NC STATE UNIVERSITY

Stress Sweep Rutting (SSR) Test: AMPT

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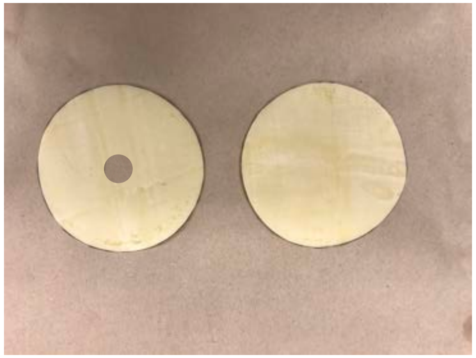
Topics

- **Overview:** the basics of the SSR experiment
- **Research:** development and verification
- **Practical:** draft standard specification

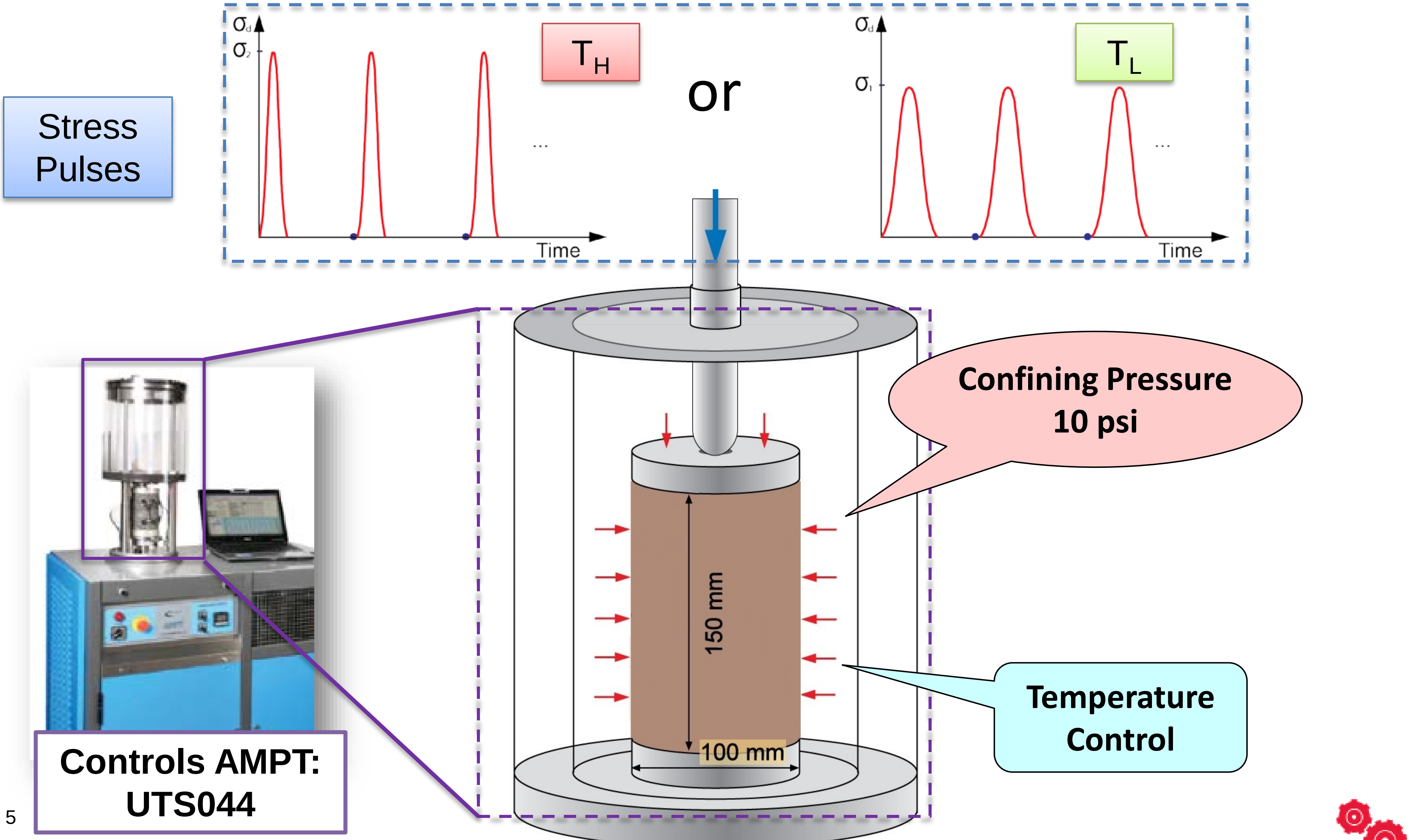
What is the Stress Sweep Rutting (SSR) Experiment?

- AMPT compatible test for rutting performance
  - RLPD and TRLPD (Flow number), Creep test (Flow time), iRLPD
- Test parameters
  - **Specimen**: 100 mm dia. x 150 mm tall specimen cut and cored from 150 mm dia. x 180 mm tall gyratory sample
  - **Test temperature**: T_H and T_L
  - **Loading**: axial compression cyclic test under 10 psi confining pressure (UTS044 in Controls AMPT)
    - <u>Loading time</u> = 0.4 seconds
    - <u>Rest period</u> = 3.6 seconds for T_H and 1.6 seconds for T_L
    - <u>Deviator stress</u> = 100, 70, and 130 psi for T_H and 70, 100, and 130 psi for T_L
    - <u>Measurements taken</u> = applied load and actuator displacement
- Two samples for each temperature for a total of four samples in one day

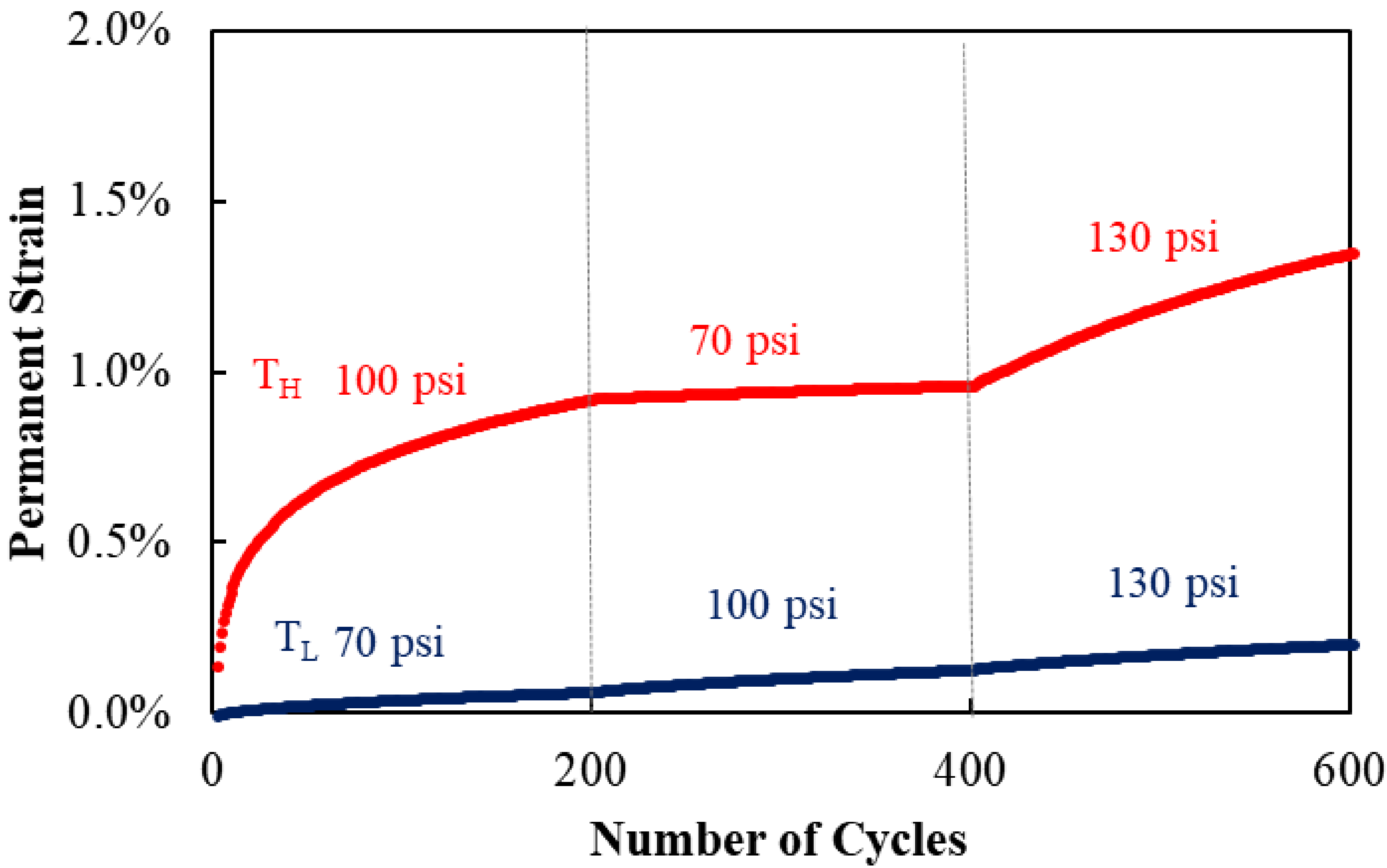
SSR Experiment Setup



SSR Experiment

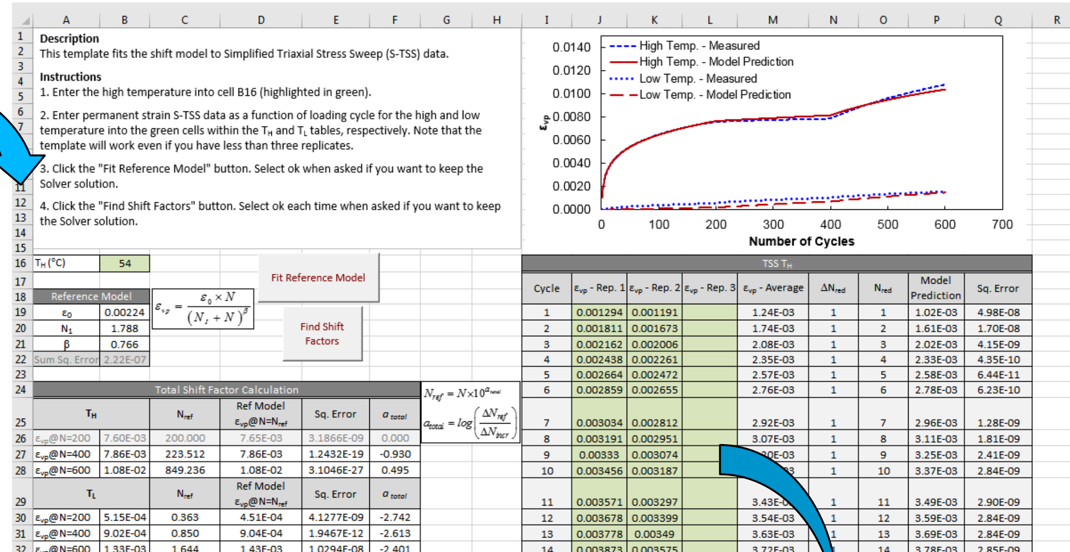


SSR Experiment Outcome

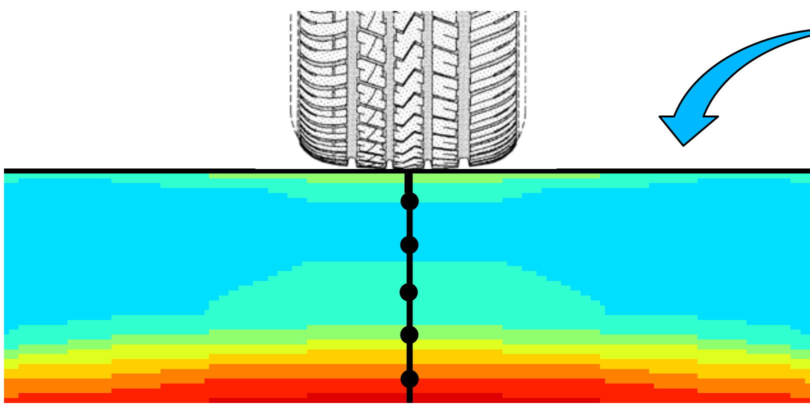


Why Stress Sweep Rutting (SSR) Test?

