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16. Abstract

VESYS5 is a probabilistic and mechanistic flexible pavement analysis computer program. It predicts asphalt pavement performance (rutting, fatigue cracking, present serviceability index ([PSI], etc.) over time. Also, it has been successfully used to analyze asphalt pavement performance under field traffic and under accelerated pavement testing loads. In the past year the Texas Transportation Institute has upgraded and enhanced the VESYS5 program to the Windows version with user-friendly input and output interfaces. This report documents the guidelines for developing the input parameters for the enhanced VESYS5 program.

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GUIDELINES FOR DEVELOPING INPUT PARAMETERS OF ENHANCED VESYS5 PROGRAM

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GUIDELINES FOR DEVELOPING INPUT PARAMETERS OF ENHANCED VESYS5 PROGRAM

VESYS5 is a probabilistic and mechanistic flexible pavement analysis computer program. The VESYS series has been under development at the Federal Highway Administration under Mr. Bill Kenis's leadership for more than 30 years. VESYS5 is one of the most powerful programs in the VESYS family. It is based on the elastic model of layered homogeneous material in half-infinite space with some viscoelastic-plastic theory applications. It predicts asphalt pavement performance (rutting, fatigue cracking, present serviceability index ([PSI]), etc.) with time. Also, it has been successfully used to analyze asphalt pavement performance under the field traffic and under accelerated pavement testing loads. In addition, its running speed is very fast. However, it works only in a DOS operation system, and its input and output parameters are so complicated that it is impossible to use routinely. These defects significantly block the application of VESYS5. In the last year, the Texas Transportation Institute (TTI) has upgraded and enhanced the DOS version of VESYS5 into a user-friendly Windows version.

The Windows version of the VESYS5 enhanced program provides a user-friendly input and output interface and significantly improves the usability of the existing VESYS5 program. By thoroughly studying and examining VESYS5 input, TTI researchers were able to simplify user input and visualize output data. As shown in Figure 1, the input data have been categorized into four types: general information, climate, structure and material properties, and traffic data. Among these input parameters, material properties including modulus, permanent deformation, and fatigue cracking are critical to the enhanced VESYS5 program. Guidelines for providing these critical parameters are presented as follows.

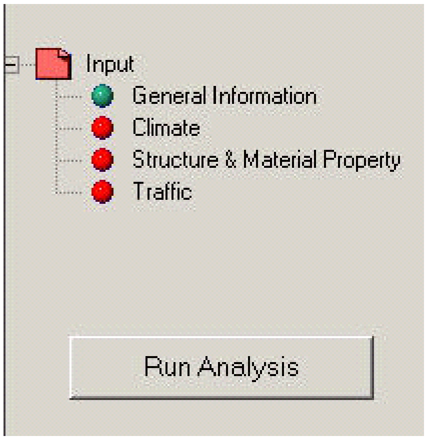

Figure 1. Overview of Input Data of Enhanced VESYS5.

A hierarchical two-level input has been adopted for pavement material properties in the enhanced VESYS5 program. The Level 1 input is designed for routine use. These default material properties include modulus and permanent deformation properties for each pavement layer material and fatigue cracking property of the asphalt mixture. These default values were developed based on extensive laboratory test results (dynamic modulus [AASHTO TP 62-03]), resilient modulus [see Appendix A], repeated load test [see Appendix B], and literature review (*1-11*). Table 1 presents the default material properties built into the enhanced VESYS5 program.

For any important project, Level 2 input is recommended. This level input requires laboratory tests to characterize the pavement materials. Dynamic modulus, repeated load, and beam fatigue tests are used to determine the dynamic modulus, permanent deformation properties (Alpha and Mu), and fatigue cracking properties (K_1, K_2, and K_3) of asphalt layer(s). The test protocols for these tests are listed in the following:

- AASHTO TP 62-03: Determining Dynamic Modulus of Hot Mix Asphalt Concrete Mixtures;
- Test Protocol on Resilient Modulus and Alpha and Mu for Base, Subbase, and Subgrade (Appendix A);
- VESYS Test Protocol on Alpha and Mu for Asphalt Mixtures (Appendix B); and
- AASHTO TP 8-94: Method for Determining the Fatigue Life of Compacted Hot Mix Asphalt (HMA) Subjected to Repeated Flexural Bending.

Table 1. Default Material Properties Built in the Enhanced VESYS5.

