



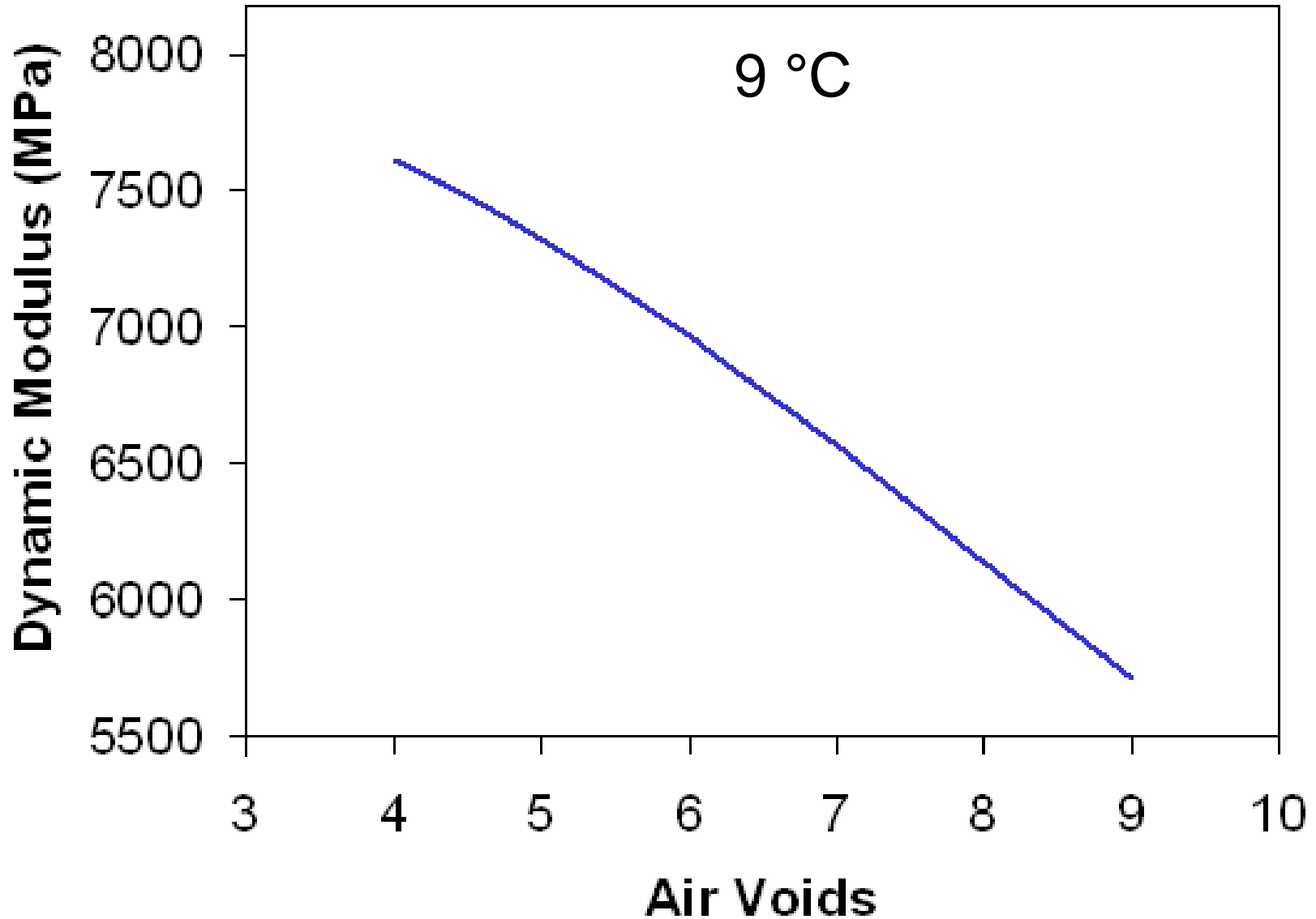
# Performance Models

**Pavement Design Systems and Pavement Performance Models**  
**March 22-23, 2007 - Reykjavik, Iceland**

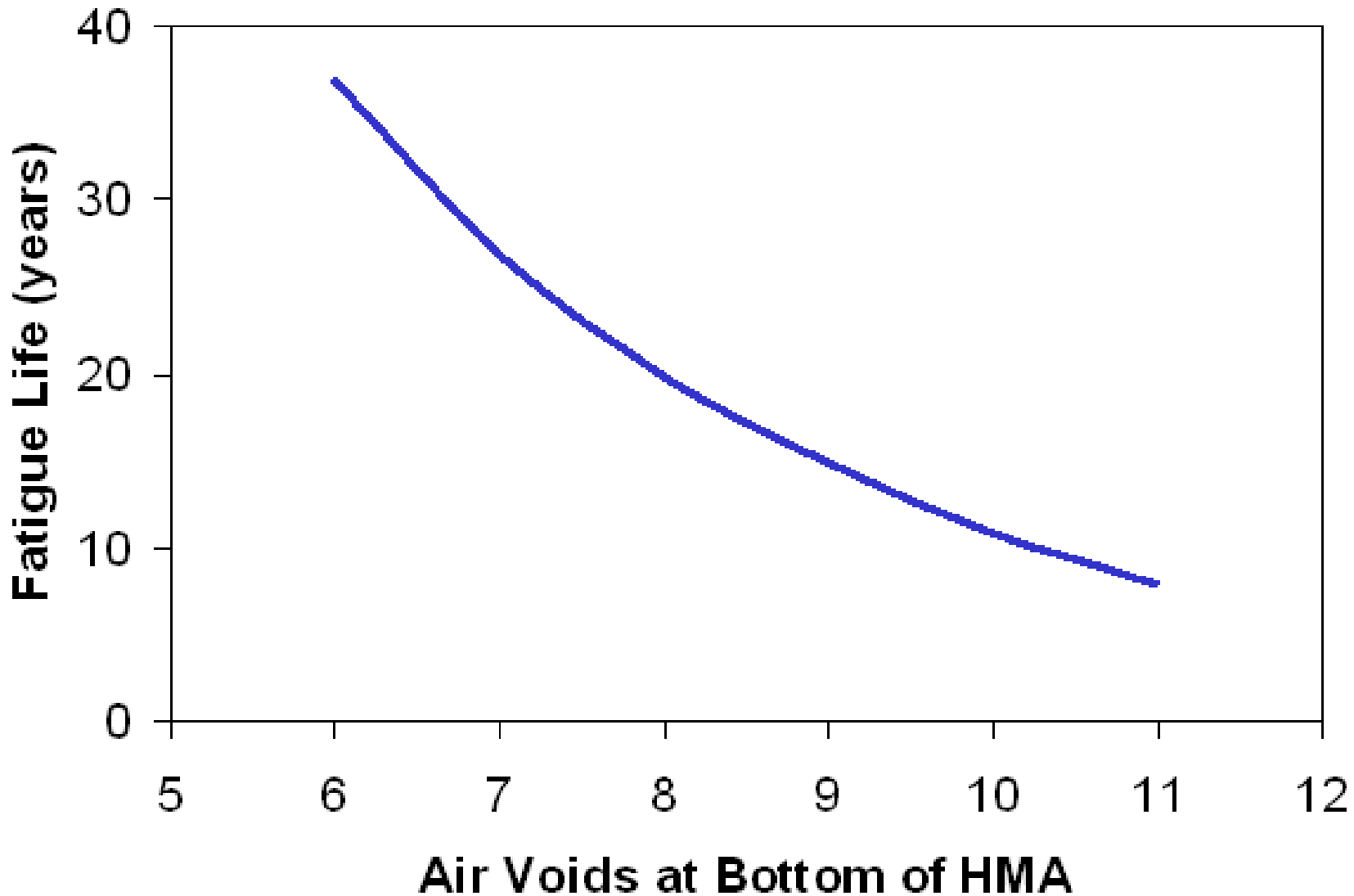
Bruce Tanquist  
Assistant Pavement Design Engineer  
Minnesota Department of Transportation  
[www.dot.state.mn.us](http://www.dot.state.mn.us)



# Effect of Air Voids on Dynamic Modulus



# Effect of Air Voids on Fatigue Life



# Validation/Calibration Process

1. Compare MnPAVE output with current procedure and experience
2. Analyze reasonableness of predicted performance, adjust if necessary
3. Compare MnROAD performance



# MnPAVE – Calibration

- Fatigue and rutting transfer functions
- Not many failures in Minnesota
- Preliminary calibration based on R-Value designs



# Miner's Hypothesis

$$Damage = \sum_{i=1}^k \sum_{j=1}^m \frac{n_{season_i, load_j}}{N_{season_i, load_j}}$$

Where:

$n$  = applied load repetitions

$N$  = allowed load repetitions

$k$  = total number of seasons

$m$  = number of load configurations

Damage  $\geq 1$  indicates failure



# Transfer Functions: Fatigue

## Fred Finn/Asphalt Institute model

$$N = C \times S \times (4.32 \times 10^{-3}) \varepsilon^{-3.291} E^{-0.854}$$

**Where**

**$N$  = Allowed load repetitions for fatigue**

**$S$  = Shift factor\***

**$\varepsilon$  = Tensile strain at bottom of HMA**

**$E$  = HMA dynamic modulus (MPa)**

**$C$  = correction factor based on air voids and binder content**

\* Preliminary MnPAVE shift factor of 92.6 is based on calibration with existing R-Value designs.



