Standard Practice for

Determining Asphalt Mixture Critical Conditions for Rutting Evaluation by Means of Dynamic Repeated Load Triaxial (RLT) Test

AASHTO Designation: R XX-13

1. SCOPE

1.1. This standard practice describes the methodology for rutting susceptibility evaluation for hot mix asphalt (HMA) by means of dynamic Repeated Load Triaxial (RLT) test. This practice is intended for different types of asphalt mixtures having unmodified or modified asphalt binders.

1.2. This practice addresses the procedure to determine the RLT testing conditions regarding the loading pulse duration, rest period, and the deviator and confinement stresses. In addition, a mechanistic-based procedure to evaluate the rutting susceptibility of HMA mixtures is described in this practice.

1.3. *This standard practice may involve hazardous materials, operations, and equipment. This practice does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this procedure to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use*.

2. REFERENCED DOCUMENTS

2.1. *AASHTO Standards:*
- R 30, Mixture Conditioning of Hot Mix Asphalt (HMA)
- PP 60, Preparation of Cylindrical Performance Test Specimens Using the Superpave Gyratory Compactor (SGC)
- PP 61, Developing Dynamic Modulus Master Curves for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)
- TP 79, Determining the Dynamic Modulus and Flow Number for Hot Mix Asphalt (HMA) Using the Asphalt Mixture Performance Tester (AMPT)
- T 312, Preparing and Determining the Density of Hot Mix Asphalt (HMA) Specimens by Means of the Superpave Gyratory Compactor
- T 342, Determining Dynamic Modulus of Hot Mix Asphalt (HMA)

2.2. *ASTM Standard:*
- E 4, Standard Practices for Force Verification of Testing Machines

2.3. *Other References:*

- Ulloa, A., "Development of a Mechanistic-Based Approach to Evaluate Critical Conditions of Hot Mix Asphalt Mixtures", Retrieved from ProQuest Dissertations and Theses database, UMI No. 3566297, Department of Civil and Environmental Engineering, University of Nevada-Reno, Nevada, 2013.
- NCHRP, "Guide for Mechanistic-Empirical Design of New and Rehabilitated Structures" Final Report for Project 1-37A, National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, D.C., 2004.

3. TERMINOLOGY

3.1. *permanent deformation*—the non-recovered deformation in a repeated-load test.

3.2. *rut* —a longitudinal depression in a wheelpath consisting of consecutive rut depth determinations that measure a depression and extend for more than 50 m (150 ft.).

3.3. *reliability*—probability that a pavement section will perform satisfactorily over the anticipated traffic and environmental conditions for the design period.

3.4. *complex modulus*, (E*)—a complex number that defines the relationship between stress and strain for a linear viscoelastic material.

3.5. *dynamic modulus*, |E*|—the absolute value of the complex modulus calculated by dividing the maximum (peak-to-peak) stress by the recoverable (peak-to-peak) axial strain for a material subjected to a sinusoidal loading.

3.6. *loading pulse time* (t_p)—a repeated haversine axial compressive deviator load pulse duration that closely simulates the conditions encountered in the pavement under traffic loading.

3.7. *rest time* (t_r)—dwell time between compressive load applications.

3.8. *confining stress*(σ_c)—the uniform stress applied to all surfaces in a triaxial test.

3.9. *deviator stress*(σ_d)—the difference between the total axial stress (major principal stress) and the confining pressure (minor principal stress) in a triaxial test.

3.10. *equivalent annual asphalt pavement temperature*(T_{EAAPT})—equivalent annual asphalt pavement temperature that will result in the same level of rutting at the end of the 20-year design period with the rutting predicted using the actual climate and structure of a specific project.

3.11. *effective annual asphalt pavement temperature* ($T_{Effective}$)—equivalent annual asphalt pavement temperature that will result in a 90% reliability rut depth of 6.4 mm (0.25 in.) or 12.7 mm (0.50 in.) at the end of the 20-year design period.

3.12. *flow number*—number of load cycles corresponding to the minimum rate of change of permanent axial strain during a dynamic repeated load triaxial test. It also defines the transition between the secondary and tertiary stage in the permanent deformation versus number of cycles relationship.

3.13. *effective flow number* ($FN_{T\text{-}Effective}$)—average flow number measured at the effective annual pavement temperature.

3.14. *critical temperature*— minimum temperature at which the HMA mixture will exhibit a tertiary stage in the dynamic repeated load test under a given number of loading cycles and testing conditions.