Material Type		Modulus (ksi)	Poisson's Ratio	μ	α	K_1	K_2	K_3
Asphalt	HMA Dense Graded A	300-450	0.30	0.35-0.15	0.70-0.85	-	3.9492	1.281
	HMA Dense Graded B	400-550	0.30	0.35-0.15	0.70-0.85			
	HMA Dense Graded C	500-700	0.30	0.35-0.15	0.70-0.85			
	HMA Dense Graded D	500-700	0.30	0.35-0.15	0.70-0.85			
	Rut Resistant HMA	900-1200	0.30	0.30-0.10	0.75-0.89			
	Fatigue Resistant HMA	600-800	0.30	0.37-0.20	0.72-0.83			
	Modified HMA	800-1200	0.30	0.30-0.10	0.75-0.89			
	Other	>1200	0.30	<0.30	0.79-0.89			
Base/ Subbase	Granular-Class 1 Base	50-90	0.35	0.20-0.08	0.85-0.93			
	Granular-Class 2 Base	50-80	0.35	0.25-0.08	0.84-0.92			
	Heavily Stabilized Base	150-400	0.25	0.10-0.04	0.92-0.97			
	Lightly Stabilized Base	100-175	0.30	0.15-0.04	0.91-0.96			
	Asphalt Permeable Base	200-400	0.35	0.25-0.16	0.78-0.87			
	Other	>100	0.30	<0.10	0.87-0.96			
Soils	Gravelly Soils	12-20	0.35	0.20-0.09	0.87-0.95			
	Sandy Soils	8-17	0.35	0.21-0.10	0.87-0.95			
	High PI Clay	2-6	0.40	0.30-0.15	0.87-0.95			
	Low PI Clay	4-10	0.40	0.28-0.10	0.87-0.95			
	Other	>8	0.40	<0.30	0.87-0.95			

Note: PI = Plasticity Index

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APPENDIX A

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 property 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 454 kg (10 lb) Rammer and 457 mm (18 inch) 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

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

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

3.5 Material Type 3 – Includes all untreated subgrade soils that have a maximum particle size less than 9.5 mm (3/8 inch) and that meet the criteria of more than 10 percent passing the 75 mm (No. 200) sieve. Materials classified as Type 3 shall be molded in a 102 mm (4 inch) 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 uncovered 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 (resilient) 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 seconds).

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 property 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 initial 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 is used to contain 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 A1. The axial deformation is measured internally, directly on the specimen, using normal gauges with rubber bands (shown in Figure A2), 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 linear variable differential transformers (LVDTs) extending between the

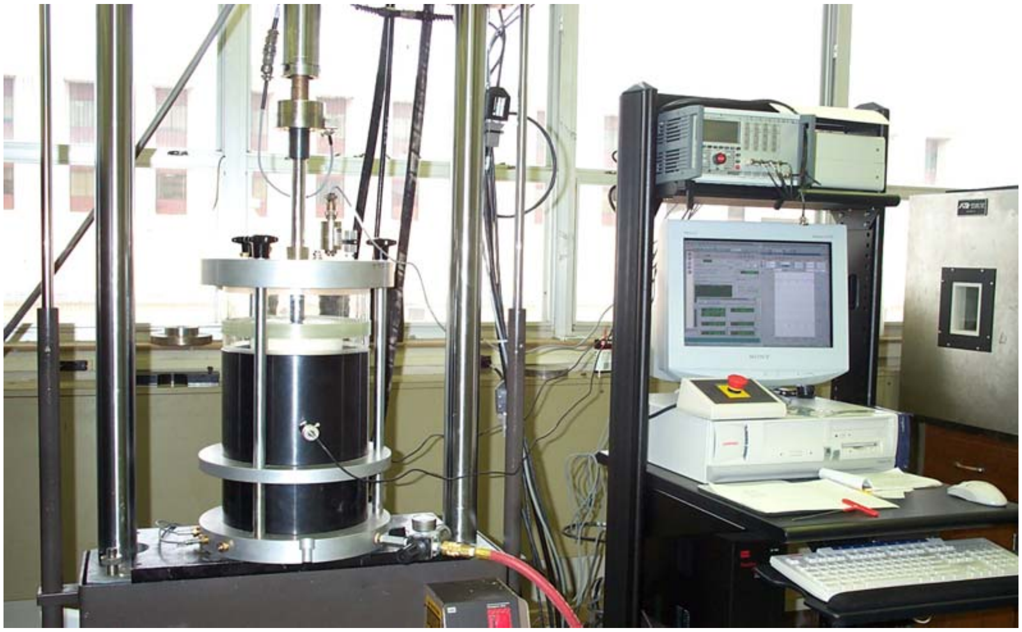

Figure A1. Triaxial Cell and Test System.

