Technical Report Documentation Page

1. Report No. FHWA/TX-09/0-5798-P1	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle LABORATORY AND FIELD PROCEDURES USED TO CHARACTERIZE MATERIALS	5. Report Date December 2008 Published: January 2009 6. Performing Organization Code
7. Author(s) Fujie Zhou, Emmanuel Fernando, and Tom Scullion	8. Performing Organization Report No. Report 0-5798-P1
9. Performing Organization Name and Address Texas Transportation Institute The Texas A&M University System College Station, Texas 77843-3135	10. Work Unit No. (TRAIS) 11. Contract or Grant No. Project 0-5798
12. Sponsoring Agency Name and Address Texas Department of Transportation Research and Technology Implementation Office P. O. Box 5080 Austin, Texas 78763-5080	13. Type of Report and Period Covered Product: September 2007-August 2008 14. Sponsoring Agency Code

15. Supplementary Notes

Project performed in cooperation with the Texas Department of Transportation and the Federal Highway Administration.

Project Title: Develop Test Procedures to Characterize Material Response Behavior and Transfer Functions for TxDOT M-E Design

URL: http://tti.tamu.edu/documents/0-5798-P1.pdf

16. Abstract

The objective of TxDOT Project 0-5798 is to develop the framework for the development and implementation of the next level of Mechanistic-Empirical Pavement Design Guide (MEPDG) for TxDOT (Tex-ME). A very important aspect of this project is to identify laboratory testing procedures, which can be used to provide TxDOT with the material properties needed as inputs to both the pavement response and performance prediction models. This product documents the laboratory and field procedures used to characterize materials; it includes the research team's recommendations for Level 1 tests needed to characterize the rutting potential of asphalt, granular, and soil layers and also the cracking potential of asphalt layers.

These procedures should be considered as drafts at this time, they will continue to be refined for the duration of this study, and the final versions will be included in the project final report.

17. Key Words Flexible Pavement Design, Overlay Test, Repeated Load Test, Rutting, Fatigue Cracking, Tex-ME	18. Distribution Statement No restrictions. This document is available to the public through NTIS: National Technical Information Service Springfield, Virginia 22161 http://www.ntis.gov

19. Security Classif.(of this report) Unclassified	20. Security Classif.(of this page) Unclassified	21. No. of Pages 44	22. Price

Form DOT F 1700.7 (8-72) **Reproduction of completed page authorize**

LABORATORY AND FIELD PROCEDURES USED TO CHARACTERIZE MATERIALS

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December 2008
Published: January 2009

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DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation. The engineer in charge was Tom Scullion, P.E. (Texas, #62683).

ACKNOWLEDGMENTS

This project was made possible by the Texas Department of Transportation (TxDOT) in cooperation with the Federal Highway Administration. In particular, the guidance and technical assistance provided by the project director (PD) Joe Leidy, P.E., of TxDOT and the program coordinator (PC) Darrin Grenfell, P.E., proved invaluable. The following project advisors also provided valuable input throughout the course of the project, and their technical assistance is acknowledged: Mark McDaniel, P.E., Construction Division, TxDOT; Billy Pigg, P.E., Waco District; and Ricky Boles, P.E., Lufkin District.

INTRODUCTION

The objective of Texas Department of Transportation (TxDOT) Project 0-5798 is to develop the framework for the development and implementation of the next level of MEPDG (Mechanistic-Empirical Pavement Design Guide) for TxDOT (Tex-ME). As specified in the Project Statement, this initial study in the development process will focus on the following areas:

1. Identify and evaluate test procedures that characterize material properties needed to predict pavement response.

2. Assemble existing performance prediction models (transfer functions), and evaluate their feasibility of being implemented in Texas. Key considerations will be the models' performance in basic sensitivity analysis, the practicality of the data input requirements, and their performance at simulating results from accelerated pavements tests (APT).

3. Calibrate the selected transfer functions with available performance data from the LTPP databases, various test track studies, and whatever performance data is available from the databases being assembled in Texas.

In the first year of this study, a comprehensive review was made of the available models for predicting the major distresses in flexible pavements. These being cracking of asphalt layers, permanent deformation of asphalt layers, and permanent deformation of granular base and subgrade layers. In conducting these reviews, the latest models under consideration in both national efforts and various state development efforts were reviewed. The models identified for each of the major distresses were presented in the year 1 Report 0-5798-1.

Another very important aspect of this project is to identify laboratory or field testing procedures which can be used to provide TxDOT with the material properties needed as inputs to both the pavement response and performance prediction models. As stated in the Texas Transportation Institute (TTI) proposal, the eventual Tex-ME program will (as is proposed in other ME programs) will provide the user with various levels of flexibility when selecting material properties. At the lowest level, default values will be available for all of the design items used by TxDOT. However, Level 2 will use properties derived from the current specification and acceptance/design tests that are run on a routine basis by TxDOT. Level 1 is the highest level where advanced materials characterization techniques will be used on all layers in the pavement structure. The following sections of this letter report includes the research team's recommendations for Level 1 tests needed to characterize the rutting potential of asphalt, granular, and soil layers and also the cracking potential of asphalt layers.

These procedures should be considered as draft at this time, they will continue to be refined for the duration of this study, and the final versions will be included in the project final report.

RECOMMENDED LABORATORY TEST PROCEDURES OVERLAY TEST PROTOCOL FOR FATIGUE FRACTURE PROPERTIES OF HMA MIXES

1. SCOPE

1.1 This test method determines the fatigue fracture properties of bituminous mixtures. This test method is very similar to the regular overlay test procedure, Tex-248-F, but not exactly the same.

1.2 The values given in parentheses (if provided) are not standard and may not be exact mathematical conversions. Use each system of units separately. Combining values from the two systems may result in nonconformance with the standard.

2. APPARATUS

2.1 *Overlay Tester*—The device is an electro-hydraulic system that applies repeated direct tension loads to specimens. The machine features two blocks. One is fixed, and the other slides horizontally. The device automatically measures and records load, displacement, and temperature every 0.1 sec.

The sliding block applies tension in a cyclic triangular waveform to a constant maximum displacement of 0.025 in (0.63 mm). The sliding block reaches the maximum displacement and then returns to its initial position in 10 sec (one cycle).

Note 1 —The constant maximum opening displacement of 0.025 in (0.63 mm) may need to be reduced to be 0.015 in (0.38 mm), depending on how stiff the bituminous mixtures are.

Additionally, the device includes:

- an air bath chamber that controls the test temperature,
- a linear variable differential transducer to measure the displacement of the block,
- an electronic load cell to measure the load resulting from the displacement,
- aluminum or steel base plates to restrict shifting of the specimen during testing, and
- a mounting jig to align the two base plates for specimen preparation.

Refer to manufacturer for equipment range and accuracy for LVDT and load cell.

2.2 *Cutting Template*—Refer to Figure 1.

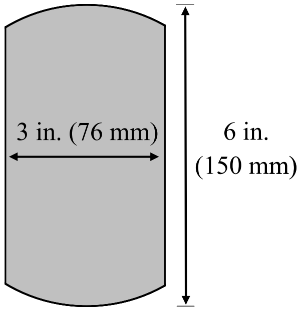


Figure 1. Cutting Template.

2.3 *3/8-in. Socket Drive Handle with a 3 in (7.6 cm) extension.*

2.4 *Hacksaw with carbide grit blade.*

3. MATERIALS

3.1 Two-part epoxy with a minimum 24 hr tensile strength of 600 psi (4.1 MPa) and 24-hr shear strength of 2000 psi (13.8 MPa) according to Tex-614-J.

3.2 10 lb (4.5 kg) weight.

3.3 1/4-in. width adhesive tape.

3.4 Paint or permanent marker.

4. SPECIMENS

4.1 *Laboratory Molded Specimens*—Prepare specimens according to Tex-205-F and Tex-241-F. Specimen diameter must be 6 in (150 mm) and specimen height should be 4.5 ± 0.2 in (115 ± 5 mm). Density of the laboratory molded specimen should be targeted such that the trimmed specimen density is 93 ± 1 percent.

Note 2 —Select molded specimen density depending on experience and knowledge of materials used, typically 92 ± 1 percent.

Note 3 —Mixture weights for specimens prepared in the laboratory typically vary between 4500 to 4700 g to achieve density. Mixture weights for specimens prepared in the laboratory vary with different aggregate sources and with different mix types.

4.2 *Core Specimens*—Specimen diameter must be 6 ±0.1 in (150 ± 3 mm), and specimen height should be a minimum of 1.5 in (38 mm). There is not a specific density requirement for core specimens.

5. PROCEDURE

5.1 *Sample Preparation*

5.1.1 Use three cylindrically molded specimens, or collect three roadway cores according to Section 4.

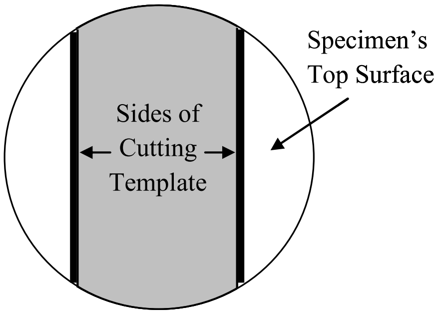
5.2 *Trimming of Cylindrical Specimen*

5.2.1 Place the cutting template on the top surface of the laboratory molded specimen or roadway core. Trace the location of the first two cuts by drawing lines using paint or a permanent marker along both sides of the cutting template.

