Long-Term Pavement Performance

Protocol P46

Resilient Modulus of Unbound Granular Base/Subbase Materials and Subgrade Soils

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U.S. Department of Transportation

Federal Highway Administration

Pavement Performance Division

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For LTPP Test Designation: UG07, SS07

RESILIENT MODULUS OF UNBOUND GRANULAR BASE/SUBBASE MATERIALS AND SUBGRADE SOILS

1. SCOPE

1.1 General

This LTPP program protocol describes the laboratory preparation and testing procedures for the determination of the Resilient Modulus (M_r) of unbound granular base and subbase materials and subgrade soils under specified conditions representing stress states beneath flexible and rigid pavements subjected to moving wheel loads. This protocol is based partially on the test standard AASHTO T292-91I, Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials. The test shall be carried out in accordance with the following protocol procedure.

The methods described are applicable to: undisturbed samples of natural and compacted subgrade soils, and to disturbed samples of unbound base and subbase and subgrade soils prepared for testing by compaction in the laboratory.

In this protocol, stress levels used for testing specimens for resilient modulus will be based upon the location of the specimen within the pavement structure. Samples located within the base and subbase will be subjected to different stress levels as compared to those specimens that are from the subgrade. Generally, specimen size for testing depends upon the type of material based upon the gradation and the plastic limit of the material as described in a later section.

The value of resilient modulus (M_r) determined from this protocol procedure is a measure of the elastic modulus of unbound base and subbase materials and subgrade soils recognizing certain nonlinear characteristics.

Resilient modulus (M_r) values can be used with structural response analysis models to calculate the pavement structural response to wheel loads, and with pavement design procedures to design pavement structures.

1.2 Summary of Test Method

A repeated axial cyclic stress of fixed magnitude, load duration (0.1 second), and cycle duration (1 second) is applied to a cylindrical test specimen. During testing, the specimen is subjected to a dynamic cyclic stress and a static confining stress provided by means of a triaxial pressure chamber. The total resilient (recoverable) axial deformation response of the specimen is measured and used to calculate the resilient modulus.

1.3 Significance and Use

The resilient modulus test provides a basic constitutive relationship between stress and deformation of pavement construction materials for use in structural analysis of layered pavement systems.

The resilient modulus test provides a means of characterizing pavement construction materials, including subgrade soils under a variety of conditions (i.e. moisture, density, etc.) and stress states that simulate the conditions in a pavement subjected to moving wheel loads.

1.4 Sample Storage

Thin-walled tube samples of the subgrade for use in resilient modulus testing shall be kept in an environmentally protected (enclosed area not subjected to the natural elements) storage area at temperatures between 5°C (40°F) and 21°C (75°F). They shall be stored on their ends in the same orientation as retrieved in the field.

Bulk samples of base/subbase and subgrade materials should be kept in an environmentally protected storage area at temperatures between 5°C (40°F) and 38°C (100°F).

Each sample shall have a label or tag attached that clearly identifies the material, the project number/test section from which is was recovered and the sample number, as a minimum. Bulk granular samples shall be marked with two tags. One shall be placed inside the bag and one attached to the outside.

1.5 Units

In this protocol, the International System of Units (SI - The Modernized Metric System) is regarded as the standard. Units are expressed first in their "soft" metric form followed, in parenthesis, by their U.S. Customary unit equivalent.

2. TESTING

2.1 Testing Prerequisites

Resilient modulus testing shall be conducted after; (1) approval by the FHWA Contracting Officer's Technical Representative (COTR) to begin unbound material resilient modulus testing, (2) approval of Form L04 by the FHWA-LTPP RCOC, (3) appropriate material classification tests are completed and (4) final layer assignments (corrected form L04, if needed) have been completed. To attain approval under item (1), the laboratory must; (a) submit and obtain approval of the Quality Assurance/Quality Control (QA/QC) plan for the unbound materials resilient modulus testing, (b) demonstrate that their testing equipment meets or exceeds the specifications contained in this protocol, and (c) successfully complete all applicable requirements of the Start-up and Quality Control Procedure for LTPP P46 Resilient Modulus Testing.

2.2 Test Sample Locations and Assignment of Laboratory Test Numbers

The test shall be performed on the test specimens prepared from bulk samples of the unbound granular base and subbase materials retrieved from BA-type, 305 mm (12 inch) diameter, boreholes from the test pit(s) or from other bulk sampling locations as dictated by the sampling plans for the particular LTPP section.

For the subgrade soils, the test shall be carried out on undisturbed thin-walled tube samples retrieved from A-type, 152 mm (6 inch) diameter, boreholes and other sampling areas; if available. If the thin-walled tube samples are unavailable or unsuitable for testing, or if directed by the FHWA COTR, then bulk samples of subgrade soils shall be used to remold test specimens for resilient modulus tests. Bulk samples of subgrade soils are retrieved from BA-type, 305 mm (12 inch) diameter boreholes, test pit(s) or from other bulk sampling locations as dictated by the sampling plans for the particular LTPP test section.

The test results shall be reported separately for test samples obtained from the bulk samples collected at the beginning and end of the test section as follows:

(a) Beginning of the Section (Stations 0-): Bulk and thin-wall tube samples of each layer that are retrieved from areas in the approach end of the test section (stations preceding 0+00) shall be assigned Laboratory Test Number '1'.

(b) End of the Section (Stations 5+): Bulk and thin-wall tube samples of each layer that are retrieved from areas in the leave end of the test section (stations after 5+00) shall be assigned Laboratory Test Number '2'.

(c) Within the Section (Stations 0+00 - 5+00): Bulk and thin-wall tube samples of each layer that are retrieved from areas within the test section shall be assigned Laboratory Test Number '3'.

3. DEFINITIONS

The following definitions are used throughout this protocol:

(a) Layer: That part of the pavement produced with similar material and placed with similar equipment and techniques. The material within a particular layer is assumed to be homogeneous. The layer thickness of unbound granular base and subbase materials is determined from field exploration logs (borehole logs and/or test pit log).

(b) Sample: A representative portion of material from one or more pavement layers received from the field. A sample can be a core, block, chunk, pieces, bulk, thin-walled tube or jar sample.

(c) Bulk Sample: That part of the pavement material that is removed from an unbound base or subbase layer or from the subgrade. Bulk samples are retrieved from the borehole(s) or a test pit at the designated locations. The bulk sample of each layer is shipped in one or more bag(s) to the Regional Laboratory Material Testing Contractor. The material from one layer should <u>never</u> be mixed with the material from another layer - even if there is less than the desired amount to perform the specified tests.

(d) Test Sample: That part of the bulk sample of an unbound base or subbase layer or subgrade which is prepared and used for the specified test. The quantity of the test sample may be the same but will usually be less than the bulk sample.

(e) Test Specimen: For the purpose of this protocol, a test specimen is defined as, (i) that part of the thin-walled tube sample of the subgrade which is used for the specified tests and (ii) that part of the test sample of unbound granular base or subbase materials or untreated subgrade soils which is remolded to the specified moisture and density condition by recompaction in the laboratory.

(f) Unbound Granular Base and Subbase Materials: These include soil-aggregate mixtures and naturally occurring materials used in each layer of base or subbase. No binding or stabilizing agent is used to prepare unbound granular base or subbase layers. These materials may be classified as either Type 1 or Type 2 as subsequently defined in articles (h) and (i).

(g) Subgrade: Subgrade soils are prepared and compacted before the placement of subbase and/or base layers. These materials may be classified as either Type 1 or Type 2 as subsequently defined in articles (h) and (i).

(i) A treated subgrade layer (for example cement- or lime- treated soils) is considered a treated subbase layer in the LTPP program. Treated subgrade materials and bound or stabilized layers of subgrade soils are considered treated subbase materials and should be tested using Protocol P31.

(ii) Untreated subgrade soils include all cohesive and non- cohesive (granular) soils present in the sampling zone.

For the LTPP material sampling and testing program: the thin-walled tube sample of the subgrade is considered to be representative of the subgrade soils within the top 1.5 meters (five feet) of the subgrade; and the bulk sample of the subgrade retrieved from 305 mm (12 inch) diameter boreholes or the test pit is considered to be representative of the subgrade soils within 305 mm (12 inches) below the top of the subgrade, unless otherwise indicated on field exploration logs (borehole logs and/or test pit logs).

(h) Material Type 1: For the purposes of this protocol (resilient modulus tests), Material Type 1 includes all unbound granular base and subbase material and all untreated subgrade soils which meet the criteria of less than 70% passing the 2.00 mm (No. 10) sieve and less than 20% passing the 75 μm (No. 200) sieve, and which have a plasticity index ≤ 10. **Soils classified as Type 1 will be molded in a 152 mm (6 inch) diameter mold.**

NOTE 1: If 10 percent or less of a Type 1 sample is retained on the 37.5 mm (1.5 inch) sieve, the material greater than the 37.5 mm (1.5 inch) sieve shall be scalped off prior to testing. If more than 10 percent of the sample is retained on the 37.5 mm (1.5 inch) sieve, the material shall not be tested and the material shall be stored until further notice and the COTR shall be notified. Instructions concerning the testing of these materials will be issued at a later date.

(i) Material Type 2: For the purpose of this protocol (resilient modulus tests), Material Type 2 includes all unbound granular base/subbase and untreated subgrade soils not meeting the criteria for material Type 1 given above in (h). Generally, thin-walled tube samples of untreated subgrade soils fall in this Type 2 category. **Remolded Type 2 specimens will be compacted in a 71 mm (2.8 inch) diameter mold.**

NOTE 2: If 10 percent or less of a Type 2 sample is retained on the 12.5 mm (0.5 inch) sieve, the material greater than the 12.5 mm (0.5 inch) shall be scalped off prior to testing. If more than 10 percent of the sample is retained on the 12.5 mm (0.5 inch) sieve, the material shall not be tested and the material shall be stored until further notice and the COTR shall be notified. Instructions concerning the testing of these materials will be issued at a later date.

(j) Resilient Modulus of Unbound Materials: The modulus of an unbound material is determined by repeated load triaxial compression tests on test specimens of the unbound material samples. Resilient modulus (M_r) is the ratio of the amplitude of the repeated axial stress to the amplitude of the resultant recoverable axial strain. Figure 1 illustrates a typical load (stress) and deformation (strain) versus time relationship for P46 testing.

The necessary input values for the calculation of resilient modulus are determined from the load-time and deformation-time plots as illustrated in Figure 2 and described herein. The loads/deformations are established by using

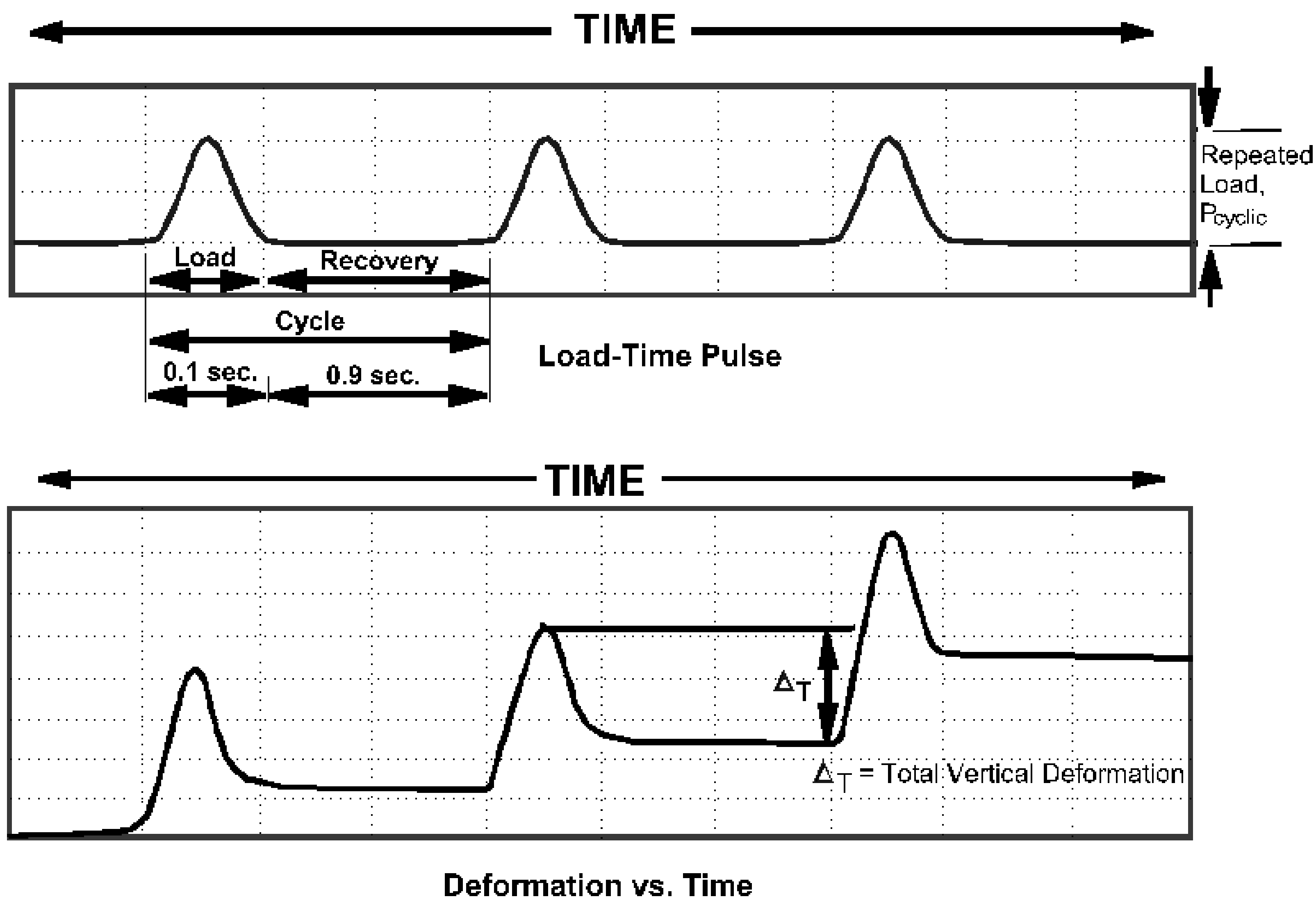


Figure 1. Typical load and deformation versus time relationships.

the maximum load/deformation value minus the minimum load/deformation value for a given cycle. The minimum load/deformation value is determined by taking the average load/deformation values from the last 75 percent (nominally 0.75 second) of the cycle. The average value is used to negate the impact of possible "overshooting" of the load on the rest period cycle. Otherwise, if a strict maximum minus minimum algorithm is used, the overshoot values would become the minimum value and thus this would bias the resulting load/deformation value.

(k) Haversine Shaped Load Form - the required load pulse form for the P46 test. The load pulse is of the form (1-COSθ)/2 and the cyclic load (P_{cyclic}) is varied from 10 to 100 percent of the maximum load (P_{max}) as shown in Figure 3.

(l) Maximum Applied Axial Load (P_{max}) - the total load applied to the sample including the contact and cyclic (resilient) loads.

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

(m) Contact Load ($P_{contact}$) - vertical load placed on the specimen to maintain a positive contact between the specimen cap and the specimen.

