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Type II Unbound Cohesive Subgrade Soil Synthetic Reference Sample Program

Garland W. Steele
Steele Engineering, Inc.
Tornado, West Virginia

Charles E. Antle
Consulting Statistician
State College, Pennsylvania

David A. Anderson
Nittany Engineers and Management Consultants, Inc.
State College, Pennsylvania

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Program Manager: *Neil F. Hawks*
Project Manager: *Adrian Pelzner*
Program Area Secretaries: *Cindy Baker, Francine A. Burgess*
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2101 Constitution Avenue N.W.
Washington, DC 20418

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Contents

List of Tables

List of Figures

Abstract

SHRP Protocol 46, "Resilient Modulus of Unbound Granular Base/Subbase Materials and Subgrade Soils" was the specified procedure for laboratories performing resilient modulus tests on research samples of unbound cohesive subgrade soil obtained from LTPP field sites. All laboratories conducting tests for the LTPP program were required to be accredited by the AASHTO Accreditation Program (AAP). AAP includes site inspections of equipment and procedures, and participation in applicable proficiency sample testing. A few critical LTPP tests, such as the triaxial resilient modulus test, were not addressed fully by the AAP, and LTPP decided to conduct supplemental testing.

P46 requires a test system which includes a triaxial pressure cell component, a closed loop electro-hydraulic repeated load component, and certain load and specimen response control, measurement, and recording components.

In view of the complexity of P46, two elements of the supplemental testing were specially important:

- verification that the system is calibrated and yielding reasonable results, and
- a practical means of performing quality checks on a daily or more frequent basis.

A set of three synthetic reference samples was acquired, instructions for testing were prepared, and the set was circulated to 14 participating laboratories for testing.

Worksheets, supporting data, analyses, final comments, and conclusions are presented. A complete set of proficiency sample statements in AASHTO/ASTM format are provided.

PART I INTRODUCTION

SHRP Protocol P46, "Resilient Modulus of Unbound Granular Base/Subbase Materials and Subgrade Soils", was the specified test procedure for laboratories performing resilient modulus tests on research samples of unbound cohesive subgrade soil obtained from long term pavement performance (LTPP) field sites.

P46 requires a test system which includes a triaxial pressure cell component, a closed loop electro-hydraulic repeated loading component, and certain load and specimen response measurement, control, and recording components.

All laboratories providing LTPP testing services were required to be accredited by the American Association of State Highway and Transportation Officials (AASHTO) accreditation program (AAP).

Many of the laboratory tests on LTPP field samples were addressed by the AAP, which includes on site inspections of equipment and procedures, and participation in applicable proficiency sample series. However, a few critical tests in the SHRP LTPP studies, such as the triaxial resilient modulus test, were not fully addressed. After extensive consultation and careful study, it was determined that supplemental programs were necessary to provide assurance of quality for these tests. Two important elements, particularly in view of the complexity of the test system required by P46, are:

- Verification that the test system is calibrated and yielding a reasonable response, and

- A practical means for performance of quality checks on a daily or more frequent basis to provide assurance that the test system is stable and continuing to yield reasonable results.

The Type II Unbound Cohesive Subgrade Soil Synthetic Reference Sample research was designed by Virgil Anderson and Robin High, consulting statisticians, and one of the authors of this report (Steele). It was approved for implementation by SHRP as a supplemental program to satisfy the first of the above noted needs. Since obtaining additional specimens for each laboratory was not feasible within the allotted time for the research, each participating laboratory was advised as follows during the course of the research:

- Obtain at least one synthetic specimen for in-house use,
- Determine and record it's response in the resilient modulus test concurrent with or shortly after successful completion of tests on the reference set, and
- Use the in-house specimen for quality control as required to satisfy the second need stated above.