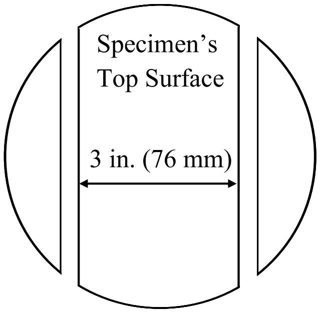
5.2.2 Trim the specimen ends by cutting the specimen perpendicular to the top surface following the traced lines. Discard specimen ends.

5.2.3 Trim off the top and bottom of the specimen to produce a sample with a height of 1.5 ± 0.02 in (38 ± 0.5 mm). Discard the top and bottom parts of the specimen.

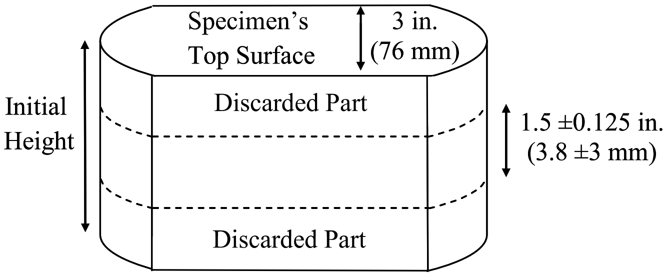
Note 4 − Refer to Figure 2.



Tracing lines using cutting template



Trimming specimen's ends



Trimming specimen to required height

Figure 2. Trimming of Cylindrical Specimen.

5.2.4 Measure the relative density of the trimmed specimen according to Tex-207-F. Density for trimmed laboratory molded specimen must be 93 ± 1 percent. Discard and prepare a new specimen if it does not meet the density requirement. Density for trimmed core specimens is for informational purpose, only.

5.2.5 Dry the trimmed specimen at a maximum temperature of 140 ± 5°F (60 ± 3°C) to constant weight.

Note 5 - Constant weight is the weight at which further oven drying does not alter the weight by more than 0.05 percent in a 2-hr interval.

5.3 *Mounting Trimmed Specimen to Base Plates*

5.3.1 Mount and secure the base plates to the mounting jig. Cut a piece of adhesive tape approximately 4 in (102 mm) in length. Center and place piece of tape over the gap between the base plates.

5.3.2 Prepare epoxy following manufacturer's instructions.

5.3.3 Glue the trimmed specimen to the base plates using the prepared epoxy. Cover the majority of both base plates with the epoxy including the tape.

5.3.4 Place a 10-lb (4.5 kg) weight on top of the glued specimen to ensure full contact of the trimmed specimen to the base plates. Allow the epoxy to cure for the time recommended by the manufacturer. Remove the weight off the specimen after the epoxy has cured.

5.3.5 Use a hacksaw to cut through the tape and dry epoxy located at the gap opening between the base plates. Slightly score the test specimen to propagate a crack at the gap opening.

5.4 *Preconditioning the OT Specimen*

5.4.1 Place the test sample assembly in a 77 ± 1°F (25 ± 0.5°C) temperature chamber, and allow to remain for a minimum of 2 hr before testing.

5.5 *Starting Testing Device*

5.5.1 Turn on the overlay tester. Turn on the computer, and wait at least 1 min to establish communication with the overlay tester. Start the overlay test software.

5.5.2 Turn on the hydraulic pump using the software after it is completely loaded on the computer. Turn the machine to load mode.

5.6 *Mounting Trimmed Test Specimen to Testing Device*

5.6.1 Enter the required test information into the overlay test software for the specimen mounted. Mount the specimen assembly onto the machine according to the manufacturer's instructions and the following recommendations.

- Clean the bottom of the base plates and the top of the testing machine blocks before placing the specimen assembly into the blocks. If not all four surfaces are clean, damage may occur to the machine, the specimen, or the base plates when tightening the base plates.

- Apply 15 lb/in of torque for each screw when fastening the base plates to the machine.

5.7 *Testing Specimen*

5.7.1 Turn the machine to stroke mode. Perform testing at a constant temperature of 77 ± 1°F (25 ± 0.5°C).

Note 6 - Ensure temperature of trimmed test specimen is 77 ± 1°F (25 ± 0.5°C).

5.7.2 Start the test by enabling the start button in the program. Perform testing until a 93% reduction (or more) of the maximum load measured from the first opening cycle occurs. If 93 percent is not reached, run the test to 100 cycles.

Note 7 —This is not a regular OT testing, a maximum of 100 cycles is enough for determining fracture properties A and n.

Note 8 —the constant maximum opening displacement of 0.025 in. (0.63 mm) may need to be reduced to be 0.015 in. (0.38 mm), if the cycles to reach 93% load reduction are less than 25 cycles. Repeat the test at the lower opening displacement if necessary.

5.7.3 Remove specimen assembly.

Note 9 —Ensure machine is in load mode before removing specimen assembly.

6. DATA ANALYSIS AND REPORT

An Excel© Macro has been developed to directly read the output file from the overlay test and automatically determine the fracture properties (A and n) of the specimen. Figure 3 shows the macro, and the A and n results from this macro are shown in Figure 4. Note that the only input the macro requires is modulus of the specimen that can be measured from the dynamic modulus test.

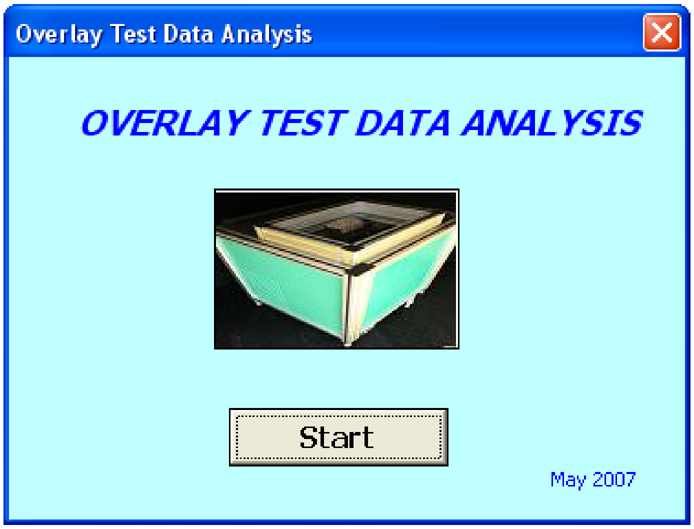


Figure 3. Macro for Fracture Properties (A and n).

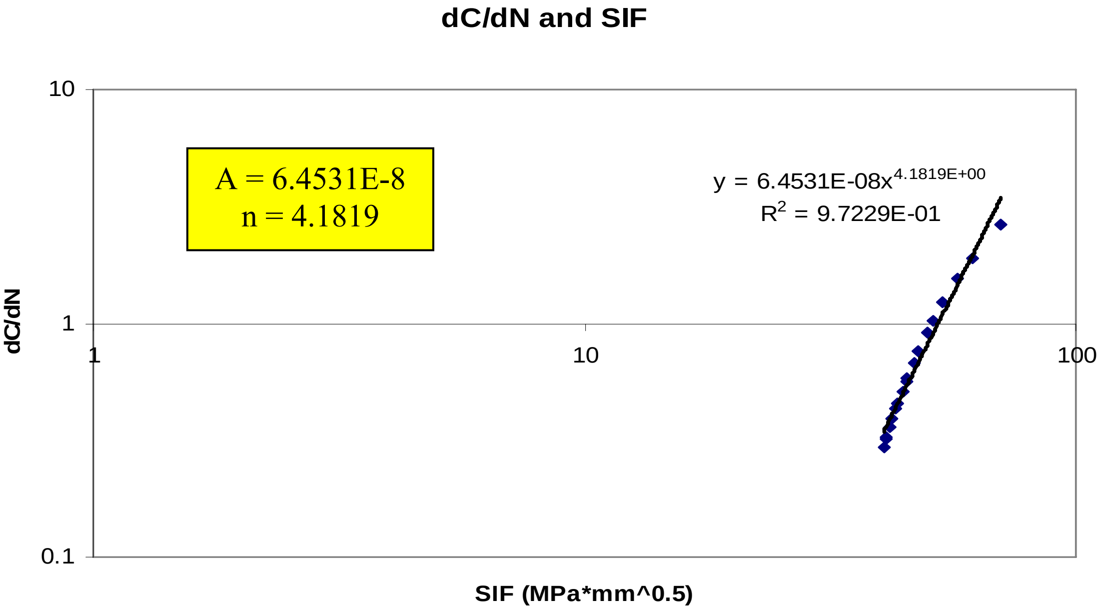


Figure 4. A and n Output from the Macro.

REPEATED LOAD TEST PROTOCOL FOR ASPHALT MIXES

1. TEST SAMPLES

1.1 Size

Testing shall be performed on 4 in (100 mm) diameter by 6 in (150 mm) high or more test samples from laboratory or cores from field.

1.2 Aging

For laboratory compacted samples, mixture shall be aged in accordance with the short-term oven aging procedure in AASHTO PP2.

1.3 Gyratory Specimens

For laboratory compacted samples, prepare 6 in (150 mm) high samples to the required air void content in accordance with AASHTO TP-4. The gyratory compactor is shown in Figure 5.

1.4 End Preparation

The ends of all test samples shall be smooth and perpendicular to the axis of the specimen. Prepare the ends of the samples by milling with a single- or double-bladed saw. To ensure that the sawed samples have parallel ends, the sample ends shall have a cut surface waviness height within a tolerance of ± 0.05 mm across any diameter.

1.5 Air Void Content

Determine the air void content of the final test sample in accordance with AASHTO T269. Reject samples with air voids that differ by more than 0.5 percent from the target air voids.

1.6 Replicates

The number of test samples required depends on the number of axial strain measurements made per sample and the desired accuracy of the average permanent deformation. Normally, two replicates are acceptable for each sample with three LVDTs.