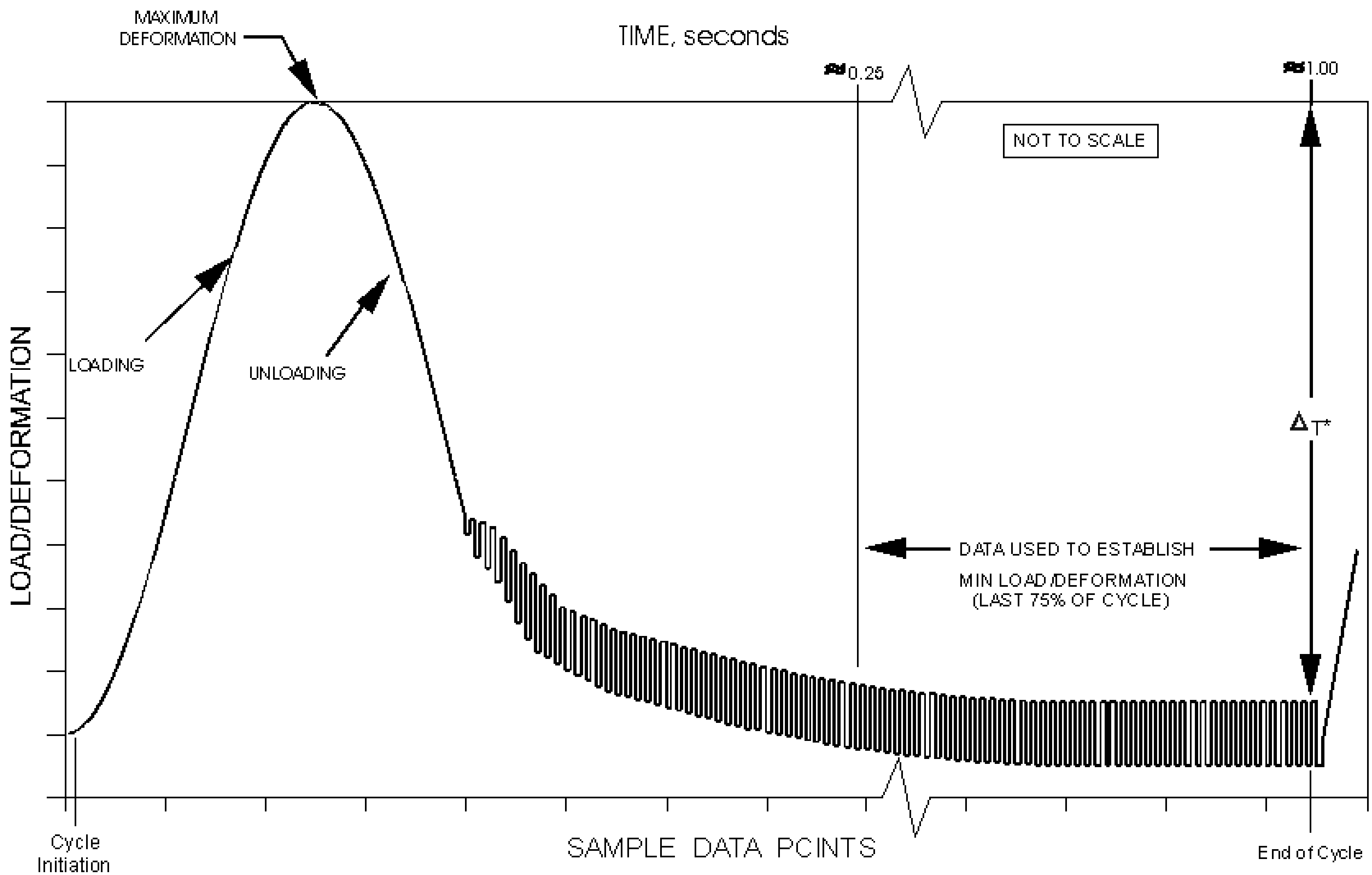
$$P_{contact} = 0.1P_{max}$$

(n) Cyclic Axial Load (Resilient Vertical Load, P_{cyclic}) - repetitive load applied to a test specimen which is used to calculate resilient modulus.

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

(o) Maximum Applied Axial Stress (S_{max}) - the total stress applied to the sample including the contact stress and the cyclic (resilient) stress.

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



* AVERAGE OF THE LAST 75 PERCENT OF CYCLE DATA POINTS

Figure 2. Theoretical determination of maximum/minimum load and deformation.

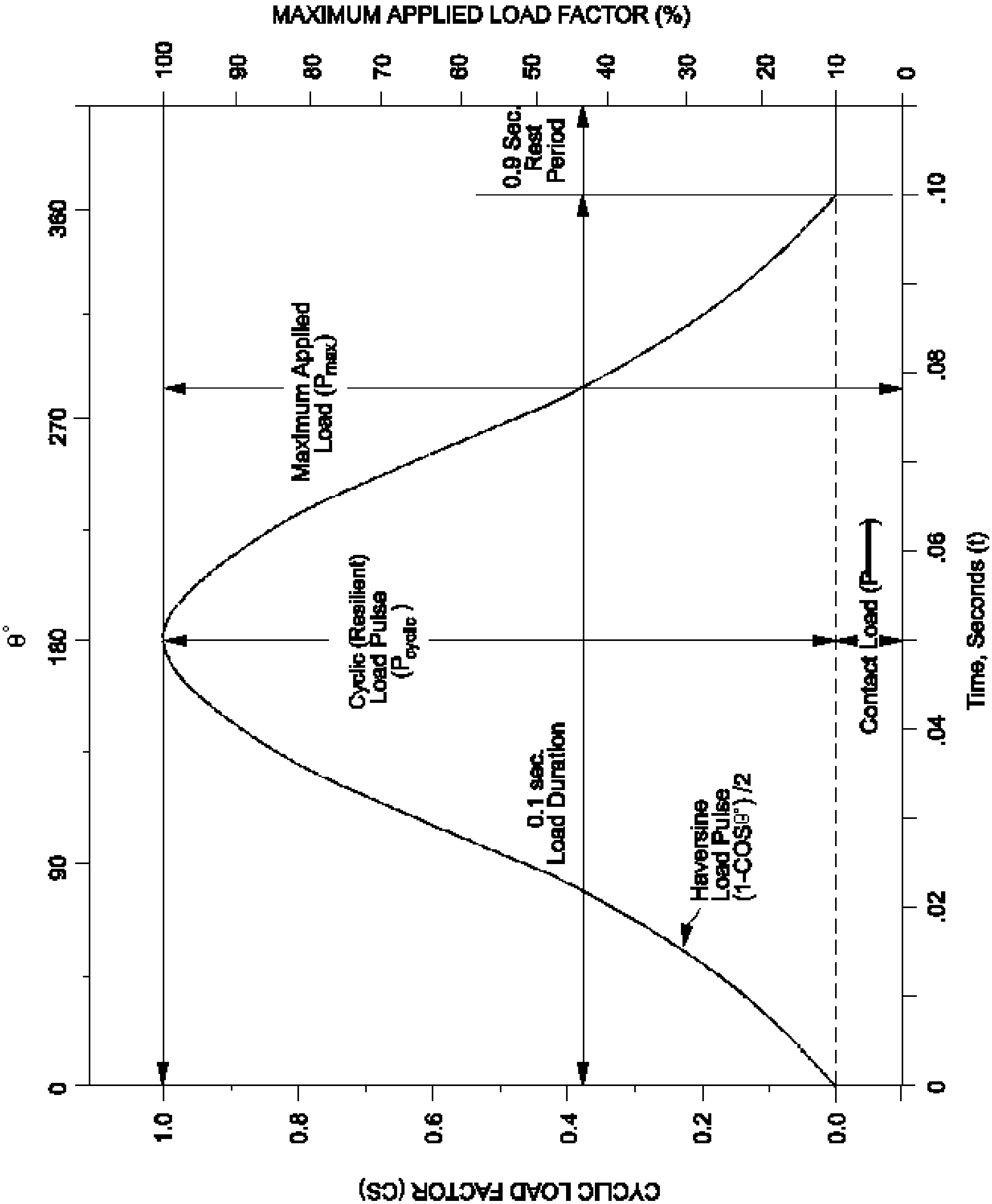


Figure 3. Definition of resilient modulus terms.

where:

A = cross sectional area of the sample.

(p) Cyclic Axial Stress (Resilient Stress, S_{cyclic}) - cyclic (resilient) applied axial stress.

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

where:

A = original cross sectional area of the sample (using the caliper measured diameter prior to testing).

(q) Contact Stress ($S_{contact}$) - axial stress applied to a test specimen to maintain a positive contact between the specimen cap and the specimen.

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

where:

A = cross sectional area of the sample (using the caliper measured diameter prior to testing).

Also:

$S_{contact} = 0.1S_{max}$

(r) S_3 is the total radial stress; that is, the applied confining pressure in the triaxial chamber (minor principal stress).

(s) e_r is the resilient (recovered) axial deformation due to S_{cyclic}.

(t) ε_r is the resilient (recovered) axial strain due to S_{cyclic}.

$\varepsilon_r = e_r/L$

where:

L = original specimen length (using caliper measured length prior to testing).

NOTE 3: "L" is considered to be the original test specimen length. This calculation of strain is only valid for testing equipment with LVDTs positioned outside of the triaxial chamber. If measurement devices are mounted on the specimen, then the value of "L" in the strain calculation becomes equal to the gage length of the transducers.

(u) Resilient Modulus (M_r) is defined as S_{cyclic}/ε_r.

(v) Load duration is the time interval the specimen is subjected to a cyclic stress (nominally 0.1 sec.).

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

4. APPLICABLE DOCUMENTS

4.1 AASHTO Standards

T88 Particle Size Analysis of Soils
T99 The Moisture-Density Relations of Soils Using a 5.5 lb. Rammer and 12-Inch Drop
T100 Specific Gravity of Soils
T233 Density of Soil-in-Place by Block, Chunk or Core Sampling
T234 Strength parameters of soils by Triaxial Compression
T265 Laboratory Determination of Moisture Content of Soils
T292 Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials
T238 Density of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)
T239 Moisture Content of Soil and Soil-Aggregate in Place by Nuclear Methods (Shallow Depth)

4.2 LTPP Protocols

P41 Gradation of Unbound Granular Base and Subbase Materials
P42 Hydrometer Analysis of Subgrade Soils
P43 Determination of Atterberg Limits of Unbound Granular Base and Subbase Materials and Subgrade Soils
P44 Moisture-Density Relations of Unbound Granular Base and Subbase Materials
P47 Classification and Description of Unbound Granular Base and Subbase Materials
P49 Determination of Natural Moisture Content
P51 Sieve Analysis of Subgrade Soils
P52 Classification and Description of Subgrade Soils
P55 Moisture-Density Relations of Subgrade Soils

4.3 ASTM Standards

E380 Standard Practice for Use of the International System of Units (SI) (The Modernized Metric System)

5. UNBOUND MATERIALS TESTING PREREQUISITES

5.1 Laboratory Testing Prerequisites for Unbound Granular Base/Subbase Materials

For testing unbound granular base/subbase materials, the following tests shall be performed prior to resilient modulus testing:

- Natural Moisture Content (LTPP Test Designation UG10, Protocol P49)
- Particle Size Analysis (LTPP Test Designations UG01 and UG02, Protocol P41)
- Atterberg Limits (LTPP Test Designation UG04, Protocol P43)
- Classification and Description (LTPP Test Designation UG08, Protocol P47)
- Moisture-Density Relations (LTPP Test Designation UG05, Protocol P44)

For the General Pavement Studies (GPS) testing program, in addition to this testing of unbound granular base/subbase materials, the following information shall be available from the field sampling and testing data sheets:

- In situ moisture content (AASHTO T238). If the nuclear moisture information is not available, the optimum moisture content (LTPP Protocol P44) data will be used.
- In situ density (AASHTO T239). If nuclear density information is not available, then moisture-density relationship data (LTPP Protocol P44) will be used.

If the available bulk sample is insufficient in size and a sample from one test is reused for other test(s) and/or the resilient modulus, then the appropriate comment code shall be used in reporting the test results for P46.

5.2 Laboratory Testing Prerequisites for Untreated Subgrade Soils

(a) For testing subgrade materials obtained from bulk samples, the following tests shall be performed prior to resilient modulus testing:

- Natural Moisture Content (LTPP Test Designation SS09, Protocol P49)
- Sieve Analysis (LTPP Test Designation SS01, Protocol P51)
- Hydrometer Analysis (LTPP Test Designation SS02, Protocol P42)
- Atterberg Limits (LTPP Test Designation SS03, Protocol P43)
- Classification and Description (LTPP Test Designation SS04, Protocol P52)
- Moisture-Density Relations (LTPP Test Designation SS05, Protocol P55)

For the General Pavement Studies (GPS) testing program, in addition to this testing of subgrade materials, the following information shall be available from the field sampling and testing data sheets:

- In situ moisture content (AASHTO T238). If the nuclear moisture information is not available, the optimum moisture content (LTPP Protocol P55) data will be used.
- In situ density (AASHTO T239). If nuclear density information is not available, then moisture-density relationship data (LTPP Protocol P55) will be used.

If the available bulk sample is insufficient in size and a sample from one test is reused for other test(s) and/or the resilient modulus, then the appropriate comment code shall be used in reporting the test results for P46.

(b) Instructions for undisturbed thin-walled tube samples of subgrade soils:

If the thin-walled tubes are available and acceptable for the resilient modulus test the "undisturbed" thin-walled tube sample shall be used in the resilient modulus testing. The comment code 87 shall be used in reporting the test results for P46.

(c) If a thin-walled tube sample is not available or acceptable for testing then use bulk samples to reconstitute the test specimen for the resilient modulus testing. The comment code 88 shall be used in reporting the test results for P46. Additional comment codes, if applicable, shall be used to identify the manner of reconstitution for the material.

6. 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 testing of soils is shown in Figure 4. The deformation is measured <u>externally</u> with two spring loaded LVDT's as shown in Figure 4.

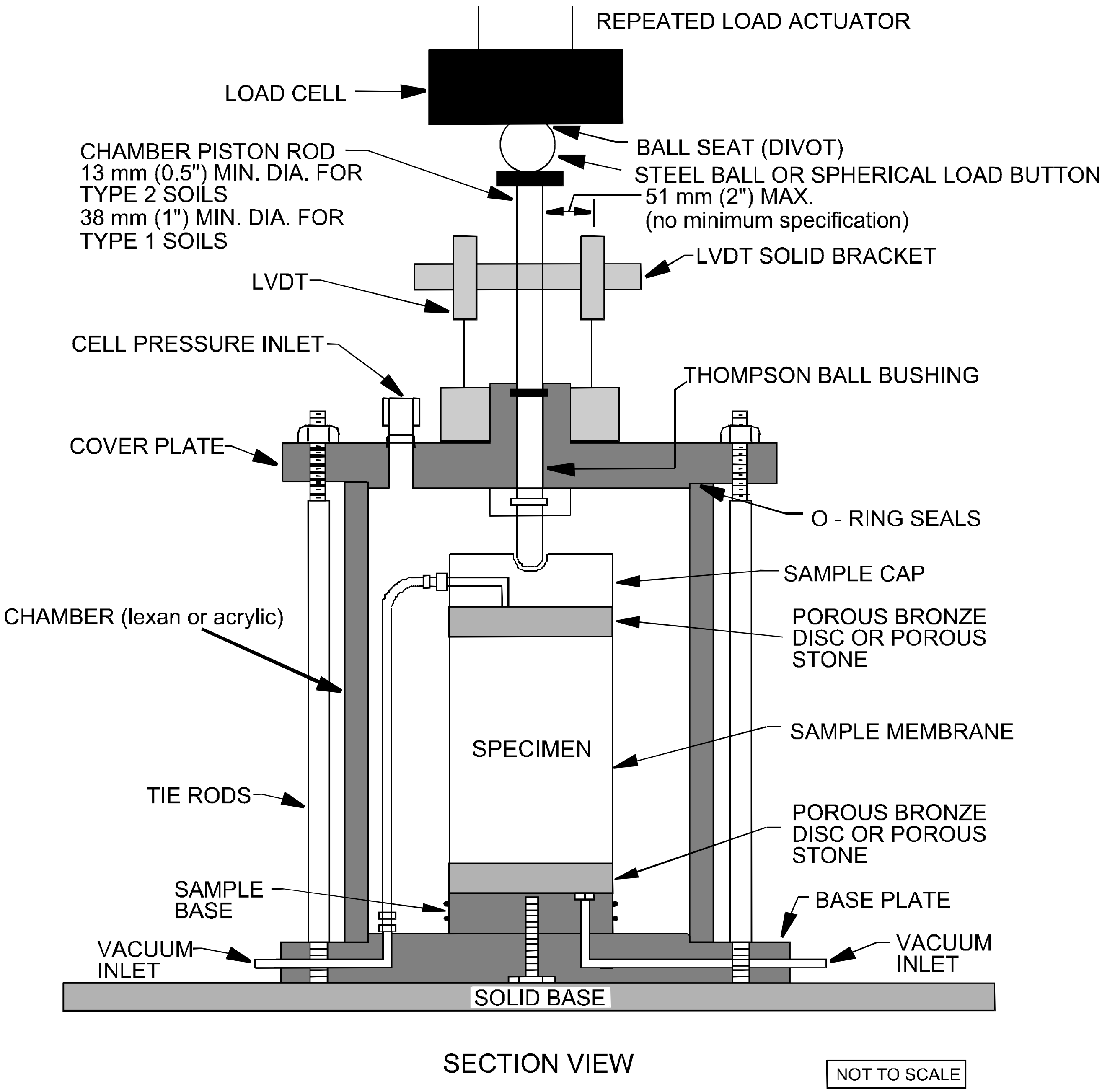
6.1.1 Air shall be used in the triaxial chamber as the confining fluid for all LTPP testing.