The set of three Type II Unbound Cohesive Subgrade Soil Synthetic Reference Samples were supplied by Professor Kenneth H. Stokoe, II, from the University of Texas. A range of resilient modulus target values were derived by the University of Nevada-Reno laboratory under the direction of Mary Stroupe Gardiner. Instructions for testing and reporting of results were prepared and participating laboratories notified of the pending shipment of the Type II Reference Set by the Maryland Department of Transportation Laboratory under the direction of A. Haleem Tahir, Deputy Chief Engineer. Management and oversight of the research was performed by Steele Engineering, Inc.(SEI), Tornado, West Virginia.

In this research program, a set of three reference specimens was rotated to all participating laboratories for testing in accordance with certain specified parameters (see ~~part II~~ Appendix A of this report). The reference specimens were right circular cylinders with a nominal 2.8 inch diameter by 5.6 inch length, dimensions equivalent to those of specimens taken from a standard Shelby tube. The set was cast from three different urethane materials: one specimen cast from Conathane TU-700, one specimen cast from the Conap product DP-TU-15029 (identified elsewhere in this report as DPTU 1560), and one specimen cast from Conathane TU-960.

The initial reference specimen tests by each participant were blind, that is, the participant did not know the reference values. In subsequent testing by the same participant (which has with few exceptions occurred) the acceptable range of reference values was revealed. The intent of this procedure was to provide participants with an opportunity to verify the calibration of their triaxial resilient modulus testing system by testing the set of three synthetic reference specimens using standardized parameters. When response was not within the anticipated range, recalibration or maintenance of the system was indicated. When response was within the anticipated range, successful verification of system calibration was deemed to have been accomplished.

Fourteen laboratories participated in the program. All participants made significant contributions to the success of the LTPP research effort. A list of participants is in Part II of this report.

A copy of the initiating letters and worksheets for this program is included in appendix A of this report.

The final comments, analyses, conclusions and recommendations resulting from the Type II Unbound Cohesive Subgrade Soil Synthetic Reference Sample Program are contained in Part III of this report.
A set of precision statements in AASHTO/ASTM format is contained in Part IV.

PART II PARTICIPATING LABORATORIES

College of Engineering and Applied Science
Office of Research, Development & Administration
Arizona State University
Tempe, AZ 85287-1903

Department of Civil Engineering
238 Harbert Engineering Center
Auburn University, AL 36849

Braun Intertech Engineering, Inc.
6801 Washington Ave South
PO Box 39108
Minneapolis, MN 55439

California Department of Transportation
Division of New Technology, Materials, and Research
5900 Folsom Boulevard, PO Box 19128
Sacramento, CA 95819

Federal Highway Administration
Central Direct Federal Division
Building 52, Denver Federal Center
Lakewood, CO 80225

Kansas Department of Transportation
Materials and Research Center
2300 Van Buren Street
Topeka, KS 66611

Department of Civil Engineering
University of Mississippi
University, Mississippi, 38677

Law Engineering
396 Plasters Avenue
Atlanta, GA 30324

Office of Materials and Research
Maryland State Highway Administration
2323 West Joppa Road
Brooklandville, MD 21022

Nevada Department of Transportation
1263 South Stewart Street
Carson City, NV 89712

College of Engineering
Department of Civil Engineering
University of Nevada-Reno
Reno, NV 89557-0030

Oregon Department of Transportation
Highway Engineering Laboratory
800 Airport Road SE
Salem, OR 97310

Kentucky Transportation Center
College of Engineering
University of Kentucky
Lexington, KY 40506-0043

West Virginia Department of Transportation
Division of Highways
312 Michigan Avenue
Charleston, WV 25311

PART III RESEARCH ANALYSES, OBSERVATIONS, AND CONCLUSIONS

1. Background

The objectives for this experiment were given in the Introduction (Part I) of this report. In this part (Part III), statistical model which is appropriate for this experiment is given. In particular, a model for the measured M_R which allows for the estimation of the components of variance is presented. The analysis of the data with this model provides the information needed for Part IV of this report.

It was observed in a preliminary analysis of these data that the measured modulus was sometimes increased with the level of the deviator stress, contrary ~~with~~ to what would be expected. This question is also considered in this part of the report.