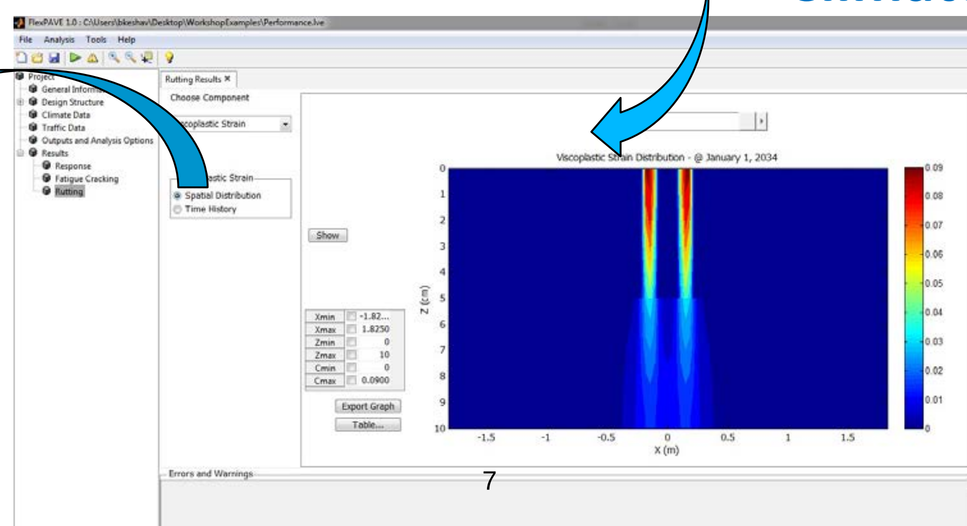
SSR Test in AMPT



✓ Structure ✓ Traffic ✓ Climate



Rutting Prediction



Topics

- **Overview:** the basics of the SSR experiment
- **Research:** development and verification
- **Practical:** draft standard specification

Where did this test come from?

- Origins in NCHRP 9-19 and DTFH61-03-H-00116 where the effect of repeated pulses of load, wave shape, temperature, rest period, etc. were examined
- More directly
  1. **Multiple TRLPD** tests at different load durations, load levels, and temperatures → Established a model form
  2. **Triaxial stress sweep test** (TSS) using repeated stress pulses of varying magnitude at multiple temperatures and one TRLPD test at a reference condition → Simplified testing
  3. **Stress sweep rutting** (SSR) using repeated stress pulses of varying magnitude, pulse time, and temperatures → Further simplified testing

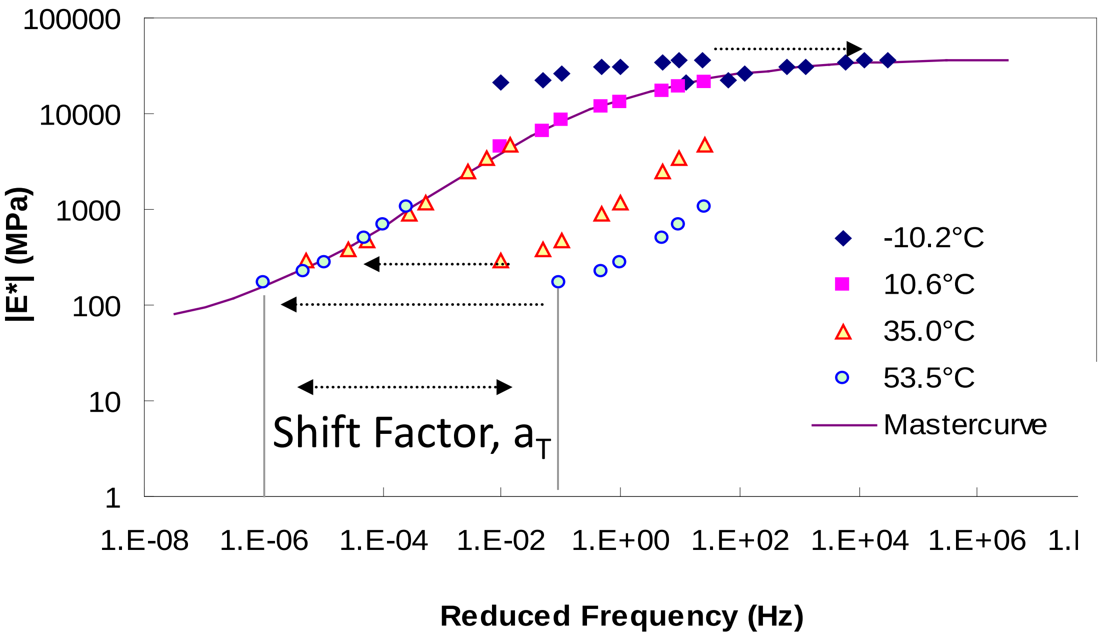
Model Foundation and Experimental Evolution

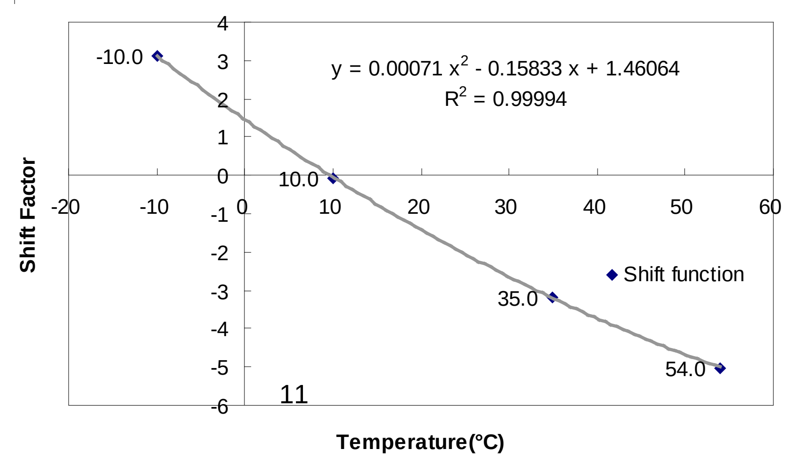
- Model basis:
  - The **equivalence of loading frequency and temperature** in permanent strain accumulation.
  - The **equivalence of stress level and number of loading repetitions** in permanent strain accumulation.

Equivalence of Loading Frequency and Temperature – *Linear Viscoelasticity*

Time (loading frequency) and temperature are interchangeable.

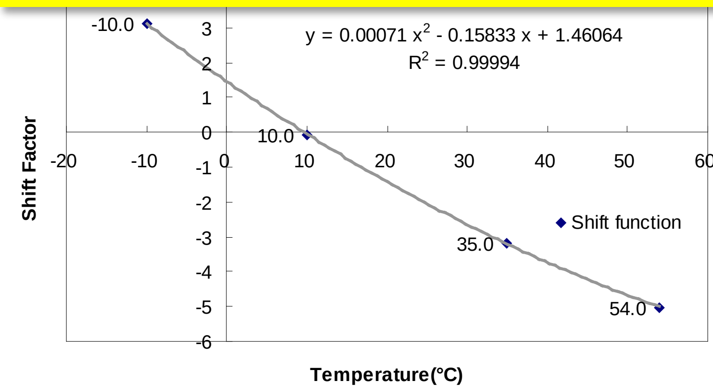
- Create a continuous mastercurve by horizontally shifting data from different temperatures

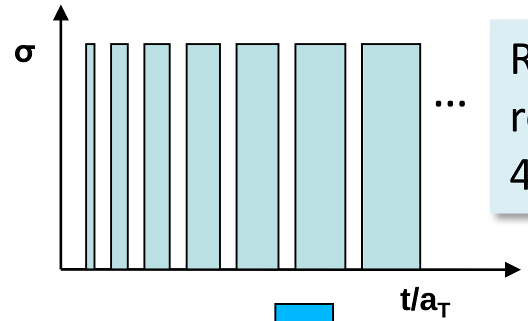




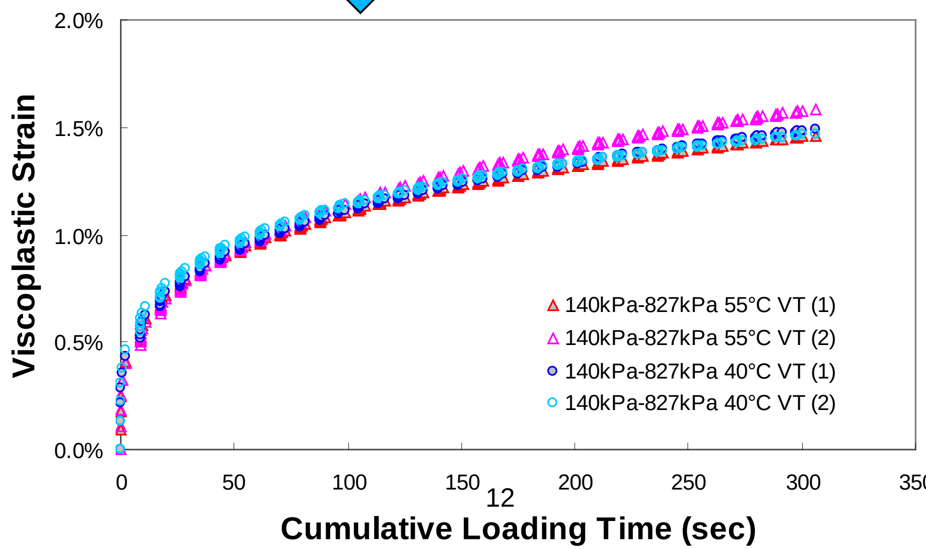
Equivalence of Loading Frequency and Temperature – *with Damage*