2. TEST SAMPLE INSTRUMENTATION

2.1 Attach mounting studs for the axial LVDTs to the sample with 120-degree intervals (in plan view) using epoxy cement (shown in Figure 6). Make sure the studs are aligned using a glue gig (see Figure 6).

Figure 5. Superpave Gyratory Compactor.

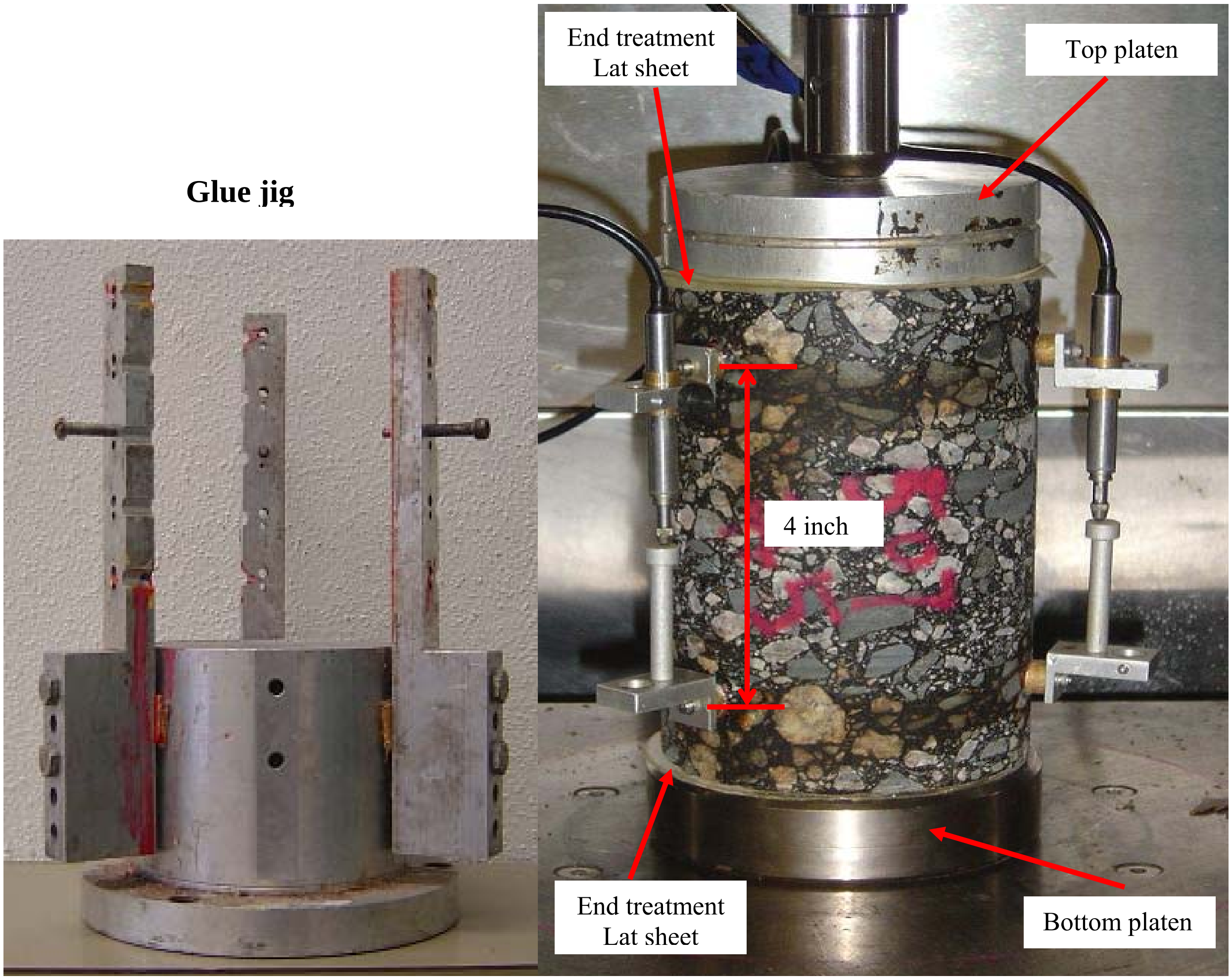


Figure 6. Glue Jig and Samples with Studs.

2.2 The gauge length for measuring axial deformations shall be 4 in ± 0.04 in (100 mm ± 1 mm). The gauge length is normally measured between the stud centers.

3. TEST PROCEDURES

3.1 The recommended test protocol for Alpha and Mu used in the VESYS program consists of testing the asphalt mix at two temperatures with specified stress level. Table 1 shows the recommended test temperatures and associated stress level.

Table 1. Recommended Test Temperatures and Associated Stress Level.

Test Temperature (°F [°C])	Test Stress Level (psi [kPa])
77 (25)	30 (207)
104 (40)	20 (138)

3.2 Place the test sample in the environmental chamber and allow it to equilibrate to the specified testing temperature. A dummy specimen with a temperature sensor mounted at the center can be monitored to determine when the specimen reaches the specified test temperature. In the absence of the dummy specimen, Table 2 provides a recommended temperature equilibrium time for samples starting from room temperature (77°F).

Table 2. Recommended Equilibrium Times.

Test Temperature (°F [°C])	Time (min)
77 (25)	10
104 (40)	30

3.3 After temperature equilibrium is reached, place one of the friction-reducing end treatments on top of the platen at the bottom of the loading frame. Place the sample on top of the lower end treatment, and mount the axial LVDTs to the studs glued to the sample. 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. Note that the end treatments shall consist of two 0.5 mm (0.02 in) thick latex sheets separated with silicone grease, as shown in Figure 6.

3.4 Place the upper friction-reducing end treatment and platen on top of the sample (see Figure 6). Center the specimen with the load actuator visually in order to avoid eccentric loading.

3.5 Apply a contact load equal to 5 percent of the total load level that will be applied to the specimen, while monitoring the proper response of the LVDTs (i.e., check for proper direction sensing for all LVDTs).

3.6 Close the environmental chamber, and allow sufficient time (normally 10 to 15 min) for the temperature to stabilize within the specimen and the chamber.

3.7 After the time required for the sample to reach the testing temperature, apply the haversine load that yields the desired stress on the specimen. The procedure uses a loading cycle of 1.0 Hz frequency and consists of applying 0.1 sec haversine load followed by a 0.9 sec rest period. The maximum applied load (P_{max}) is the maximum total load applied to the sample, including the contact and cyclic load: $P_{max} = P_{contact} + P_{cyclic}$.

3.8 The contact load ($P_{contact}$) is the vertical load placed on the sample to maintain a positive contact between loading strip and the sample: $P_{contact} = 0.05 \times P_{max}$.

3.9 The cyclic load (P_{cyclic}) is the load applied to the test sample that is used to calculate the permanent deformation parameters: $P_{cyclic} = P_{max} - P_{contact}$.

3.10 Apply the haversine load (P_{cyclic}), and continue until 5000 cycles or until the sample fails and results in excessive tertiary deformation, whichever comes first.

3.11 During the load applications, record the load applied and the axial deflection measured from all LVDTs through the data acquisition system. All data should be collected in real time and collected so as to minimize phase errors due to sequential channel sampling. Researchers recommend to using the data acquisition of the cycles shown in Table 3.

Table 3. Suggested Data Collection for VESYS Rutting Test.

Data Collected during Cycles	Data Collected during Cycles	Data Collected during Cycles
1 through 10	598 through 600	2723 through 2725
18 through 20	698 through 700	2998 through 3000
28 through 30	798 through 800	3248 through 3250
48 through 50	898 through 900	3498 through 3500
78 through 80	998 through 1000	3723 through 3725
98 through 100	1248 through 1250	3998 through 4000
148 through 150	1498 through 1500	4248 through 4250
198 through 200	1723 through 1725	4498 through 4500
298 through 300	1998 through 2000	4723 through 4725
398 through 400	2248 through 2250	4998 through 5000
498 through 500	2498 through 2500	

4. CALCULATIONS

4.1 Calculate the average axial deformation for each specimen by averaging the readings from the two axial LVDTs. Convert the average deformation values to total axial strain by dividing by the gauge length (4 in [100 mm]).

4.2 Compute the cumulative axial permanent strain and resilient strain (ε_r) at the 100th load repetition.

4.3 Plot the cumulative axial permanent strain versus number of loading cycles in log-log space (Figure 7). Determine the permanent deformation parameters, intercept (a), and slope (b) from the linear portion of the permanent strain curve.

4.4 Compute the rutting parameters: Alpha, Mu:

$$\mu = \frac{ab}{\varepsilon_r}$$

$$\alpha = 1 - b$$

5. REPORT

Report all sample information including mix identification, dates of manufacturing (or cored) and testing, sample diameter and length, volumetric properties, stress levels used, and axial permanent deformation parameters: α, μ (or ε_r, a, b).

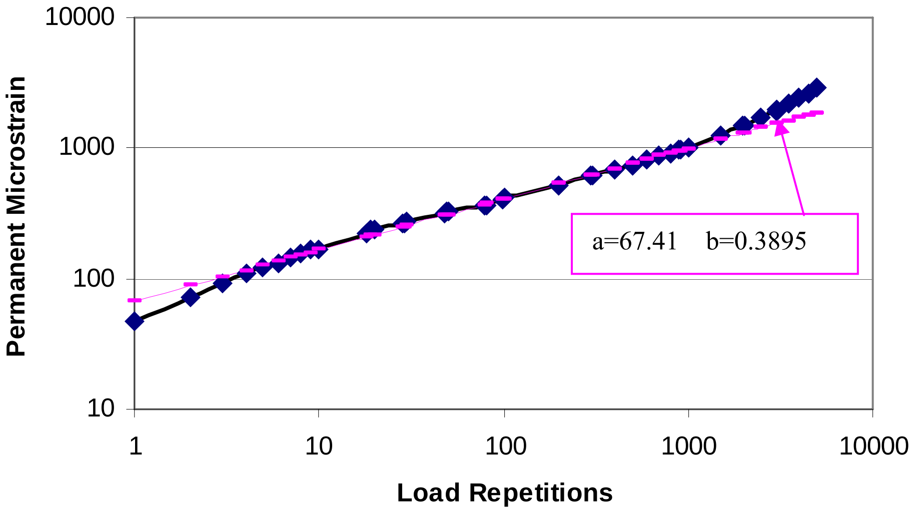


Figure 7. Plot of Regression Constants "a" and "b" from Log Permanent Strain – Log Number of Loading Cycles.

