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)
    - **Loading time** = 0.4 seconds
    - **Rest period** = 3.6 seconds for $T_H$ and 1.6 seconds for $T_L$
    - **Deviator stress** = 100, 70, and 130 psi for $T_H$ and 70, 100, and 130 psi for $T_L$
    - **Measurements taken** = applied load and actuator displacement

- Two samples for each temperature for a total of four samples in one day
SSR Experiment Setup
SSR Experiment

or

Stress Pulses

Confining Pressure
10 psi

Temperature Control

Controls AMPT: UTS044
SSR Experiment Outcome

![Graph showing the permanent strain over the number of cycles for different pressure conditions.]

- TH: 100 psi
- TL: 70 psi
- 100 psi
- 130 psi

Number of Cycles vs. Permanent Strain
Why Stress Sweep Rutting (SSR) Test?

- Structure
- Traffic
- Climate

SSR Test in AMPT

Rutting Prediction

Graph showing rutting prediction over different conditions.
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**

\[ y = 0.00071 x^2 - 0.15833 x + 1.46064 \]

\[ R^2 = 0.99994 \]

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

\[ \sigma \]

\[ t/a_T \]

- 10.0
- 10.
- 9.
- 8.
- 7.
- 6.
- 5.
- 4.
- 3.
- 2.
- 1.
0
1
2
3
4
5
6
7
8
9
10.

Temperature(°C)

- 20
- 10
0
10
20
30
40
50
60

Viscoplastic Strain

- 2.0%
- 1.5%
- 1.0%
- 0.5%
0.0%

Cumulative Loading Time (sec)

- 140kPa-827kPa 55°C VT (1)
- 140kPa-827kPa 55°C VT (2)
- 140kPa-827kPa 40°C VT (1)
- 140kPa-827kPa 40°C VT (2)
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**

Horizontal shift distance is termed the loading time reduced load time shift factor, $a_{ξp}$. 

![Graph showing permanent strain (%) vs. physical cycles (N) and effective cycles (N) for different loading times and temperatures.](image)
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

Vertical shift distance is termed the vertical stress shift factor, $a_{SV}$.
Shift Model for Rutting

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

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

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

\[ a_{\sigma_v} = D \times (\log(\sigma_v/P_a) - 0.877) \]

\[ D = d_1 \times T + d_2 \]

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

Describes permanent strain evolution at the shifted, or reference condition

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

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

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

- \( a_{\xi_p} = p_1 \log(\xi_p) + p_2 \)
- \( a_{\sigma_v} = D \times (\log(\sigma_v/P_a) - 0.877) \)

\[ D = d_1 \times T + d_2 \]

- 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 (\(T_H\))

- 0.4s x 600 cycles or more

Stress Sweep Test at \(T_H\), \(T_I\), \(T_L\)

- 0.4s x 200 cycles for each loading block
Shift Model for Rutting

\[ E_{vp} = \frac{\varepsilon_0 \times N_{\text{red}}}{(N_I + N_{\text{red}})^\beta} \]

\[ N_{\text{red}} = N \times 10^{a_{\xi_p}} \times 10^{a_{\sigma_v}} \]

\[ a_{\xi_p} = p_1 \log(\xi_p) + p_2 \]
\[ a_{\sigma_v} = D \times \left( \log\left( \frac{\sigma_v}{P_a} \right) - 0.877 \right) \]
\[ D = d_1 \times T + d_2 \]

Characterized using reference test at \( T_H \)

Shift Factors

Separated by Stress Level and Temperature
Model Verification

Random Loading Test

Permanent Strain: Random

Predicted

Measured

Cycles (N)

Measuring Time (sec)

Deviator (psi)

Measured
Predicted
Shift Model in FlexPAVE™

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

\[ RD = \sum_{i=1}^{N} \varepsilon_{vp,i} \times h_i \]
Rutting Prediction by TSS/FlexPAVE™

\[ y = 1.0676x - 0.348 \]
\[ R^2 = 0.7785 \]

Line of Equality

- NCAT
- MIT-WMA
- MIT-RAP
## Simplification of TSS to SSR

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

![Graph showing permanent strain vs. number of cycles for different stresses and temperatures]
## Simplification of TSS to SSR

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<thead>
<tr>
<th>Test Method</th>
<th>TSS</th>
<th>SSR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reference</td>
<td>1 ($T_H$)</td>
<td>-</td>
</tr>
<tr>
<td>Temp.</td>
<td>3 ($T_H$, $T_I$, and $T_L$)</td>
<td>2 ($T_H$ and $T_L$)</td>
</tr>
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<td>100, 70, 130 ($T_H$) 70, 100, 130 ($T_L$)</td>
</tr>
<tr>
<td>Number of Samples</td>
<td>8 (2 replicates of each experiment)</td>
<td>4 (2 replicates of each experiment)</td>
</tr>
<tr>
<td>Displacement Measurement</td>
<td>On-specimen LVDTs</td>
<td>Actuator</td>
</tr>
<tr>
<td>Testing Time incl. Pre-conditioning</td>
<td>16 hrs for 8 TSS experiments</td>
<td>6 hrs for 4 SSR experiments</td>
</tr>
</tbody>
</table>
Shift Factors between TSS and SSR