3.15. *critical flow number* ($FN_{Critical}$)—minimum required flow number at the critical temperature, obtained in the repeated load triaxial test, to result in acceptable HMA rutting performance.

3.16. *design equivalent single axle load (ESAL))*—Number of 80 kN (18-kip) single axles that causes the same pavement damage as caused by the actual mixed axle load and axle configuration traffic.

4. SUMMARY OF THE PRACTICE

4.1. This practice describes procedures for determining the asphalt mixture critical conditions for rutting evaluation. A series of steps are conducted in order to determine the HMA rutting susceptibility at an associated 90% reliability level.

4.2. *Project Information*—Project characteristics such as location, traffic, pavement structure, and environmental conditions are collected. The paving project properties are used as inputs to determine the laboratory testing conditions and conduct the HMA rutting evaluation.

4.3. *Laboratory Testing*—Dynamic modulus master curve at the initial in-place density of interest for the given HMA mixture is developed. The effective pavement temperature, associated with the selected rut depth criterion, along with the testing conditions to be used in the RLT test are computed. A minimum of two specimens are prepared in accordance with PP 60 for RLT testing. Average flow number is computed for the determined testing conditions.

4.4. Figure 1 shows the schematic of the repeated load triaxial test

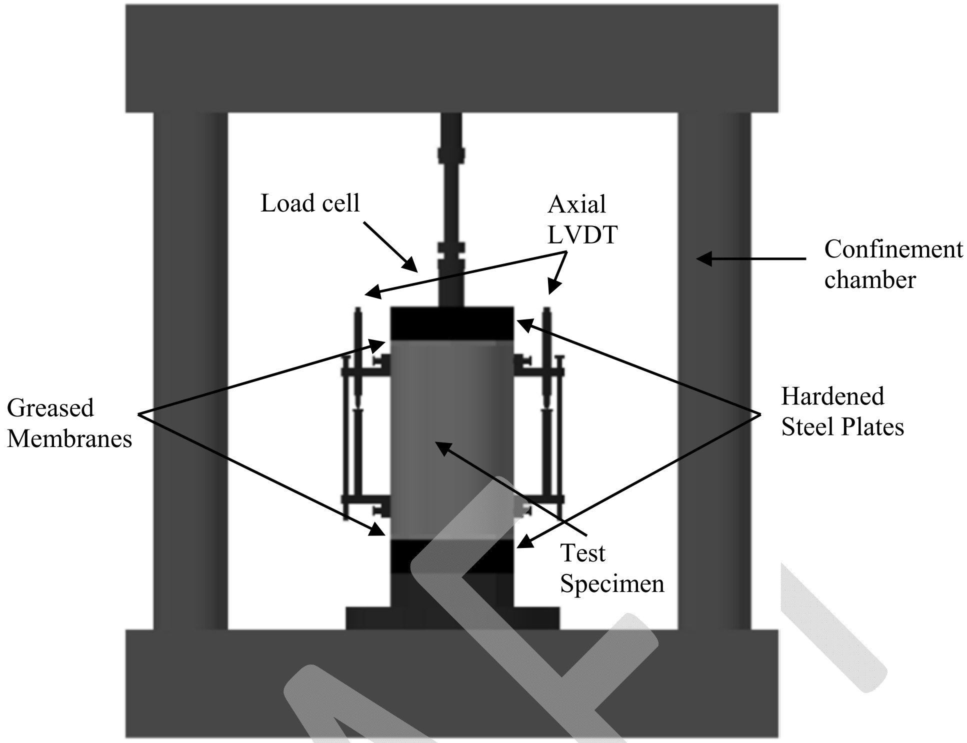

Figure 1—General Schematic of Repeated Load Triaxial Test

4.5. *Evaluate HMA Critical Conditions for Rutting*—The computed average flow number at the effective pavement temperature is compared to the critical flow number for the 20-year design traffic level. If the laboratory determined flow number is greater than the critical flow number, the HMA mixture is not considered prone to rutting at the associated rut depth criterion with 90% reliability level. If the HMA mixture is not satisfactory for a given project conditions, modification of mixture properties may be needed.

5. SIGNIFICANCE AND USE

5.1. The repeated load triaxial test is used to determine the flow number of the HMA mixture under specific testing conditions that closely simulate the actual project traffic loading and environmental characteristics.