Example: Alpha and Mu Calculation

$\varepsilon_r = 88.1250$

$a = 67.4100$

$b = 0.3895$

$\mu = a \times b/\varepsilon_r = 67.41 \times 0.3895/88.125 = 0.2979$

$\alpha = 1 - b = 1 - 0.3895 = 0.6105$

RECOMMENDED PERMANENT DEFORMATION AND RESILIENT MODULUS LABORATORY TEST PROTOCOLS FOR UNBOUND GRANULAR BASE/SUBBASE MATERIALS AND SUBGRADE SOILS

1. SCOPE

1.1 This test method describes the laboratory preparation and testing procedures for the determination of permanent deformation and resilient modulus (M_r) of unbound granular base/subbase materials and subgrade soils for pavement performance prediction. The stress conditions used in the test represent the ranges of stress states likely to be developed beneath flexible pavements subjected to moving wheel loads. This test procedure has been adapted from the standard test methods given in the VESYS user manual, National Cooperative Highway Research Program (NCHRP) 1-28A Draft Report (unpublished), and AASHTO designation: T294-92, TP46, and T292-91.

1.2 The methods described herein are applicable to laboratory-molded samples of unbound granular base/subbase materials and subgrade soils.

1.3 In this test procedure, stress states used for permanent deformation and resilient modulus testing are based upon whether the specimen is located in the base/subbase or the subgrade. Specimen size for testing depends upon the maximum particle size of the material.

1.4 The values of permanent deformation and resilient modulus determined from these procedures are the measures of permanent deformation properties and the elastic modulus of unbound granular base/subbase materials and subgrade soils with the consideration of their stress-dependency.

1.5 Resilient modulus values can be used with structural response analysis models to calculate the pavement structural response to wheel loads, and with the combination of permanent deformation properties and pavement design procedures to predict rutting performance.

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

2. Referenced Documents

2.1 AASHTO Standards:

- T88 Particle Size Analysis of Soils;

- T89 Determining the Liquid Limit of Soils;
- T90 Determining the Plastic Limit and the Plasticity Index of Soils;
- T100 Specific Gravity of Soils;
- T180 Moisture-Density Relations of Soils using a 10 lb (454 kg) Rammer and 18 in (457 mm) Drop;
- T233 Density of Soil-in-Place by Block, Chunk, or Core Sampling;
- T292-91 Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials;
- T296 Strength Parameters of Soils by Triaxial Compression; and
- T265 Laboratory Determination of Moisture Content of Soils.

3. TERMINOLOGY

3.1 *Unbound Granular Base and Subbase Materials* – These include soil-aggregate mixtures and naturally occurring materials. No binding or stabilizing agent is used to prepare unbound granular base or subbase layers. These materials are classified as Type 1 and Type 2, as subsequently defined in 3.3 and 3.4.

3.2 *Subgrade* – Subgrade soils may be naturally occurring or prepared and compacted before the placement of subbase and/or base layers. These materials are classified as Type 1, Type 2, and Type 3, as subsequently defined in 3.3, 3.4, and 3.5.

3.3 *Material Type 1* – These include all unbound granular base and subbase materials and all untreated subgrade soils with maximum particle sizes greater than 3/8 in (9.5 mm). All material greater than 1.0 in (25.4 mm) shall be scalped off prior to testing. Materials classified as Type 1 shall be molded in either a 6 in (152 mm) diameter mold or a 4 in (102 mm) diameter mold. Materials classified as Type 1 shall be compacted by impact or vibratory compaction.

3.4 *Material Type 2* – These include all unbound granular base and subbase materials and all untreated subgrade soils that have a maximum particle size less than 3/8 in (9.5 mm) and that meet the criteria of less than 10 percent passing the No. 200 (75 μm) sieve. Materials classified as Type 2 shall be molded in a 4 in (102 mm) diameter mold and compacted by vibratory compaction.

3.5 *Material Type 3* – These includes all untreated subgrade soils that have a maximum particle size less than 3/8 in (9.5 mm) and that meet the criteria of more than 10 percent passing the No. 200 (75 mm) sieve. Materials classified as Type 3 shall be molded in a 4 in (102 mm) diameter mold and compacted by impact compaction.

3.6 *Permanent Deformation* – Permanent deformation is determined by repeated load compression tests on specimens of the unbound materials. Permanent deformation is the unrecovered deformation during the testing.

3.7 *Resilient Modulus* – The resilient modulus is determined by repeated load compression tests on test specimens of the unbound materials. Resilient modulus (M_r) is the ratio of the peak axial repeated deviator stress to the peak recoverable axial strain of the specimen.

3.8 *Loading Wave Form* – Test specimens are loaded using a haversine load pulse with 0.1-second loading and 0.9-second rest period.

3.9 *Maximum Applied Axial Load* (P_{max}) – The load applied to the sample consisting of the contact load and cyclic load (confining pressure is not included):

$$P_{max} = P_{contact} + P_{cyclic}$$

3.10 *Contact Load* ($P_{contact}$) – Vertical load placed on the specimen to maintain a positive contact between the loading ram and the specimen top cap. The contact load includes the weight of the top cap and the static load applied by the ram of the loading system.

3.11 *Cyclic Axial Load* – Repetitive load applied to a test specimen:

$$P_{cyclic} = P_{max} – P_{contact}$$

3.12 *Maximum Applied Axial Stress* (S_{max}) – The axial stress applied to the sample consisting of the contact stress and the cyclic stress (the confining stress is not included):

$$S_{max} = P_{max}/A$$

where: A = cross sectional area of the sample.

3.13 *Cyclic Axial Stress* – Cyclic applied axial stress:

$$S_{cyclic} = P_{cyclic}/A$$

3.14 *Contact Stress* ($S_{contact}$) – Axial stress applied to a test specimen to maintain a positive contact between the specimen cap and the specimen:

$$S_{contact} = P_{contact} /A$$

The contact stress shall be maintained so as to apply a constant anisotropic confining stress ratio:

$$(S_{contact} + S_3)/S_3 = 1.2$$

where: S_3 = confining pressure.

3.15 S_3 is the applied confining pressure in the triaxial chamber (i.e., the minor principal stress σ_3).

3.16 e_r is the resilient (recoverable) axial deformation due to S_{cyclic}.

3.17 ε_r is the resilient (recoverable) axial strain due to S_{cyclic}:

$$\varepsilon_r = e_r/L$$

where: L = distance between measurement points for resilient axial deformation, e_r.

3.18 e_p is the permanent (unrecoverable) axial deformation due to S_{cyclic}.

3.19 ε_p is the permanent (unrecoverable) axial strain due to S_{cyclic}:

$$\varepsilon_p = e_p/L$$

where: L = distance between measurement points for permanent axial deformation, e_p.

3.20 *Resilient Modulus* (M_r) is defined as:

$$M_r = S_{cyclic}/\varepsilon_r$$

3.21 Load duration is the time interval the specimen is subjected to a cyclic stress pulse.

3.22 Cycle duration is the time interval between the successive applications of a cyclic stress (usually 1.0 sec).

4. SUMMARY OF METHOD

4.1 A repeated axial stress of fixed magnitude, load duration, and cycle duration is applied to a cylindrical test specimen. The test is performed in a triaxial cell, and the specimen is subjected to a repeated (cyclic) stress and a constant confining stress provided by means of cell air pressure. Both total resilient (recoverable) and permanent axial deformation responses of the specimen are recorded and used to calculate the permanent deformation properties and the resilient modulus.

5. SIGNIFICANCE AND USE

5.1 The resilient modulus test results provide a basic constitutive relationship between stiffness and stress state of pavement materials for use in the structural analysis of layered pavement systems. Furthermore, permanent deformation properties of pavement materials also can be determined from the first 10,000 cycles of the repeated load test. The information is critical for pavement rutting performance prediction. The permanent deformation and resilient modulus tests simulate the conditions in a pavement with the application of moving wheel loadings.

6. PERMANENT DEFORMATION AND RESILIENT MODULUS TEST APPARATUS

6.1 *Triaxial Pressure Chamber* – The pressure chamber contains the test specimen and the confining fluid during the test. A typical triaxial chamber suitable for use in resilient modulus testing of soils is shown in Figure 8. The axial deformation is measured internally, directly on the specimen, using normal gauges with rubber bands (shown in Figure 9), an optical extensometer, non-contact sensors, or clamps. For soft and very soft subgrade specimens (i.e., $S_u < 36$ kPa or 750 psf, where S_u is the undrained shear strength of the soil), rubber bands or clamps should not be used since they may damage the specimen. However, a pair of LVDTs extending between the top and bottom platens can be used to measure axial deformation of these weak soils.