6.1.2 The chamber shall be made of Lexan, Acrylic or other suitable "see-through" material to facilitate the observation of the specimen during testing.

6.2 Loading Device

The loading device shall be a top loading, closed loop electrohydraulic testing machine with a function generator which is capable of applying repeated cycles of a haversine-shaped load pulse nominally 0.1 second in duration; followed by rest periods of nominally 0.9 second duration.

The haversine shaped load pulse shall conform to definition (k), Section 3 of this protocol. All preconditioning and testing shall be conducted using a haversine-shaped



Note 1: LVDT tips shall rest on the triaxial cell itself or on a plate/bracket which is rigidly attached to the triaxial cell

Note 2: Triaxial chamber should be bolted or tightly fastened to bottom loading platen of the test device. For Type 1 this should consist of a minimum of 4 bolts/fasteners and for Type 2 this should consist of a minimum of 3 bolts/fasteners load pulse. The system

Figure 4. Typical triaxial chamber with external LVDTs and load cell

generated haversine waveform and the response waveform shall be displayed to allow the operator to adjust the gains to ensure that they coincide during preconditioning and testing.

6.3 Load and Specimen Response Measuring Equipment

6.3.1 The axial load measuring device should be an electronic load cell located between the actuator and the chamber piston rod as shown in Figure 4. The following load cell capacities are required:

Sample Diameter mm, (inches)	Maximum Load Capacity kN (lbs.)	Required Accuracy N (lbs.)
71 (2.8)	2.2 (500)	± 4.5 (± 1)
152 (6.0)	22.24 (5000)	± 22.24 (± 5)

NOTE 4: During periods of resilient modulus testing, the load cell shall be monitored and checked once every two weeks or after every 50 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 insert an additional calibrated load cell and independently measure the load applied by the original load cell to ensure accurate loadings. Additionally, the load cell shall be checked at any time that the laboratory's in-house QA/QC testing indicates non-compliance or there is a suspicion of a load cell problem. Resilient modulus testing shall not be conducted if the testing system is found to be out of calibration or if the load cell does not meet the manufacturer's tolerance requirements or the tolerance requirements stated above for accuracy, whichever of the two is of the higher accuracy. In addition, all requirements regarding the load cell contained in the Start-up and Quality Control Procedure for LTPP P46 Resilient Modulus Testing must be adhered to at all times.

6.3.2 Test chamber pressures shall be monitored with conventional pressure gages, manometers or pressure transducers accurate to 0.7 kPa (0.1 psi).

6.3.3 Axial Deformation - Measuring equipment for all materials shall consist of 2 Linear Variable Differential Transducers (LVDT's) fixed to opposite sides of the piston rod outside the test chamber as shown in Figure 4. These two transducers shall be located equidistant, and as close as possible to, the piston rod and shall bear on hard, fixed surfaces which are perpendicular to the LVDT axis. Spring-loaded LVDT's are required. The following LVDT ranges are required:

Sample Diameter In Inches	Range
2.8	± 0.05 inch
6.0	± 0.25 inch

Both LVDT's shall meet the following specifications:

Linearity	± 25% of full scale
Repeatability	± 1% of full scale
Minimum Sensitivity	2mv/v(AC) or 5mv/v(DC)

A positive contact between the vertical LVDT's and the surface on which the tips of the transducers rest shall always be maintained during the test procedure. In addition, the two LVDT's shall be wired so that each transducer can be read and reviewed independently and the results averaged for calculation purposes.

NOTE 5: Misalignment, or dirt on the shaft of the transducer can cause the "sticking" of the shafts of the LVDT. The laboratory technician shall depress and release each LVDT prior to each test to assure that there is no sticking. An acceptable cleaner/lubricant (as specified by the manufacturer) shall be applied to the transducer shafts on a regular basis.

NOTE 6: The response of the LVDT's shall be checked daily with the laboratory's in-house QA/QC program. Additionally, the LVDT's shall be calibrated every two weeks, or after every 50 resilient modulus tests, whichever comes first, using a micrometer with compatible resolution or a set of specially machined gauge blocks. Resilient modulus testing shall not be conducted if the LVDT's do not meet the manufacturer's tolerance requirements for accuracy.

6.3.4 Suitable signal excitation, conditioning, and recording equipment are required for simultaneous recording of axial load and deformations. The signal shall be clean and free of noise (use shielded cables for connections). If a filter is used, it should have a frequency which cannot attenuate the signal. The LVDT's shall be wired separately so each LVDT signal can be monitored independently. A minimum of 500 data points from each LVDT shall be recorded per load cycle.

6.4 Specimen Preparation Equipment

A variety of equipment is required to prepare undisturbed samples for testing and to obtain 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. See the attachments (A, B and C) to this procedure for specimen preparation (Attachment A), specimen compaction equipment and compaction procedures for Type 1 (Attachment B) and Type 2 materials (Attachment C), respectively.

6.5 Thin-walled Tube Trimming Equipment

Equipment for trimming test specimens from undisturbed thin-walled tube samples of subgrade soils shall be as described in AASHTO T234-85, Strength Parameters of Soils by Triaxial Compression.

6.6 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 (0.01 to 0.031 inch) thickness, rubber O-rings, vacuum source with bubble chamber and regulator, membrane expander, porous stones (subgrade), porous bronze discs (base/subbase), scales, moisture content cans and data sheets, as required.

6.7 System Calibration and Periodic Checks

The entire system (transducer, conditioning and recording devices) shall be calibrated every two weeks or after every fifty resilient modulus tests using the laboratory's in-house QA/QC program. Daily and other periodic checks of the system may also be performed as per the laboratory's in-house QA/QC program.

Documentation of these calibrations and all other QA/QC activities shall be maintained for review by the FHWA COTR. No resilient modulus testing will be conducted unless the entire system meets the established calibration requirements of the approved QA/QC program and the laboratory meets all applicable requirements of the Start-up and Quality Control Procedure for LTPP P46 Resilient Modulus Testing.

7. PREPARATION OF TEST SPECIMENS

7.1 GPS Materials Characterization Program - General

Unless otherwise directed by the FHWA COTR, the following preparation steps shall be followed for the GPS materials characterization program, based on the sieve analysis test results (See Form T41 or T51 as appropriate).

7.1.1 Use the 71 mm (2.8-inch) diameter undisturbed specimen from the thin-walled tube samples for cohesive subgrade soils (Material Type 2). The specimen length shall be at least two times the diameter (minimum length of 142 mm (5.6 inches)) and the specimen shall be prepared as described in Section 7.2. If undisturbed subgrade samples are unavailable or unsuitable for testing, then 71 mm (2.8-inch) diameter molds shall be used to reconstitute Type 2 test specimens.

NOTE 7: If 10 percent or less of a Type 2 sample is retained on the 12.5 mm (0.5 inch) sieve, the material greater than the 12.5 mm (0.5 inch) sieve shall be scalped off prior to testing. If <u>more</u> than 10 percent of the sample is retained on the 12.5 mm (0.5 inch) sieve, the material shall not be tested and the material shall be stored until further notice. Instructions concerning the testing of these materials will be issued at a later date.

7.1.2 Use 152 mm (6.0 inch) diameter split molds to prepare 305 mm (12 inch) high test specimens for all Type 1 materials with nominal particle sizes less than or equal to 37.5 mm (1 ½ inches).

NOTE 8: If 10 percent or less of a Type 1 sample is retained on the 37.5 mm (1.5 inch) sieve, the material greater than the 37.5 mm (1.5 inch) sieve shall be scalped off prior to testing. If <u>more</u> than 10 percent of the sample is retained on the 37.5 mm (1.5 inch) sieve, the material shall not be tested and the material shall be stored until further notice. Instructions concerning the testing of these materials will be issued at a later date.

7.2 GPS - Undisturbed Subgrade Soil Specimens

Undisturbed subgrade soil specimens are trimmed and prepared as described in AASHTO T234-85, Strength Parameters of Soils by Triaxial Compression, using the thin-walled tube samples of the subgrade soil. The natural moisture content (w) of the tube sample shall be determined after triaxial M_r testing, following the procedure outlined in LTPP Protocol P49 (AASHTO T265-86), and recorded in the test report. The following procedure shall be followed for the thin-walled tube samples:

7.2.1 Examine the thin-walled tube samples obtained from the same sampling location separately. Select the sample most suitable for testing (see NOTE 9) giving priority to samples extracted near the surface of the subgrade. That is, the sample should be taken from the top of the first tube pushed, if it is suitable for testing. If not, examine samples from increasing depths in the subgrade, selecting the first sample suitable for testing. In any case, the depth in relation to the top of the subgrade that the sample is obtained from should be noted on Laboratory Test Data Sheet T46.

NOTE 9: To be suitable for testing, a specimen of sufficient length (at least twice the diameter of the specimen after preparation) must be cut from the tube sample, and must be free from defects that would result in unacceptable or biased test results. Such defects include cracks in the specimen, corners broken off that cannot be repaired during preparation, presence of particles much larger than that typical for the material (example, + 19.0 mm (+ 3/4-inch) stones in a fine-grained soil), presence of "foreign objects" such as large roots, wood particles, organic material and gouges due to gravel hanging on the edge of the tube. If the gradation and plasticity index tests indicate that the material (from a bulk sample) corresponding to a thin-wall tube is actually a Type 1 material, the thin-walled tube shall not be used and a specimen must be recompacted (as a Type 1 material) using the bulk sample. If the gradation test indicates that more than 10 percent of a Type 2 sample is retained on the 12.5 mm (0.5 inch) sieve, the material shall not be tested and the material shall be stored until further notice. Instructions concerning the testing of these materials will be issued at a later date.

7.2.2 If a good undisturbed subgrade sample is unavailable from a particular location, a reconstituted specimen shall be prepared from the bulk sample from the same end of the test section and same layer. Select a sample for reconstitution, again giving priority to samples extracted near the surface of the subgrade.

7.3 GPS - Laboratory Compacted Specimens

Reconstituted test specimens of both Type 1 and Type 2 materials shall be prepared to approximate the in situ wet density (γ_w) and moisture content (w). These laboratory compacted specimens shall be prepared for all unbound granular base and subbase material and for all subgrade soils for which undisturbed tube specimens could not be obtained.

This protocol states that reconstituted test specimens should be compacted to in-situ moisture and density conditions as measured in the field using nuclear methods (AASHTO T239) whenever these data are available. This requirement was instituted in the protocol in an attempt to better correlate laboratory test results and those from the analysis of deflection measurements performed immediately prior to sampling. It is important to recognize that correlating the laboratory determined resilient modulus values of soils and unbound aggregate at in-situ moisture and density with that obtained from analysis of pavement deflection measurements is an important objective of the LTPP GPS materials characterization program.

However, for some samples, it may be virtually impossible to compact specimens to the measured in-situ moisture and density. In this case, the sample shall be compacted using the alternative compaction requirements of P46 - compact at optimum moisture content and 95 percent of the maximum dry density of the material (section 7.3.3). The decision to use the alternate compaction procedure is at the discretion of the laboratory Supervisory Engineer and should be made on a case-by-case basis. <u>However, every effort shall be made to compact the samples to in-situ conditions prior to electing the alternative sample compaction procedure.</u>

In those cases where the measured in-situ properties at the time of sampling are not available, the sample should also be prepared following the alternative compaction procedure. However, the unavailability of this data must be verified with the corresponding LTPP Regional Coordination Office Contractor prior to sample preparation. This caveat only applies to the GPS materials characterization program.

For the SPS materials characterization program all samples shall be compacted to optimum moisture and 95 percent maximum dry density as described in Section 7.4 of this protocol.

7.3.1 Moisture Content - The moisture content of the laboratory compacted specimen shall be the in-situ moisture content obtained in the field using AASHTO T238 (nuclear method) for that layer. If data is not available on in-situ moisture content, then refer to Section 7.3.3.

The moisture content of the laboratory compacted specimen should not vary by more than ± 1.0 percent for Type 1 materials or ± 0.5 percent for Type 2 materials from the in situ moisture content obtained for that layer.

7.3.2 Compacted Density - The density of the compacted specimen shall be the in-place wet density obtained in the field using AASHTO T239 (nuclear method) for that layer. If this data is not available on in-situ density, then refer to Section 7.3.3.

The wet density of the laboratory compacted specimen should not vary more than ± 3 percent of the in-place wet density for that layer.

7.3.3 If either the in-situ moisture content or the in-place density data is not available, then use the optimum moisture content and 95 percent of the maximum dry density (previously determined using LTPP Protocol P44 (Base/Subbase) or LTPP Protocol P55 (Subgrade) for preparing the reconstituted specimen.

The moisture content of the laboratory compacted specimen should not vary by more than ± 1.0 percent for Type 1 materials or ± 0.5 percent for Type 2 materials from the target moisture content. Also, the wet density of the laboratory compacted specimen should not vary more than ± 3 percent of the target wet density.

7.3.4 Sample Reconstitution - Reconstitute the specimen for Type 1 and Type 2 materials in accordance with the provisions given in Attachment A. The target moisture content and density to be used in determining needed material quantities are as established in Section 7.3. Attachment A provides guidelines for reconstituting the material to obtain a sufficient amount of material to prepare the appropriate specimen type at the designated moisture content and density. After this step is completed, specimen compaction can begin.

7.4 SPS Materials Characterization Program

Unless otherwise directed by the FHWA COTR, the following preparation steps shall be followed for the SPS materials characterization program.

7.4.1 Undisturbed Subgrade Soil Specimens - Undisturbed subgrade soil specimens are trimmed and prepared as described in AASHTO T234-85, Strength Parameters of Soils by Triaxial Compression, using the thin-walled tube samples of the subgrade soil. The specimen length shall be at least two times the diameter (minimum length of 142 mm (5.6 inch)). The natural moisture content (w) of the tube sample shall be determined after triaxial M_r testing, following the procedure outlined in LTPP Protocol P49 (AASHTO T265-86), and recorded in the test report.

The following procedure shall be followed for the thin-walled tube samples:

Examine the thin-walled tube samples obtained from the same sampling location separately. Select the sample most suitable for testing (see NOTE 10) giving priority to samples extracted near the surface of the subgrade. That is, the sample should be taken from the top of the first tube pushed, if it is suitable for testing. If not, examine samples from increasing depths in the subgrade, selecting the first sample suitable for testing. In any case, the depth in relation to the top of the subgrade that the sample is obtained from should be noted on Laboratory Test Data Sheet T46.

NOTE 10: To be suitable for testing, a specimen of sufficient length (at least twice the diameter of the specimen after preparation) must be cut from the tube sample, and must be free from defects that would result in unacceptable or biased test results. Such defects include cracks in the specimen, corners broken off that cannot be repaired during preparation, presence of particles much larger than that typical for the material (example, + 19.0 mm (+ 3/4-inch) stones in a fine-grained soil), presence of "foreign objects" such as large roots, wood particles, organic material and gouges due to gravel hanging on the edge of the tube. If the gradation and plasticity index tests indicate that the material (from a bulk sample) corresponding to a thin-wall tube is actually a Type 1 material, the thin-walled tube shall not be used.