Time-temp. shift factor from |E*| test





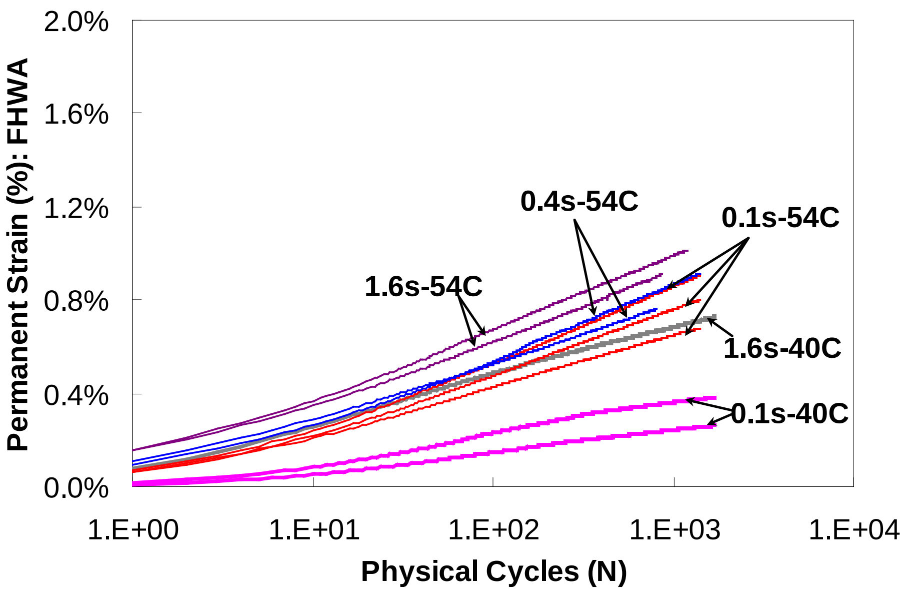
Repeated creep and recovery test at 40° and 55°C



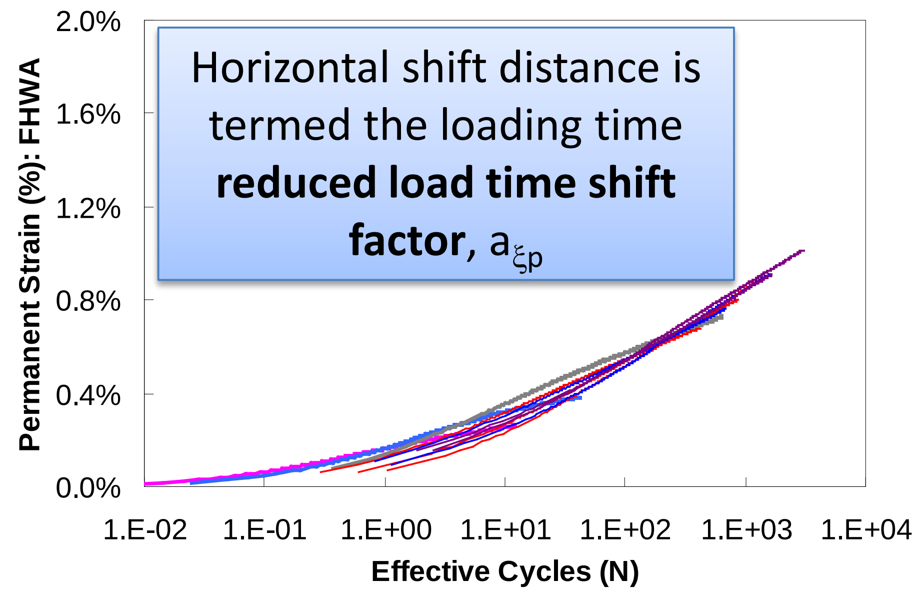
Equivalence of Loading Frequency and Temperature – *with Plastic Strains*

- Experiments = Multiple TRLPD at 90 psi deviatoric but with varying loading times and temperatures.

FHWA ALF Control 90 psi



After Shifting
Reference: 0.1s-54°C

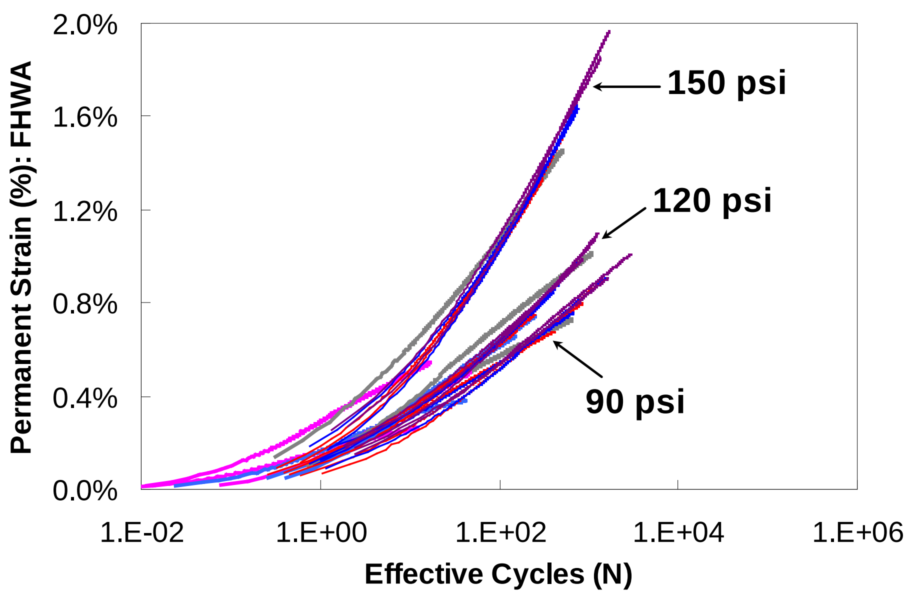


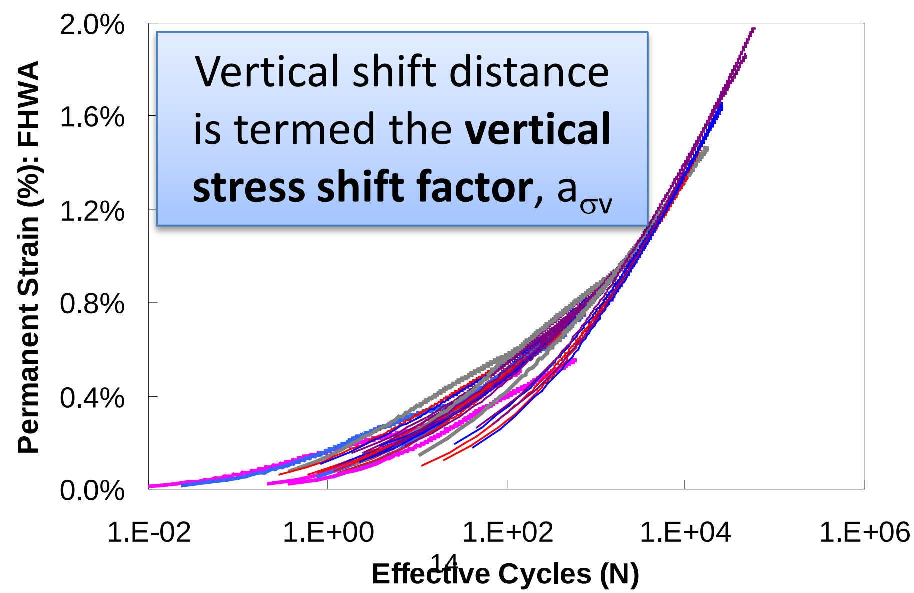
Equivalence of Stress Level and Number of Loading Repetitions

- Experiments = Multiple TRLPD at varying deviatoric stresses and with varying loading times and temperatures.

After Load Time Shifting

Mastercurve at 90 psi





Shift Model for Rutting

$$\varepsilon_{vp} = \frac{\varepsilon_0 \times N_{red}}{\left(N_I + N_{red}\right)^{\beta}}$$

Describes permanent strain evolution at the shifted, or reference condition

$$N_{red} = N \times 10^{a_{\xi p}} \times 10^{a_{\sigma v}}$$

$$a_{\xi_p} = p_1 \log\left(\xi_p\right) + p_2$$

$$a_{\sigma_v} = D \times \left(\log\left(\sigma_v / P_a\right) - 0.877\right)$$

$$D = d_1 \times T + d_2$$

$$N_{red} = N\left[\left(10^{p_2} \times 10^{-0.877D}\right)\left(\frac{\xi_p}{1}\right)^{p_1}\left(\frac{\sigma_v}{P_a}\right)^{D}\right]$$

Explains how cycle wise repetitions at a given loading time and temperature are equivalent to those repetitions at the reference condition

Shift Model for Rutting

$$\varepsilon_{vp} = \frac{\varepsilon_0 \times N_{red}}{\left(N_I + N_{red}\right)^{\beta}}$$

$$N_{red} = N \times 10^{a_{\xi_p}} \times 10^{a_{\sigma_v}}$$

$$a_{\xi_p} = p_1 \log\left(\xi_p\right) + p_2$$

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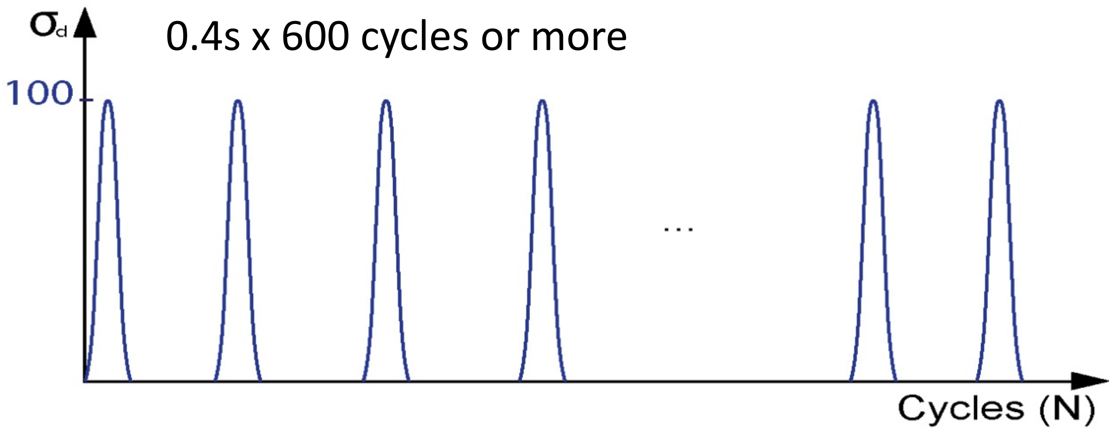
$$D = d_1 \times T + d_2$$

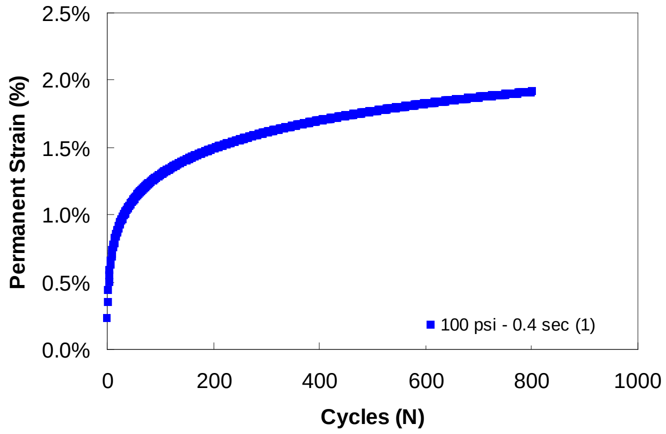
$$N_{red} = N\left[\left(10^{p_2} \times 10^{-0.877D}\right)\left(\frac{\xi_p}{1}\right)^{p_1}\left(\frac{\sigma_v}{P_a}\right)^{D}\right]$$

- With Multiple TRLPD tests shifting and fitting of the results yields the variables circled here.
- **Problem:** Testing is extensive as TRLPD must be run in its entirety for multiple temperatures, pulse times, and stress levels.