Figure A2. Sample with Instruments.

top and bottom platens can be used to measure axial deformation of these weak soils.

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 second duration followed by a rest period of 0.9 second duration for base/subbase materials and 0.2 second duration followed by a rest period of 0.8 second duration for subgrade materials. For non-plastic granular material, it is permissible, if desired, to reduce the rest period to 0.4 second to shorten testing time; the loading time may be increased to 0.15 second 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 A1.

Table A1. Load Cell Capacity.

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

Note 1 – 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 0.69 kPa (0.1 psi).

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 A2. Deformation shall be measured over approximately the middle ½ of the specimen. Axial deformations shall be measured at a minimum of two locations 180° apart (in plan view), and a pair of spring-loaded LVDTs are placed on the specimen at ¼ point. 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 2 – Table A2 summarizes the specifications for spring-loaded LVDTs.

Table A2. Specifications for Axial LVDTs.

Material/specimen diameter (inch)		Min. range (inch)	Approximate resilient specimen displacement (inch)
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 3 – 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 is 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 0.5 mm [0.02 inch]), rubber membranes from 0.25 to 0.79 mm (0.02 to 0.031 inch) thickness, rubber O-rings, vacuum source with bubble chamber and regulator, membrane expander, porous stones (subgrade), 6.4 mm (0.25 inch) 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 preformed 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 152 mm (6.0 inch) diameter and 305 mm (12 inch) high specimens for all materials with maximum particle sizes greater than 19 mm (0.75 inch). All material of particle size greater than 25.4 mm (1.0 inch) shall be scalped off prior to testing.

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

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 in accordance with the provisions given in Appendix A. 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, 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.

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 103.5 kPa (15.0 psi) 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 41.4 kPa (6 psi) and a corresponding cyclic stress of 20.7 kPa (3 psi) using a haversine-shaped, 0.1 second load pulse followed by 0.9 second rest period.

<u>Permanent Deformation Test</u>

8.1.7 Apply the haversine loading (P_{cyclic}) equivalent to a maximum axial stress of 227.7 kPa (33 psi) and a corresponding cyclic stress of 207 kPa (30 psi) using a haversine shaped, 0.1 second load pulse followed by 0.9 second 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.

8.1.8 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, it is recommended to use the data acquisition of the cycles shown in Table A3.

Table A3. 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

8.1.9 Specimen Testing: If the vertical permanent strain has not reached 5 percent or failed during permanent deformation test, use the same specimen to perform the resilient modulus test following the load sequence shown in Table A4. Begin by decreasing the maximum axial stress to 14.5 kPa (2.1 psi) (Sequence No. 1 Table A4) and set the confining pressure to 20.7 kPa (3 psi).

Table A4. 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

If the vertical permanent strain has reached 5 percent or failed during permanent deformation test, mold a new specimen, then go back to section 8.1.1. In addition, reduce the load repetitions from 10,000 to 5,000 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 A4. Begin by decreasing the maximum axial stress to 14.5 kPa (2.1 psi) (Sequence No. 1 Table A4) and set the confining pressure to 20.7 kPa (3 psi).

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

8.1.11 Increase the maximum axial stress to 30 kPa (4.2 psi) and the confining pressure to 41.4 kPa (6 psi) (Sequence No. 2 Table A4) and repeat the previous step at this new stress level.

8.1.12 Continue the test for the remaining stress sequences in Table A4 (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.

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

8.1.14 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 75 µm (No. 200) sieve is less than 35 percent. Reconstructed specimens will usually be compacted directly on the pedestal of the triaxial cell.

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 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.

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

Permanent Deformation Test

8.2.7 Apply the haversine loading (P_{cyclic}) equivalent to a maximum axial stress of 60.7 kPa (8.8 psi) and a corresponding cyclic stress of 55.2 kPa (8 psi) using a haversine-shaped, 0.2 second load pulse followed by 0.8 second 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, it is recommended to use the data acquisition of the cycles shown in Table A5.

Resilient Modulus Test

8.2.9 Specimen Testing: If the vertical permanent strain has not reached 5 percent or failed during permanent deformation test, use the same specimen to perform the resilient modulus test following the load sequence shown in Table A6. Begin by decreasing the maximum axial stress to 9.66 kPa (1.4 psi) (Sequence No. 1 Table A6) and set the confining pressure to 13.8 kPa (2 psi).