It was also observed in a preliminary analysis of these data that, as expected, the measured modulus for these synthetic specimens did not depend very much on the value of the confining pressure. That observation would still appear to be correct at this time and expected for the synthetic materials. No generalization to the soil samples is implied where the modulus would be expected to increase with confining pressure.

2. Design of the Experiment

The experiment as considered in this part of the report simply called for each laboratory in the study to measure the resilient modulus of the three synthetic specimens with certain values of the confining pressure (sometimes noted as CONF) and the deviator stress (sometimes noted as DYN). They were to report the results at each combination of the levels for two tests (confining pressure x deviator stress). These two tests provide the means for the evaluation of a within laboratory component of error.

The levels of the confining pressure were 0 and 4 psi. The levels for the deviator stress were 2, 6, and 10 psi. The tests at the six combinations of these factors were carried out in a sequence without removing or demounting the specimen. Thus the evaluation of the effects of these levels should be more precise than it could have been if these data were from independent measured values. It should be noted, however, that this sequence is typically followed with unbound cohesive materials. The testing error is the only component of error that affects the differences in the measured M_R values. These averaged differences may then be tested by simple t tests.

3. Observations

It is helpful to look at the graphs of the averaged M_R as given in figures 1-6 where it will be observed that

- The differences among the Laboratory averages are reasonable if laboratory B is omitted for specimen TU-700 and laboratories J and L are omitted for specimen DPTU-1560. Although Laboratory A was not ommited from the further analyses it is clear that its values are large for specimens DPTU-1560 and TU-960.

- The laboratory means for specimens DPTU-1560 and TU-960 (See Figures 2 and 3) tend to follow the same pattern. This would indicate that the laboratories could be better calibrated in this range to reduce the variability among laboratories. With the exception of laboratory A, the pattern is also seen in Figure 1 for specimen TU-700.

- The average of the measured M_R for specimen TU-700 does not appear to depend upon the level of the deviator stress.

- The average of the measured M_R for specimens DPTU-1560 and TU-960 tends to increase with the level of the deviator stress.

The statistical analyses in the next section will provide the means for evaluating the above observations.