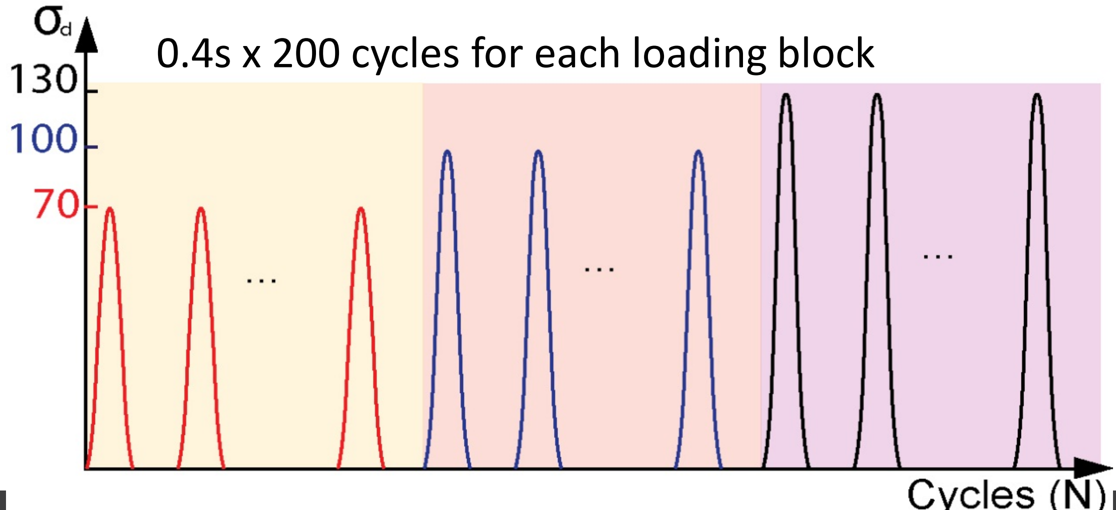
Triaxial Stress Sweep (TSS) Test

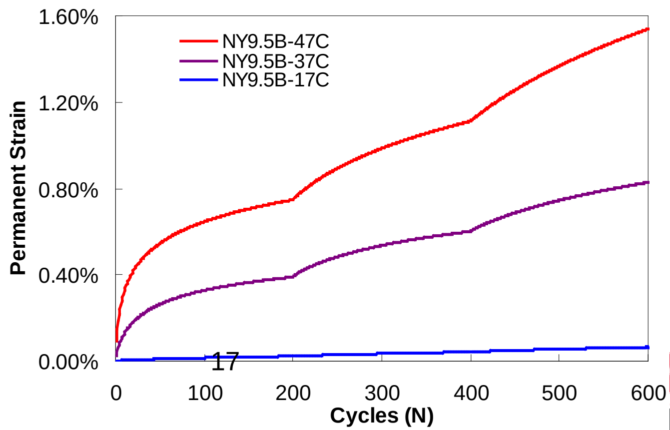
Reference Test (T_H)





Stress Sweep Test at T_H, T_I, T_L





Shift Model for Rutting

$$\varepsilon_{vp} = \frac{\varepsilon_0 \times N_{red}}{\left(N_I + N_{red}\right)^{\beta}}$$

Characterized using reference test at T_H

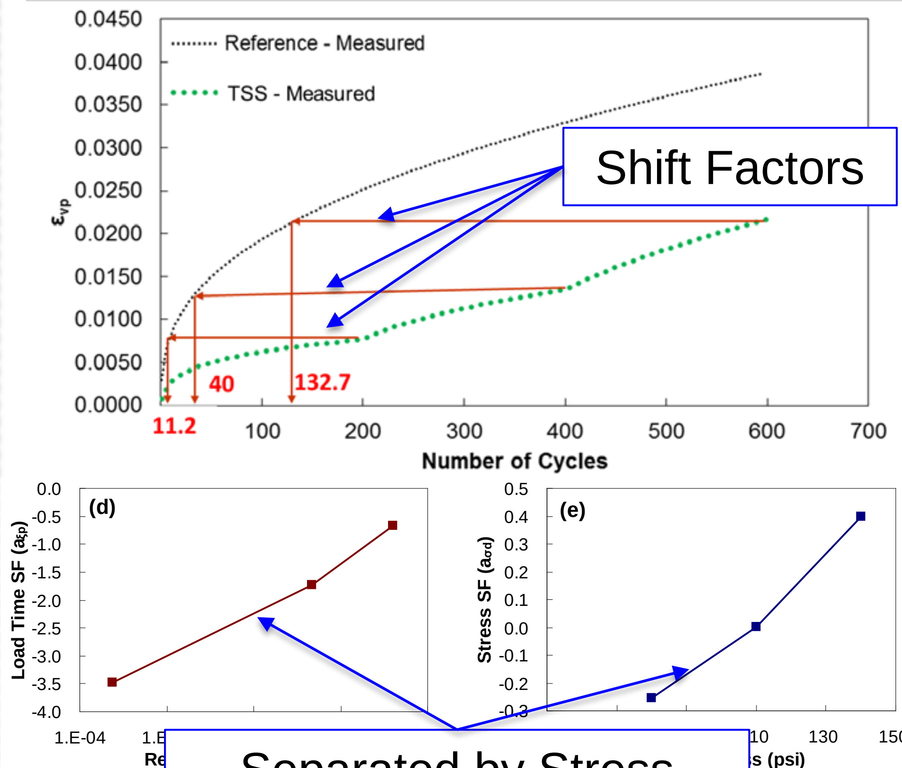
$$N_{red} = N \times 10^{a_{\xi_p}} \times 10^{a_{\sigma_v}}$$

$$a_{\xi_p} = p_1 \log\left(\xi_p\right) + p_2$$

$$a_{\sigma_v} = D \times \left(\log\left(\sigma_v / P_a\right) - 0.877\right)$$

$$D = d_1 \times T + d_2$$

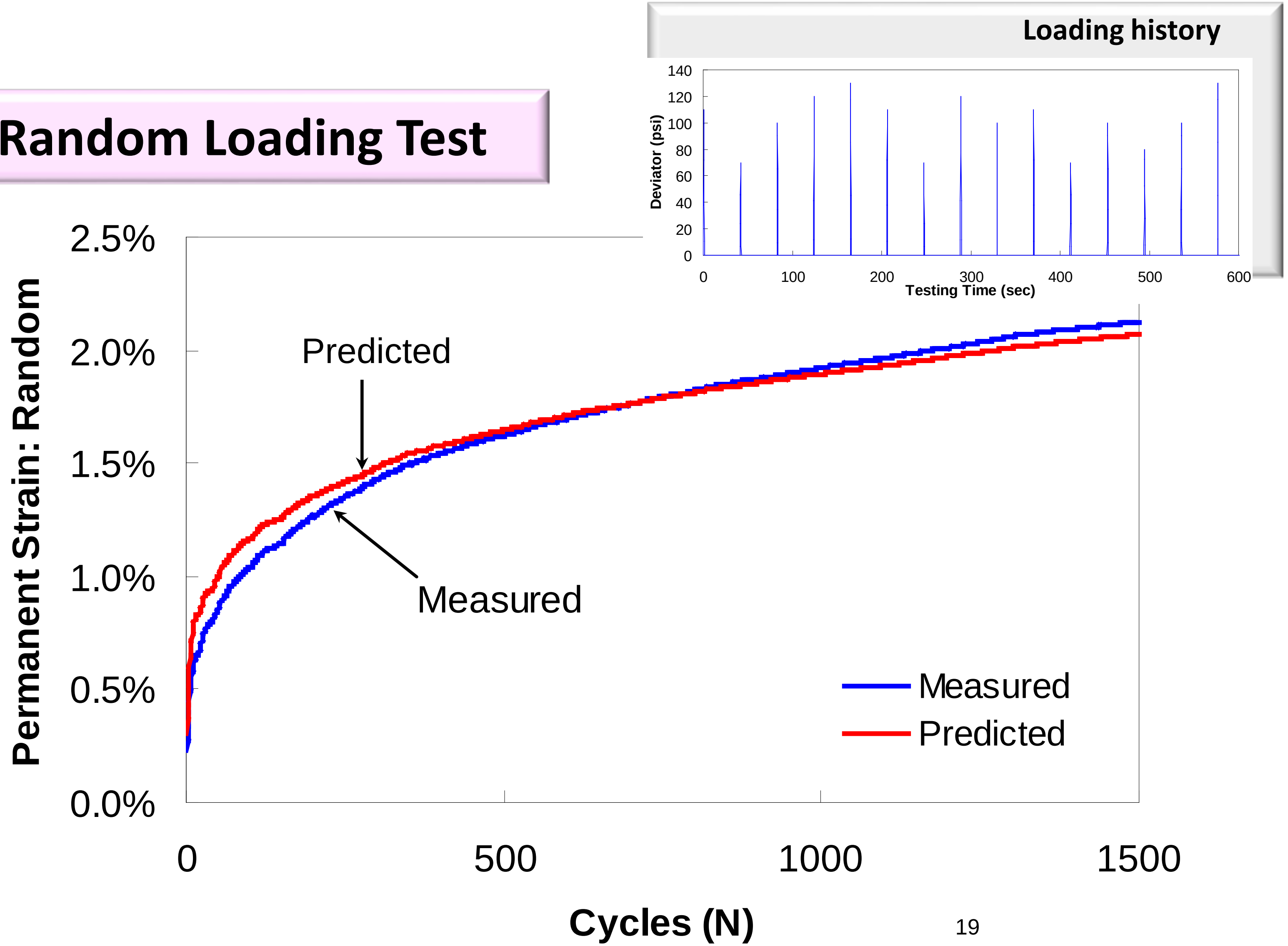
$$N_{red} = N\left[\left(10^{p_2} \times 10^{-0.877 D}\right)\left(\frac{\xi_p}{1}\right)^{p_1}\left(\frac{\sigma_v}{P_a}\right)^{D}\right]$$