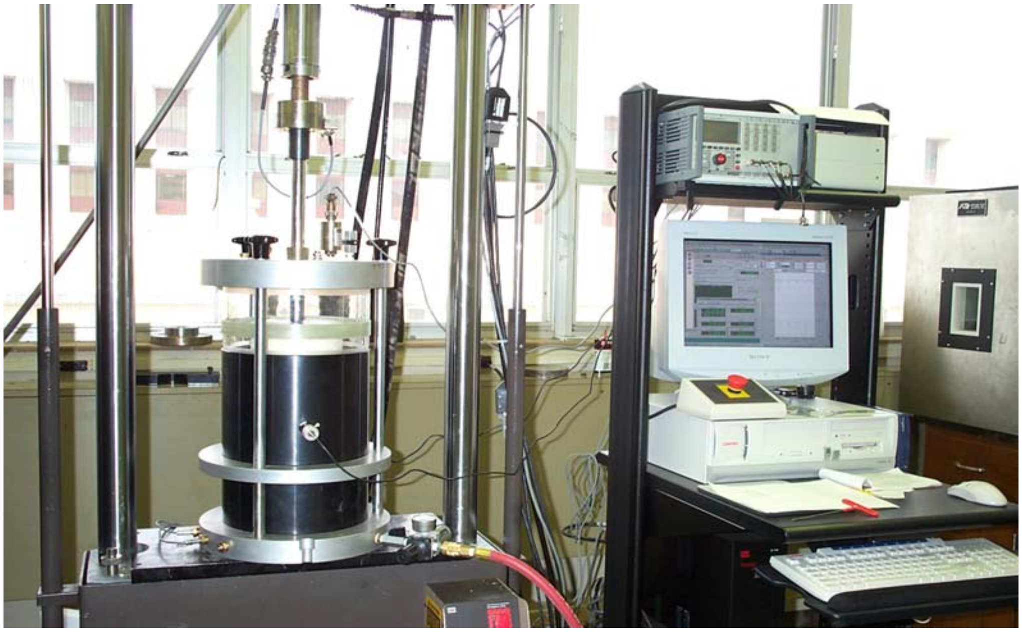


Figure 8. Triaxial Cell and Test System.

Figure 9. Sample with Instruments.

6.1.1 Air shall be used in the triaxial chamber as the confining fluid for all testing.

6.1.2 The chamber shall be made of suitable transparent material (such as polycarbonate).

6.2 *Loading Device* – The loading device shall be a top-loading, closed-loop electro-hydraulic testing machine with a function generator that is capable of applying repeated cycles of a haversine-shaped load pulse. Each pulse shall have a 0.1 sec duration followed by a rest period of 0.9 sec duration for base/subbase materials and 0.2 sec duration followed by a rest period of 0.8 sec duration for subgrade materials. For non-plastic granular material, it is permissible, if desired, to reduce the rest period to 0.4 sec to shorten testing time; the loading time may be increased to 0.15 sec if required.

6.2.1 All conditioning and testing shall be conducted using a haversine-shaped load pulse. The electro-hydraulic system-generated haversine waveform and the response waveform shall be displayed to allow the operator to adjust the gains to ensure they coincide during conditioning and testing.

6.3 Load and Specimen Response Measuring Equipment

6.3.1 The axial load measuring device should be an electronic load cell, which is preferred to be located inside the triaxial cell. The load cell should have the capacities presented in Table 4.

Table 4. Load Cell Capacity.

Sample Diameter in (mm)	Max. Load Capacity lb (kN)	Required Accuracy lb (N)
4.0 (102)	2000 (8.9)	±4 (±17.8)
6.0 (152)	5000 (22.24)	±5 (±22.24)

Note 10 – During periods of permanent deformation and resilient modulus testing, the load cell shall be monitored and checked once every two weeks or after every 50 permanent deformation and resilient modulus tests with a calibrated proving ring to assure that the load cell is operating properly. An alternative to using a proving ring is to inset an additional calibrated load cell and independently measure the load applied by the original cell. Additionally, the load cell shall be checked at any time there is a suspicion of a load cell problem. The testing shall not be conducted if the testing system is found to be out of calibration.

6.3.2 The chamber pressures shall be monitored with conventional pressure gauges, manometers, or pressure transducers accurate to 0.1 psi (0.69 kPa).

6.3.3 Axial Deformation: Axial deformation is to be measured with displacement transducers referenced to gauge points contacting the specimen with rubber bands as shown in Figure 9. Deformation shall be measured over approximately the middle half of the specimen. Axial deformations shall be measured at a minimum of two locations 180 degrees apart (in a plan view), and a pair of spring-loaded LVDTs are placed on the specimen at quarter points. Spring-loaded LVDTs shall be used to maintain a positive contact between the LVDTs and the surface on which the tips of the transducers rest.

Note 11 – Table 5 summarizes the specifications for spring-loaded LVDTs.

Table 5. Specifications for Axial LVDTs.

Material/Specimen Diameter (in)		Min. Range (in)	Approximate Resilient Specimen Displacement (in)
Aggregate Base	6	±0.25	0.001
	4	±0.10	0.00065
Subgrade Soil (sand and cohesive)	4	±0.25	0.0014

Note: For soft subgrade soil, permanent and resilient displacement shall be measured over entire specimen height.

Note 12 – Misalignment or dirt on the shaft of the transducer can cause the shafts of the LVDTs to stick. The laboratory technician shall depress and release each LVDT back and forth a number of times prior to each test to assure that they move freely and are not sticking. A cleaner/lubricant specified by the manufacturer shall be applied to the transducer shafts on a regular basis.

6.3.4 Data Acquisition: An analog-to-digital (A/D) data acquisition system is required. The overall system should include automatic data reduction to minimize production. Suitable signal excitation, conditioning, and recording equipment are required for simultaneous recording of axial load and deformations. The system should meet or exceed the following additional requirements: (1) 25 μs A/D conversion time; (2) 12-bit resolution; (3) single- or multiple-channel throughput (gain = 1), 30 kHz; (4) software selectable gains; (5) measurement accuracy of full scale (gain = 1) of ±0.02 percent; and (6) non-linearity of ±0.5 percent. The signal shall be clean and free of noise. Filtering the output signal during or after data acquisition is discouraged. If a filter is used, it should have a frequency higher than 10 to 20 Hz. A supplemental study should be made to ensure correct peak readings are obtained from filtered data compared to unfiltered data. A minimum of 200 data points from each LVDT shall be recorded per load cycle.

6.4 *Specimen Preparation Equipment* – A variety of equipment is required to prepare compacted specimens that are representative of field conditions. Use of different materials and different methods of compaction in the field requires the use of varying compaction techniques in the laboratory.

6.5 *Miscellaneous Apparatus* – This includes calipers, micrometer gauge, steel rule (calibrated to 0.02 in [0.5 mm]), rubber membranes from 0.02 to 0.031 in (0.25 to 0.79 mm) thickness, rubber O-rings, vacuum source with bubble chamber and regulator, membrane expander, porous stones (subgrade), 0.25 in (6.4 mm) thick porous stones or bronze discs (base/subbase), scales, moisture content cans, and data sheets.

6.6 *Periodic System Calibration* – The entire system (transducers, signal conditioning, and recording devices) shall be calibrated every two weeks or after every 50 tests. Daily and other periodic checks of the system may also be performed as necessary. No permanent deformation and resilient modulus testing will be conducted unless the entire system meets the established calibration requirements.

7. PREPARATION OF TEST SPECIMENS

7.1 The following guidelines, based on the sieve analysis test results, shall be used to determine the test specimen size:

7.1.1 Use 6.0 in (152 mm) diameter and 12 in (305 mm) high specimens for all materials with maximum particle sizes greater than 0.75 in (19 mm). All material of particle size greater than 1.0 in (25.4 mm) shall be scalped off prior to testing.

7.1.2 Use 4.0 in (102 mm) diameter and 8.0 in (204 mm) high specimens for all materials with maximum particle sizes less than 0.75 in (19 mm).

7.2 *Laboratory Compacted Specimens* – Reconstituted test specimens of all types shall be prepared to the specified or in situ dry density (γ_d) and moisture content (w). Laboratory compacted specimens shall be prepared for all unbound granular base and subbase material and for all subgrade soils.

7.2.1 *Moisture Content* – For in situ materials, the moisture content of the laboratory compacted specimen shall be the in situ moisture content for that layer obtained in the field using T238. If data are not available on in situ moisture content, refer to Section 7.2.3.

7.2.1.1 The moisture content of the laboratory compacted specimen should not vary from the required value by more than ±0.5 percent for all materials.

7.2.2 *Compacted Density* – The density of a compacted specimen shall be the in-place dry density obtained in the field for that layer using T239 or other suitable methods. If these data are not available on in situ density, then refer to Section 7.2.3.

7.2.2.1 The dry density of a laboratory compacted specimen should not vary more than ±1.0 percent from the target dry density for that layer.

7.2.3 If either the in situ moisture content or the in-place dry density is not available, then use the optimum moisture content and 95 percent of the maximum dry density by using T180 for the base/subbase and 95 percent of T99 for the subgrade.

7.2.3.1 The moisture content of the laboratory compacted specimen should not vary from the required value by more than ±0.5 percent for all materials. The dry density of a laboratory compacted specimen should not vary more than ±1.0 percent from the target dry density for that layer.

7.2.4 *Sample Reconstitution* – Reconstitute the specimen for all materials. The target moisture content and density to be used in determining needed material qualities are given in Section 7.2. After this step is completed, specimen compaction can begin.

7.3 Compaction Methods and Equipment for Reconstituting Specimens

7.3.1 Specimens of Type 1 materials shall be compacted by vibratory or impact compaction. The general method of vibratory compaction is given in T292-91. The general method of impact compaction is given in T292.

7.3.2 Specimens of Type 2 materials shall be compacted by vibratory compaction. The general method of vibratory compaction is presented in T292-92.