7.4.2 Laboratory Compacted Specimens - Reconstituted test specimens of both Type 1 and Type 2 materials shall be prepared to the optimum moisture content and 95 percent of the maximum dry density (previously determined using LTPP Protocol P44 (Base/Subbase) or LTPP Protocol P55 (Subgrade)). Use 71 mm (2.8 inch) diameter molds to reconstitute Type 2 test specimens and 152 mm (6.0 inch) diameter split molds to reconstitute Type 1 materials.

NOTE 11: If 10 percent or less of a Type 2 sample is retained on the 12.5 mm (0.5 inch) sieve, the material greater than the 12.5 mm (0.5 inch) sieve shall be scalped off prior to testing. If more than 10 percent of the sample is retained on the 12.5 mm (0.5 inch) sieve, the material shall not be tested and the material shall be stored until further notice. Instructions concerning the testing of these materials will be issued at a later date.

NOTE 12: If 10 percent or less of a Type 1 sample is retained on the 37.5 mm (1.5 inch) sieve, the material greater than the 37.5 mm (1.5 inch) sieve shall be scalped off prior to testing. If more than 10 percent of the sample is retained on the 37.5 mm (1.5 inch) sieve, the material shall not be tested and the material shall be stored until further notice. Instructions concerning the testing of these materials will be issued at a later date.

The moisture content of the laboratory compacted specimen should not vary by more than ± 1.0 percent for Type 1 materials or ± 0.5 percent for Type 2 materials from the target moisture content. Also, the wet density of the laboratory compacted specimen should not vary more than ± 3 percent of the target wet density.

7.4.3 Sample Reconstitution - Reconstitute the specimen for Type 1 and Type 2 materials in accordance with the provisions given in Attachment A. The target moisture content and density to be used in determining needed material quantities are as established in this section. Attachment A provides guidelines for reconstituting the material to obtain a sufficient amount of material to prepare the appropriate specimen type at the designated moisture content and density. After this step is completed, specimen compaction can begin.

7.5 GPS and SPS - Compaction Methods and Equipment for Reconstituting Specimens

7.5.1 Compacting Specimens for Type 1 Materials - The general method of compaction for Type 1 materials will be that of Attachment B of this protocol.

7.5.2 Compacting Specimens for Type 2 Materials - The general method of compaction for Type 2 materials will be that of Attachment C of this protocol.

7.5.3 The prepared specimens should be protected from moisture change by applying the triaxial membrane and tested within 5 days of completion. Prior to storage and directly after removal from storage, the specimen shall be weighed to determine if there was any moisture loss. If moisture loss exceeds 1 percent for Type 1 material or 0.5 percent for Type 2 materials, then the prepared specimens will not be tested. However, a new specimen will need to be prepared for testing. Material from the specimens not tested may be reused.

8. TEST PROCEDURE

8.1 Resilient Modulus Test for Subgrade Soils

The procedure described in this section is used for undisturbed or laboratory compacted specimens of subgrade soils. This can include specimens classified as Type 1 (152 mm - 6 inch diameter specimens) or Type 2 (71 mm - 2.8 inch diameter specimens) material.

8.1.1 Assembly of Triaxial Chamber - Specimens trimmed from undisturbed samples and laboratory compacted specimens are placed in the triaxial chamber and loading apparatus in the following steps.

8.1.1.1 Place a dry porous stone on the top of the sample base of the triaxial chamber as shown in Figure 4). Paper filters should be placed between the porous stone and the sample.

8.1.1.2 Carefully place the specimen on the porous stone. Place the membrane on a membrane expander, apply vacuum to the membrane expander, then carefully place the membrane on the sample and remove the vacuum and the membrane expander. Seal the membrane to the pedestal (or bottom plate) with an O-ring or other pressure seals.

8.1.1.3 Place the dry porous stone and the top platen on the specimen, fold up the membrane, and seal it to the top platen with an O-ring or some other pressure seal. Paper filters should be placed between the porous stone and the sample.

After the "specimen assembly" is in-place, the top platen shall be checked to ensure that it is level. A "cross-check" level, or similar, may be used for this determination.

8.1.1.4 If the specimen has been compacted or stored inside a rubber membrane and the porous stones and sample are already attached to the rubber membrane in place, steps 8.1.1.1, 8.1.1.2, and 8.1.1.3 are omitted. Instead, the "specimen assembly" is placed on the base plate of the triaxial chamber.

8.1.1.5 Connect the specimen's bottom drainage line to the vacuum source through the medium of a bubble chamber. Apply a vacuum of 7 kPa (1 psi). If bubbles are present, check for leakage caused by poor connections, holes in the membrane, or imperfect seals at the cap and base. The existence of an airtight seal ensures that the membrane will remain firmly in contact with the specimen. Leakage through holes in the membrane can frequently be eliminated by coating the surface of the membrane with liquid rubber latex or by using a second membrane.

8.1.1.6 When leakage has been eliminated, disconnect the vacuum supply and place the chamber on the base plate, and the cover plate on the chamber. Insert the loading piston and obtain a firm connection with the load cell. Tighten the chamber tie rods firmly. The cover plate of the triaxial chamber shall be checked to ensure that it is level after tightening the tie rods. A "cross-check" level, or similar, may be used for this determination.

8.1.1.7 Slide the assembly apparatus into position under the axial loading device. Positioning of the chamber is extremely critical in eliminating all possible side forces on the piston rod. Couple the loading device to the triaxial chamber piston rod.

Bolt or firmly fasten the triaxial chamber to the bottom loading platen of the test device. For Type 1 samples, a minimum of 4 bolts or fasteners should be used, for Type 2 samples a minimum of 3 bolts should be used. After fastening the triaxial chamber to the bottom platen, the top of the chamber shall be checked to ensure that it is level.

8.1.2 Conduct the Resilient Modulus Test - The following steps are required to conduct the resilient modulus test on a subgrade specimen which has been installed in the triaxial chamber and placed under the loading frame.

8.1.2.1 Open all drainage valves leading into the specimen to atmospheric pressure.

8.1.2.2 If it is not already connected, connect the air pressure supply line to the triaxial chamber and apply the specified pre-conditioning confining pressure of 41.4 Kpa (6 psi) to the test specimen. A contact stress of 10 percent $\pm$ .7 kPa ($\pm$ .1 psi) of the maximum applied axial stress during each sequence number shall be maintained.

8.1.2.3 Conditioning - Begin the test by applying a minimum of 500 repetitions of a load equivalent to a maximum axial stress of 27.6 kPa (4 psi) and corresponding cyclic stress of 24.8 kPa (3.6 psi) using a haversine shaped load pulse consisting of a 0.1 second load followed by a 0.9 second rest period. If the sample is still decreasing in height at the end of the conditioning period, stress cycling shall be continued up to 1000 repetitions prior to testing.

The foregoing stress sequence constitutes sample conditioning, that is, the elimination of the effects of the interval between compaction and loading and the elimination of initial loading versus reloading. This conditioning also aids in minimizing the effects of initially imperfect contact between the sample cap and the test specimen.

If the total vertical permanent strain reaches 5 percent during conditioning, the conditioning process shall be terminated. For recompacted samples, a review shall be conducted of the compaction process to identify any reason(s) why the sample did not attain adequate compaction. If this review does not provide an explanation, the material shall be re-fabricated and tested a second time. If the sample again reaches 5 percent total vertical permanent strain during preconditioning, then the test shall be terminated and the appropriate item on the data sheet shall be completed. No further testing of this material is necessary.

If the sample is a thin-wall tube, sample handling procedures shall be reviewed to determine if the sample was damaged. If this review does not provide an explanation, another thin-wall tube sample shall be used for the testing. If the sample from the second thin-wall tube also reaches 5 percent total vertical permanent strain during preconditioning, then the test shall be terminated and the appropriate item on the data sheet shall be completed. No further testing of this material is necessary.

NOTE 13: The operator/technician shall conduct appropriate QA/QC comparative checks of the individual deformation output from the two vertical transducers during the conditioning phase of each M_r test in order to recognize specimen misplacement and misalignment. During the preconditioning phase, the two vertical deformation curves should be viewed to ensure that acceptable vertical deformation ratios are being measured. Desired vertical deformation ratios (R_v) are defined as $R_v = Y_{max}/Y_{min} \leq 1.10$, where Y_{max} equals the larger of the two vertical deformations and Y_{min} equals the smaller of the two vertical deformations. Unacceptable vertical deformations are obtained when $R_v > 1.30$. In this case, the test should be discontinued and specimen placement/alignment difficulties alleviated. Once acceptable vertical deformation values are obtained, ($R_v < 1.30$) then the test should be continued to completion. It is emphasized that specimen alignment is critical for proper M_r results.

8.1.2.4 Testing Specimen - The testing is performed following the loading sequence shown in Table 1. Begin by decreasing the maximum axial stress to 13.8 kPa (2 psi) (Sequence No. 1, Table 1) and set the confining pressure to 41.4 kPa (6 psi).

NOTE 14: The contact stresses shown in Table 1 should be adjusted to compensate for the resultant force created by the chamber pressure (upward force) and the weight of the chamber piston rod, including the LVDT holder, (downward force). Instructions for adjusting the contact load are given in Attachment D of this procedure.

8.1.2.5 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 for each LVDT separately for the last five cycles on Worksheet T46.

8.1.2.6 Increase the maximum axial stress to 27.6 kPa (4 psi) (Sequence No. 3) and repeat step 8.1.2.5 at this new stress level.

8.1.2.7 Increase the cyclic stress to 6 psi (Sequence No. 3) and repeat step 8.1.2.4 at this new stress level.

8.1.2.8 Continue the test for the remaining load sequences in Table 1 (4 to 15) recording the vertical recovered deformation. If at any time the total vertical permanent strain (after preconditioning) exceeds 5 percent, stop the test and report the results on Worksheet T46.

Table 1. Testing sequence for subgrade soils.

Sequence No.	Confining Pressure, S_3		Max. Axial Stress S_{max}		Cyclic Stress S_{cyclic}		Contact Stress $0.1S_{max}$		No. of Load Applications
	kPa	psi	kPa	psi	kPa	psi	kPa	psi	
0	41.4	6	27.6	4	24.8	3.6	2.8	.4	500-1000
1	41.4	6	13.8	2	12.4	1.8	1.4	.2	100
2	41.4	6	27.6	4	24.8	3.6	2.8	.4	100
3	41.4	6	41.4	6	37.3	5.4	4.1	.6	100
4	41.4	6	55.2	8	49.7	7.2	5.5	.8	100
5	41.4	6	68.9	10	62.0	9.0	6.9	1.0	100
6	27.6	4	13.8	2	12.4	1.8	1.4	.2	100
7	27.6	4	27.6	4	24.8	3.6	2.8	.4	100
8	27.6	4	41.4	6	37.3	5.4	4.1	.6	100
9	27.6	4	55.2	8	49.7	7.2	5.5	.8	100
10	27.6	4	68.9	10	62.0	9.0	6.9	1.0	100
11	13.8	2	13.8	2	12.4	1.8	1.4	.2	100
12	13.8	2	27.6	4	24.8	3.6	2.8	.4	100
13	13.8	2	41.4	6	37.3	5.4	4.1	.6	100
14	13.8	2	55.2	8	49.7	7.2	5.5	.8	100
15	13.8	2	68.9	10	62.0	9.0	6.9	1.0	100

NOTE: load sequences 14 and 15 are not to be used for materials designated as Type 1.

8.1.2.9 After completion of the resilient modulus test procedure, check the total vertical permanent strain that the specimen was subjected to during the resilient modulus (after preconditioning) portion of the test procedure. If the total vertical permanent strain did not exceed 5 percent, continue with the quick shear test procedure (Section 8.1.2.10). If the total vertical permanent strain exceeds 5 percent, the test is completed. No additional testing is to be conducted on the specimen.

8.1.2.10 Apply a confining pressure of 27.6 kPa (4 psi) to the specimen. Apply a load so as to produce an axial strain at a rate of 1 percent per minute under a strain controlled loading procedure. Continue loading until either (1) the load values decrease with increasing strain, (2) 5 percent strain is reached (from the initiation of the quick shear test) or (3) the capacity of the load cell is reached. Data from the internally mounted deformation transducer in the actuator shaft and from the load cell shall be used to record specimen deformation and loads at a maximum of 3 second intervals.

NOTE 15: It has been noted that even though some samples visually bulge and appear to have failed, they do not achieve the above definition of failure at the maximum strain value (5 percent). In some cases, the stress-strain curves "level out" and the load values remain at, or near, constant and do not decrease with increasing strain. If a sample appears to fail without achieving the aforementioned criteria, a comment note should be added to the test data reporting sheet to document this occurrence.

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

8.1.2.12 Remove the membrane from the specimen and use the entire specimen to determine moisture content in accordance with LTPP Protocol P49. Record this value on Form T46.

8.1.2.13 Plot the stress-strain curve for the specimen for the triaxial shear test procedure.

8.2 Resilient Modulus Test for Base/Subbase Materials

The procedure described in this section applies to all unbound granular base and subbase materials. This can include specimens classified as Type 1 (152 mm - 6 inch diameter specimens) or Type 2 (71 mm - 2.8 inch diameter specimens) material.

8.2.1 Assembly of the Triaxial Chamber - Follow Steps 8.1.1.1 through 8.1.1.7. When compaction is completed, place the paper filter, dry porous bronze disc and sample cap on the top surface of the specimen. Roll the rubber membrane off the rim of the mold and over the sample cap. If the sample cap projects above the rim of the mold, the membrane should be sealed tightly against the cap with the O-ring seal. If it does not, the seal can be applied later. Install the sample in the triaxial chamber as in steps 8.1.1.1 through 8.1.1.7.

8.2.1.1 Connect the chamber pressure supply line and apply a confining pressure of 103.4 Kpa (15 psi).

8.2.1.2 Remove the vacuum supply from the vacuum saturation inlet and open the top and bottom head drainage ports to atmospheric pressure.

8.2.2 Conduct the Resilient Modulus Test - After the test specimen has been prepared and placed in the loading device as described in 8.2.1, the following steps are necessary to conduct the resilient modulus testing:

8.2.2.1 If not already done, adjust the position of the axial loading device or triaxial chamber base support as necessary to couple the load-generation device piston and the triaxial chamber piston. The triaxial chamber piston should bear firmly on the load cell. A contact stress of 10 percent ± .7 kPa (±.1 psi) of the maximum applied axial stress during each sequence number shall be maintained.

8.2.2.2 Adjust the recording devices for the LVDT's and load cell as needed.

8.2.2.3 Conditioning - Set the confining pressure to 103.4 kPa (15 psi) and apply a minimum of 500 repetitions of a load equivalent to a maximum axial stress of 103.4 kPa (15 psi) and corresponding cyclic axial stress of 93.1 kPa (13.5 psi) using a haversine shaped load pulse consisting of a 0.1 second load followed by a 0.9 second rest period. If the sample is still decreasing in height at the end of the conditioning period, stress cycling shall be continued up to 1000 repetitions prior to testing.

The foregoing stress sequence constitutes sample conditioning, that is, the elimination of the effects of the interval between compaction and loading and the elimination of initial loading versus reloading. This conditioning also aids in minimizing the effects of initially imperfect contact between the sample cap and base plate and the test specimen. The drainage valves should be open throughout the resilient testing.

If the total vertical permanent strain reaches 5 percent during conditioning, the conditioning process shall be terminated. A review shall be conducted of the compaction process to identify any reason(s) why the sample did not attain adequate compaction. If this review does not provide an explanation, the material shall be re-fabricated and tested a second time. If the sample again reaches 5 percent total vertical permanent strain during preconditioning, then the test shall be terminated and the appropriate item on the data sheet shall be completed. No further testing of this material is necessary.