5.2. The flow number measured at the effective annual asphalt pavement temperature is used to relate the resistance of HMA to permanent deformation at a 90% reliability level. An HMA is considered appropriate for a specific project location and traffic if the measured flow number is greater than the critical flow number corresponding to a rut depth of 6.4 mm (0.25 in.) or 12.7 mm (0.50 in.).

5.3. This standard practice describes procedures for determining the RLT test conditions regarding the loading pulse duration, rest period, and the deviator and confinement stresses of asphalt mixture specimens.

5.4. This procedure is applicable to newly prepared asphalt mixtures, reheated/compacted mixtures, and asphalt pavement cores having at least 6 inches in height. The loose mixtures are subjected to short term aging according to the procedure explained in R 30.

6. APPARATUS

6.1. *Specimen Fabrication Equipment*—For fabricating dynamic modulus and repeated load triaxial test specimens as described in PP 60 and T 342.

6.2. *Dynamic Modulus Test System*—A dynamic modulus test system consisting of a testing machine, environmental chamber, and data acquisition measuring system.

Note 1—This test system is used to collect the necessary data to develop the hot-mix asphalt dynamic modulus master curve. A HMA dynamic modulus predictive model (e.g. Witczak equation, Hirsch model) could be used in lieu of dynamic modulus obtained from laboratory tests.

6.3. *Testing Machine*—A servo-controlled testing machine capable of producing a controlled haversine compressive pulse loading coupled with a controlled rest period. The testing machine shall have a capability of applying load over a range of pulse times from 0.01 to 0.2 seconds and stress level up to 1035 kPa (150 psi). Testing machine shall be capable to apply a uniform all-around confinement stress level up to 414 kPa (60 psi). Air shall be used in the triaxial chamber as the confining fluid. Test chamber pressure shall be monitored with conventional pressure gages, manometers, or pressure transducers to an accuracy of ±0.7 kPa (0.1 psi).

6.4. *Environmental Chamber*—A chamber for controlling the test specimen to the desired testing temperature. The environmental chamber shall be capable of controlling the temperature of the specimen over a temperature range from 20 to 60ºC (68 to 140ºF) to an accuracy of ±0.5ºC (±1ºF).

6.5. *Measuring system*—The system shall be fully computer-controlled, capable of measuring and recording the loading and dwelling time history of the applied load and the axial deformations. Confinement pressure shall remain constant throughout the entire test period.

6.6. *Load Cell*—The load shall be measured with an electronic load cell in contact with one for the specimen caps. The load cell shall be calibrated in accordance with ASTM E 4. The load measuring system shall have a minimum range of 0 to 25 kN (0 to 5600 lb) with a resolution of 1.2 N (0.24 lb).

6.7. *Axial Deformations*—Axial deformations shall be measured with linear variable differential transformers (LVDT) mounted between gauge points glued to the specimen. Figure 2 shows the schematic for the axial deformation measurement system. The deformations shall be measured at a minimum at two locations 180 degrees apart. The LVDT shall have a range of ±0.5 mm (±0.02 in.). The deformation measuring system shall have auto zero.