7.3.3 Specimens of Type 3 materials shall be compacted by impact compaction. The general method of impact compaction is given in T292-91.

8. TEST PROCEDURE

Following this test procedure, a permanent deformation and resilient modulus test is performed on all materials using a triaxial cell (confined).

8.1. Base/Subbase Materials – The procedure described in this section applies to all unbound granular base and subbase materials.

Apparatus and Sample Preparation

8.1.1 Assembly of the triaxial cell: If not already in place, place the specimen with end platens into position on the pedestal of the triaxial cell. Proper positioning of the specimen is extremely critical in applying a concentric load to the specimen. Couple the loading device to the specimen using a smooth steel ball. To center the specimen, slowly rotate the ball as the clearance between the load piston ball decreases and a small amount of load is applied to the specimen. Be sure the ball is concentric with the piston that applies the load (watch the gap around the ball). Shift the specimen laterally to achieve a concentric loading.

8.1.2 Check and adjust the axial displacement measurement system, load cell, and data acquisition system, and make sure they are working properly.

8.1.3 If not already connected, connect the confining air pressure supply line to the triaxial chamber.

8.1.4 Open all valves on drainage lines leading to the inside of the specimen. This is necessary to develop confining pressure on the specimen.

8.1.5 Apply the specified conditioning confining pressure of 15.0 psi (103.5 kPa) to the test specimen. A contact stress equal to 20 percent of the confining pressure shall be applied to the specimen so that the load piston stays in contact with the top platen at all times.

8.1.6 Preconditioning: Apply 100 repetitions of a load equivalent to a maximum axial stress of 6 psi (41.4 kPa) and a corresponding cyclic stress of 3 psi (20.7 kPa) using a haversine-shaped, 0.1 sec load pulse followed by 0.9 sec rest period.

Permanent Deformation Test

8.1.7 Apply the haversine loading (P_{cyclic}) equivalent to a maximum axial stress of 33 psi (227.7 kPa) and a corresponding cyclic stress of 30 psi (207 kPa) using a haversine-shaped, 0.1 sec load pulse followed by 0.9 sec rest period, and continue until 10,000 cycles (2.8 hr) or until the specimen fails and the vertical permanent strain reaches 5 percent during the testing, whichever comes first. The total number of cycles or the testing time will depend on the stress levels applied.

8.1.8 During the load applications, record the load applied and the axial deformation measured from two LVDTs through the data acquisition system. Signal-to-noise ratio should be at least 10. All data should be collected in real time and collected/processed so as to minimize phase errors due to sequential channel sampling. In order to save storage space during data acquisition for 10,000 cycles, researchers recommend using the data acquisition of the cycles shown in Table 6.

Table 6. Suggested Data Collection for Triaxial Repeated Load Permanent Deformation Test for Granular Base and Subbase.

Data Collection During Cycles	Data Collection During Cycles	Data Collection During Cycles	Data Collection During Cycles
1-15	450	1300	4000
20	500	1400	4500
30	550	1500	5000
40	600	1600	5500
60	650	1700	6000
80	700	1800	6500
100	750	1900	7000
130	800	2000	7500
160	850	2200	8000
200	900	2400	8500
250	950	2600	9000
300	1000	2800	9500
350	1100	3000	10000
400	1200	3500	

Resilient Modulus Test

Specimen Testing – If the vertical permanent strain has neither reached 5 percent nor failed during permanent deformation test, use the same specimen to perform the resilient modulus test following the load sequence shown in Table 7. Begin by decreasing the maximum axial stress to 14.5 kPa (2.1 psi) (Sequence No. 1 Table 7), and set the confining pressure to 20.7 kPa (3 psi).

If the vertical permanent strain has reached 5 percent or failed during permanent deformation test, mold a new specimen, and then go back to section 8.1.1. In addition, reduce the load repetitions from 10,000 to 5000 during the repeated load permanent deformation test. If the sample again reaches 5 percent total vertical permanent strain during repeated load test, then the test shall be terminated. No further testing of this material is necessary. If not, perform the resilient modulus test following the load sequence shown in Table 7. Begin by decreasing the maximum axial stress to 2.1 psi (14.5 kPa) (Sequence No. 1 in Table 7) and set the confining pressure to 3 psi (20.7 kPa).

8.1.9 Apply 100 repetitions of the corresponding cyclic axial stress using a haversine-shaped load pulse consisting of a 0.1 sec load followed by a 0.9 sec rest period. Record the average recovered deformations from each LVDT separately for the last five cycles.

8.1.10 Increase the maximum axial stress to 4.2 psi (30 kPa) and the confining pressure to 6 psi (41.4 kPa) (Sequence No. 2 in Table 7), and repeat the previous step at this new stress level.

8.1.11 Continue the test for the remaining stress sequences in Table 7 (3 to 30) recording the vertical recovered deformation. If at any time the total permanent strain of the sample exceeds 5 percent, stop the test and report the result on the appropriate worksheet.

Table 7. Permanent Deformation and Resilient Modulus Test Sequence for Granular Base and Subbase.

Sequence	Confining Pressure		Contact Stress		Cyclic Stress		Maximum Stress		$N_{rep.}$
	kPa	psi	kPa	psi	kPa	psi	kPa	psi	
Preconditioning	103.5	15.0	20.7	3.0	20.7	3.0	41.4	6.0	100
Permanent Deformation	103.5	15.0	20.7	3.0	207.0	30.0	227.7	33.0	10000
1	20.7	3.0	4.1	0.6	10.4	1.5	14.5	2.1	100
2	41.4	6.0	8.3	1.2	20.7	3.0	29.0	4.2	100
3	69.0	10.0	13.8	2.0	34.5	5.0	48.3	7.0	100
4	103.5	15.0	20.7	3.0	51.8	7.5	72.5	10.5	100
5	138.0	20.0	27.6	4.0	69.0	10.0	96.6	14.0	100
6	20.7	3.0	4.1	0.6	20.7	3.0	24.8	3.6	100
7	41.4	6.0	8.3	1.2	41.4	6.0	49.7	7.2	100
8	69.0	10.0	13.8	2.0	69.0	10.0	82.8	12.0	100
9	103.5	15.0	20.7	3.0	103.5	15.0	124.2	18.0	100
10	138.0	20.0	27.6	4.0	138.0	20.0	165.6	24.0	100
11	20.7	3.0	4.1	0.6	41.4	6.0	45.5	6.6	100
12	41.4	6.0	8.3	1.2	82.8	12.0	91.1	13.2	100
13	69.0	10.0	13.8	2.0	138.0	20.0	151.8	22.0	100
14	103.5	15.0	20.7	3.0	207.0	30.0	227.7	33.0	100
15	138.0	20.0	27.6	4.0	276.0	40.0	303.6	44.0	100
16	20.7	3.0	4.1	0.6	62.1	9.0	66.2	9.6	100
17	41.4	6.0	8.3	1.2	124.2	18.0	132.5	19.2	100
18	69.0	10.0	13.8	2.0	207.0	30.0	220.8	32.0	100
19	103.5	15.0	20.7	3.0	310.5	45.0	331.2	48.0	100
20	138.0	20.0	27.6	4.0	414.0	60.0	441.6	64.0	100
21	20.7	3.0	4.1	0.6	103.5	15.0	107.6	15.6	100
22	41.4	6.0	8.3	1.2	207.0	30.0	215.3	31.2	100
23	69.0	10.0	13.8	2.0	345.0	50.0	358.8	52.0	100
24	103.5	15.0	20.7	3.0	517.5	75.0	538.2	78.0	100
25	138.0	20.0	27.6	4.0	690.0	100.0	717.6	104.0	100
26	20.7	3.0	4.1	0.6	144.9	21.0	149.0	21.6	100
27	41.4	6.0	8.3	1.2	289.8	42.0	298.1	43.2	100
28	69.0	10.0	13.8	2.0	483.0	70.0	496.8	72.0	100
29	103.5	15.0	20.7	3.0	724.5	105.0	745.2	108.0	100
30	138.0	20.0	27.6	4.0	966.0	140.0	993.6	144.0	100

8.1.12 At the completion of this test, reduce the confining pressure to zero, and remove the sample from the triaxial chamber.

8.1.13 Remove the membrane from the specimen, and use the entire specimen to determine moisture content in accordance with T265.

8.2 *Coarse-Grained Subgrade Soils* – This procedure is used for all laboratory compacted specimens of subgrade soils for which the percent passing No. 200 (75 µm) sieve is less than 35 percent. Reconstructed specimens will usually be compacted directly on the pedestal of the triaxial cell.

Apparatus and Sample Preparation

8.2.1 Assembly of the triaxial cell: Refer to section 8.1.1.

8.2.2 Set up the axial displacement measurement system, and verify it is working properly.

8.2.3 If not already connected, connect the confining air pressure supply line to the triaxial chamber.

8.2.4 Open all valves on drainage lines leading to the inside of the specimen. This is necessary to develop confining pressure on the specimen.

8.2.5 Apply the specified conditioning confining pressure of 4.0 psi (27.6 kPa) to the test specimen. Apply a contact stress equal to 20 percent of the confining pressure to the specimen so that the load piston stays in contact with the top platen at all times.

8.2.6 Preconditioning: Apply 100 repetitions of a load equivalent to a maximum axial stress of 1.8 psi (12.4 kPa) and a corresponding cyclic stress of 1 psi (6.9 kPa) using a haversine-shaped, 0.2 sec load pulse followed by 0.8 sec rest period.