# Transfer Functions: Rutting

**Calibrated with existing R-Value designs**

$$N = 0.00618 \varepsilon^{-2.5592}$$

**Where**

**$N$  = Allowed load repetitions for rutting**

**$\varepsilon$  = vertical strain at top of subgrade**



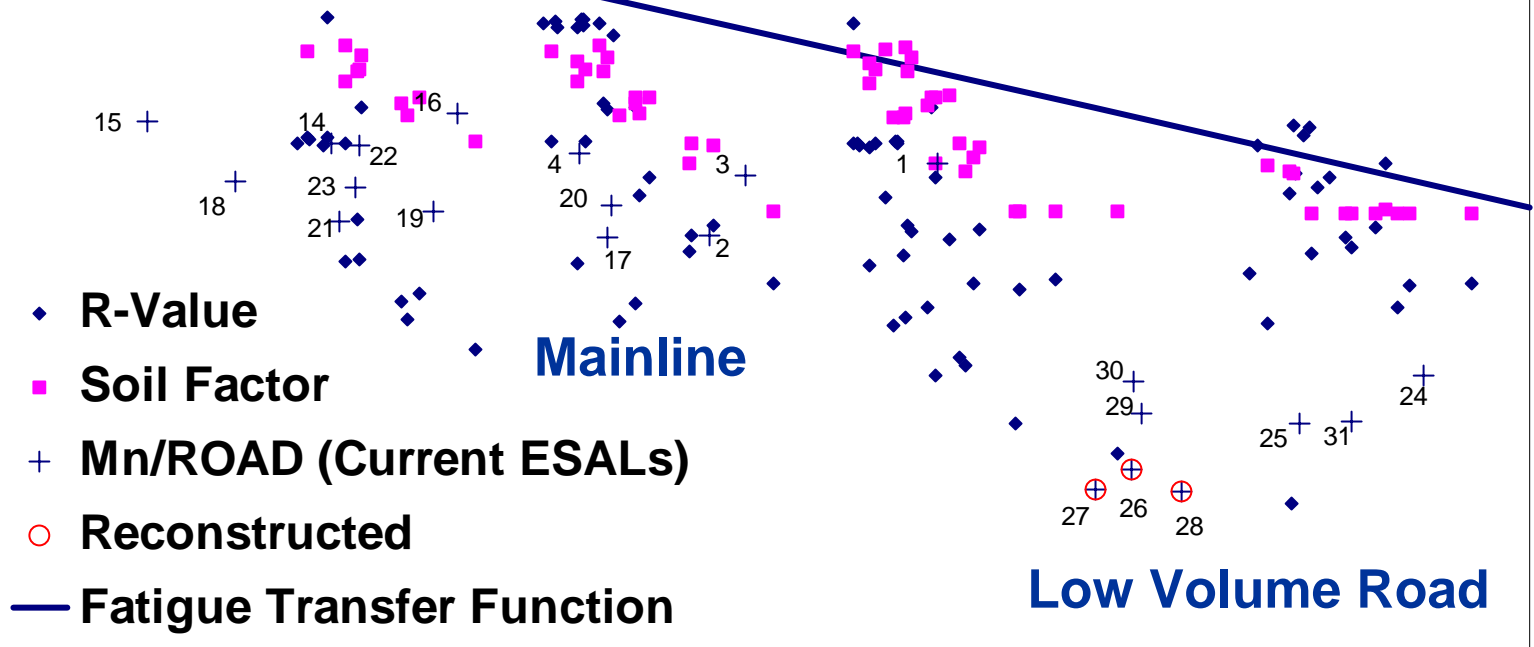
# R-Value Fatigue Calibration (2002)