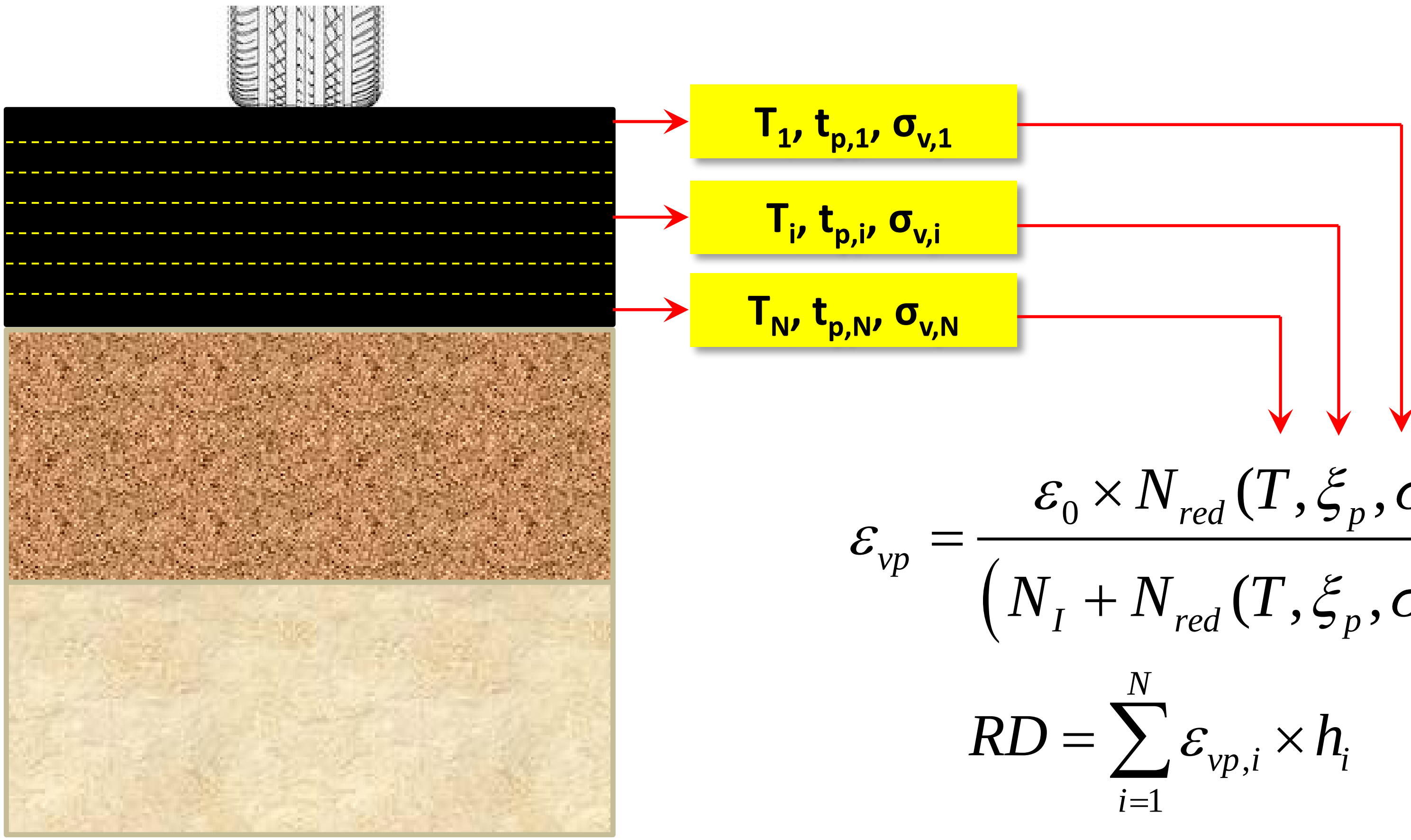
Separated by Stress Level and Temperature

Model Verification

Random Loading Test



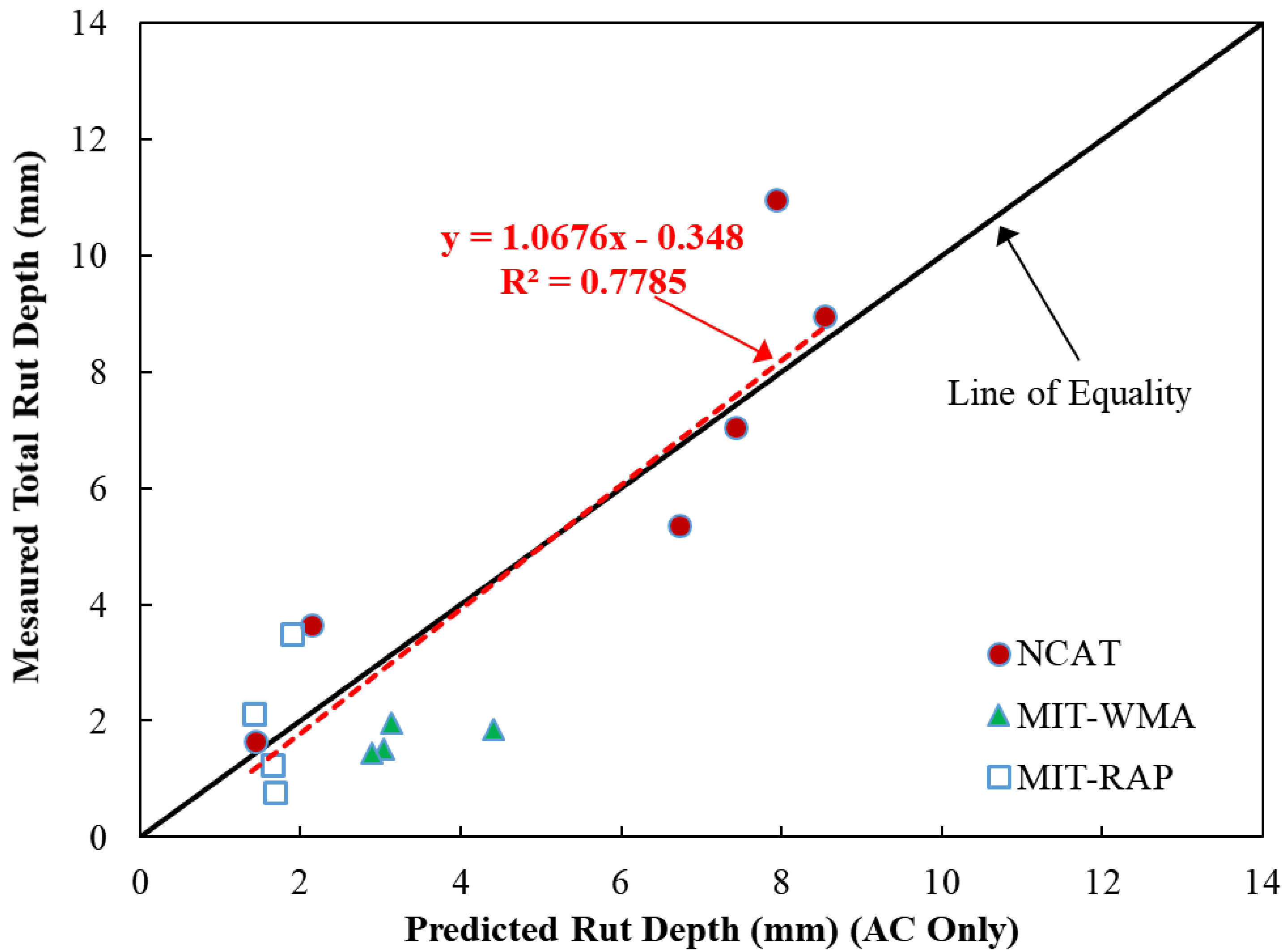
Shift Model in FlexPAVE^{TM}



$$\varepsilon_{vp} = \frac{\varepsilon_0 \times N_{red}(T, \xi_p, \sigma_v)}{\left(N_I + N_{red}(T, \xi_p, \sigma_v)\right)^{\beta}}$$

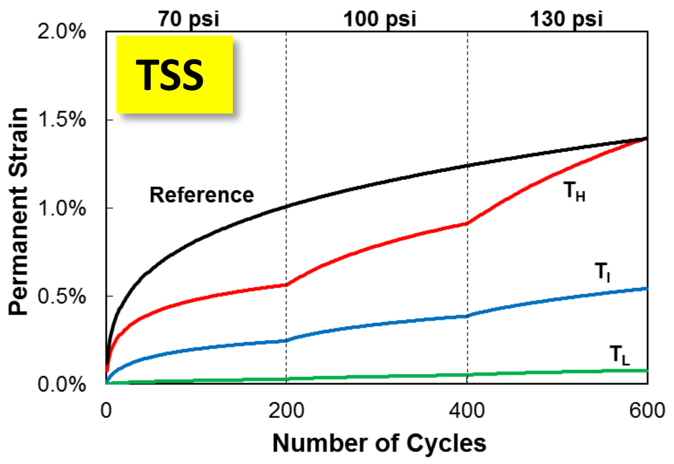
$$RD = \sum_{i=1}^{N} \varepsilon_{vp,i} \times h_i$$

Rutting Prediction by TSS/FlexPAVE™



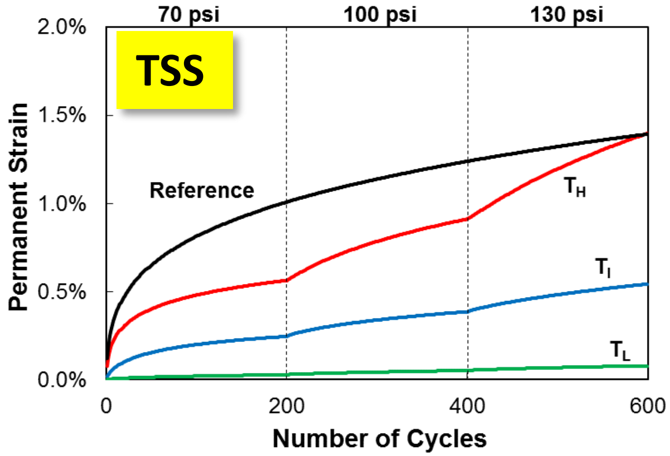
Simplification of TSS to SSR

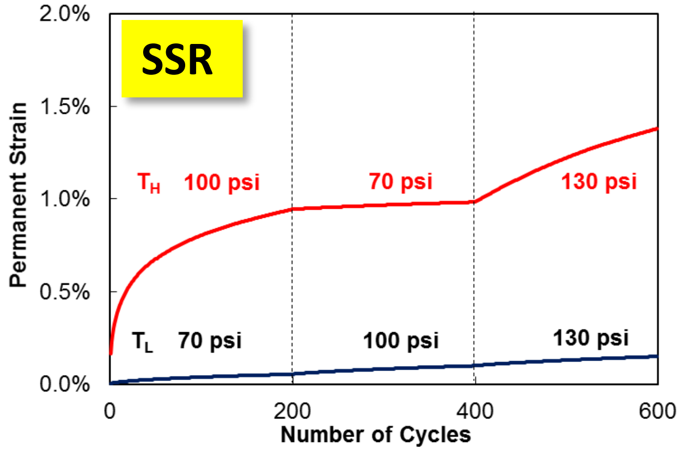
Test Method	TSS
Reference	1 (T_H)
Temp.	3 (T_H, T_I, and T_L)
Pulse Time (s)	0.4
Rest Period (s)	10 (T_H), 1.6 (T_I) 1.6 (T_L)
Deviator Stress (psi)	70, 100, 130 (T_H and T_L)
Number of Samples	8 (2 replicates of each experiment)
Displacement Measurement	On-specimen LVDTs
Testing Time incl. Pre-conditioning	16 hrs for 8 TSS experiments