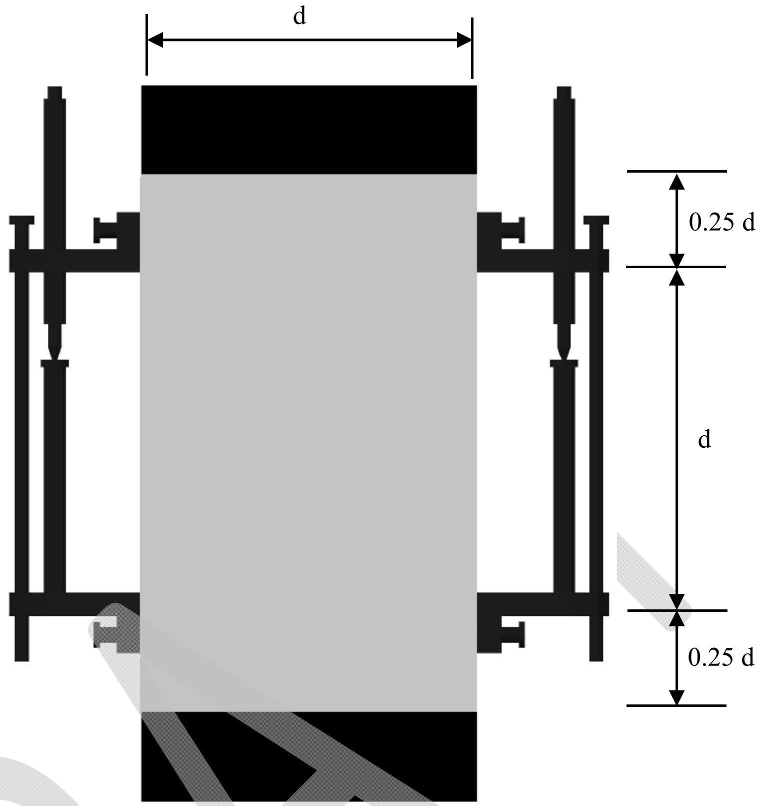

Figure 2—General Schematic of LVDT configuration (Not to Scale)

6.8. *Loading Platens*—Loading platens, sized 104.5 ±0.5 mm (4.1± 0.02 in.), are required above and below the specimen to transfer the load from the testing machine to the specimen. Generally, these platens shall be made of hardened or plated steel.

6.9. *Greased Double Latex Membrane*—Friction-reducing end greased double latex membranes 100-mm (4 in.) diameter by 0.3 mm (0.012 in.) thick shall be placed between the specimen ends and the loading platens. The end treatments shall consist of two 0.5-mm (0.02 in.) thick latex membranes separated with silicone grease. Greased double latex membranes shall be prepared in accordance with TP 79.

6.10. *Silicone Grease*—Dow Corning "Stopcock Grease" or equivalent, for manufacturing the greased double latex membranes friction reducers.

6.11. *Latex Membranes*—100-mm (4 in.) diameter, by 305-mm (12 in.) height, by 0.3 mm (0.012 in.) thick latex membranes, for use in confined RLT test.

6.12. *Miscellaneous Apparatus*—Includes calipers, rubber O-rings, scales, and report forms, as required.

6.13. *LVDT Mounting Hardware*—LVDT mounting hardware couple with epoxy cement glued mounting studs are needed to measure the axial deformations. Figure 3 shows the mounting hardware configuration.

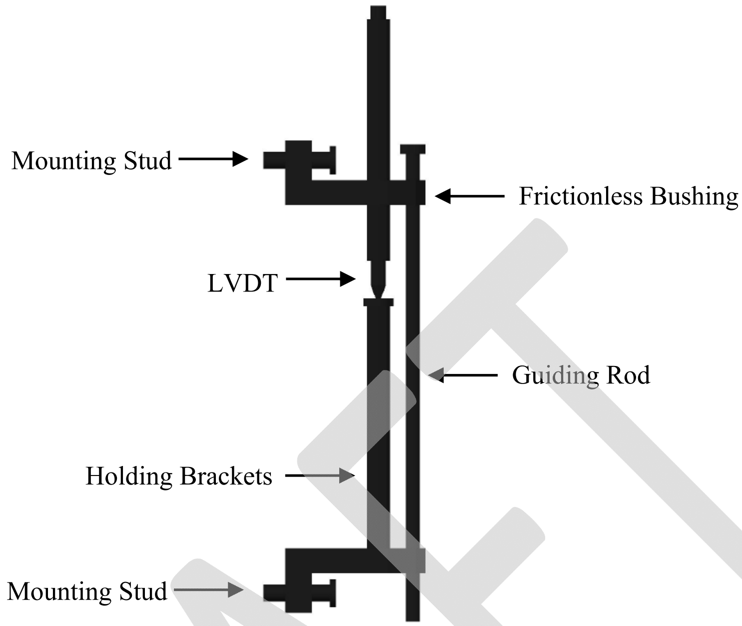

Figure 3—Mounting Hardware Schematic of LVDT Assembly

7. TEST SPECIMENS

7.1. *Aging*—Laboratory-prepared mixtures shall be temperature-conditioned in accordance with the 4-hour short-term oven conditioning procedure in R 30. Field-produced mixtures need not to be short-term aged prior to compaction.

7.2. *Size*—Dynamic modulus and Repeated Load Triaxial testing shall be performed on test specimens cored with 150-mm (6-in.) height. The average height of the test specimens shall be between 147.5 and 152.5 mm (5.81 and 6.00 in.). The average diameter of the test specimens shall be between 100 and 104 mm (3.94 and 4.1 in.) with a standard deviation of 1.0 mm (0.04 in.).