Normalized Repetitions

failed

$$N = C \times S \times (4.32 \times 10^{-3}) \varepsilon^{-3.291} E^{-0.854}$$

not failed



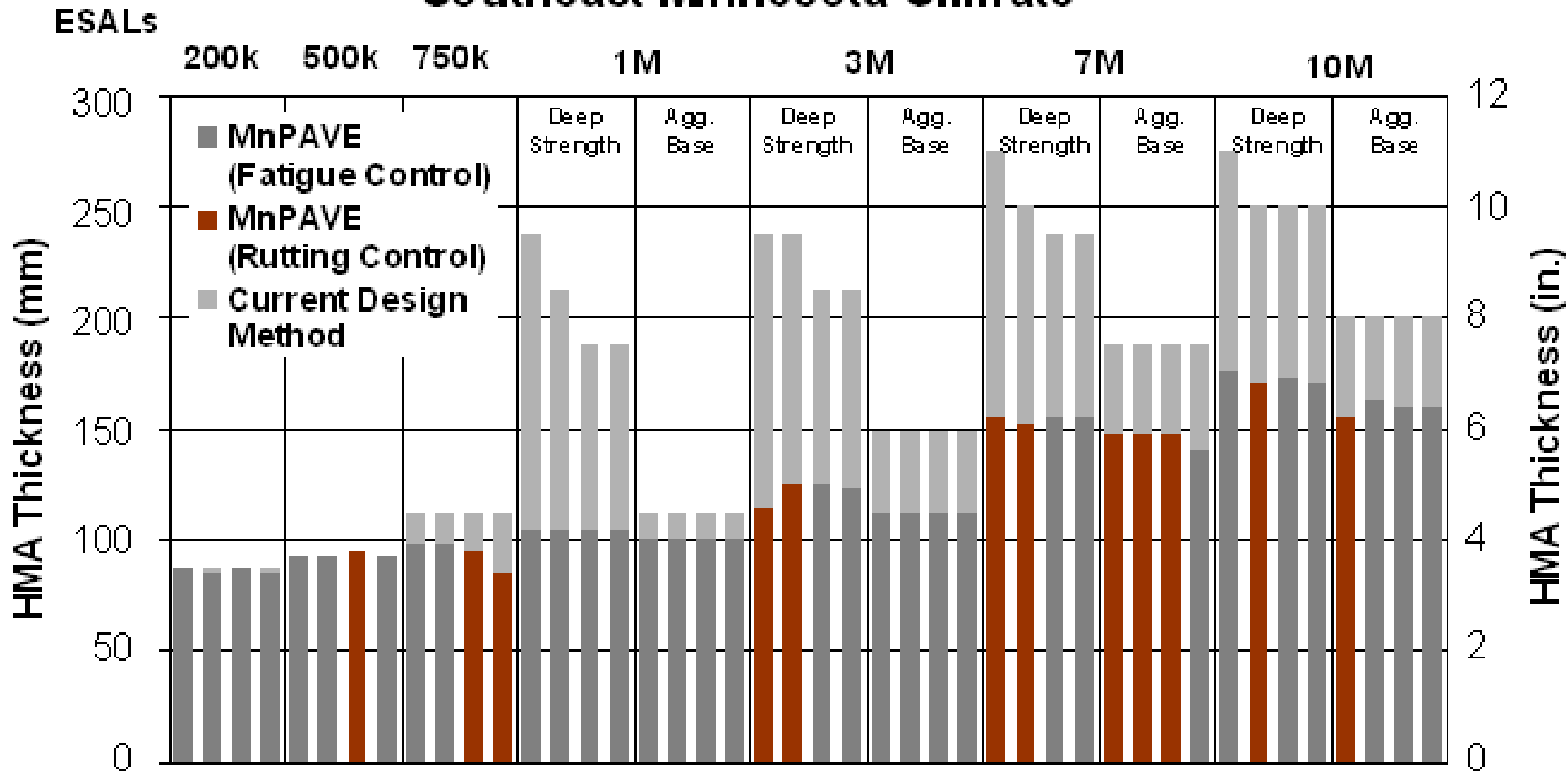
- ◆ R-Value
- Soil Factor
- + Mn/ROAD (Current ESALs)
- Reconstructed
- Fatigue Transfer Function

Thicker ←————→ Thinner



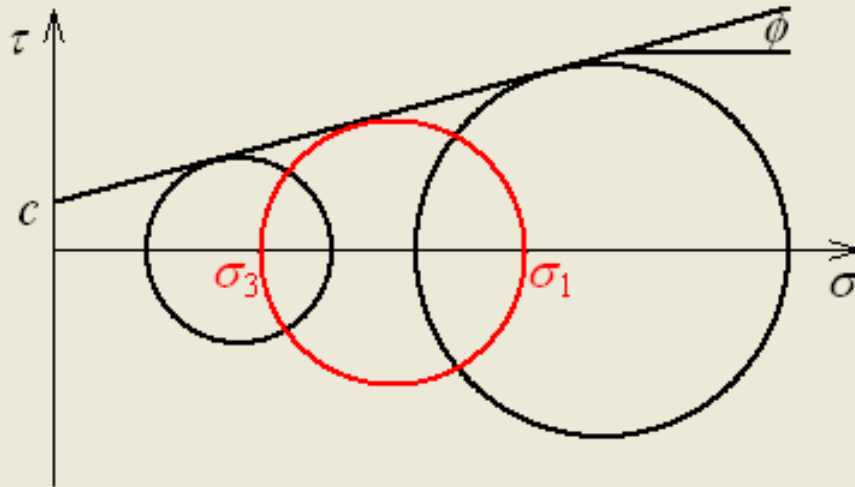
# MnPAVE Calibration

## MnPAVE & R-Value HMA Thickness Southeast Minnesota Climate



## MnPAVE - Mohr-Coulomb Criterion

Print Window Help



OK

Cancel

Material: Mn/DOT Class 6

$$\sigma_1 < \sigma_{1 \text{ critical}} = \sigma_3 \times \tan^2\left(45 + \frac{\phi}{2}\right) + 2c \times \tan\left(45 + \frac{\phi}{2}\right)$$

c  kPa

$\phi$   °

Where:

$\sigma_{1 \text{ critical}}$  = Maximum allowed stress at middle of aggregate base

$\sigma_1, \sigma_3$  = Principal stresses due to maximum axle load

c = Cohesion of granular material (from triaxial test)

$\phi$  = Friction angle of granular material (from triaxial test)

Note:

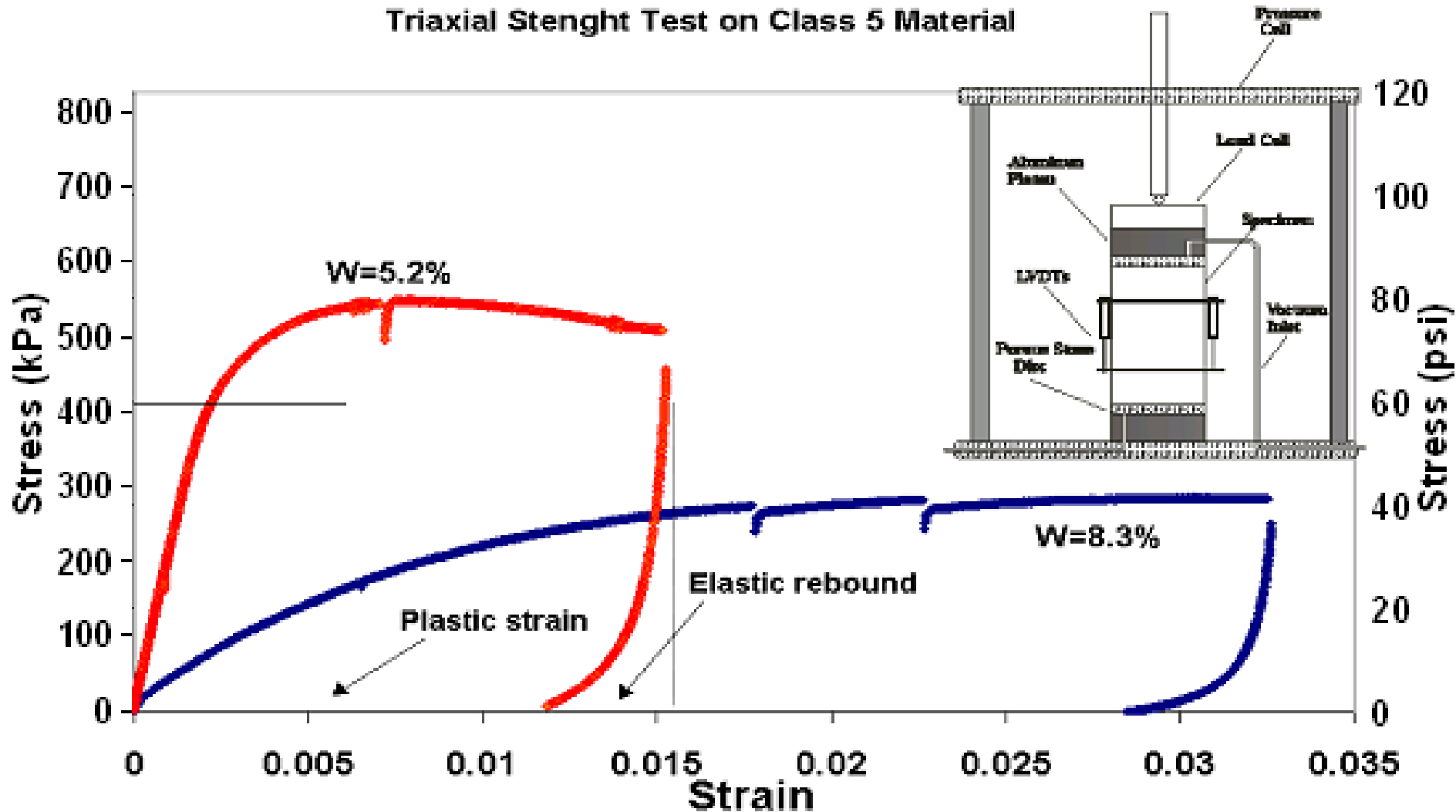
Currently all default values are derived from tests performed on Class 5 aggregate. Values for other materials will be added when testing is complete.