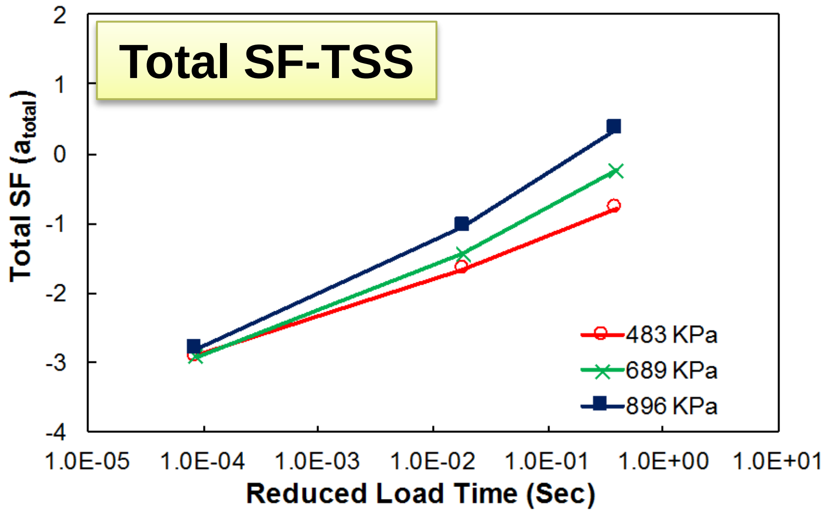
Simplification of TSS to SSR

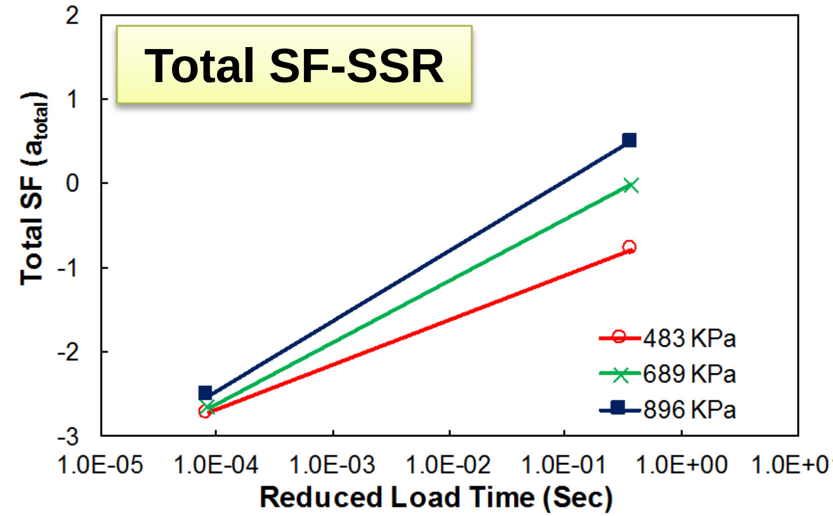
Test Method	TSS	SSR
Reference	1 (T_H)	-
Temp.	3 (T_H, T_I, and T_L)	2 (T_H and T_L)
Pulse Time (s)	0.4	0.4
Rest Period (s)	10 (T_H), 1.6 (T_I) 1.6 (T_L)	3.6 (T_H) 1.6 (T_L)
Deviator Stress (psi)	70, 100, 130 (T_H and T_L)	100, 70, 130 (T_H) 70, 100, 130 (T_L)
Number of Samples	8 (2 replicates of each experiment)	4 (2 replicates of each experiment)
Displacement Measurement	On-specimen LVDTs	Actuator
Testing Time incl. Pre-conditioning	16 hrs for 8 TSS experiments	6 hrs for 4 SSR experiments

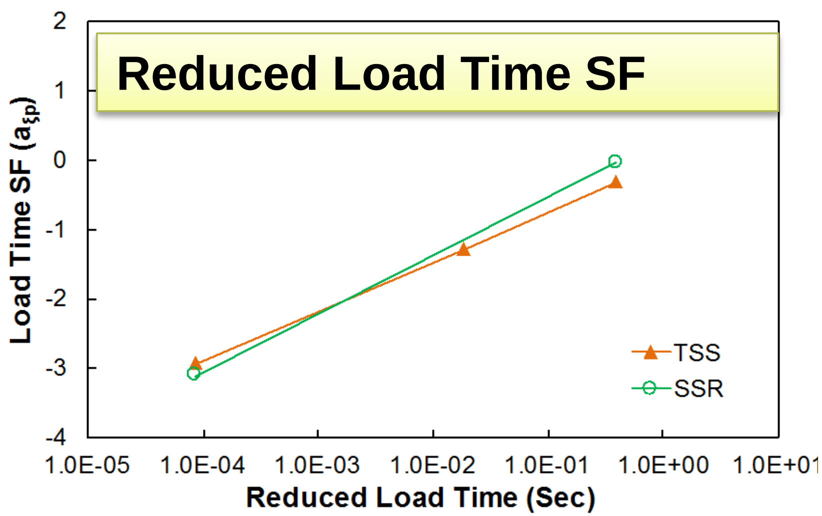


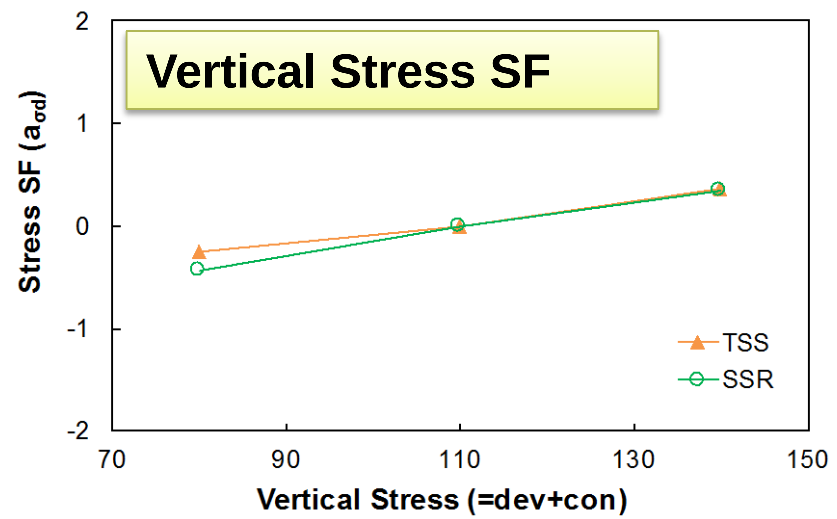


Shift Factors between TSS and SSR





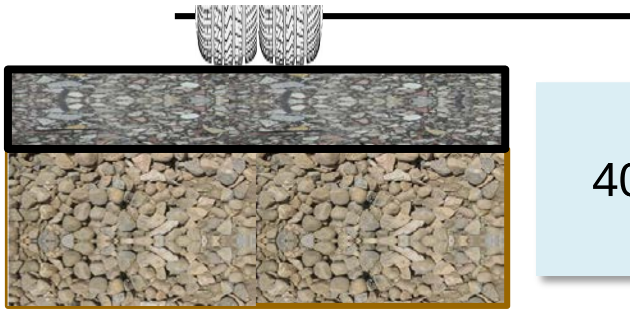




Effects of Simplifications on Rut Depths Predicted by FlexPAVE^{TM}

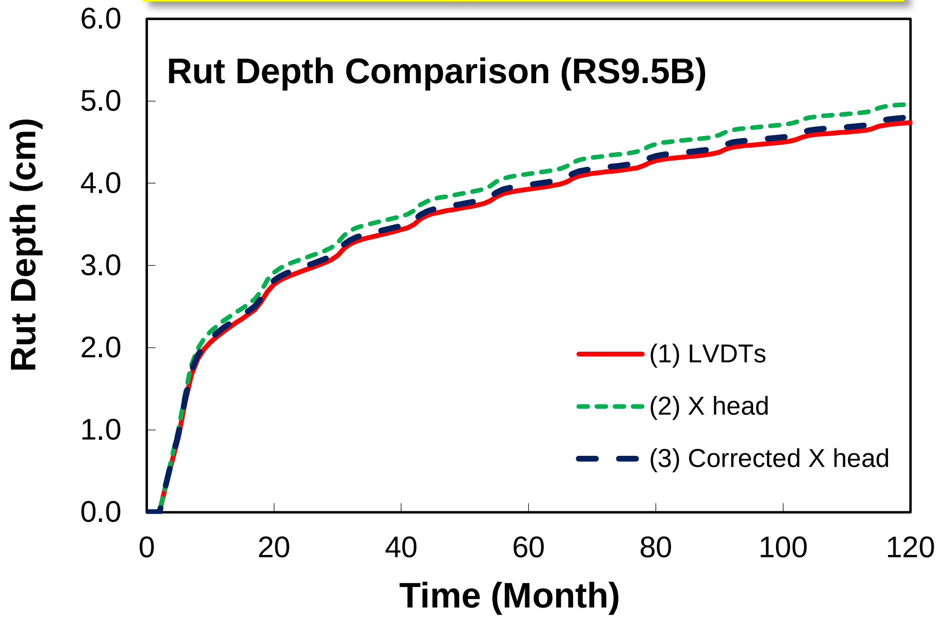
4 in. RS9.5B

10 in.
Aggregate Base

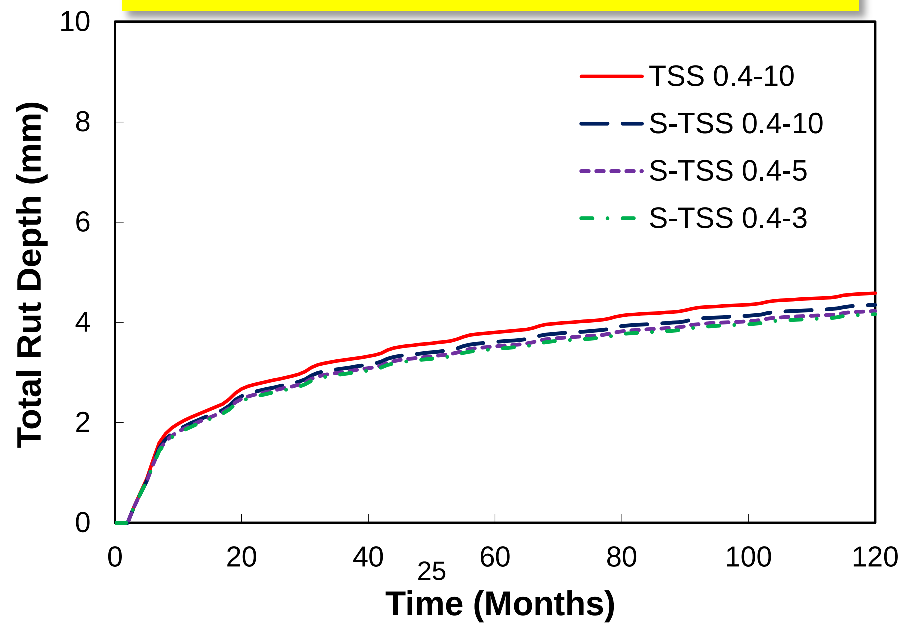


700 AADTT
40 kN wheel load
Raleigh, NC

Actuator Displacement vs. LVDT



Temperature, Reversed Loading Block, and Rest Periods



Draft AASHTO SSR Specification

Standard Method of Test for

STRESS SWEEP RUTTING (SSR) TEST USING ASPHALT MIXTURE PERFORMANCE TESTER (AMPT)

AASHTO Designation: TP xxx-xx

1 SCOPE

1.1 This standard describes a test method to characterize the resistance of asphalt mixtures to rutting using the shift model. The stress sweep rutting (SSR) tests are conducted using the Asphalt Mixture Performance Tester (AMPT).