Table A5. 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	

If the vertical permanent strain has reached 5 percent or failed during permanent deformation test, mold a new specimen, then go back to section 8.2.1. In addition, reduce the load repetitions from 10,000 to 5,000 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 A6. Begin by decreasing the maximum axial stress to 9.66 kPa (1.4 psi) (Sequence No. 1 Table A6) and set the confining pressure to 13.8 kPa (2 psi).

Table A6. 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 second load followed by a 0.8 second 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 19.32 kPa (2.8 psi) and set the confining pressure to 27.6 kPa (4 psi) (Sequence No. 2 Table A6) and repeat the previous step at this new stress level.

8.2.12 Continue the test for the remaining stress sequences in Table A6 (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 Cohesive Subgrade Soils: This procedure is used for all laboratory compacted specimens of subgrade soils for which the percent passing 75 µm (No. 200) sieve is greater than 35 percent. Reconstructed specimens will usually be compacted directly on the pedestal of the triaxial cell.

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 ($S_u > 36$ kPa (750 psf), 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 ($S_u < 36$ kPa [750 psf]) should not be measured using a rubber band circled on the specimen. If the measured resilient modulus is less than 69,000 kPa (10,000 psi), 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 69,000 kPa (10,000 psi), follow the procedure in section 8.3.2.1.

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 ¼ 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 12.4 kPa (1.8 psi) and a corresponding cyclic stress of 6.9 kPa (1 psi) using a haversine-shaped, 0.2 second load pulse followed by 0.8 second rest period.

Permanent Deformation Test

8.3.11 Apply the haversine-loading (P_{cyclic}) equivalent to a maximum axial stress of 53.8 kPa (7.8 psi) and a corresponding cyclic stress of 48.3 kPa (7 psi) using a haversine-shaped, 0.2 second load pulse followed by 0.8 second 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, it is recommended to use the data acquisition cycles shown in Table A7.

Resilient Modulus Test

8.3.13 Specimen Testing: If the vertical permanent strain has not reached 5 percent or failed during permanent deformation test, use the same specimen to perform the resilient modulus test following the load sequence shown in Table A6. Begin by decreasing the maximum axial stress to 38.6 kPa (5.6 psi) (Sequence No. 1 Table A8) and set the confining pressure to 55.2 kPa (8 psi).

If the vertical permanent strain has reached 5 percent or failed during the permanent deformation test, mold a new specimen, then go back to section 8.3.1. In addition, reduce the load repetitions from 10,000 to 5,000 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 A4. Begin by decreasing the maximum axial stress to 38.6 kPa (5.6 psi) (Sequence No. 1 Table A8) and set the confining pressure to 55.2 kPa (8 psi).

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

Table A7. 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	

8.3.15 Decrease the maximum axial stress to 35.9 kPa (5.2 psi) and set the confining pressure to 41.4 kPa (6 psi) (Sequence No. 2 Table A8) and repeat the previous step at this new stress level.

8.3.16 Continue the test for the remaining stress sequences in Table A8 (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 A8. 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 (152 mm [6 inch] for 152 mm diameter sample; 102 mm (4 inch) for 102 mm diameter sample). Typical total axial strain versus time is shown in Figure A3.

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 A4). 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 on Figure A4.

9.4 Compute the rutting parameters: Alpha, Mu

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

$$\alpha = 1 - b$$

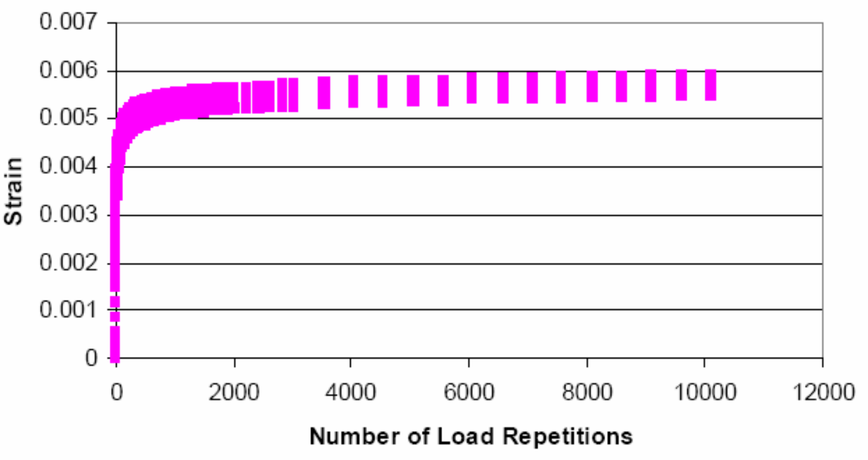

Figure A3. Triaxial Repeated Load Test Results: Strain vs. Number of Load Repetitions.