Permanent Deformation Test

8.2.7 Apply the haversine loading (P_{cyclic}) equivalent to a maximum axial stress of 8.8 psi (60.7 kPa) and a corresponding cyclic stress of 8 psi (55.2 kPa) using a haversine-shaped, 0.2 sec load pulse followed by 0.8 sec rest period, and continue until 10,000 cycles (2.8 hours) or until the specimen fails and/or the vertical permanent strain reaches 5 percent during the testing, whichever comes first. The total number of cycles or the testing time will depend on the stress levels applied.

8.2.8 During the load applications, record the load applied and the axial deformation measured from two LVDTs through the data acquisition system. All data should be collected in real time and collected/processed so as to minimize phase errors due to sequential channel sampling. In order to save storage space during data acquisition for 10,000 cycles, researchers recommend using the data acquisition of the cycles shown in Table 8.

Table 8. Suggested Data Collection for Triaxial Repeated Load Permanent Deformation Test for Granular Subgrades.

Data Collection during Cycles	Data Collection during Cycles	Data Collection during Cycles	Data Collection during Cycles
1-15	450	1300	4000
20	500	1400	4500
30	550	1500	5000
40	600	1600	5500
60	650	1700	6000
80	700	1800	6500
100	750	1900	7000
130	800	2000	7500
160	850	2200	8000
200	900	2400	8500
250	950	2600	9000
300	1000	2800	9500
350	1100	3000	10000
400	1200	3500	

Resilient Modulus Test

8.2.9 *Specimen Testing* – If the vertical permanent strain has neither reached 5 percent nor failed during permanent deformation test, use the same specimen to perform the resilient modulus test following the load sequence shown in Table 9. Begin by decreasing the maximum axial stress to 1.4 psi (9.66 kPa) (Sequence No. 1 in Table 9), and set the confining pressure to 2 psi (13.8 kPa).

If the vertical permanent strain has reached 5 percent or failed during permanent deformation test, mold a new specimen, and then go back to section 8.2.1. In addition, reduce the load repetitions from 10,000 to 5000 during the repeated load permanent deformation test. If the sample again reaches 5 percent total vertical permanent strain during the repeated load test, then terminate the test. No further testing of this material is necessary. If not, perform the resilient modulus test following the load sequence shown in Table 9. Begin by decreasing the maximum axial stress to 1.4 psi (9.66 kPa) (Sequence No. 1 in Table 9), and set the confining pressure to 2 psi (13.8 kPa).

Table 9. Permanent Deformation and Resilient Modulus Test Sequence for Granular Subgrades.

Sequence	Confining Pressure		Contact Stress		Cyclic Stress		Maximum Stress		N_{rep}
	kPa	Psi	kPa	psi	kPa	Psi	kPa	psi	
Preconditioning	27.6	4.0	5.5	0.8	6.9	1.0	12.4	1.8	100
Permanent Deformation	27.6	4.0	5.5	0.8	55.2	8.0	60.7	8.8	10,000
1	13.8	2.0	2.8	0.4	6.9	1.0	9.7	1.4	100
2	27.6	4.0	5.5	0.8	13.8	2.0	19.3	2.8	100
3	41.4	6.0	8.3	1.2	20.7	3.0	29.0	4.2	100
4	55.2	8.0	11.0	1.6	27.6	4.0	38.6	5.6	100
5	82.8	12.0	16.6	2.4	41.4	6.0	58.0	8.4	100
6	13.8	2.0	2.8	0.4	13.8	2.0	16.6	2.4	100
7	27.6	4.0	5.5	0.8	27.6	4.0	33.1	4.8	100
8	41.4	6.0	8.3	1.2	41.4	6.0	49.7	7.2	100
9	55.2	8.0	11.0	1.6	55.2	8.0	66.2	9.6	100
10	82.8	12.0	16.6	2.4	82.8	12.0	99.4	14.4	100
11	13.8	2.0	2.8	0.4	27.6	4.0	30.4	4.4	100
12	27.6	4.0	5.5	0.8	55.2	8.0	60.7	8.8	100
13	41.4	6.0	8.3	1.2	82.8	12.0	91.1	13.2	100
14	55.2	8.0	11.0	1.6	110.4	16.0	121.4	17.6	100
15	82.8	12.0	16.6	2.4	165.6	24.0	182.2	26.4	100
16	13.8	2.0	2.8	0.4	41.4	6.0	44.2	6.4	100
17	27.6	4.0	5.5	0.8	82.8	12.0	88.3	12.8	100
18	41.4	6.0	8.3	1.2	124.2	18.0	132.5	19.2	100
19	55.2	8.0	11.0	1.6	165.6	24.0	176.6	25.6	100
20	82.8	12.0	16.6	2.4	248.4	36.0	265.0	38.4	100

8.2.10 Apply 100 repetitions of the corresponding cyclic axial stress using a haversine-shaped load pulse consisting of a 0.2 sec load followed by a 0.8 sec rest period. Record the average recovered deformations from each LVDT separately for the last five cycles.

8.2.11 Increase the maximum axial stress to 2.8 psi (19.32 kPa) , and set the confining pressure to 4 psi (27.6 kPa) (Sequence No. 2 in Table 9), and repeat the previous step at this new stress level.

8.2.12 Continue the test for the remaining stress sequences in Table 9 (3 to 20) recording the vertical recovered deformation. If at any time the total permanent strain of the sample exceeds 5 percent, stop the test and report the result on the appropriate worksheet.

8.2.13 At the completion of this test, reduce the confining pressure to zero, and remove the sample from the triaxial chamber.

8.2.14 Remove the membrane from the specimen, and use the entire specimen to determine moisture content in accordance with T265.

8.3. *Fine-Grained Subgrade Soils* – This procedure is used for all laboratory compacted specimens of subgrade soils for which the percent passing No. 200 (75 µm) sieve is greater than 35 percent. Reconstructed specimens will usually be compacted directly on the pedestal of the triaxial cell.

Apparatus and Sample Preparation

8.3.1 Assembly of the Triaxial Cell: Refer to section 8.1.1.

8.3.2 *Stiff to Very Stiff Specimens*: For stiff and very stiff cohesive specimens ($S_u > 750$ psf [36 kPa]), here S_u designates the undrained shear strength of the soil), axial deformation should preferably be measured either directly on the specimen or between the solid end platens using grouted specimen ends.

8.3.3 *Soft Specimens*: The axial deformation of soft subgrade soils ($S_u < 750$ psf [36 kPa]) should not be measured using a rubber band circled on the specimen. If the measured resilient modulus is less than 10,000 psi (69,000 kPa), axial deformation can be measured between top and bottom platens. An empirical correction is not required for irregular specimen end contacts for these low modulus soils. If the resilient modulus is greater than 10,000 psi (69,000 kPa), follow the procedure in section 8.3.2.

8.3.4 Install Axial Displacement Device: Carefully install the axial displacement instrumentation selected under 8.3.2 or 8.3.3. For top to bottom displacement measurement, attach the LVDTs or proximity gauges on steel or aluminum bars extending between the top and bottom platens. If the rubber band or clamps are used, place the rubber band or clamps at the quarter points of the specimen using two height gauges to ensure that clamps are positioned horizontally at the correct height. Each height gauge can consist of two circular aluminum rods machined to the correct length. These rods are placed on each side of the clamp to ensure proper location. Then, ensure the displacement instrumentations are working properly by displacing each device and observing the resulting voltage output as shown by the data acquisition system.

8.3.5 Refer to section 8.1.1.

8.3.6 Set up the axial displacement measurement system, and verify it is working properly.

8.3.7 Open all valves on drainage lines leading to the inside of the specimen. This is necessary to develop confining pressure on the specimen.

8.3.8 If not already connected, connect the confining air pressure supply line to the triaxial chamber.

8.3.9 Apply the specified conditioning confining pressure of 27.6 kPa (4.0 psi) to the test specimen. Apply a contact stress equal to 20 percent of the confining pressure to the specimen so that the load piston stays in contact with the top platen at all times.

8.3.10 Preconditioning: Apply 100 repetitions of a load equivalent to a maximum axial stress of 1.8 psi (12.4 kPa) and a corresponding cyclic stress of 1 psi (6.9 kPa) using a haversine-shaped, 0.2 sec load pulse followed by 0.8 sec rest period.

Permanent Deformation Test

8.3.11 Apply the haversine-loading (P_{cyclic}) equivalent to a maximum axial stress of 7.8 psi (53.8 kPa) and a corresponding cyclic stress of 7 psi (48.3 kPa) using a haversine-shaped, 0.2 sec load pulse followed by 0.8 sec rest period, and continue until 10,000 cycles (2.8 hours) or until the specimen fails and the vertical permanent strain reaches 5 percent during the testing, whichever comes first. The total number of cycles or the testing time will depend on the stress levels applied.

8.3.12 During the load applications, record the load applied and the axial deformation measured from all LVDTs through the data acquisition system. Signal-to-noise ratio should be at least 10. All data should be collected in real time and collected/processed so as to minimize phase errors due to sequential channel sampling. In order to save storage space during data acquisition for 10,000 cycles, researchers recommend using the data acquisition cycles shown in Table 10.

Table 10. Suggested Data Collection for Triaxial Repeated Load Permanent Deformation Test for Fine-Grained Subgrades.

Data Collection during Cycles	Data Collection during Cycles	Data Collection during Cycles	Data Collection during Cycles
1-15	450	1300	4000
20	500	1400	4500
30	550	1500	5000
40	600	1600	5500
60	650	1700	6000
80	700	1800	6500
100	750	1900	7000
130	800	2000	7500
160	850	2200	8000
200	900	2400	8500
250	950	2600	9000
300	1000	2800	9500
350	1100	3000	10000
400	1200	3500	

Resilient Modulus Test

8.3.13 Specimen Testing–If the vertical permanent strain has neither reached 5 percent nor failed during permanent deformation test, use the same specimen to perform the resilient modulus test following the load sequence shown in Table 11. Begin by decreasing the maximum axial stress to 5.6 psi (38.6 kPa) (Sequence No.1 in Table 11), and set the confining pressure to 8 psi (55.2 kPa).