Overview of SSR

Test Parameter	Quantity
Equipment	AMPT
Temperature	2 (T_H and T_L)
Pulse Time (s)	0.4
Rest Period (s)	3.6 (T_H) or 1.6 (T_L)
Deviator Stress (psi)	100, 70, 130 (T_H) or 70, 100, 130 (T_L)
Displacement Measurement	Actuator
Test Outputs	ε_0, N_I, β, d_1, d_2, p_1, and p_2
Replicates	2
Testing Time incl. Pre-conditioning	6 hrs for 4 SSR tests

Test Temperature Update

$$T_H = 0.87(58 + 7 \times DD \; - 15 \times \log(H + 45))$$

T_H = high test temperature, °C,
DD = Degree-Days >10°C (×1000) from **LTPPBind v 3.1**, and
H = depth of layer, mm (0 for surface layer).

$$T_L = \frac{T_{HPG,98\%} + T_{LPG,50\%}}{2} + 4$$

T_L = low test temperature, °C, and
$T_{HPG,98\%}$ = continuous high temperature grade for 98% reliability
$T_{LPG,50\%}$ = continuous low temperature grade for 50% reliability

Draft AASHTO SSR Specification

Updates from first ETG review

- Wording modified to be consistent with AASHTO T378
    - Maximum aggregate size, High vacuum grease, Balances requirements, Dummy specimen preparation, Latex membrane preparation moved to Annex A, Calibration section, Air void content
- Samples must be compacted to 150 mm diameter x 180 mm tall height with the gyratory compactor, and then test specimens cored and cut from these.
- Calculation section completely rewritten so that it is easier to follow and conduct the analysis.

Section 10 Updates

$$\varepsilon_{vp} = \frac{\varepsilon_0 \times N_{red}}{\left(N_I + N_{red}\right)^{\beta}}$$

$$N_{red} = N \times 10^{a_{\xi_p}} \times 10^{a_{\sigma_v}}$$

$$a_{\xi_p} = p_1 \log\left(\xi_p\right) + p_2$$

$$a_{\sigma_v} = D \times \left(\log\left(\sigma_v / P_a\right) - 0.877\right)$$

$$D = d_1 \times T + d_2$$

$$N_{red} = N\left[\left(10^{p_2} \times 10^{-0.877D}\right)\left(\frac{\xi_p}{1}\right)^{p_1}\left(\frac{\sigma_v}{P_a}\right)^{D}\right]$$

- Section 10 describes the calculation process to obtain coefficients, ε_0, β, N_I, d_1, d_2, p_1, and p_2.
- FlexMat™ Rutting mentioned
- With these quantities a user can run FlexPave™ to predict the rutting of a pavement.
- Annex B also includes a method to use the model to predict permanent strain as possible index parameter.

Section 10: Calculations

$$\varepsilon_{vp} = \frac{\varepsilon_0 \times N_{ref}}{\left(N_I + N_{ref}\right)^{\beta}}$$

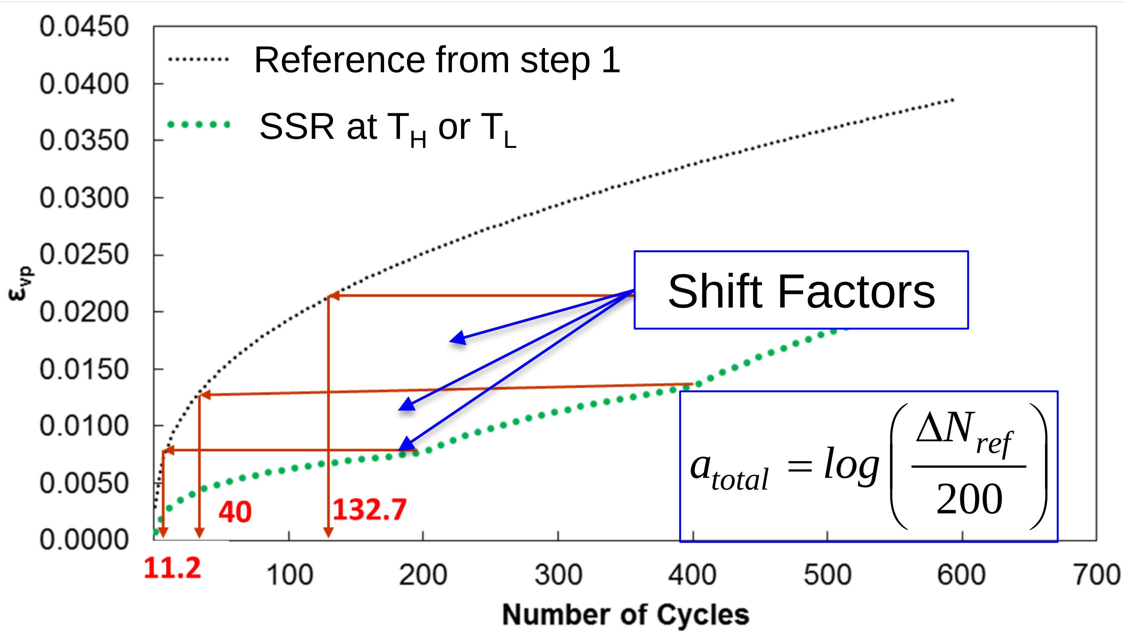
↓

Finding ε_0, β, and N_I from Reference Curve

↓

$$N_{ref} = N \times 10^{a_{total}}$$

1. Construct the reference curve (Sec. 10.3)
   - Using optimization based on the 100 psi loading block at T_H
2. Compute the total shift factor (Sec. 10.4)



Section 10: Calculations

$$\varepsilon_{vp} = \frac{\varepsilon_0 \times N_{ref}}{\left(N_I + N_{ref}\right)^{\beta}}$$

Finding $\varepsilon_{0,} \beta$, and N_I from Reference Curve

$$N_{ref} = N \times 10^{a_{total}}$$

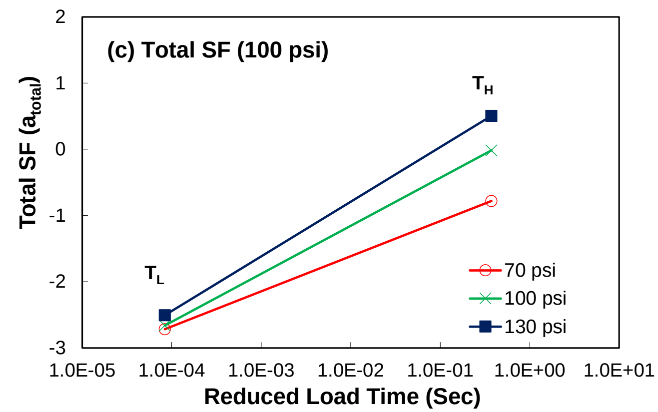
$$a_{total} = a_{\xi_p} + a_{\sigma_v}$$

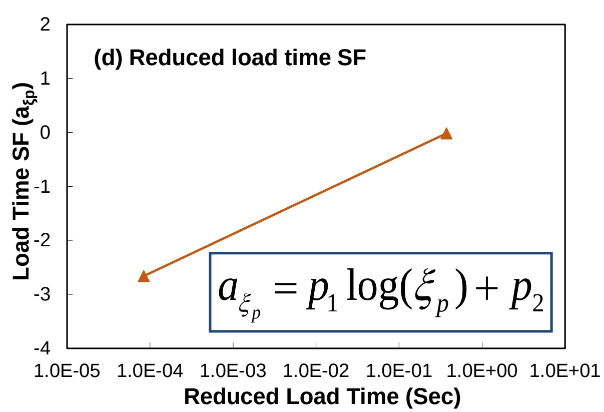
$$N_{ref} = A \cdot N \left(\frac{\xi_p}{1}\right)^{p1} \left(\frac{\sigma_v}{P_a}\right)^{D}$$

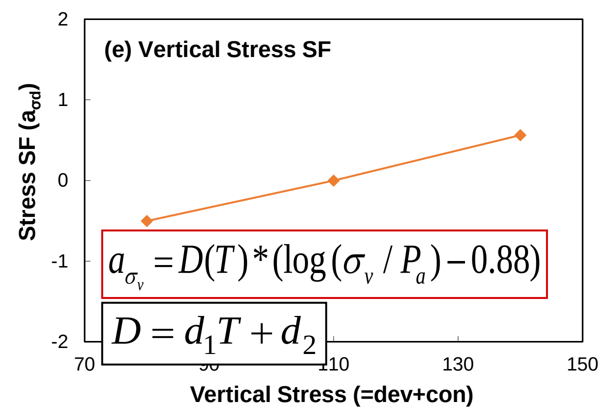
$$A = 10^{p_2} \times 10^{-0.877D}$$

$$D = d_1 T + d_2$$

3. Compute the reduced time shift factor and vertical stress shift factor (Sec. 10.5 & 10.6)







FlexMAT™-Rutting

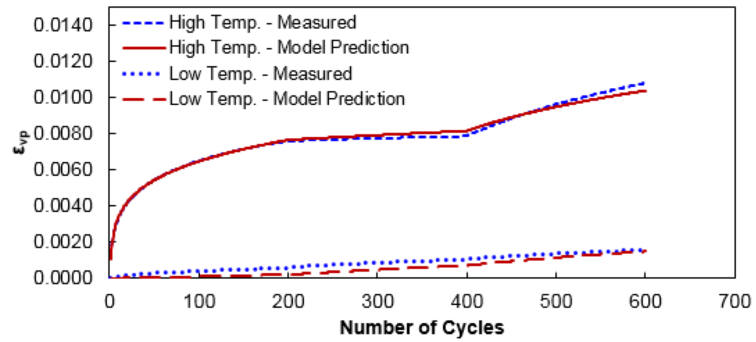
- Determines shift model coefficients from AMPT data files and generates input files for FlexPAVE™

Description

This template fits the shift model to Simplified Triaxial Stress Sweep (S-TSS) data.

Instructions

1. Enter the high temperature into cell B16 (highlighted in green).
2. Enter permanent strain S-TSS data as a function of loading cycle for the high and low temperature into the green cells within the T_H and T_L tables, respectively. Note that the template will work even if you have less than three replicates.
3. Click the "Fit Reference Model" button. Select ok when asked if you want to keep the Solver solution.
4. Click the "Find Shift Factors" button. Select ok each time when asked if you want to keep the Solver solution.