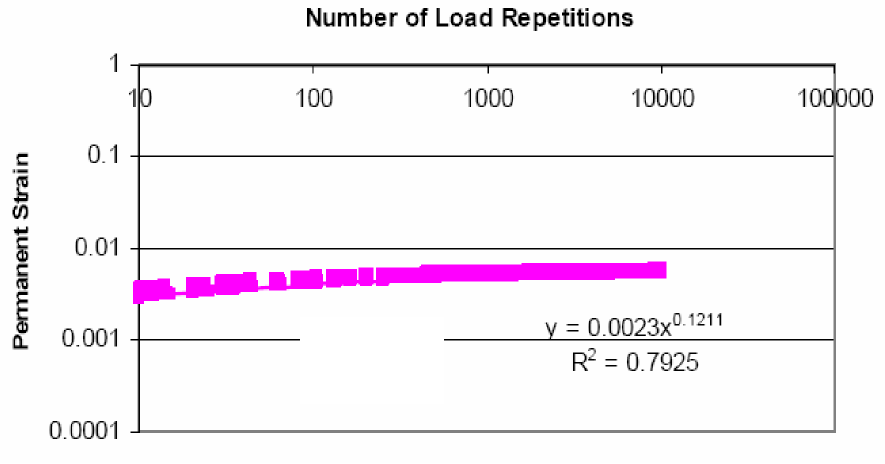

Figure A4. Permanent Strain vs. Number of Load Repetitions.

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 Fit using nonlinear regression techniques the following resilient modulus model to the data obtained from the applied procedure. The equation for the normalized log-log k_1, k_2, k_3, k_6, k_7 model is as follows:

$$M_R = k_1 p_a \left(\frac{\theta - 3k_6}{p_a} \right)^{k_2} \left(\frac{\tau_{oct}}{p_a} + k_7 \right)^{k_3}$$

$k_1, k_2 \geq 0$

$k_3, k_6 \leq 0$

$k_7 \geq 1$

where:

M_R = Resilient Modulus

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

τ_{oct} = Octahedral shear stress,

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

$\sigma_1, \sigma_2, \sigma_3$ = Principal Stresses

k = Regression constants

p_a = atmospheric pressure (14.7 psi)

Assign initial values of zero for k_6 and one for k_7; restrain all regression constants according to the model. Report the constants k_1, k_2, k_3, k_6, and k_7, the ratio of the standard error of estimate, to the standard deviation and the square of the correlation coefficient.

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

10.2.4 Report nonlinear resilient modulus model and the model parameters: k_1, k_2, k_3, k_6, and k_7.

APPENDIX B

VESYS TEST PROTOCOL FOR ASPHALT MIXES

1. Test Samples

1.1 Size

Testing shall be performed on 100 mm (4 inch) diameter by 150 mm (6 inch) or more high 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 150 mm (6 inch) high samples to the required air void content in accordance with AASHTO TP-4. The gyratory compactor is shown in Figure B1.

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 two LVDTs.

2. Test Sample Instrumentation

2.1 Attach mounting studs for the axial LVDTs to both sides of the sample with 180° intervals (in plan view) using epoxy cement (shown in Figure B2). Make sure the studs are aligned.

Figure B1. Superpave Gyratory Compactor.