If the vertical permanent strain has reached 5 percent or failed during the permanent deformation test, mold a new specimen, and then go back to Section 8.3.1. In addition, reduce the load repetitions from 10,000 to 5000 during the repeated load permanent deformation test. If the sample again reaches 5 percent total vertical permanent strain during the repeated load test, then terminate the test. No further testing of this material is necessary. If not, perform the resilient modulus test following the load sequence shown in Table 11. Begin by decreasing the maximum axial stress to 5.6 psi (38.6 kPa) (Sequence No.1 in Table 11), and set the confining pressure to 8 psi (55.2 kPa).

8.3.14 Apply 100 repetitions of the corresponding cyclic axial stress using a haversine-shaped load pulse consisting of a 0.2 sec load followed by a 0.8 sec rest period. Record the average recovered deformations from each LVDT separately for the last five cycles.

8.3.15 Decrease the maximum axial stress to 35.9 kPa (5.2 psi), set the confining pressure to 41.4 kPa (6 psi) (Sequence No. 2 in Table 11), and repeat the previous step at this new stress level.

8.3.16 Continue the test for the remaining stress sequences in Table 11 (3 to 16) recording the vertical recovered deformation. If at any time the total permanent strain of the sample exceeds 5 percent, stop the test and report the result on the appropriate worksheet.

8.3.17 At the completion of this test, reduce the confining pressure to zero, and remove the sample from the triaxial chamber.

8.3.18 Remove the membrane from the specimen, and use the entire specimen to determine moisture content in accordance with T265.

Table 11. Permanent Deformation and Resilient Modulus Test Sequence for Fine-Grained Subgrades.

Sequence	Confining Pressure		Contact Stress		Cyclic Stress		Maximum Stress		$N_{rep.}$
	kPa	psi	kPa	psi	KPa	psi	kPa	Psi	
Preconditioning	27.6	4.0	5.5	0.8	6.9	1.0	12.4	1.8	100
Permanent Deformation	27.6	4.0	5.5	0.8	48.3	7.0	53.8	7.8	10,000
1	55.2	8.0	11.0	1.6	27.6	4.0	38.6	5.6	100
2	41.4	6.0	8.3	1.2	27.6	4.0	35.9	5.2	100
3	27.6	4.0	5.5	0.8	27.6	4.0	33.1	4.8	100
4	13.8	2.0	2.8	0.4	27.6	4.0	30.4	4.4	100
5	55.2	8.0	11.0	1.6	48.3	7.0	59.3	8.6	100
6	41.4	6.0	8.3	1.2	48.3	7.0	56.6	8.2	100
7	27.6	4.0	5.5	0.8	48.3	7.0	53.8	7.8	100
8	13.8	2.0	2.8	0.4	48.3	7.0	51.1	7.4	100
9	55.2	8.0	11.0	1.6	69.0	10.0	80.0	11.6	100
10	41.4	6.0	8.3	1.2	69.0	10.0	77.3	11.2	100
11	27.6	4.0	5.5	0.8	69.0	10.0	74.5	10.8	100
12	13.8	2.0	2.8	0.4	69.0	10.0	71.8	10.4	100
13	55.2	8.0	11.0	1.6	96.0	14.0	107.6	15.6	100
14	41.4	6.0	8.3	1.2	96.0	14.0	104.9	15.2	100
15	27.6	4.0	5.5	0.8	96.0	14.0	102.1	14.8	100
16	13.8	2.0	2.8	0.4	96.0	14.0	99.4	14.4	100

9. CALCULATIONS

Calculation of Permanent Strain

9.1 Calculate the average axial deformation for each specimen by averaging the readings from the two axial LVDTs. Convert the average deformation values to total axial strain by dividing by the gauge length, L (6 in (152 mm) for 6 in (152 mm) diameter sample; 4in (102 mm) for 4 in (102 mm) diameter sample). Typical total axial strain versus time is shown in Figure 10.

9.2 Compute the cumulative axial permanent strain and resilient strain (ε_r) at 200th load repetition.

9.3 Plot the cumulative axial permanent strain versus the number of loading cycles in log space (shown in Figure 11). Determine the permanent deformation parameters, intercept (a) and slope (b), from the linear portion of the permanent strain curve (log-log scale), which is also demonstrated in Figure 11.

9.4 Compute the rutting parameters: Alpha, Mu

$$\mu = \frac{ab}{\varepsilon_r}$$

$$\alpha = 1 - b$$

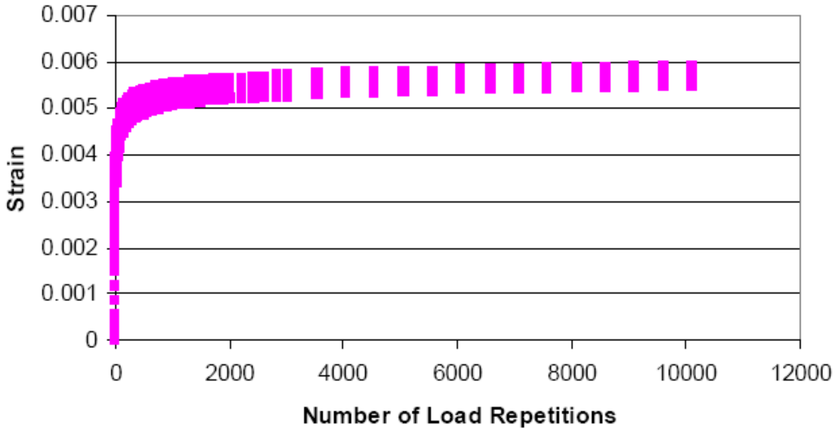


Figure 10. Triaxial Repeated Load Test Results: Strain vs. Number of Load Repetitions.

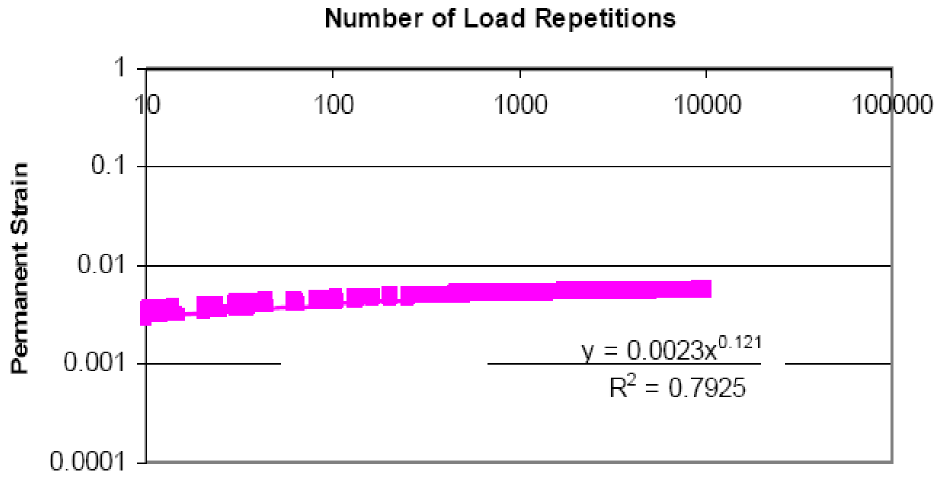


Figure 11. Permanent Strain vs. Number of Load Repetitions.

Calculation of Resilient Modulus

9.5 Perform the calculations to obtain resilient modulus values. The resilient modulus is computed from each of the last five cycles of each load sequence and then averaged. The data reduction processes should be fully automated to minimize the chance for human error.

9.6 Using nonlinear regression techniques fit the following resilient modulus model to the data obtained from the applied procedure. The equation for the normalized log-log k_1, k_2, and k_3 models is as follows:

$$M_R = k_1 p_a \left(\frac{\theta}{p_a}\right)^{k_2} \left(\frac{\tau_{oct}}{p_a} + 1\right)^{k_3}$$

$k_1, k_2 \geq 0$

$k_3 \leq 0$

where:

M_R = resilient modulus,

θ = Bulk stress, $\theta = \sigma_1 + \sigma_2 + \sigma_3$

τ_{oct} = Octahedral shear stress,

$$\tau_{oct} = \frac{1}{3}\sqrt{(\sigma_1 - \sigma_2)^2 + (\sigma_1 - \sigma_3)^2 + (\sigma_2 - \sigma_3)^2}$$

σ_1, σ_2, σ_3 = Principal stresses,

k = Regression constants,

p_a = atmospheric pressure (14.7 psi).

To facilitate the analysis, an Excel© Macro has been developed to directly read the output file from the resilient modulus test and automatically determine parameters k_1, k_2, and k_3.

10. REPORT

10.1 Permanent Deformation Test:

10.1.1 Report all specimen basic information including specimen identification, dates of manufacturing and testing, specimen diameter and length, confining pressure, stress levels used, and axial permanent deformation parameters: α, μ (or ε_r, a, and b).

10.2 Resilient Modulus Test

10.2.1 Report all specimen basic information including specimen identification, dates of manufacturing and testing, specimen diameter, and length.

10.2.2 Report the average peak stress (σ_o) and strain (ε_o) for each confining pressure–cyclic stress combination tested.

10.2.3 For each confining pressure–cyclic stress combination tested, report the resilient modulus for each replicate test specimen.

10.2.4 Report nonlinear resilient modulus model and the model parameters: k_1, k_2, and k_3.