NOTE 16: The operator/technician shall conduct appropriate QA/QC comparative checks of the individual deformation output from the two vertical transducers during the conditioning phase of each M_r test in order to recognize specimen misplacement and misalignment. During the preconditioning phase, the two vertical deformation curves should be viewed to ensure that acceptable vertical deformation ratios are being measured. Desired vertical deformation ratios (R_v) are defined as $R_v = Y_{max}/Y_{min} \leq 1.10$, where Y_{max} equals the larger of the two vertical deformations and

Y_{min} equals the smaller of the two vertical deformations. Unacceptable vertical deformations are obtained when $R_v > 1.30$. In this case, the test should be discontinued and specimen placement/alignment difficulties alleviated. Once acceptable vertical deformation values are obtained, ($R_v < 1.30$) then the test should be continued to completion. It is emphasized that specimen alignment is critical for proper M_r results.

8.2.2.4 Testing Specimen - The testing is performed following the loading sequences in Table 2 using a haversine shaped load pulse as described above. Decrease the maximum axial stress to 21.0 kPa (3 psi) and set the confining pressure to 21.0 kPa (3 psi) (Sequence No. 1, Table 2).

8.2.2.5 Apply 100 repetitions of the corresponding cyclic 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 for each LVDT separately for the last five cycles on Worksheet T46.

NOTE 17: The contact stresses shown in Table 2 should be adjusted to compensate for the resultant force created by the chamber pressure (upward force) and the weight of the chamber piston rod, including the LVDT holder, (downward force). Instructions for adjusting the contact load are given in Attachment D of this procedure.

8.2.2.6 Continue with Sequence No. 2 increasing the maximum axial stress to 41.0 kPa (6 psi) and repeat 8.2.2.5 at this new stress level.

8.2.2.7 Continue the test for the remaining load sequences in Table 2 (sequences 3 to 15) recording the vertical recovered deformation. If, at any time the total vertical permanent strain (after preconditioning) exceeds 5 percent, stop the test and report the results on Worksheet T46.

Table 2. Testing sequence for base/subbase materials.

Sequence No.	Confining Pressure, S_3		Max. Axial Stress S_{max}		Cyclic Stress S_{cyclic}		Contact Stress $0.1S_{max}$		No. of Load Applications
	kPa	psi	kPa	psi	kPa	psi	kPa	psi	
0	103.4	15	103.4	15	93.1	13.5	10.3	1.5	500-1000
1	20.7	3	20.7	3	18.6	2.7	2.1	.3	100
2	20.7	3	41.4	6	37.3	5.4	4.1	.6	100
3	20.7	3	62.1	9	55.9	8.1	6.2	.9	100
4	34.5	5	34.5	5	31.0	4.5	3.5	.5	100
5	34.5	5	68.9	10	62.0	9.0	6.9	1.0	100
6	34.5	5	103.4	15	93.1	13.5	10.3	1.5	100
7	68.9	10	68.9	10	62.0	9.0	6.9	1.0	100
8	68.9	10	137.9	20	124.1	18.0	13.8	2.0	100
9	68.9	10	206.8	30	186.1	27.0	20.7	3.0	100
10	103.4	15	68.9	10	62.0	9.0	6.9	1.0	100
11	103.4	15	103.4	15	93.1	13.5	10.3	1.5	100
12	103.4	15	206.8	30	186.1	27.0	20.7	3.0	100
13	137.9	20	103.4	15	93.1	13.5	10.3	1.5	100
14	137.9	20	137.9	20	124.1	18.0	13.8	2.0	100
15	137.9	20	275.8	40	248.2	36.0	27.6	4.0	100

8.2.2.8 After completion of the resilient modulus test procedure, check the total vertical permanent strain that the specimen was subjected to during the resilient modulus (after preconditioning) portion of the test procedure. If the total vertical permanent strain did not exceed 5 percent, continue with the quick shear test procedure (Section 8.2.2.10). If the total vertical permanent strain exceeds 5 percent, the test is completed. No additional testing is to be conducted on the specimen.

8.2.2.10 Apply a confining pressure of 34.5 kPa (5 psi) to the specimen. Apply a load so as to produce an axial strain at a rate of 1 percent per minute under a strain controlled loading procedure. Continue loading until either (1) the load values decrease with increasing strain, (2) 5 percent strain is reached (from the initiation of the quick shear test) or (3) the capacity of the load cell is reached. Data from the internally mounted deformation transducer in the actuator shaft and from the load cell shall be used to record specimen deformation and loads at a maximum of 3 second intervals.

NOTE 18: It has been noted that even though some samples visually bulge and appear to have failed, they do not achieve the above definition of failure at the maximum strain value (5 percent). In some cases, the stress-strain curves "level out" and the load values remain at, or near, constant and do not decrease with increasing strain. If a sample appears to fail without achieving the aforementioned criteria, a comment note should be added to the test data reporting sheet to document this occurrence.

8.2.2.11 At the completion of the triaxial shear test, reduce the confining pressure to zero and remove the sample from the triaxial cell.

8.2.2.12 Remove the membrane from the specimen and use the entire sample to determine the moisture content in accordance with LTPP Protocol P49. Record this value on the appropriate form (See Worksheet T46).

8.2.2.13 Plot the stress-strain curve for the specimen for the triaxial shear test procedure.

9. CALCULATIONS

Perform the calculations to obtain resilient modulus values using the tabular arrangement shown on Worksheet T46. The resilient modulus value is computed for each of the last 5 cycles of each load sequence. These values are subsequently averaged on the data sheet.

10. REPORT

The report shall consist of the following:

1. hard copy of Form T46A (recompacted specimens) or Form T46B (thin-wall tube specimens),
2. hard copy of Worksheet T46, and
3. computer diskette containing all of the information shown on Form T46A or Form T46B and Worksheet T46 in ASCII file format.

The following general information is to be recorded on all of the Laboratory Data Sheets.

10.1 Specimen Identification

The specimen identification shall include: Laboratory Identification Code, State Code, LTPP Section ID, Layer Number, Field Set Number, Layer Type (1 = subgrade, 2 = base/subbase), Sampling Area No. (SPS-only), Sample Location Number, LTPP Sample Number, and Material Type (Type 1 or Type 2).

NOTE 19: When bulk samples are retrieved from the same general area from several BA-type 12 inch diameter boreholes, these bulk samples are combined, prepared and reduced to a representative test size in accordance with AASHTO T87 and AASHTO T248. Because the bulk samples are combined from several locations, the Location Number of the sample shall have an asterisk placed as the third digit. Similarly, the LTPP Sample Number should have an asterisk placed as the third and fourth digits.

10.2 Test Identification

The test identification shall include: LTPP Test Designation, LTPP Protocol Number, LTPP Laboratory Test Number, and Test Date.

10.3 Data Reporting

Report the following information on the appropriate data sheet:

10.3.1 Form T46A shall be used to record general information concerning the specimen and layer being tested. This form shall be completed only for those specimens that are recompacted from bulk samples. This form shall not be used to record information for thin-wall tube samples.

10.3.1.1 Item 8 - Record a "Y" (Yes) or "N" (No) to denote whether the sample reached 5% total vertical permanent strain during the preconditioning stage of the test procedure (Sections 8.1.2.3 and 8.2.2.3). Also, note with a "Y" (Yes) or "N" (No) whether or not the sample reached 5% total vertical permanent strain during the testing sequence. Record the number of test sequences completed, either partially or completely, for the given sample.

10.3.1.2 Item 9 - Record the specimen dimensions and perform the area and volume calculations.

10.3.1.3 Item 10 - Record the compaction weights as per Attachment B (Type 1) or Attachment C (Type 2).

10.3.1.4 Item 11 - Record the in situ moisture content/density values used as the basis for compaction of the specimen as per sections 7.3.1 and 7.3.2. These values were obtained from nuclear methods in the field (GPS test sections). If these values are not available (or not used), record the optimum moisture content, maximum dry density and 95% maximum dry density values used as the basis for compaction of the specimen as per section 7.3.3.

10.3.1.5 Item 12 - Record the moisture content of the compacted material as per section 3.16 of Attachment B (Type 1) or section 3.12 of Attachment C (Type 2). Record the moisture content of the material after the resilient modulus test as per section 8.1.2.12 (Subgrade) or section 8.2.2.12 (Base/subbase). Also, record the target density used for specimen recompaction.

10.3.1.6 Item 13 - Record the results and accompanying information for the quick-shear test procedure as per section 8.1.2.10 (Subgrade) or 8.2.2.10 (Base/Subbase).

10.3.2 Form T46B shall be used to record general information concerning the specimen and layer being tested. This form shall be completed only for thin-wall tube specimens. This form shall not be used to record information for recompacted samples.

10.3.2.1 Item 8 - Record the approximate distance from the top of the subgrade to the top of the specimen. This information can be found on the field data sheets for the test section in question.

10.3.2.2 Item 9 - Record a "Y" (Yes) or "N" (No) to denote whether the sample reached 5% total vertical permanent strain during the preconditioning stage of the test procedure (Sections 8.1.2.3 and 8.2.2.3). Also, note with a "Y" (Yes) or "N" (No) whether or not the sample reached 5% total vertical permanent strain during the testing sequence. Record the number of test sequences completed, either partially or completely, for the given sample.

10.3.2.3 Item 10 - Record the specimen dimensions and perform the area and volume calculations. Record the weight of the specimen.

10.3.2.4 Item 11 - Record the moisture content (in situ) prior to resilient modulus testing. For thin-wall tube samples, this value shall be the moisture content of the layer being tested as per the nuclear methods in the field, or in the absence of this information, the jar moisture sample results. Record the moisture content at the completion of resilient modulus testing as per section 8.1.2.12. Record the wet and dry density of the thin-wall tube sample.

10.3.2.5 Item 12 - Record the results and accompanying information for the quick-shear test procedure as per section 8.1.2.10 (Subgrade).

10.3.3 Record the test data for each specimen in a format similar to Worksheet T46 and attach with Laboratory Data Form T46A or Form T46B. The testing data for all test sequences shall be submitted to the FHWA COTR. Table 3 illustrates the completion of Worksheet T46 for one testing sequence. The following information shall be recorded on Worksheet T46:

10.3.3.1 Column 1 - Record the chamber confining pressure for the testing sequence. Only one entry need be made for the last five load cycles. This entry should correspond exactly with the confining pressure levels shown in Table 1 (Subgrade) or Table 2 (Base/subbase).

10.3.3.2 Column 2 - Record the nominal axial cyclic stress for the testing sequence. Only one entry need be made for the last five load cycles. This entry should correspond exactly with the nominal axial cyclic stress required in Table 1 (Subgrade) or Table 2 (Base/subbase).

10.3.3.3 Columns 4 through 9 - Record the actual applied loads and stresses for each of the last five load cycles as shown on the worksheet.

10.3.3.4 Columns 10 through 12 - Record the recoverable axial deformation of the sample for each LVDT independently for each of the last five load cycles. Average the response from

1. ***LABORATORY IDENTIFICATION CODE*** 111
2. ***STATE CODE*** 91
3. ***SHRP SECTION ID*** 910101
4. ***FIELD SET NO.*** 1
5. ***LAYER NUMBER*** 1
6. ***LAYER TYPE*** (1 = subgrade, 2 = base/subbase) 1
7. ***SAMPLING AREA NO.*** (SA-) 11
8. ***SHRP LABORATORY TEST NUMBER*** 1
9. ***LOCATION NUMBER*** A1
10. ***SHRP SAMPLE NUMBER*** TS01
11. ***MATERIAL TYPE*** 2
12. ***TEST DATE*** 01-02-93
13. ***RESILIENT MODULUS TESTING***

Initial length = 141.7 mm
Initial area = 4168 mm^2

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PARAMETER	*Chamber Confining Pressure*	*Nominal Maximum Axial Stress*	*Cycle No.*	*Actual Applied Max. Axial Load*	*Actual Applied Cyclic Load*	*Actual Applied Contact Load*	*Actual Applied Max. Axial Stress*	*Actual Applied Cyclic Stress*	*Actual Applied Contact Stress*	*Recov Def. LVDT #1 Reading*	*Recov Def. LVDT #2 Reading*	*Average Recov Def. LVDT 1 and 2*	*Resilient Strain*	*Resilient Modulus*
DESIGNATION	S_3	S_{cyclic}	c_i	P_{max}	P_{cyclic}	$P_{contact}$	S_{max}	S_{cyclic}	$S_{contact}$	H_1	H_2	H_{avg}	ε_r	M_r
UNIT	kPa	kPa	---	N	N	N	kPa	kPa	kPa	mm	mm	mm	mm/mm	MPa
DATA FORMAT	_ _ _ . _	_ _ _ . _	-	_ _ _ _._	_ _ _ _._	_ _ _._	_ _ _._	_ _ _._	_ _._	_._ _ _ _ _	_._ _ _ _ _	_._ _ _ _ _	_._ _ _ _ _	_ _ _.
LAST 5 LOAD CYCLES	41.4	13.8	1	57.5	51.8	5.7	13.8	12.4	1.4	.01118	.01120	.01119	.000079	157.0
			2	57.0	51.3	5.7	13.7	12.3	1.4	.01120	.01123	.01122	.000079	155.4
			3	58.0	52.2	5.8	13.9	12.5	1.4	.01118	.01122	.01120	.000079	158.1
			4	57.5	51.8	5.7	13.8	12.4	1.4	.01116	.01119	.01118	.000079	157.2
			5	57.7	51.9	5.8	13.8	12.4	1.4	.01119	.01119	.01119	.000079	157.0
	COLUMN AVERAGE			57.5	51.8	5.7	13.8	12.4	1.4	.01118	.01121	.01119	.000079	157.0
	STANDARD DEV.			0.4	0.3	0.1	0.1	0.1	0 0	.00001	.00002	.00001	.000000	1.0

Table 3. Example partially completed worksheet Worksheet T46 (one testing sequence)

the two LVDTs and record this value in column 12. This value will be used to calculate the axial strain of the material.

10.3.3.5 Column 13 – Compute the axial strain for each of the last five load cycles. This value is computed by divideing colum 12 by the original length of the specimen, L_0, which was recorded on Laboratory Test Data Form T46A (recompacted specimens) or Form T46B (thin-wall tube specimens).

10.3.3.6 Column 14 – Compute the resilient modulus for each of the last five load cycles. This value is computed by dividing column 8 by column 13.

10.3.3.7 Average – Compute the average of the last five load cycles for each column.

10.3.3.8 Standard Deviation – Compute the standard deviation of the values for each column for the last five load cycles using the equation:

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}} = \sqrt{\frac{\sum x_i^2 - \frac{(\sum x_i)^2}{n}}{n-1}}$$

10.4 Comment Codes

Comments on Laboratory Data Form T46A (recompacted specimens) or Form T46B (thin-wall tube specimens) shall include LTPP standard comment code(s), as shown on page E.1-3 (GPS) or page E.2-3 (SPS) of the LTPP Laboratory Material Testing Guide and any other note as needed. Additional codes associated with resilient modulus testing are:

Code	Comment
80	Due to the insufficient size of the bulk sample, the test sample used for the last test (Protocol P46, if the sample was reconstituted) was saved and stored for possible future use by the LTPP Program.
81	A separate test sample was used for classification and description tests (Protocol P46 or P52).
82	Due to the insufficient size of the bulk sample, the test sample for the gradation test (Protocol P41 or P51) was also used to complete the classification and description tests (Protocol P47 or P52).
83	Due to the insufficient size of the bulk sample, the test sample for the moisture-density test (Protocol P44 or Protocol P55) was saved after the test and reused for the resilient modulus testing (Protocol P46).
85	Due to the insufficient size of the bulk sample, only dry sieving was used for the gradation test (Protocol P41 or P51). The test sample after the gradation test was saved and reused to reconstitute the test sample of the resilient modulus testing (Protocol P46).
86	Due to the insufficient size of the bulk sample, only dry sieving was used for the gradation test (Protocol P41 or P51). The test sample was reused for other designated tests and the remnant of the sample was saved and stored for possible future use by the LTPP program.
87	The "undisturbed" thin-wall tube sample was used for the resilient modulus testing (Protocol P46).
88	The thin-wall tube sample was not suitable, therefore a reconstituted sample from the bulk samples was used for the resilient moudlus testing.
89	The thin-wall tube sample was not available. The test sample for the resilient modulus testing (Protocol P46) was reconsitituted from the bulk sample.