### Total SF-TSS
- Reduced Load Time SF
- Vertical Stress SF

### Total SF-SSR
- Reduced Load Time SF
- Vertical Stress SF
Effects of Simplifications on Rut Depths Predicted by FlexPAVE™

- Actuator Displacement vs. LVDT
- Rut Depth Comparison (RS9.5B)
- Total Rut Depth (mm) vs. Time (Months)
- Temperature, Reversed Loading Block, and Rest Periods

4 in. RS9.5B
10 in. Aggregate Base

700 AADTT
40 kN wheel load
Raleigh, NC
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 SCOE

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

<table>
<thead>
<tr>
<th>Test Parameter</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment</td>
<td>AMPT</td>
</tr>
<tr>
<td>Temperature</td>
<td>2 ($T_H$ and $T_L$)</td>
</tr>
<tr>
<td>Pulse Time (s)</td>
<td>0.4</td>
</tr>
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<td>100, 70, 130 ($T_H$) or 70, 100, 130 ($T_L$)</td>
</tr>
<tr>
<td>Displacement Measurement</td>
<td>Actuator</td>
</tr>
<tr>
<td>Test Outputs</td>
<td>$\varepsilon_0$, $N$, $\beta$, $d_1$, $d_2$, $p_1$, and $p_2$</td>
</tr>
<tr>
<td>Replicates</td>
<td>2</td>
</tr>
<tr>
<td>Testing Time incl. Pre-conditioning</td>
<td>6 hrs for 4 SSR tests</td>
</tr>
</tbody>
</table>
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

Section 10 describes the calculation process to obtain coefficients, $\varepsilon_0$, $\beta$, $N_I$, $d_1$, $d_2$, $p_1$, 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

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)

\[
\varepsilon_{vp} = \frac{\varepsilon_0 \times N_{ref}}{(N_I + N_{ref})^\beta}
\]

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

\[
a_{total} = \log \left( \frac{\Delta N_{ref}}{200} \right)
\]
Section 10: Calculations

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

\[ \varepsilon_{vp} = \varepsilon_0 \times N_{ref} \left( N_1 + N_{ref} \right)^{\beta} \]

Finding \( \varepsilon_0, \beta, \) and \( N_I \) from Reference Curve

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

\[ a_{total} = a_{\varepsilon_p} + a_{\sigma_v} \]

\[ N_{ref} = A \cdot N \left( \frac{\varepsilon_p}{1} \right)^{p_1} \left( \frac{\sigma_v}{P_a} \right)^D \]

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

\[ D = d_1 T + d_2 \]
FlexMAT™-Rutting

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

![Graph showing strain vs. number of cycles with Fit Reference Model and Find Shift Factors options]

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

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>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.</td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Reference Model</td>
<td>6</td>
<td>7</td>
<td>8</td>
<td>9</td>
<td>10</td>
<td>11</td>
<td>12</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>ε₀</td>
<td>0.00224</td>
<td></td>
<td>N₁</td>
<td>1.78777</td>
<td></td>
<td>β</td>
<td>0.76643</td>
<td></td>
<td></td>
<td></td>
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<td>Reduced Load Time</td>
<td></td>
<td></td>
<td>p₁</td>
<td>0.705</td>
<td></td>
<td>p₂</td>
<td>0.281</td>
<td></td>
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<td></td>
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<tr>
<td>Vertical Stress Shift</td>
<td></td>
<td></td>
<td>d₁</td>
<td>3.191</td>
<td></td>
<td>d₂</td>
<td>-2.782</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tref (°C)</td>
<td>54</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

\[
\varepsilon_x = \frac{\varepsilon_0 \times N}{(N_I + N)^\beta}
\]

\[
\varepsilon_{\varepsilon} = \frac{\varepsilon_0 \times N_{\text{red}}}{(N_I + N_{\text{red}})^\beta}
\]

\[
N_{\text{red}} = A \cdot N \left( \frac{\xi_P}{1} \right)^{p_1} \left( \frac{\sigma_v}{P_a} \right)^d
\]

\[
A = 10^{p_2} \cdot 10^{d_2}
\]

Export FlexPAVE Inputs
Material Properties Input in FlexPAVE™
Stress Sweep Rutting (SSR) Test

SSR Test in AMPT

✓ Structure  ✓ Traffic  ✓ Climate

Rutting Prediction
Thank you