7.3. *Gyratory Specimens*—Prepare 170-mm (6.7-in.) tall specimens at the paving project initial in-place air void content in accordance with T 312.

7.4. *Coring*—Core the nominal 101.6 mm (4.0-in.) diameter test specimen from the center of the gyratory specimens. The resulting test specimen is cylindrical with sides that shall be smooth, parallel, and free from grooves.

7.5. *Diameter*—Measure the diameter of the test specimen at the mid-height and third points along axis that are 90 degrees apart. Record each of the six measurements to the nearest 1 mm (0.04 in.). If the standard deviation of the measured diameters is greater than 2.5 mm (0.10 in.), discard the specimen.

7.6. *Specimen ends*—Specimen ends shall have a cut surface waviness height within a tolerance of ±0.05 mm (±0.002 in.) across any diameter. This requirement shall be checked in a minimum of three portions at approximately 120-degree intervals using a straightedge and feeler gauges approximately 8.1 to 12.5 mm (0.32 to 0.49 in.) wide. The specimen end shall not depart from perpendicular to the axis of the specimen by more than 1 degree. This requirement shall be checked on each specimen using a machinist's square and feeler gauges.

7.7. *Air void content*—Determine the air void content of the final test specimen in accordance with T 312. Reject specimens with air voids that differ by more than 0.5 percent from the target air voids.

8. HAZARDS

8.1. This practice and associated standards involve handling of hot asphalt binder, aggregates, and HMA. It also includes the use of sawing and coring machinery and servo-controlled testing equipment. Use standard safety precautions, equipment, and clothing when handling hot materials and operating machinery.

9. COLLECTING PROJECT INFORMATION

9.1. Collect project information needed to determine the RLT testing conditions and to compute the effective pavement temperature. Obtain the paving project features including project location, latitude, longitude and elevation.

9.2. Obtain the pavement construction information including construction date, pavement structure, layer thicknesses, and initial in-place air void level of the paving project.

9.3. Estimate the project location environmental conditions including the mean annual air temperature (MAAT), the mean monthly air temperature standard deviation (σMMAT), the mean annual wind speed (Wind), the mean annual percentage sunshine, and the annual cumulative rainfall depth (Rain).

Note 2—Climate characteristics are obtained over a period of years starting when the paving project is constructed. Data is obtained through one or more weather stations nearby the project location with similar elevation and geographical characteristics. The necessary information can be determined using the Enhanced Integrated Climatic Model (EICM).

9.4. Estimate the traffic characteristics including project's vehicle operational speed, the anticipated 20-year period design traffic expressed in ESALs.

Note 3—Regardless of the actual design life of the roadway; determine the design ESALs for 20 years.

9.5. Select the rut depth criterion of 6.4 mm (0.25 in.) or 12.7 mm (0.50 in.) for a 20-year design period and a 90% reliability level.

10. DEVELOPING DYNAMIC MODULUS MASTER CURVE

10.1. Fabricate at least two test specimens at the initial in-place air void content ± 0.5 percent coupled with the aging condition in accordance with PP 60.

10.2. Develop the dynamic modulus master curve in accordance with PP 61 or TP 79.

Note 4—Dynamic modulus master curve can be obtained using a predictive model (e.g. Witczak equation, Hirsch model).

11. DETERMINING EFFECTIVE PAVEMENT TEMPERATURE

11.1. The effective pavement temperature ($T_{Effective}$) is obtained as the equivalent annual asphalt pavement temperature (T_{EAAPT}) that will result in the same level of rutting at the end of the 20-year design period at 90% reliability rut depth of 6.4 mm (0.25 in.) or 12.7 mm (0.50 in.).

11.2. Determine $T_{Effective}$ as the testing temperature to be used in the RLT test using Equation 1 or Equation 2:

For rut depth criterion of 6.4 mm (0.25 in.):

$$T_{Effective} = 20.6099 + 0.8764(MAAT) + 1.5870(\sigma MMAT) - 2.0006(Wind) + 0.1079(Sunshine) - 0.0891(Rain) + 14.7893(\log(Freq)) - 3.5748(\log(ESALs)) + 0.1677(PG_{HT}) \quad (1)$$