90 An excess portion of the thin-wall tube sample was saved and stored for possible future use by the LTPP program.

94 The test was not performed because of oversize aggregate; sample was stored until further instruction from the FHWA-LTPP division.

ATTACHMENT A
SAMPLE PREPARATION

The following provides guidelines for reconstituting the material to be tested so as to produce a sufficient amount of material needed to prepare the appropriate sample type (Type 1 or Type 2 sample) at the designated moisture content and density.

1. SAMPLE CONDITIONING

If the sample is damp when received from the field, dry it until it becomes friable. Drying may be in air or by use of a drying apparatus such that the temperature does not exceed 60°C (140°F). Then thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles. Moderate pressure and a 4.75 mm (No. 4 sieve) have been found to be adequate to break down clay lumps.

2. SAMPLE PREPARATION

2.1 Determine the moisture content (w_1) of the sample as per LTPP Protocol P49. The sample for moisture content shall weigh not less than 200 g for samples with a maximum particle size smaller than the 4.75 mm (No. 4) sieve and not less than 500 g for samples with a maximum particle size greater than the 4.75 mm (No. 4) sieve.

2.2 Determine the appropriate total volume (V) of the compacted specimen to be prepared. The total volume must be based on a height of the compacted specimen slightly greater than that required for resilient testing to allow for trimming of the specimen ends if necessary. Compacting to a height/diameter ratio of 2.1 to 2.2 will provide adequate material for this purpose.

2.3 Determine the weight of oven-dry soil solids (W_s) and water (W_w) required to obtain the desired dry density (γ_d) and moisture content (w) as follows:

W_s (pounds) = γ_d (pounds per cubic foot) x V (cubic feet)
W_s (grams) = W_s (pounds) x 454
W_w (pounds) = W_s (pounds) x w (%/100)
W_w (grams) = W_w (pounds) x 454

2.4 Determine the total weight of the prepared material sample (W_t) required to obtain W_s to produce the desired specimen of volume V at dry density γ_d and moisture content w.

$$W_t \text{ (grams)} = W_s \times (1 + w/100)$$

2.5 Determine the weight of the dried sample (W_{ad}), with the moisture content (w_1), required to obtain W_s, including an additional amount W_{as} of at least 500 grams to provide material for the determination of moisture content at the time of compaction.

$$W_{ad} \text{ (grams)} = (W_s + W_{as}) \times (1 + w_1/100)$$

2.6 Determine the weight of water (W_{aw}) required to increase the weight from the existing dried weight of water (W_1) to the weight of water (W_w) corresponding to the desired compaction moisture content (w).

$$W_1 \text{ (grams)} = (W_s + W_{as}) \times (w_1/100)$$
$$W_2 \text{ (grams)} = (W_s + W_{as}) \times (w/100)$$
$$W_{aw} \text{ (grams)} = W_2 - W_1$$

2.7 Place the sample (W_{ad}) determined in 7.3.7 into a mixing pan.

2.8 Add the water (W_{aw}) to the sample in small amounts and mix thoroughly after each addition.

2.9 Place the mixture in a plastic bag. Seal the bag and place it in a second bag and seal it.

2.10 After mixing and storage at a minimum of overnight and a maximum of two days, weigh the wet soil and container to the nearest gram and record this value on the appropriate form (see Worksheet T46).

2.11 The material is now ready for compaction.

ATTACHMENT B
COMPACTION OF TYPE 1 SOILS

Type 1 soils will be recompacted using a 152 mm (6.0 inch) split mold and vibratory compaction. Split molds with an inside diameter of 152 mm (6 inches) shall be used to prepare 305 mm (12 inch) high test samples for all Type 1 materials with nominal particle sizes less than or equal to 37.5 mm (1 ½ inches). If 10 percent or less of a Type 1 sample is retained on the 37.5 mm (1.5 inch) sieve, the material greater than the 37.5 mm (1.5 inch) sieve shall be scalped off prior to testing. If more than 10 percent of the sample is retained on the 37.5 mm (1.5 inch) sieve, the material shall not be tested and the material shall be stored until further notice. Instructions concerning the testing of these materials will be issued at a later date.

Cohesionless soils shall be compacted in 6 lifts in a split mold mounted on the base of the triaxial cell as shown in Figure 5. Compaction forces are generated by a vibratory impact hammer without kneading action powered by air or electricity and of sufficient size to provide the required laboratory densities while minimizing damage to the sample membrane.

1. SCOPE

This method covers the compaction of Type 1 soils for use in resilient modulus testing.

2. APPARATUS

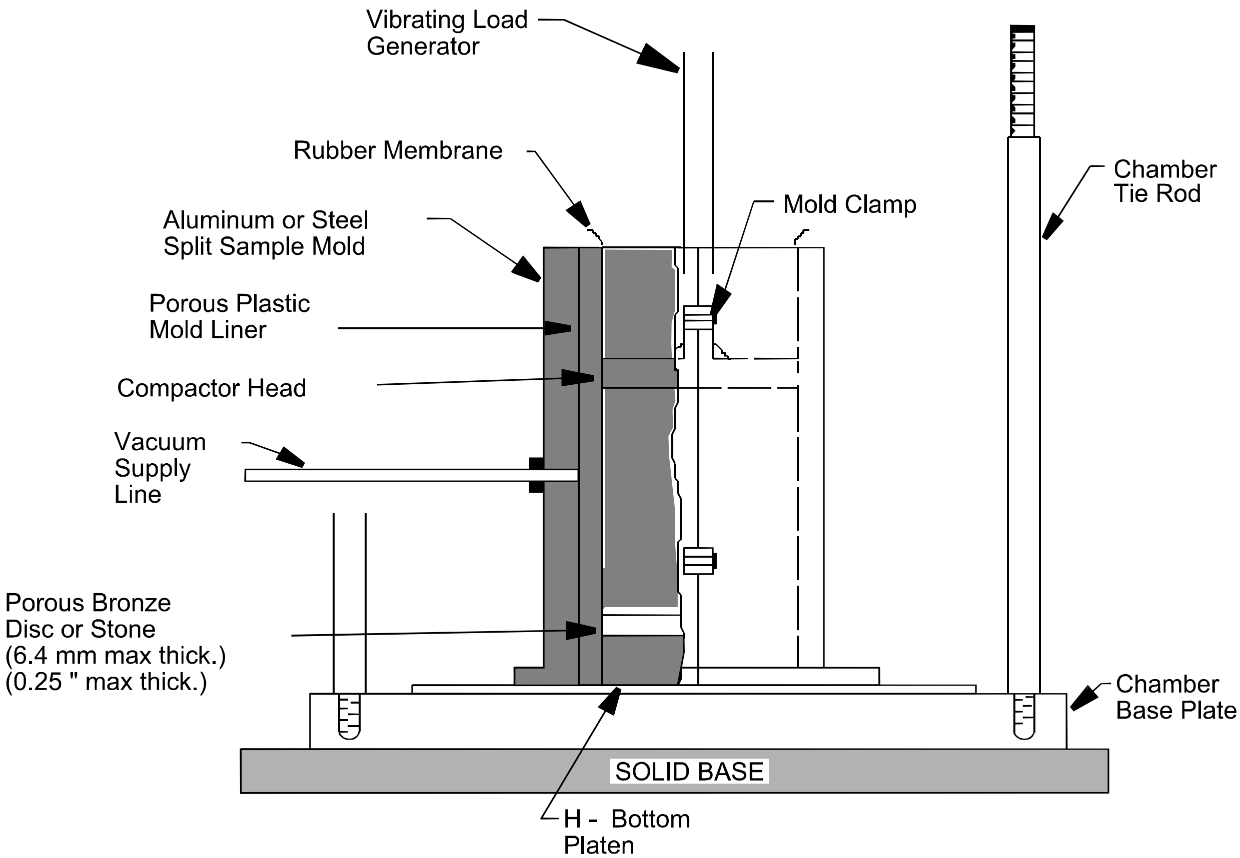
2.1 A split mold, with an inside diameter of 152 mm (6 inches) having a minimum height of 381 mm (15 inches) (or a sufficient height to allow guidance of the compaction head for the final lift).

2.2 Vibratory Compaction Device

Vibratory compaction shall be provided using electric rotary or demolition hammers. The specifications for the hammers are listed below:

Rated watts input: 750-1250 watts
Blows per minute: 1800-3000

The compactor head shall be at least 13 mm (0.5 in.) thick and have a diameter of not less than 146 mm (5.75 in.).



Note: Compactor head should be 6.35 ± 0.5 mm (0.25 ± 0.02") smaller than specimen diameter.

Figure 5. Typical apparatus for vibratory compaction of Type 1 unbound materials

NOTE 20: The vibratory compaction device shall be approved by the FHWA COTR prior to the initiation of the testing program.

3. PROCEDURE

3.1 For removable platens, tighten the bottom platen into place on the triaxial cell base. It is essential that an airtight seal is obtained and that the bottom platen interface constitutes a rigid body since calculations of strain assume zero movement of the bottom platen under load.

3.2 Place the paper filters, two bronze discs/porous stones and the top platen on the bottom platen. Determine the total height of the top and bottom platens and stones to the nearest 0.25 mm (0.01 inch).

3.3 Remove the top platen and bronze disc/porous stone. Measure the thickness of the rubber membrane with a micrometer.

3.4 Place the rubber membrane over the bottom platen, lower bronze disc/porous stone and paper filters. Secure the membrane to the bottom platen using an O-ring or other means to obtain an airtight seal.

3.5 Place the split mold around the bottom platen and draw the membrane up through the mold. Tighten the split mold firmly in place. Exercise care to avoid pinching the membrane.

3.6 Stretch the membrane tightly over the rim of the mold. Apply a vacuum to the mold sufficient to draw the membrane in contact. If wrinkles are present in the membrane, release the vacuum, adjust the membrane and reapply the vacuum. The use of a porous plastic forming jacket liner helps to ensure that the membrane fits smoothly inside the mold. The vacuum is maintained throughout the compaction procedure.

3.7 Measure, to the nearest 0.25 mm (0.01 inch), the inside diameter of the membrane lined mold and the distance between the top of the lower porous stone and the top of the mold.

3.8 Determine the volume, V, of the specimen to be prepared using the diameter determined in step 3.7 and a value of height between 305 to 318 mm (12 and 12.5 inches).

3.9 Determine the weight of material, at the prepared water content, to be compacted into the volume, V, to obtain the desired density.

3.10 For 152 mm (six inch) diameter specimens (specimen height of 305 mm (12 inches)) 6 layers of two inches per layer are required for the compaction process. Determine the weight of wet soil, W_L required for each layer.

$$W_L = W_t/N$$

where:

W_t = total weight of test specimen to produce appropriate density,
N = number of layers to be compacted.

3.11 Place the total required weight of soil for all lifts, W_{ad} into a mixing pan. Add the required amount of water, W_{aw} and mix thoroughly.

3.12 Determine the weight of wet soil and the mixing pan.

3.13 Place the amount of wet soil, W_L, into the mold. Avoid spillage. Using a spatula, draw soil away from the inside edge of the mold to form a small mound at the center.

3.14 Insert the vibrator head and vibrate the soil until the distance from the surface of the compacted layer to the rim of the mold is equal to the distance measured in step 3.7 minus the thickness of the layer selected in step 3.10. This may require removal and reinsertion of the vibrator several times until experience is gained in gaging the vibration time which is required.

3.15 Repeat steps 3.13 and 3.14 for each new layer after first scarifying the top surface of the previous layer to a depth of 6.4 mm (1/4 inch). The measured distance from the surface of the compacted layer to the rim of the mold is successively reduced by the layer thickness selected in step 3.10. The final surface shall be a smooth horizontal plane. As a recommended final step where porous bronze discs are used, the top plate shall be placed on the sample and seated with the vibrator head. If necessary, due to degradation of the first membrane, a second membrane can be applied to the sample at the conclusion of the compaction process.

3.16 When the compaction process is completed, weigh the mixing pan and the excess soil. This weight subtracted from the weight determined in step 3.12 is the weight of the wet soil used (weight of specimen). Verify the compaction water, W_c of the excess soil using care in covering the pan of wetted soil during compaction to avoid drying and loss of moisture. The moisture content of this sample shall be conducted using LTPP Protocol P49.

Proceed with section 8.2 of this protocol.

ATTACHMENT C
COMPACTION OF TYPE 2 SOILS

The general method of compaction of Type 2 soils will be that of static loading (a modified version of the double plunger method). If testable thin-walled tubes are available, specimens shall not be recompacted.

Specimens shall be recompacted in a 71 mm (2.8 inch) diameter mold. The process is one of compacting a known weight of soil to a volume that is fixed by the dimensions of the mold assembly (mold shall be of a sufficient size to produce specimens 71 mm (2.8 inches) in diameter and 152 mm (6 inches) in height). A typical mold assembly is shown in Figure 6. As an alternative for soils lacking in cohesion, a mold with the membrane installed and held by vacuum, as in Attachment B, may be used. Several steps are required for static compaction as follows in the Procedures section of this attachment and as illustrated in Figures 7-11.

NOTE 21: Alternatively, the sample can be molded to 165 mm (6.5 inch) rather than 152 mm (6.0 inch) and then a miter box can be used to square the ends of the sample and reach the final testable length of 142 mm (5.6 inch). This tends to produce more consistently shaped (level) specimens.

1. SCOPE

This method covers the compaction of Type 2 soils for use in resilient modulus testing.

2. APPARATUS

As shown in Figure 6.

NOTE 22: As an alternative for soils lacking in cohesion, a mold with the membrane installed and held by vacuum, as in Attachment B, may be used.

3. PROCEDURE

3.1 Five layers of equal weight shall be used to compact the specimens using this procedure. Determine the weight of wet soil, W_L to be used per layer where $W_L = W_t/5$.

3.2 Place one of the spacer plugs into the specimen mold.

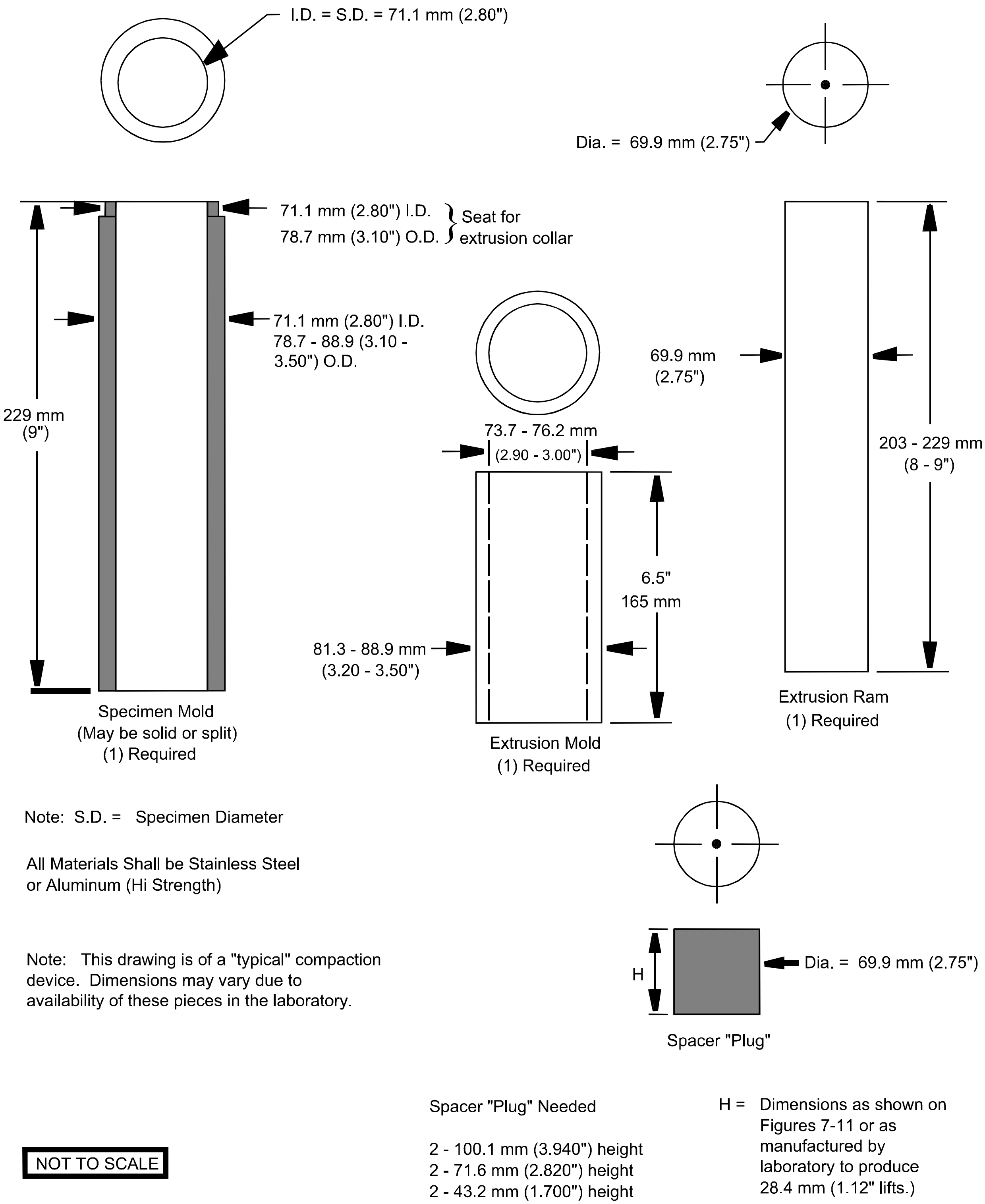


Figure 6. Typical apparatus for static compaction of Type 2 materials.