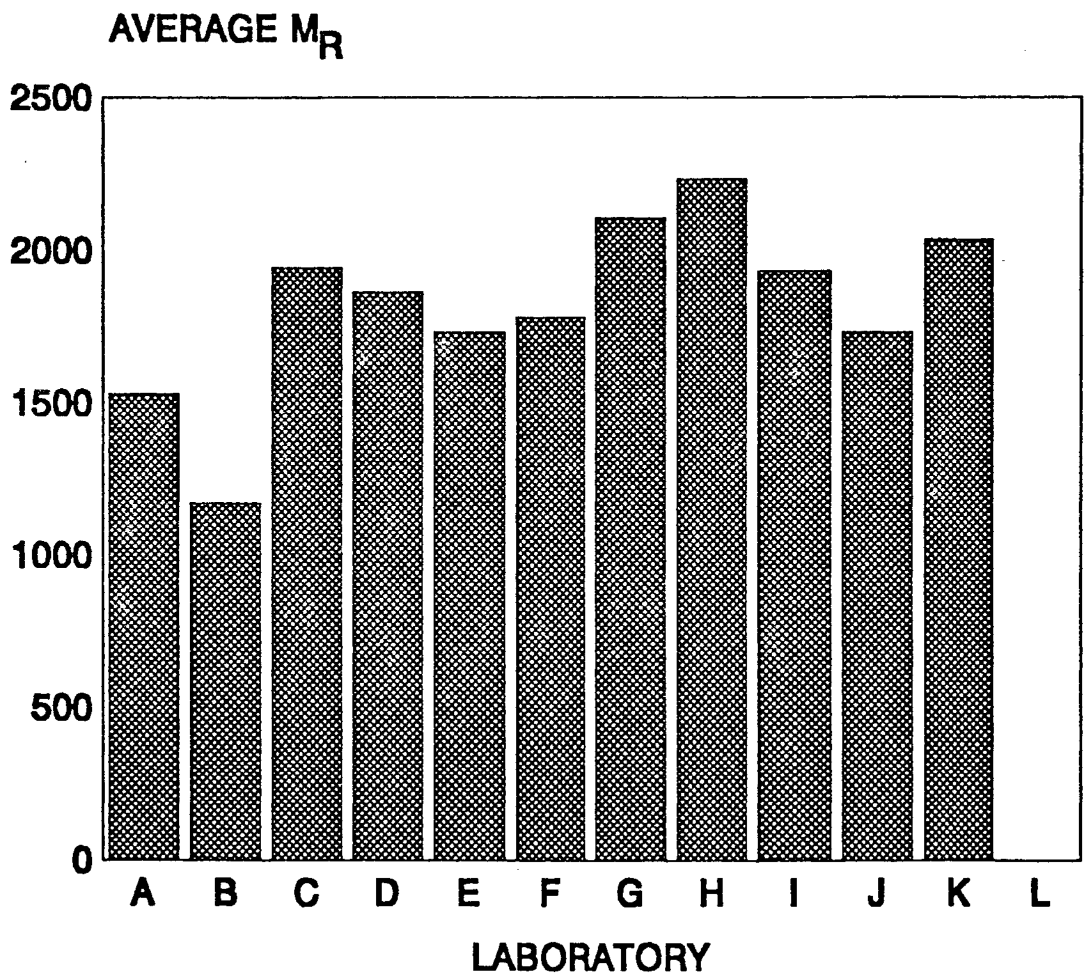


Figure 1. Laboratory Averages for Synthetic Specimen TU-700.