# Triaxial Test

Allowable stress criteria for aggregate base

Triaxial Stenght Test on Class 5 Material



# MnPAVE Mohr-Coulomb Results

Mohr-Coulomb Results
✕

Material: AggBase: Cl.5  
 Location: Middle of layer

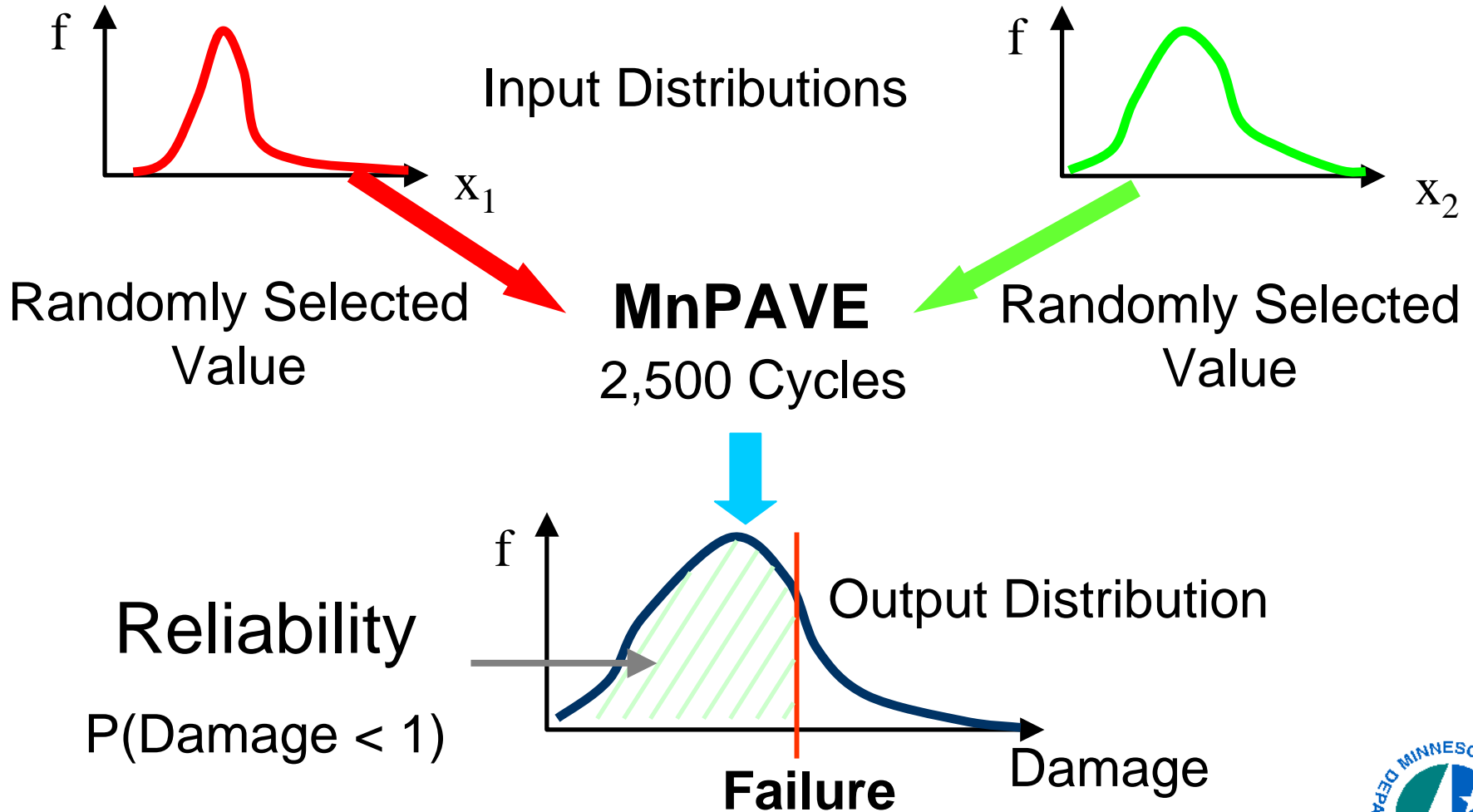
Adjust Layer 1 Thickness to Meet Requirements

$c$   psi  
 $\phi$   °

	Current Thickness	Required Thickness	
Layer 1 Thickness (in.)	<input style="width: 50px;" type="text" value="4"/>	<input style="width: 50px;" type="text" value="5.5"/>	
$\sigma_1$ psi	<input style="width: 50px;" type="text" value="24.95"/>	<input style="width: 50px;" type="text" value="18.2"/>	<input type="checkbox"/> Always show Mohr-Coulomb results
$\sigma_3$ psi	<input style="width: 50px;" type="text" value="0"/>	<input style="width: 50px;" type="text" value="0"/>	<input checked="" type="checkbox"/> Only show if material fails
$\sigma_1$ critical psi	<input style="width: 50px;" type="text" value="19.77"/>	<input style="width: 50px;" type="text" value="19.77"/>	