T_H (°C)	54

Fit Reference Model

Find Shift Factors

Reference Model	
ε_0	0.00224
N_1	1.788
β	0.766
Sum Sq. Error	2.22E-07

$$\varepsilon_{vp} = \frac{\varepsilon_0 \times N}{(N_I + N)^{\beta}}$$

Total Shift Factor Calculation

T_H		N_{ref}	Ref Model ε_{vp}@N=N_{ref}	Sq. Error	a_{total}
ε_{vp}@N=200	7.60E-03	200.000	7.65E-03	3.1866E-09	0.000
ε_{vp}@N=400	7.86E-03	223.512	7.86E-03	1.2432E-19	-0.930
ε_{vp}@N=600	1.08E-02	849.236	1.08E-02	3.1046E-27	0.495
T_L		**N_{ref}**	**Ref Model ε_{vp}@N=N_{ref}**	**Sq. Error**	**a_{total}**
ε_{vp}@N=200	5.15E-04	0.363	4.51E-04	4.1277E-09	-2.742
ε_{vp}@N=400	9.02E-04	0.850	9.04E-04	1.9467E-12	-2.613
ε_{vp}@N=600	1.33E-03	1.644	1.43E-03	1.0294E-08	-2.401

$$N_{ref} = N \times 10^{a_{total}}$$

$$a_{total} = \log\left(\frac{\Delta N_{ref}}{\Delta N_{incr}}\right)$$

TSS T_H

Cycle	ε_{vp} - Rep. 1	ε_{vp} - Rep. 2	ε_{vp} - Rep. 3	ε_{vp} - Average	ΔN_{red}	N_{red}	Model Prediction	Sq. Error
1	0.001294	0.001191		1.24E-03	1	1	1.02E-03	4.98E-08
2	0.001811	0.001673		1.74E-03	1	2	1.61E-03	1.70E-08
3	0.002162	0.002006		2.08E-03	1	3	2.02E-03	4.15E-09
4	0.002438	0.002261		2.35E-03	1	4	2.33E-03	4.35E-10
5	0.002664	0.002472		2.57E-03	1	5	2.58E-03	6.44E-11
6	0.002859	0.002655		2.76E-03	1	6	2.78E-03	6.23E-10
7	0.003034	0.002812						
8	0.003191	0.002951						
9	0.00333	0.003074						
10	0.003456	0.003187						
11	0.003571	0.003297						
12	0.003678	0.003399						
13	0.003778	0.00349						
14	0.003873	0.003575						

Note: Old screenshot: Updated FlexMat™ Rutting sheet that is 508 compliant is currently being developed

Export Data to FlexPAVE™

Description: Provides a summary of the shift factor model coefficients, which can be exported as an input file to FlexPAVE. Not data entry is required.
Instructions: To export a FlexPAVE input file, press the **Export FlexPAVE Inputs** button.

Reference Model	
ε_0	0.00224
N_1	1.78777
β	0.76643

$$\varepsilon_{vp} = \frac{\varepsilon_0 \times N}{(N_I + N)^{\beta}}$$

$$\varepsilon_{vp} = \frac{\varepsilon_0 \times N_{red}}{(N_I + N_{red})^{\beta}}$$

$$N_{red} = A \cdot N \left(\frac{\xi_p}{1}\right)^{p1} \left(\frac{\sigma_v}{P_a}\right)^{d1}$$

$$A = 10^{p_2} \cdot 10^{d_2}$$

Export FlexPAVE Inputs

Reduced Load Time	
p_1	0.705
p_2	0.281

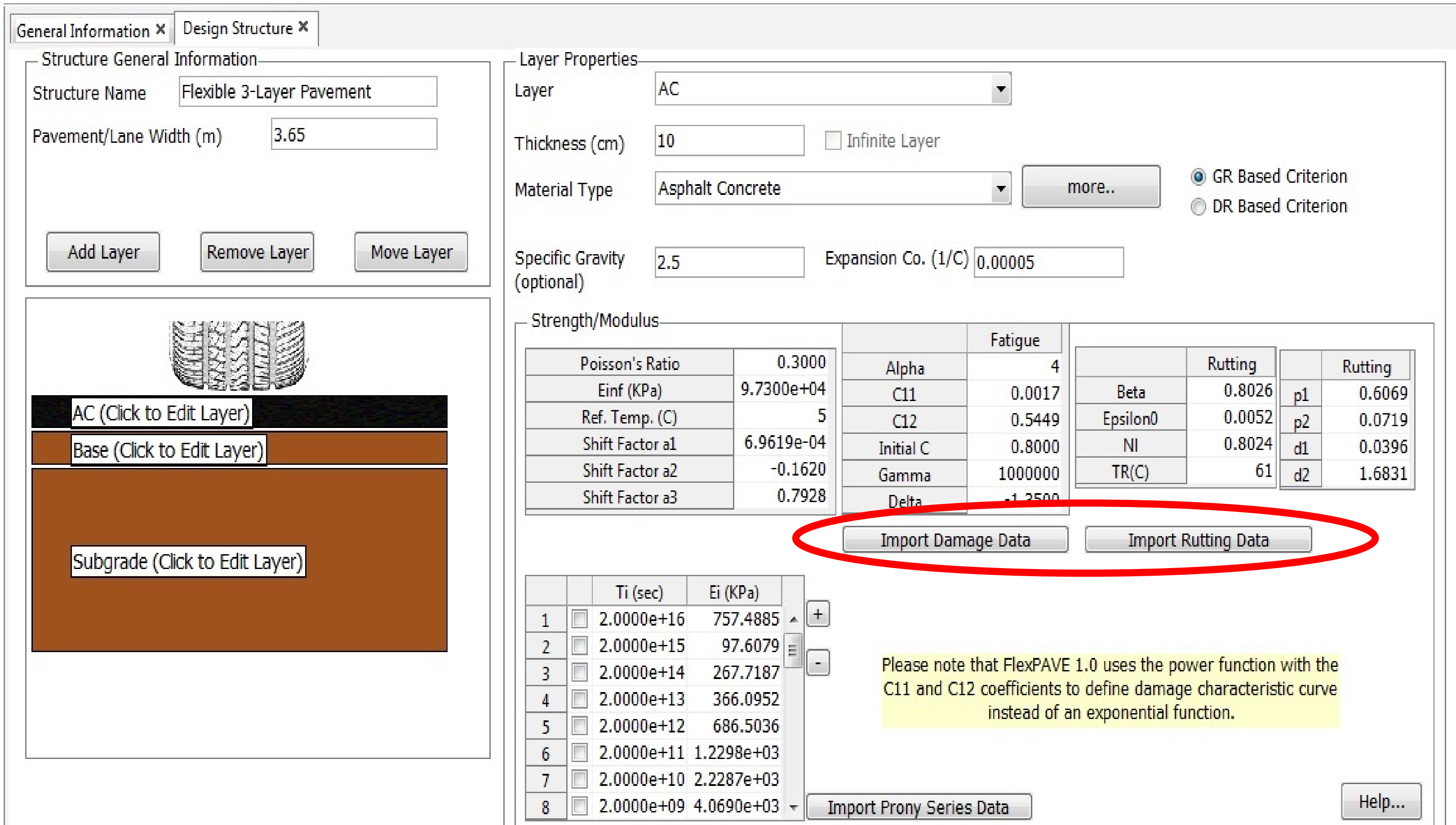
$$a_{\xi_p} = p_1 \log(\xi_p) + p_2$$

Vertical Stress Shift	
d_1	3.191
d_2	-2.782

$$a_{\sigma_v} = d_1 \log(\sigma_v / P_a) + d_2$$

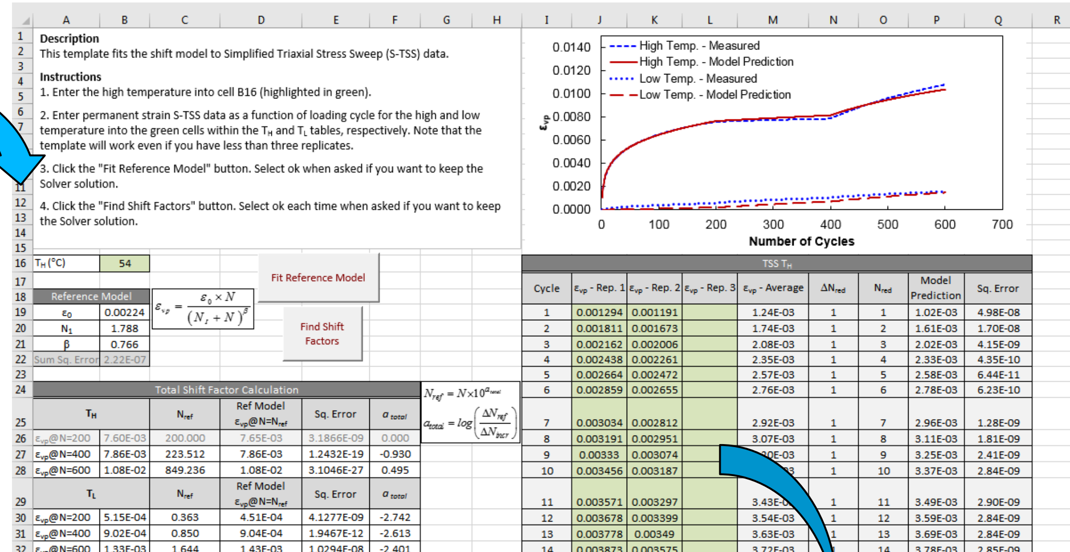
T_{ref} (°C)	54

Material Properties Input in FlexPAVE™

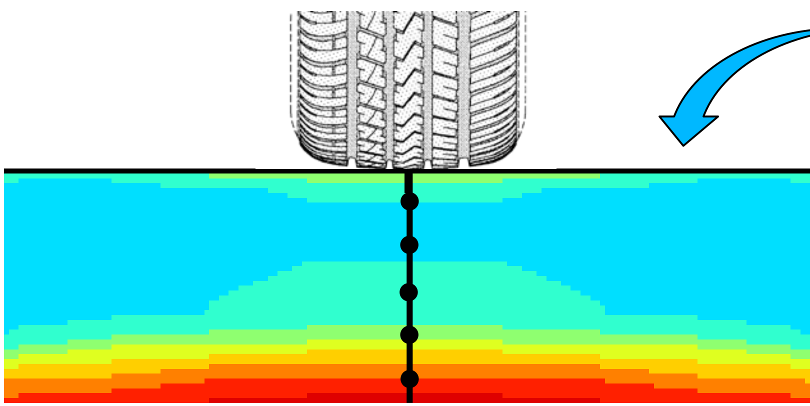


Stress Sweep Rutting (SSR) Test

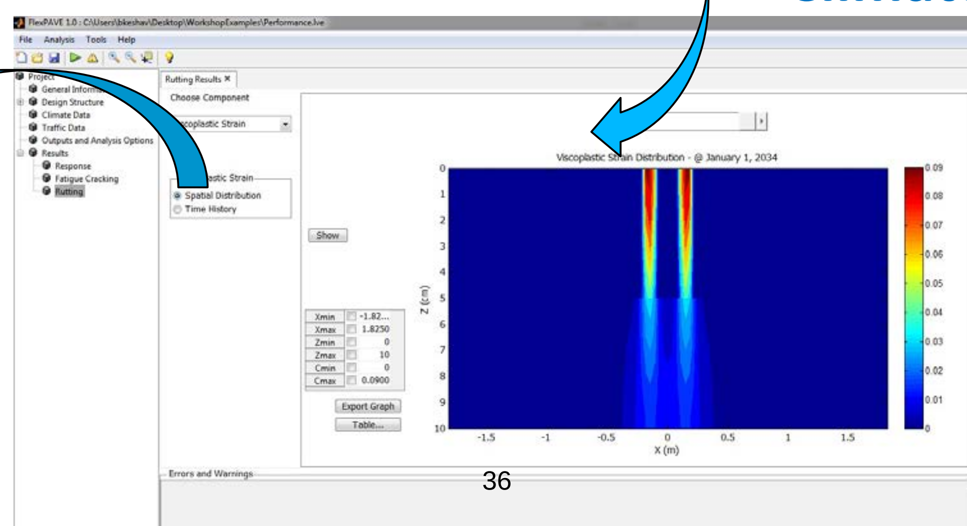
SSR Test in AMPT



✓ Structure ✓ Traffic ✓ Climate



Rutting Prediction



Thank you