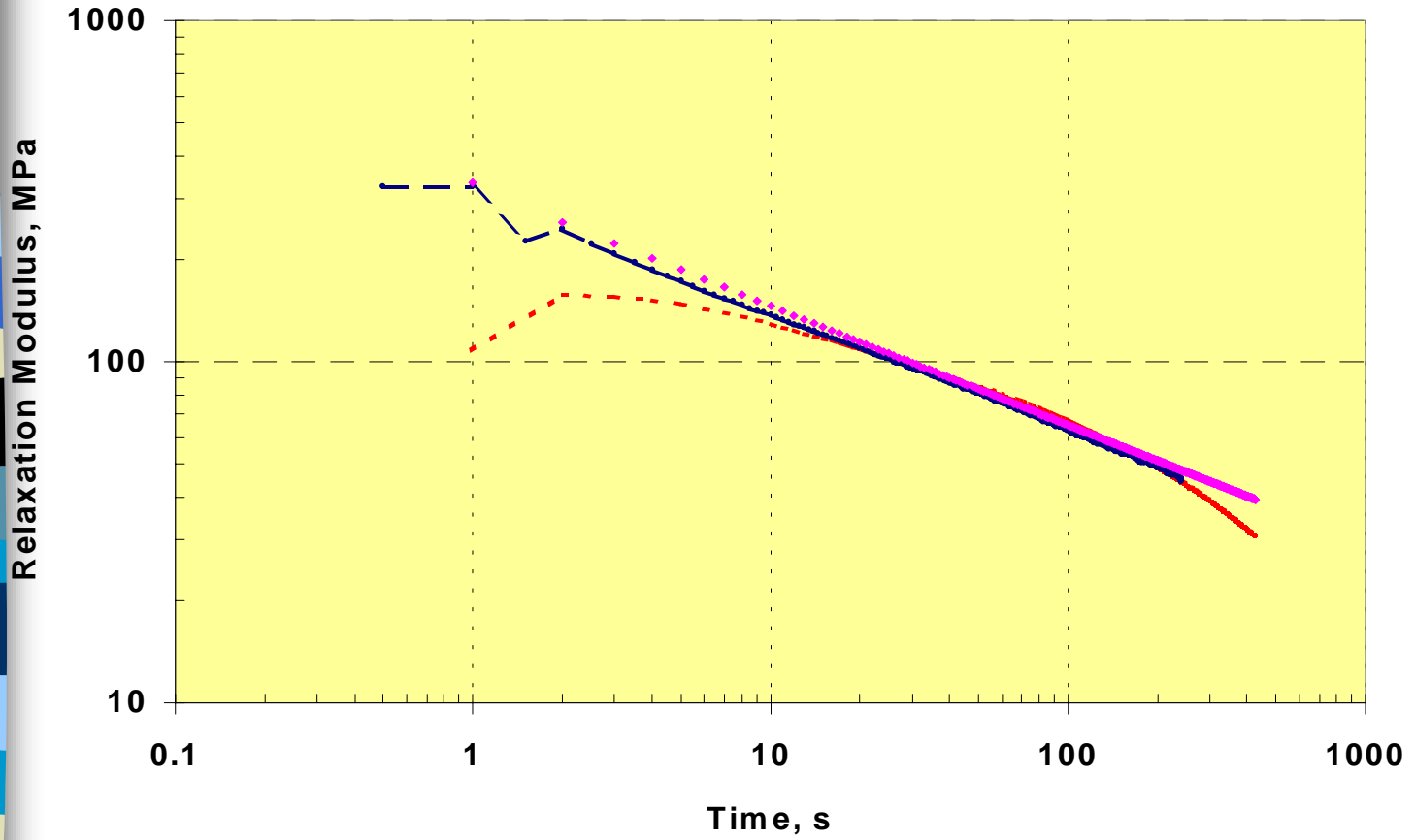
AI-095 - PG76-22



AI-107 - PG76-22



PG70-22 Oxd.





Findings

- BBR and DTT produce identical results
- Flexure and Uniaxial geometry produce the same results
- Non-Linearity was not found at the PG grade temperatures
- When Converting Stress-Strain Curves From the DTT into Relaxation Modulus
 - Use True Stress Vs True Strain
 - Use the Derivative of the True Stress vs True Strain



Test for The Audience

- What is one other thing we learned about the DTT that is not always apparent?



Acknowledgements

- FHWA-John D'Angelo and TE-39 Laboratory Staff



Thank You!