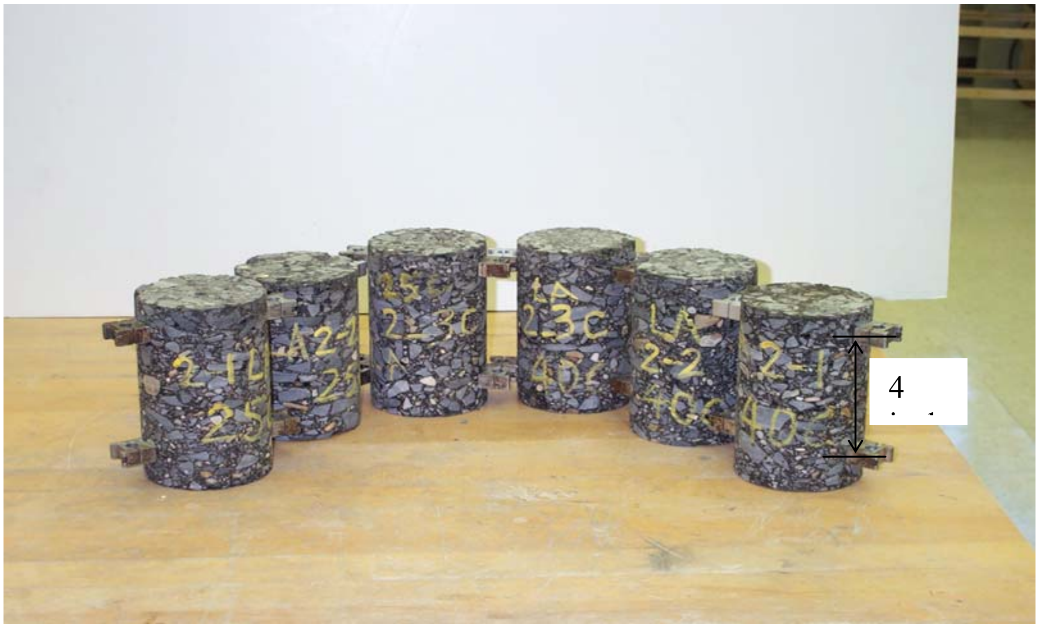

Figure B2. Samples with Studs.

2.2 The gauge length for measuring axial deformations shall be 100 mm ± 1 mm (4 inch ± 0.04 inch). 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 B1 shows the recommended test temperatures and associated stress level.

Table B1. 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 B2 provides a simply recommended temperature equilibrium time for samples starting from room temperature (77°F).

Table B2. 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.

3.4 Place the upper friction-reducing end treatment and platen on top of the sample. 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 minutes) 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 second haversine load followed by 0.9 second 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: $P_{contact} = 0.05 \text{ x } P_{max}$.

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

3.10 Apply the haversine loading (P_{cyclic}) and continue until 5,000 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. It is recommended to use the data acquisition of the cycles shown in Table B3.

Table B3. 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 (100 mm [4 inch]).

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

4.3 Plot the cumulative axial permanent strain versus number of loading cycles in log-log space (Figure B3). 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, axial permanent deformation parameters: α, μ (or ε_r, a, b).

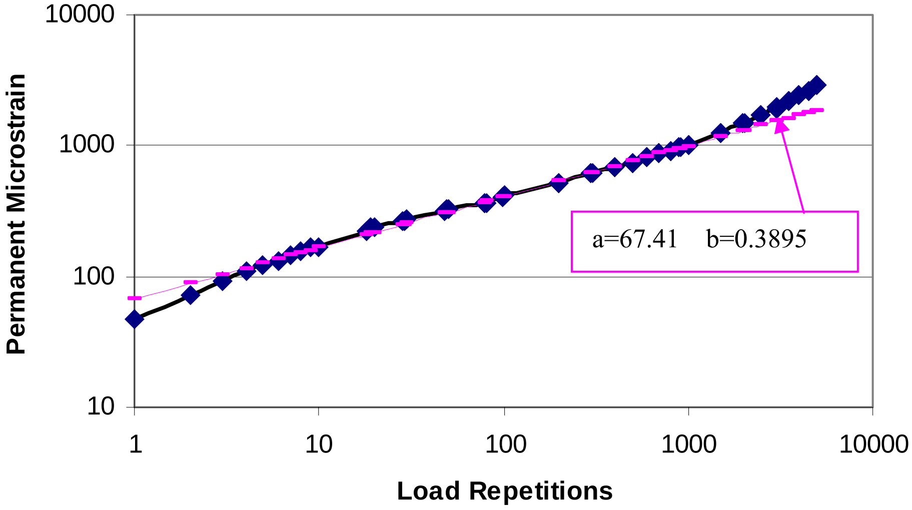

Figure B3. Plot of Regression Constants "a" and "b" from Log Permanent Strain – Log Number of Loading Cycles.

Example: Alpha and Mu Calculation

$\varepsilon_r = 88.1250$

$A = 67.4100$

$b = 0.3895$

$\mu = a \text{ x } b/\varepsilon_r = 67.41 \text{ x } 0.3895/88.125 = 0.2979$

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