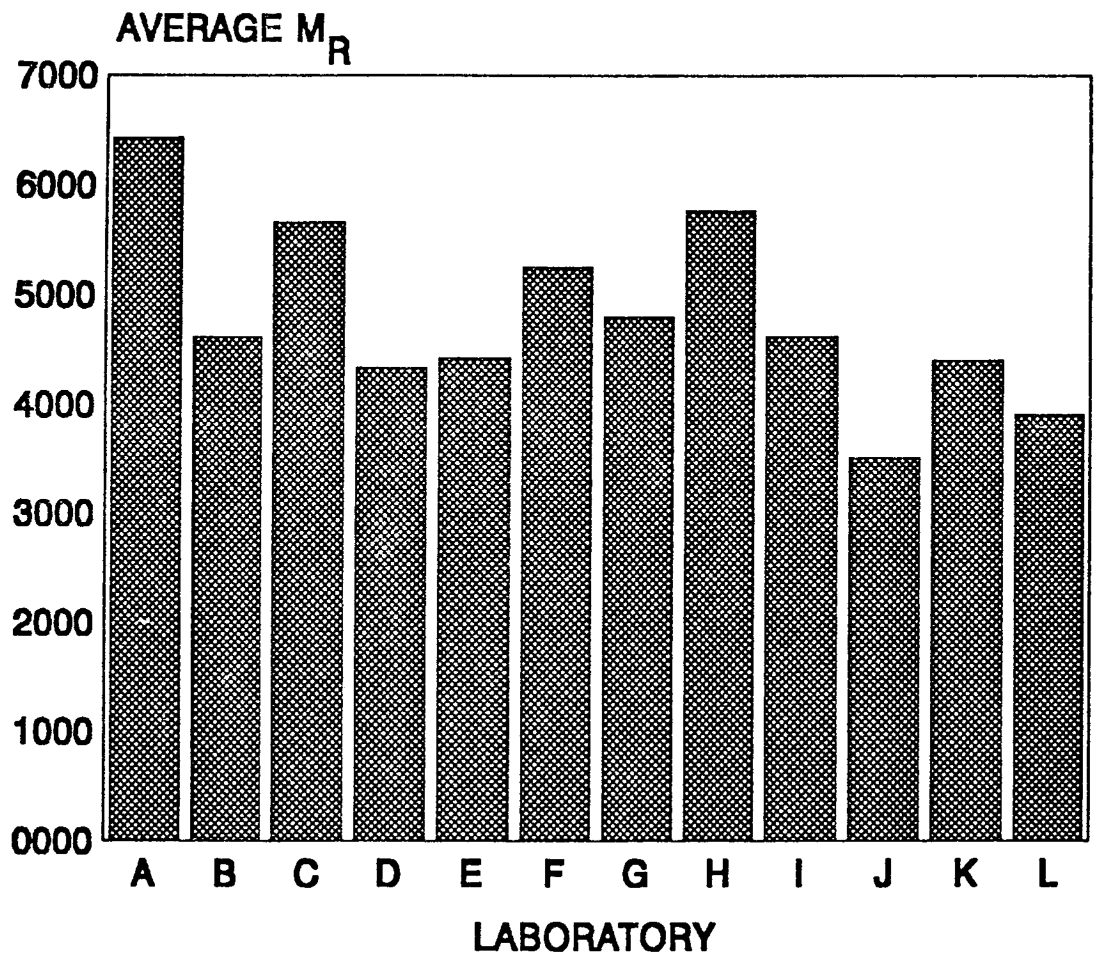


Figure 2. Laboratory Averages for Synthetic Specimen DPTU-1560.

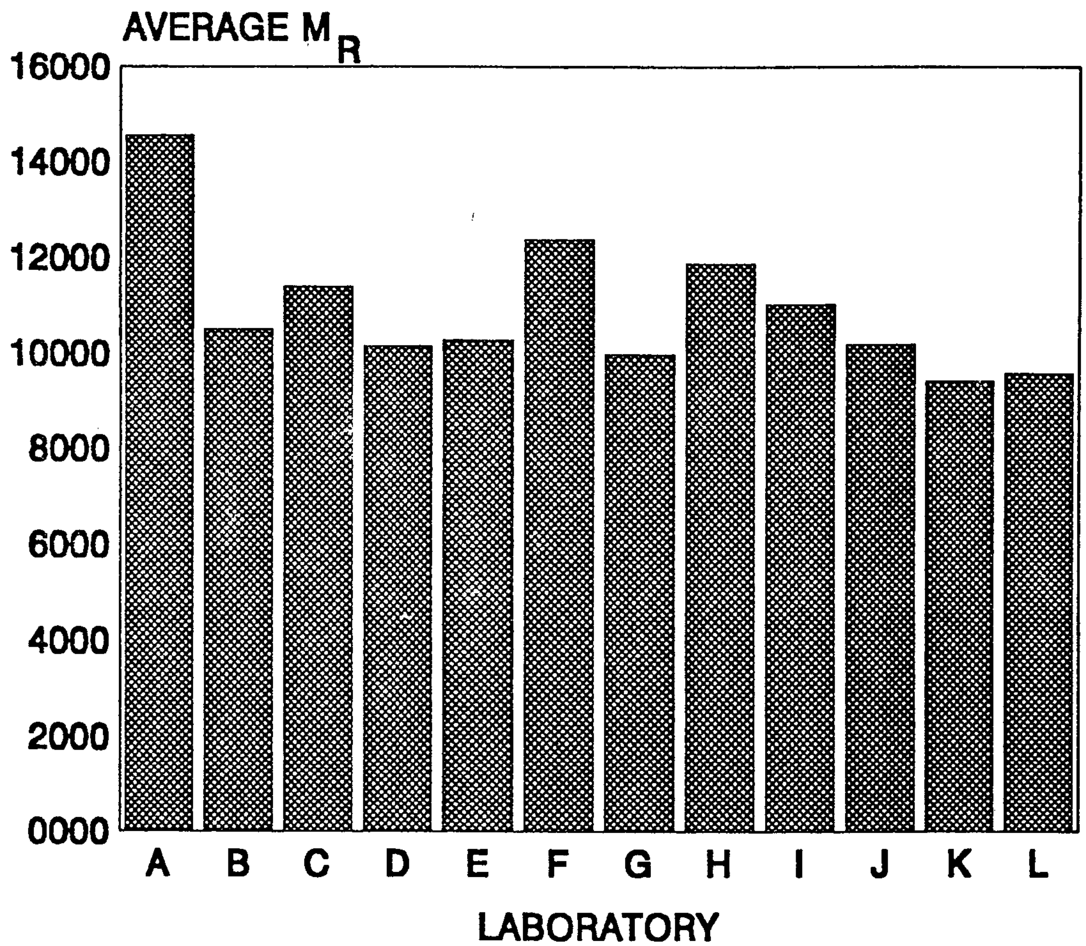


Figure 3. Laboratory Averages for Synthetic Specimen TU-960.