Step 3.5 - Lift 1:

- Measure correct wet mass of soil to use for a layer.
- Place in mold, spade.
- Insert *plugs* of given height.
- Double plunge until *plugs* are flush with top and bottom of mold.
- Remove top *plug*.
- Scarify the exposed surface of Lift 1.
- Proceed with next step.

Compaction *plugs* to be solid cylinders of specified height and 70.9 mm (2.79") diameter.

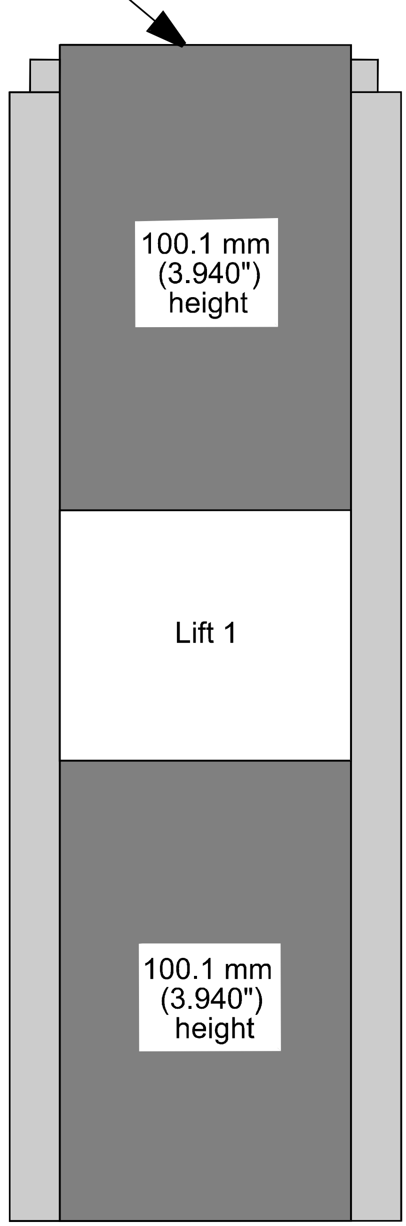


Figure 7. Compaction of Type 2 soil, lift 1.

Step 3.7 - Lift 2:

- Measure correct wet mass of soil to use for a layer.
- Place in mold, spade.
- Insert 71.6 mm (2.820") *plug.*
- Plunge until *plugs* are flush with top and bottom of mold.
- Flip mold over and remove 100.1 mm (3.940") *plug*, keeping the 71.6 mm (2.820") *plug* in place.
- Scarify the exposed surface of Lift 1.
- Proceed with next step.

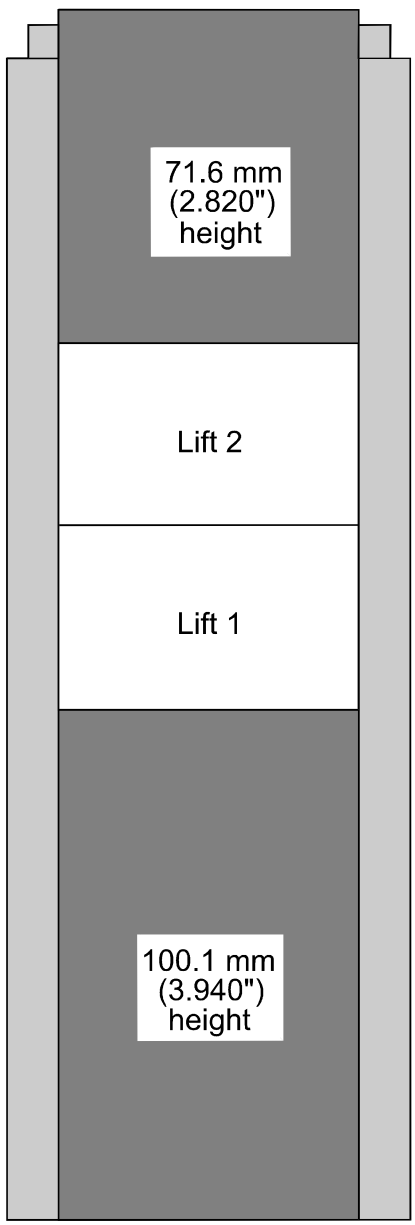


Figure 8. Compaction of Type 2 soil, lift 2.

Step 3.9 - Lift 3:

- Measure correct wet weight of soil to use for a layer.
- Place in mold, spade.
- Insert 71.6 mm (2.820") *plug*.
- Plunge until *plugs* are flush with top and bottom of mold.
- Flip mold over and remove 71.6 mm (2.820") *plug*, from the top of Lift 2, keeping the 71.6 mm (2.820") *plug* (on Lift 3) in place.
- Scarify the exposed surface of Lift 2.
- Proceed with next step.

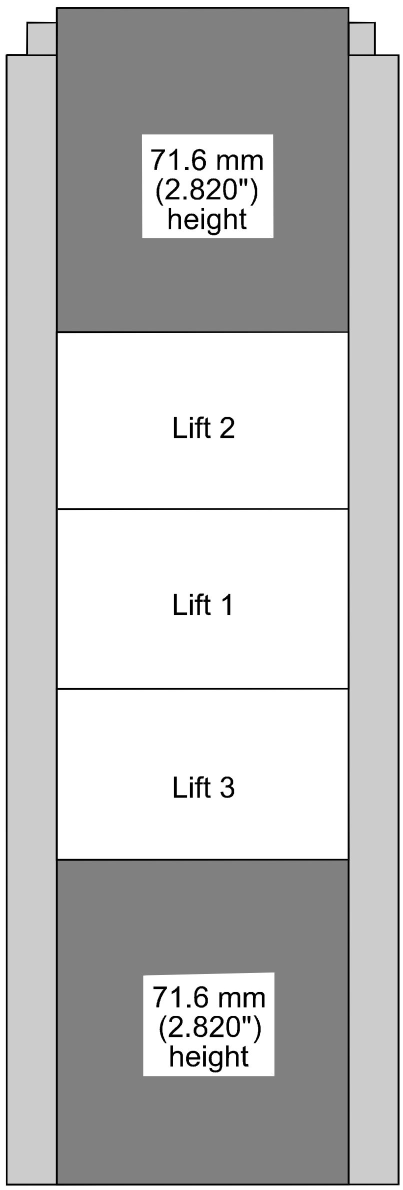


Figure 9. Compaction of Type 2 soil, lift 3.

Step 3.11 - Lift 4:

- Measure correct wet weight of soil to use for a layer.
- Place in mold, spade.
- Insert 43.2 mm (1.700") *plug.*
- Plunge until *plugs* are flush with top and bottom of mold.
- Flip mold over and remove 71.6 mm (2.820") *plug*, keeping the 43.2 mm (1.700") *plug* in place.
- Scarify the exposed surface of Lift 3.
- Proceed with next step.

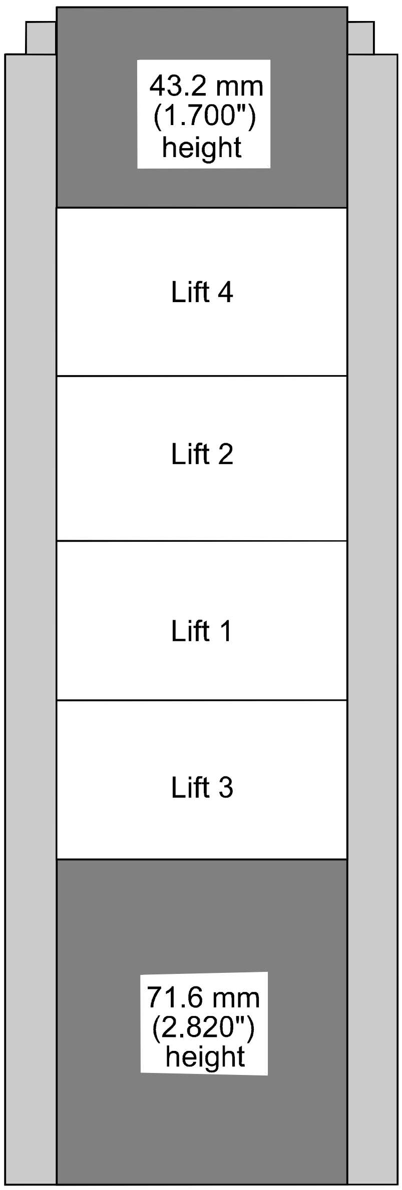


Figure 10. Compaction of Type 2 soil, lift 4.

Step 3.13 - Lift 5:

- Measure correct wet weight of soil to use for a layer.
- Place in mold, spade.
- Insert 43.2 mm (1.700") *plug.*
- Plunge until *plugs* are flush with top and bottom of mold.
- Extrude compacted sample from mold using extruding apparatus or extrusion mold.
- Place in rubber membrane.
- Test for M_r .

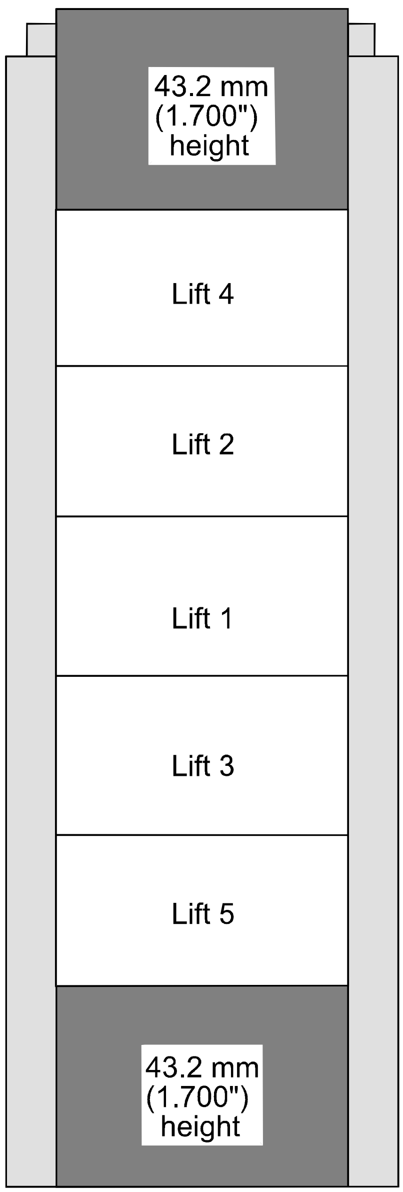


Figure 11. Compaction of Type 2 soil, lift 5.

3.3 Place the weight of soil, W_L determined in Step 3.1 into the specimen mold. Using a spatula, draw the soil away from the edge of the mold to form a slight mound in the center.

3.4 Insert the second plug and place the assembly in the static loading machine. Apply a small load. Adjust the position of the mold with respect to the soil weight, so that the distances from the mold ends to the respective spacer plug are equal. Soil pressure developed by the initial loading will serve to hold the mold in place. By having both spacer plugs reach the zero volume change simultaneously, more uniform layer densities are obtained.

3.5 Slowly increase the load until the plugs rest firmly against the mold ends. Maintain this load for a period of not less than one minute. The amount of soil rebound depends on the rate of loading and load duration. The slower the rate of loading and the longer the load is maintained, the less the rebound (see Figure 7).

NOTE 23: To obtain uniform densities, extreme care must be taken to center the first soil layer exactly between the ends of the specimen mold. Checks and any necessary adjustments should be made after completion of steps 4 and 5.

NOTE 24: Use of compaction by measuring the plunge movements to determine that the desired volume has been reached for each layer is an acceptable alternative to the use of the spacer plugs.

3.6 Decrease the load to zero and remove the assembly from the loading machine.

3.7 Remove the loading ram. Scarify the top surface of the compacted layer to a depth of 3.2 mm (1/8 inch) and put the weight of wet soil W_L for the second layer in place and form a mound. Add a spacer plug of the height shown in Figure 8.

3.8 Slowly increase the load until the plugs rest firmly against the top of the mold end. Maintain load for a period of not less than one minute (see Figure 8).

3.9 Remove the load and flip the mold over and remove the bottom plug keeping the top plug in place. Scarify the bottom surface of layer 1 and put the weight of wet soil W_L for the third layer in place and form a mound. Add a spacer ring of the height shown in Figure 9.

3.10 Place the assembly in the loading machine. Increase the load slowly until the spacer plugs firmly contact the ends of the specimen mold. Maintain this load for a period of not less than one minute.

3.11 Follow the steps presented in Figure 10 and 11 to compact the remaining two layers.

3.12 After compaction is completed, determine the moisture content of the remaining soil using LTPP Protocol P49. Record this value on LTPP Laboratory Data Form T46A.

3.13 Using the extrusion ram, press the compacted soil out of the specimen mold and into the extrusion mold. Extrusion should be done slowly to avoid impact loading the specimen.

3.14 Using the extrusion mold, carefully slide the specimen off the ram, onto a solid end platen. The platen should be circular with a diameter equal to that of the specimen and have a minimum thickness of 13 mm (0.5 in). Platens shall be of a material which will not absorb soil moisture.

3.15 Determine the weight of the compacted specimen to the nearest gram. Measure the height and diameter to the nearest 0.25 mm (0.01 inch). Record these values on Worksheet T46.

3.16 Place a platen similar to the one used in step 3.13 on top of the specimen.

3.17 Using a vacuum membrane expander, place the membrane over the specimen. Carefully pull the ends of the membrane over the end platens. Secure the membrane to each platen using O-rings or other means to provide an airtight seal.

Proceed with Section 8.1 of this protocol.

ATTACHMENT D
DETERMINATION OF APPLIED CONTACT LOAD

Prior to conduct of the resilient modulus test procedure, the contact load levels must be adjusted to compensate for the resultant force created by the chamber pressure (upward force) and the weight of the chamber piston rod, including the LVDT holder, (downward force). This attachment provides guidelines and an example as to the proper method with which to establish the contact load levels.