For rut depth criterion of 12.7 mm (0.50 in.):

$$T_{Effective} = 25.7540 + 0.8287(MAAT) + 1.4932(\sigma MAAT) - 2.1949(Wind) + 0.1101(Sunshine) - 0.0967(Rain) + 16.2478(log(Freq)) - 4.0479(log(ESALs)) + 0.1416(PG_{HT}) \quad (2)$$

where:
$T_{Effective}$ = effective pavement temperature at 90% reliability level for 20-year design period, ºF;
MAAT = mean annual air temperature, ºF;
σMMAT = mean monthly air temperature standard deviation, ºF;
Wind = Mean annual wind speed, mph;
Sunshine = Mean annual percentage sunshine, %;
Rain = annual cumulative rainfall depth, inches;
Freq = traffic-induced loading frequency at a depth of one inch below the pavement surface, obtained as recommended in the Mechanistic Empirical Pavement Design Guide (MEPDG) Appendix CC-3, Hz;
ESALs = 20-year design equivalent single axle load (ESAL);
PG_{HT} = High temperature asphalt binder performance grade, ºC.

12. DETERMINING THE RLT TESTING CONDITIONS

12.1. The selected testing conditions shall ensure that the testing state of stresses and loading pulse characteristics are appropriate and best simulate the stress and loading pulse conditions encountered in the pavement under traffic loads.

12.2. Compute the deviator stress pulse time (t_p) using Equation 3:

$$\log(t_p) = -0.00353(T_{Effective}) - 0.0236(S) + 0.00015(S)^2 - 0.6654 \quad (3)$$

where:
t_p = deviator stress pulse time, seconds;
$T_{Effective}$ = effective pavement temperature, ºC;
S = vehicle operational speed, mph.

12.3. Compute the deviator stress rest period (t_r) using Equation 4:

$$t_r = \frac{L}{S} \quad (4)$$

where:
t_r = deviator stress rest time, seconds;
L = distance between the front and rear driving axles of an eighteen-wheel truck;
S = vehicle operational speed, mph.

12.4. Compute the deviator and confining stress using the following equations depending on the HMA paved layer thickness.

For a HMA paved layer thickness less than or equal to 100-mm (4.0 in.):

$$\sigma_d = -0.0844(T_{Effective}) + 0.06|E^*| + 83.708 \quad (5)$$

$$\sigma_c = 0.0232(T_{Effective}) - 0.0169|E^*| + 32.495 \quad (6)$$

For a HMA paved layer thickness less than or equal to 150-mm (6.0 in.):

$$\sigma_d = -0.804(T_{Effective}) + 0.0066(T_{Effective}{}^2) + 0.076(S) - 0.000922(T_{Effective})(S) - 7.045 \times log(|E^*|) + 114.37 \quad (7)$$

$$\sigma_c = -0.000967(T_{Effective}{}^2) - 0.1107(S) + 0.00171(T_{Effective})(S) + 0.00139(T_{Effective})(|E^*|) + 31.41 \quad (8)$$

For HMA paved layer thickness less than or equal to 200-mm (8.0 in.):

$$\sigma_d = 0.000576(T_{Effective}{}^2) + 0.000316(S^2) + 0.0463(|E^*|) - 0.00199(T_{Effective})(|E^*|) + 79.01 \quad (9)$$

$$\sigma_c = -0.000826(T_{Effective}{}^2) - 0.11284(S) + 0.00168(T_{Effective})(S) + 0.00139(T_{Effective})(|E^*|) + 30.26 \quad (10)$$

where:

σ_d = deviator stress, psi;
σ_c = confinement stress, psi;
$T_{Effective}$ = effective pavement temperature, ºC;
$|E^*|$ = dynamic modulus of the mixture at two inches below pavement surface and at $T_{Effective}$, ksi.
S = vehicle operational speed, mph.

13. RLT TESTING PROCEDURE

13.1. In the RLT test procedure, a HMA specimen at the effective annual asphalt pavement temperature is subjected to a repeated haversine axial compressive load pulse, a rest period, and deviator and confinement stresses. Those test conditions are obtained using regression equations based on specific project characteristics and imposed traffic-induced loading and environmental conditions. The resulting permanent axial strains, measured during the RLT test, as a function of the number of load cycles are analyzed and fitted to determine the flow number.

13.2. Fabricate at least two test specimens as indicated in Section 7.

13.3. Glue the mounting studs to the test specimen. Insert the test specimen into the latex membrane. Place the LVDT mounting hardware outside the membrane as illustrated in Figure 3.