# Monte Carlo Simulation



# Overlay Design

MnPAVE - MnPAVE1

File Edit View Window Help

MnPAVE1

**Output**  Life  Damage

Traffic Type: ESAL Total Repetitions: 3,000,000

Expected Life

Years: Fatigue 22

Rutting is present in old HMA

Adjust Materials

	H (in.)
HMA: PG 58-34	2
Old: PG 58-34	4
AggBase: CI.5	12
EngSoil: CL	24
UndSoil: CL	

Recalculate

Units:  English  SI

Go Back to Control Panel

Basic | Batch Mode | Reliability

Spring Axle Load Limit

PSR: 1.971 Age, yrs: 20

Percent of Total Damage

Fall	Winter	Early Spring	Late Spring	Summer
16.3	0.1	2.5	25.4	55.7

MnPAVE Fatigue

Export:  Design Summary  Damage Details

Export to File

For Help, press F1



# Lukanen Report: Pavement Performance Prediction Models 1992

$$PSR = PSR_{initial} - e^{(a-b \times c^t)}$$

Where:

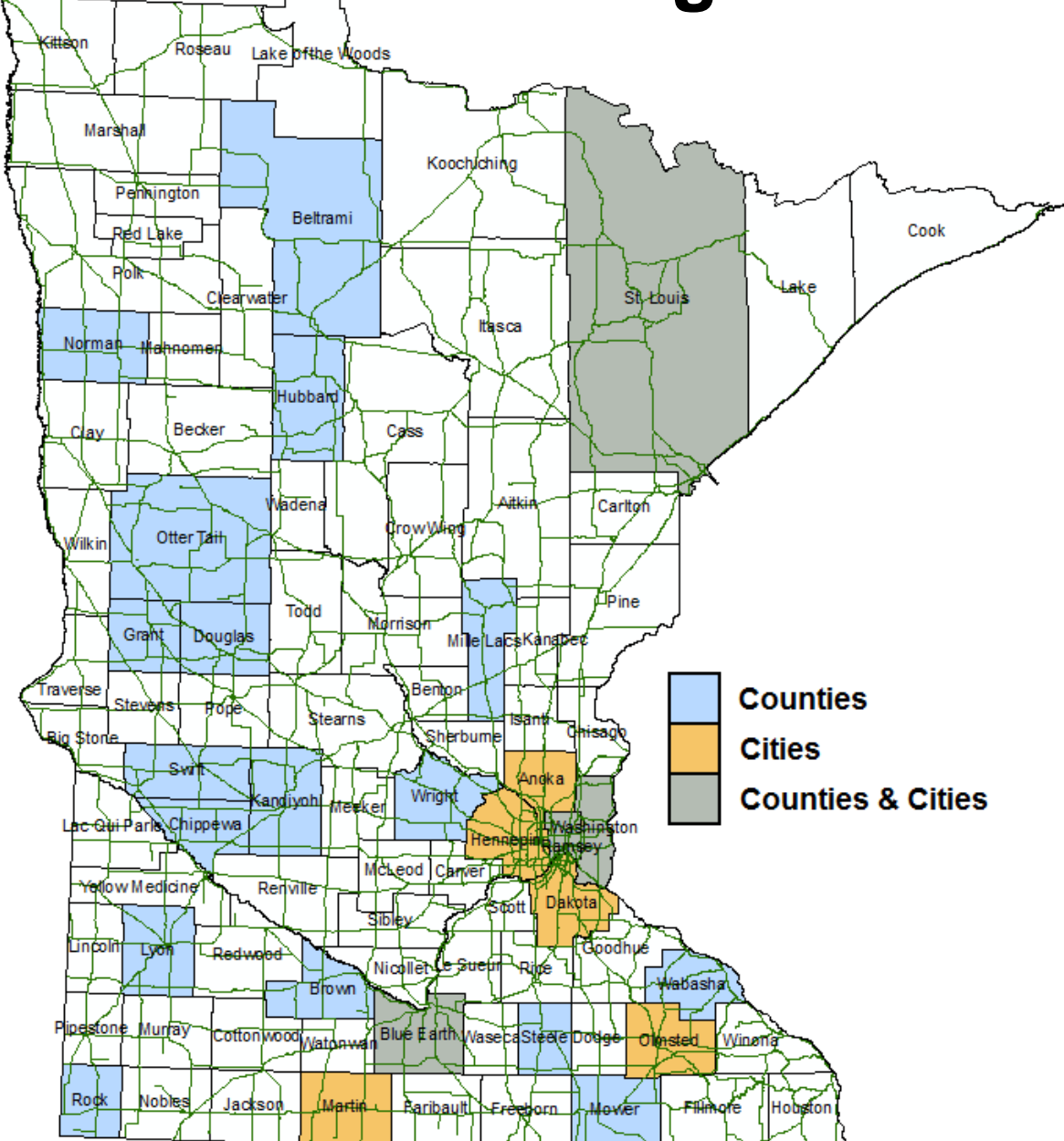
$$t = \ln\left(\frac{1}{Age}\right)$$



LRRB 828



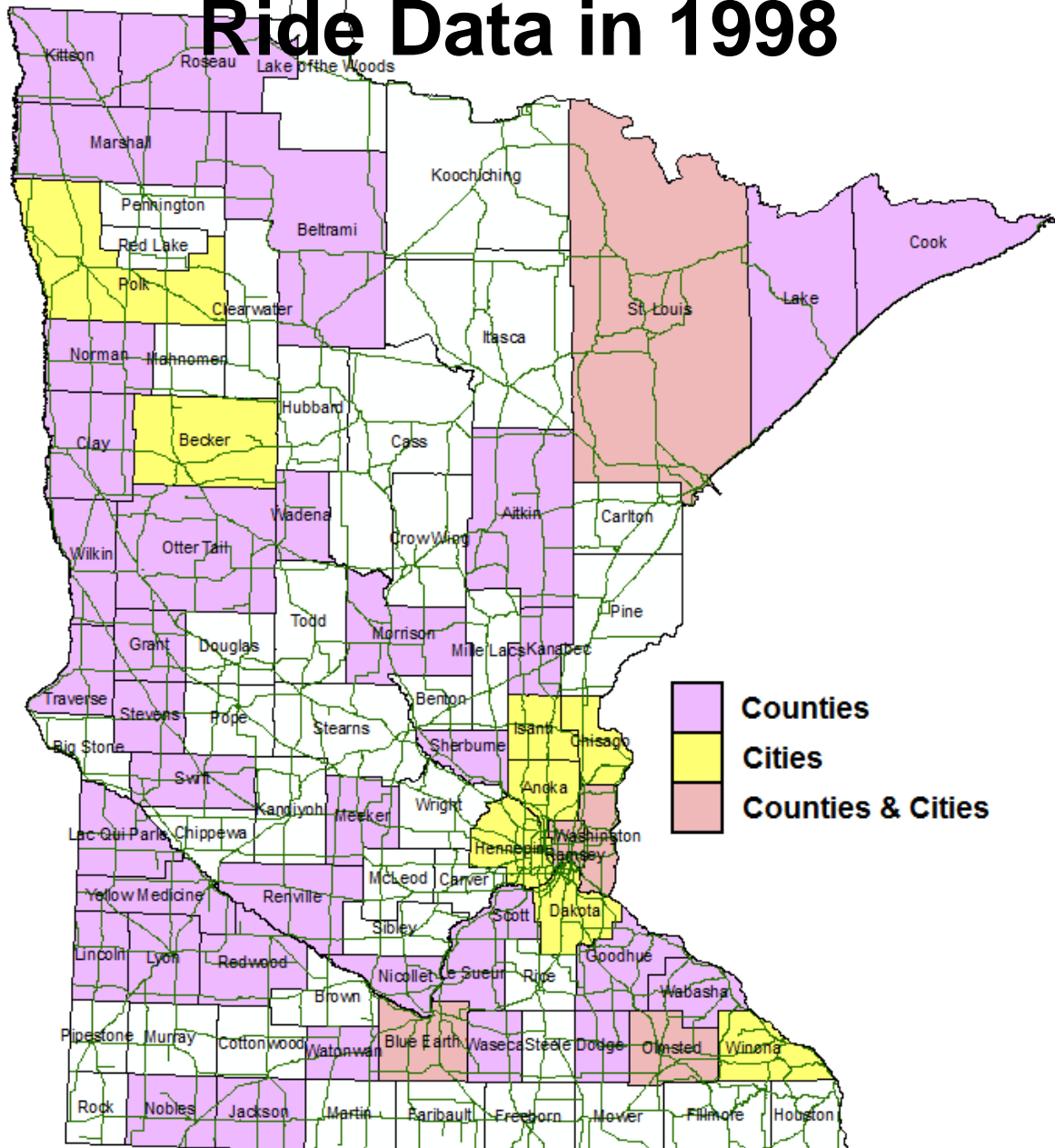
# Cities & Counties Using PMS in 1998







# Cities & Counties Collecting Ride Data in 1998



# Other Development Tools

- GIS – Geographic Information System
  - Roads
  - Soils
  - Groundwater
- MPS – Materials Performance System
  - Soil and Aggregate Test Results
  - Pavement History
  - FWD
  - Traffic



# Future Work

- Refine transfer functions
- Expand procedure to cover rehabilitation
  - Overlays
  - CIR
  - Rubblization
- Performance specifications
- Further work needed to characterize modified base gradations, select granular, Superpave, etc.





# Questions

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