1. PROCEDURE

Using the confining pressure in kPa (A), the area of the rod in m^2 (B) and the weight of the rod in kN (C), the following equation can be used to determine the resultant force (F) from the downward force of the chamber piston rod assembly and the uplift force of the confining pressure on the chamber piston rod assembly:

$$F\ (kN) = (A \times B) - C$$

For this equation, the force is positive if the resultant force is upward and negative if the resultant force is in the downward direction. This result is then added to the contact load placed on the specimen (the sign of "F", positive or negative, will determine the direction of the adjustment). Therefore:

$$P_{contact\text{-}adjusted} = P_{contact} + F.$$

NOTE 25: For very low loads (primarily Type 2 subgrade samples), this may result in an adjusted load that is less than 5 N. In this case, a minimum of 5 N (or the lowest sensitivity rating of the load cell) is always used as the absolute minimum contact load to stay within the load cell sensitivity range.

After establishing $P_{contact\text{-}adjusted}$, the maximum load must also be adjusted to produce the correct cyclic load on the specimen. This is a straightforward procedure governed by the following equation:

$$P_{max\text{-}adjusted} = P_{contact\text{-}adjusted} + P_{cyclic},$$

Where, P_{max} and P_{cyclic} are as defined in section 3 of the main body of this protocol.

2. EXAMPLE

An example follows for a Type 1 sample.

The following test setup is given:

Specimen Diameter = 152 mm
Chamber Piston Rod Diam. = 25.4 mm
Chamber Piston Rod Assembly Weight = .01588 kN

Using this information, the following values can be calculated:

Area of Sample: .01815 m^2
Area of Chamber Piston Rod: .00051 m^2

For Type 1 testing of base/subbase materials, confining pressures of 21, 35, 69, 103 and 138 kPa are used. Therefore, using all of the above values and the equations in section 1 of this attachment, the adjusted contact force ($P_{contact-adjusted}$) can be determined as shown in table 4.

Using $P_{contact-adjusted}$, the adjusted maximum loading parameters can be determined using the equation:

$P_{max-adjusted} = P_{cyclic} + P_{contact-adjusted}$.

These calculations need to be made and the contact and maximum loads adjusted for each combination of pavement layer and material type (base/subbase - Type 1 and Type 2, subgrade - Type 1 and Type 2) and for each triaxial cell (since each triaxial cell may have a different resultant force, "F") that is used for resilient modulus testing.

Table 4. Example calculation matrix for $P_{contact-mod}$.

Sequence Number	Confining Press., kPa	Required Contact Load, kN[1] ($P_{contact}$)	Resultant Force, kN[2] (F)	Adjusted Contact Load, kN[3] ($P_{contact-adjusted}$)
0	103	0.188	0.037	0.224
1	21	0.0375	-0.00517	0.0324
2	21	0.0751	-0.00517	0.0699
3	21	0.113	-0.00517	0.107
4	35	0.0626	0.00197	0.0645
5	35	0.125	0.00197	0.127
6	35	0.188	0.00197	0.190
7	69	0.125	0.01931	0.144
8	69	0.250	0.01931	0.270
9	69	0.375	0.01931	0.395
10	103	0.125	0.0367	0.162
11	103	0.188	0.0367	0.224
12	103	0.375	0.0367	0.412
13	138	0.188	0.0545	0.242
14	138	0.250	0.0545	0.305
15	138	0.501	0.0545	0.555

1. From Table 2.
2. Use equation from Section 1 of this attachment.
3. $P_{contact-adjusted} = P_{contact} + F$.

Table 5. Example calculation matrix for modified Type 1 loadings

Sequence Number	$P_{contact\text{-}adjusted}$, kN[1]	P_{cyclic}, kN[2]	$P_{max\text{-}mod}$, kN[3]
0	0.224	1.690	1.91
1	0.0324	0.338	0.370
2	0.0699	0.677	0.747
3	0.107	1.02	1.12
4	0.0645	0.563	0.627
5	0.127	1.13	1.252
6	0.190	1.69	1.88
7	0.144	1.13	1.27
8	0.270	2.25	2.52
9	0.395	3.38	3.77
10	0.162	1.13	1.29
11	0.224	1.69	1.91
12	0.412	3.38	3.79
13	0.242	1.69	1.93
14	0.305	2.25	2.56
15	0.555	4.51	5.06

1. From Table 4.
2. From Table 2.
3. $P_{max\text{-}adjusted} = P_{cyclic} + P_{contact\text{-}adjusted}$.

LABORATORY MATERIAL HANDLING AND TESTING

SHEET NO _____ OF _____

LABORATORY MATERIAL TEST DATA

RESILIENT MODULUS OF UNBOUND GRANULAR BASE/SUBBASE MATERIALS AND SUBGRADE SOILS

LABORATORY DATA SHEET T46A - RECOMPACTED SAMPLES

UNBOUND GRANULAR BASE/SUBBASE LAYERS AND SUBGRADE SOILS
SHRP TEST DESIGNATION UG07, SS07/SHRP PROTOCOL P46

LABORATORY PERFORMING TEST:____
LABORATORY IDENTIFICATION CODE: __ __ __ __
SAMPLES FROM: SHRP REGION____________ STATE________ ***STATE CODE***: __ __
LTPP EXPT. NO.: ____________ ***SHRP SECTION ID***.: __ __ __ __ __ __
SAMPLED BY: ________________________________ ***FIELD SET NO***.: __
DRILLING AND SAMPLING CONTRACTOR/AGENCY
SAMPLING DATE: __ __-__ __-19 __ __

1. ***LAYER NUMBER*** (FROM LAB SHEET L04) __
2. ***LAYER TYPE*** (1 = subgrade, 2 = base/subbase) __
3. ***SAMPLING AREA NO.*** (SA-) __ __
4. ***SHRP LABORATORY TEST NUMBER*** __
5. ***LOCATION NUMBER*** __ __ __
6. ***SHRP SAMPLE NUMBER*** __ __ __ __
7. ***MATERIAL TYPE*** (Type 1 or Type 2) __
8. ***TEST INFORMATION***
   - ***PRECONDITIONING - GREATER THAN 5% PERM. STRAIN? (Y = YES OR N = NO)*** __
   - ***TESTING - GREATER THAN 5% PERM. STRAIN? (Y = YES OR N = NO)*** __
   - ***TESTING - NUMBER OF LOAD SEQUENCES COMPLETED (0 - 15)*** __ __
9. ***SPECIMEN INFO.***:
   - ***SPEC. DIAM.***, mm
     - ***TOP*** __ __ __ . __
     - ***MIDDLE*** __ __ __ . __
     - ***BOTTOM*** __ __ __ . __
     - ***AVERAGE*** __ __ __ . __
     - ***MEMBRANE THICKNESS(1)***, mm __ . __ __
     - ***MEMBRANE THICKNESS(2)***, mm __ . __ __
   - ***NET DIAM***, mm __ __ __ . __
   - ***HEIGHT OF SPECIMEN, CAP AND BASE***, mm __ __ __ . __
   - ***HEIGHT OF CAP AND BASE***, mm __ __ __ . __
   - ***INITIAL LENGTH*** L_o, mm __ __ __ . __
   - ***INITIAL AREA***, A_o, mm^2 __ __ __ __ __ .
   - ***INITIAL VOLUME***, A_oL_o, mm^3 __ __ __ __ __ __ __ .
10. ***SOIL SPECIMEN WEIGHT***:
    - ***INITIAL WEIGHT OF CONTAINER AND WET SOIL, grams*** __ __ __ __ __ . __ __
    - ***FINAL WEIGHT OF CONTAINER AND WET SOIL, grams*** __ __ __ __ __ . __ __
    - ***WEIGHT OF WET SOIL USED, grams*** __ __ __ __ __ . __ __
11. ***SOIL PROPERTIES:***
    - ***IN SITU MOISTURE CONTENT (NUCLEAR)***, % __ __ . __
    - ***IN SITU WET DENSITY (NUCLEAR)***, kg/m^3 __ __ __ __ . __
    - or
    - ***OPTIMUM MOISTURE CONTENT***, % __ __ . __
    - ***MAX. DRY DENSITY***, kg/m^3 __ __ __ __ . __
    - ***95% MAX. DRY DENSITY***, kg/m^3 __ __ __ __ . __
12. ***SPECIMEN PROPERTIES***:
    - ***COMPACTION MOISTURE CONTENT***, % __ __ . __
    - ***MOISTURE CONTENT AFTER RESILIENT MODULUS TESTING***, % __ __ . __
    - ***COMPACTION DRY DENSITY***, γ_d, kg/m^3 __ __ __ __ . __
13. ***QUICK SHEAR TEST***
    - ***STRESS-STRAIN PLOT ATTACHED*** (Y = YES OR N = NO) __
    - ***TRIAXIAL SHEAR MAXIMUM STRENGTH*** (MAX. LOAD/X-SECTION AREA), kPa __ __ __ __.
    - ***SPECIMEN FAIL DURING TRIAXIAL SHEAR?*** (Y = YES, N = NO) __
14. ***COMMENTS*** (Section 10.4 of Protocol P46)
    - (a) ***CODE*** __ __, __ __, __ __, __ __, __ __, __ __
    - (b) ***NOTE*** ______________________________
15. ***TEST DATE*** __ __ - __ __ - __ __

____

GENERAL REMARKS:____

SUBMITTED BY, DATE

____

LABORATORY CHIEF
Affiliation______________

CHECKED AND APPROVED, DATE

____

Affiliation__________________

LABORATORY MATERIAL HANDLING AND TESTING — SHEET NO ____ OF ____

LABORATORY MATERIAL TEST DATA

RESILIENT MODULUS OF UNBOUND GRANULAR BASE/SUBBASE MATERIALS AND SUBGRADE SOILS

LABORATORY DATA SHEET T46B - THINWALL TUBE SAMPLES

UNBOUND GRANULAR BASE/SUBBASE LAYERS AND SUBGRADE SOILS
SHRP TEST DESIGNATION UG07, SS07/SHRP PROTOCOL P46

LABORATORY PERFORMING TEST:______________________________

LABORATORY IDENTIFICATION CODE: __ __ __ __

SAMPLES FROM: SHRP REGION__________ STATE______ ***STATE CODE***: __ __

LTPP EXPT. NO.: __________ ***SHRP SECTION ID***.: __ __ __ __ __ __

SAMPLED BY: ______________________________ ***FIELD SET NO***.: __

DRILLING AND SAMPLING CONTRACTOR/AGENCY

SAMPLING DATE: __ __-__ __-19 __ __

1. ***LAYER NUMBER*** (FROM LAB SHEET L04) __
2. ***LAYER TYPE*** (1 = subgrade, 2 = base/subbase) __
3. ***SAMPLING AREA NO.*** (SA-) __ __
4. ***SHRP LABORATORY TEST NUMBER*** __
5. ***LOCATION NUMBER*** __ __ __
6. ***SHRP SAMPLE NUMBER*** __ __ __ __
7. ***MATERIAL TYPE*** (Type 1 or Type 2) __
8. ***APPROX. DISTANCE FROM TOP OF SUBGRADE TO SAMPLE***, m __ . __ __
9. ***TEST INFORMATION***
   - ***PRECONDITIONING - GREATER THAN 5% PERM. STRAIN? (Y = YES OR N = NO)*** __
   - ***TESTING - GREATER THAN 5% PERM. STRAIN? (Y = YES OR N = NO)*** __
   - ***TESTING - NUMBER OF LOAD SEQUENCES COMPLETED (0 - 15)*** __ __
10. ***SPECIMEN INFO.***:
    - ***SPEC. DIAM.***, mm
      - ***TOP*** __ __ __ . __
      - ***MIDDLE*** __ __ __ . __
      - ***BOTTOM*** __ __ __ . __
      - ***AVERAGE*** __ __ __ . __
      - ***MEMBRANE THICKNESS(1)***, mm __ . __ __
      - ***MEMBRANE THICKNESS(2)***, mm __ . __ __
    - ***NET DIAM***, mm __ __ __ . __
    - ***INITIAL LENGTH*** L_o, mm __ __ __ . __
    - ***INITIAL AREA***, A_o, mm^2 __ __ __ __ __ .
    - ***INITIAL VOLUME***, A_oL_o, mm^3 __ __ __ __ __ __ __ .
    - ***INITIAL WEIGHT***, grams __ __ __ __ __ . __
11. ***SOIL PROPERTIES***:
    - ***IN SITU MOISTURE CONTENT***, % __ __ . __
    - ***MOISTURE CONTENT AFTER RESILIENT MODULUS TESTING***, % __ __ . __
    - ***WET DENSITY***, γ_w, kg/m^3 __ __ __ __ . __
    - ***DRY DENSITY***, γ_d, kg/m^3 __ __ __ __ . __
12. ***QUICK SHEAR TEST***
    - ***STRESS-STRAIN PLOT ATTACHED*** (Y = YES OR N = NO) __
    - ***TRIAXIAL SHEAR MAXIMUM STRENGTH*** (MAX. LOAD/X-SECTION AREA), kPa __ __ __ __.
    - ***SPECIMEN FAIL DURING TRIAXIAL SHEAR?*** (Y = YES, N = NO) __
13. ***COMMENTS*** (Section 10.4 of Protocol P46)
    - (a) ***CODE*** __ __, __ __, __ __, __ __, __ __, __ __
    - (b) ***NOTE*** ______________________________
14. ***TEST DATE*** __ __ - __ __ - __ __

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GENERAL REMARKS:______________________________

SUBMITTED BY, DATE — CHECKED AND APPROVED, DATE

______________ — ______________

LABORATORY CHIEF

Affiliation__________ — Affiliation__________

1. *LABORATORY IDENTIFICATION CODE* __ __ __ __
2. *STATE CODE* __ __
3. *SHRP SECTION ID* __ __ __ __ __ __
4. *FIELD SET NO.* __
5. *LAYER NUMBER* __
6. *LAYER TYPE* (1 = subgrade, 2 = base/subbase) __
7. *SAMPLING AREA NO.* (SA-) __ __
8. *SHRP LABORATORY TEST NUMBER* __
9. *LOCATION NUMBER* __ __
10. *SHRP SAMPLE NUMBER* __ __ __ __
11. *MATERIAL TYPE* __
12. *TEST DATE* __ __ - __ __ - __ __
13. *RESILIENT MODULUS TESTING*

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
PARAMETER	*Chamber Confining Pressure*	*Nominal Maximum Axial Stress*	*Cycle No.*	*Actual Applied Max. Axial Load*	*Actual Applied Cyclic Load*	*Actual Applied Contact Load*	*Actual Applied Max. Axial Stress*	*Actual Applied Cyclic Stress*	*Actual Applied Contact Stress*	*Recov Def. LVDT #1 Reading*	*Recov Def. LVDT #2 Reading*	*Average Recov Def. LVDT 1 and 2*	*Resilient Strain*	*Resilient Modulus*
DESIGNATION	S_3	S_{cyclic}	c_i	P_{max}	P_{cyclic}	$P_{contact}$	S_{max}	S_{cyclic}	$S_{contact}$	H_1	H_2	H_{avg}	ε_r	M_r
UNIT	kPa	kPa	---	N	N	N	kPa	kPa	kPa	mm	mm	mm	mm/mm	MPa
PRECISION	_ _ _ . _	_ _ _ . _	_	_ _ _ _._	_ _ _ _._	_ _ _._	_ _ _._	_ _ _._	_ _._	_._ _ _ _ _	_._ _ _ _ _	_._ _ _ _ _	_._ _ _ _ _	_ _ _.
SEQUENCE 1			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SEQUENCE 2			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SEQUENCE 3			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SEQUENCE 4			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SEQUENCE 5			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SEQUENCE 6			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SEQUENCE 7			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SEQUENCE 8			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SEQUENCE 9			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SEQUENCE 10			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SEQUENCE 11			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SEQUENCE 12			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SEQUENCE 13			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SEQUENCE 14			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

COLUMN #	1	2	3	4	5	6	7	8	9	10	11	12	13	14
SEQUENCE 15			1											
			2											
			3											
			4											
			5											
	COLUMN AVERAGE													
	STANDARD DEV.													

SUBMITTED BY, DATE

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LABORATORY CHIEF
Affiliation ______________________

CHECKED AND APPROVED, DATE

Affiliation