13.4. Place the test specimen and the attached LVDT mounting hardware in the environmental chamber and allow it to be uniformly conditioned at the computed $T_{Effective}$ ±0.3ºC (±1ºF). Testing temperature shall be monitored with a thermocouple mounted at the center of the specimen to determine when the specimen reaches the specified test temperature. A minimum recommended equilibrium temperature time of 3 hours is provided as a guideline.

13.5. Place the bottom greased double latex membrane friction-reducing end treatments on top of the hardened steel plate at the bottom of the loading frame. Place the specimen on top of the lower end treatment. Stretch the membrane over the specimen and bottom loading platen. Install the lower O-ring seal. Place the top greased double latex membrane and top platen on top of the specimen and stretch the membrane over the top platen. Install the upper O-ring seal.

13.6. Adjust the LVDT to near the end of its linear range to allow the full range to be available for the accumulation of compressive permanent deformation during the test period. Center the specimen with the load actuator visually in order to avoid eccentric loading.

13.7. Input the computed deviator stress pulse duration, rest period, confining and deviator stresses along with the test specimen average diameter as detailed in Section 12.

13.8. Close the testing chamber and apply the confinement stress. Apply a contact stress equal to 5 percent of the deviator stress. The contact stress shall be high enough to maintain positive contact with the specimen without damaging the specimen.

13.9. Follow the software prompts to begin the test.

13.10. Apply a total of 20,000 cycles or 7% permanent axial strain, whichever occurs first. At the completion of the triaxial test, reduce the confining pressure to zero and unload the test specimen. Save the testing data for further analysis.

13.11. *Calculations:*

13.11.1. The calculations of the permanent strain for each load cycle are performed automatically by the software.

13.11.2. Use the Francken Model to identify the flow number in accordance with TP 79.

13.11.3. Compute the average and standard deviation of the flow numbers for the replicate specimens.

14. EVALUATING HMA CRITICAL CONDITIONS FOR RUTTING

14.1. Determine the average measured flow number ($FN_{T\text{-}Effective}$).

14.2. Select the critical flow number ($FN_{Critical}$) from Table 1:

Table 1—Critical flow number for non-braking conditions

Design ESALs[a] (millions)	Critical Flow Number ($FN_{Critical}$)
< 3	5,000
3 to 10	7,000
10 to 30	13,000

[a] The anticipated project traffic level expected on the design lane over a 20-year period. Regardless of the actual design life of the roadway, determine the design ESALs for 20 years.

14.3. The resulting average flow number ($FN_{T\text{-}Effective}$) is compared with the selected critical flow number ($FN_{Critical}$), to determine if the HMA mix is susceptible to rutting.

14.4. In the case that the measured $FN_{T\text{-}Effective}$ is greater than the $FN_{Critical}$, the HMA mixture is considered satisfactory at the associated rut depth criterion at a 90% reliability level.

14.5. In the case that the measured $FN_{T\text{-}Effective}$ is lower than the $FN_{Critical}$, the HMA mixture is not satisfactory at the associated rut depth criterion at a 90% reliability level for given project conditions. Modify mixture properties and repeat the procedure.

15. REPORT

15.1. This report shall include the identification of the project, construction date, location, pavement structure, traffic level, and mix design number.

15.2. The report shall include information on the HMA design aggregate structure including the source of aggregate, nominal maximum aggregate size, and gradation.

15.3. The report shall contain information about the HMA design binder including the source of binder and the performance grade.

15.4. RLT testing report shall include:

15.4.1. Specimen identification including mixture identification and asphalt performance grade.

15.4.2. Test temperature,

15.4.3. Average applied deviator stress,

15.4.4. Average applied confinement stress,

15.4.5. Applied deviator stress pulse time and rest period, and

15.4.6. Average and standard deviation of the flow numbers for the specimen tested. Report the average flow number as $FN_{T\text{-}Effective}$.

15.5. Report the selected $FN_{Critical}$ based on the design ESALs.

15.6. Report the HMA rutting susceptibility at 90% reliability level.

16. PRECISION AND BIAS

16.1. *Precision* —The work necessary to determine the precision of this test has not yet been performed.

16.2. *Bias* —No justifiable statement can be made on the bias of this test method because there is no reference value available.

17. KEYWORDS

17.1. Repeated load triaxial testing; flow number; dynamic modulus, rut depth, permanent deformation; reliability; effective pavement temperature; critical conditions; HMA.