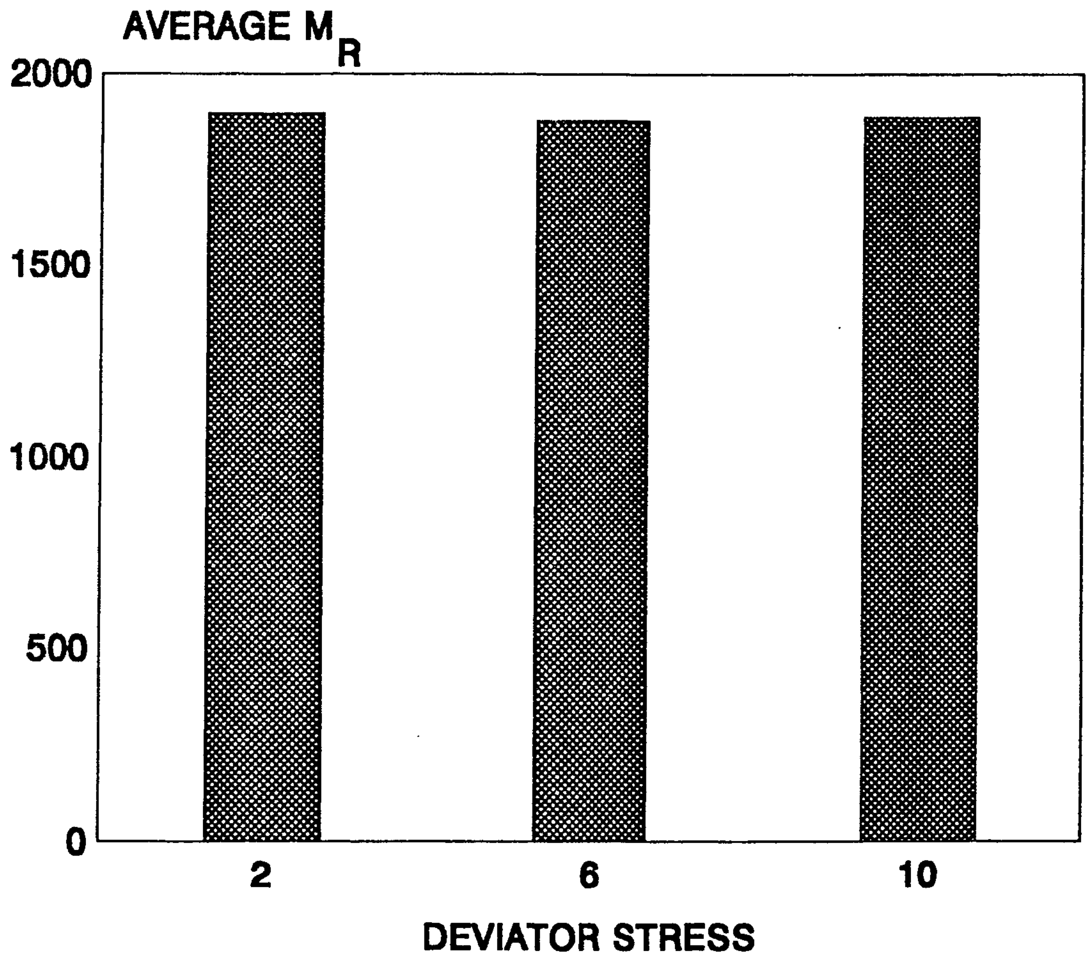


Figure 4. Average M_R by Deviator Stress for Synthetic Specimen TU-700.

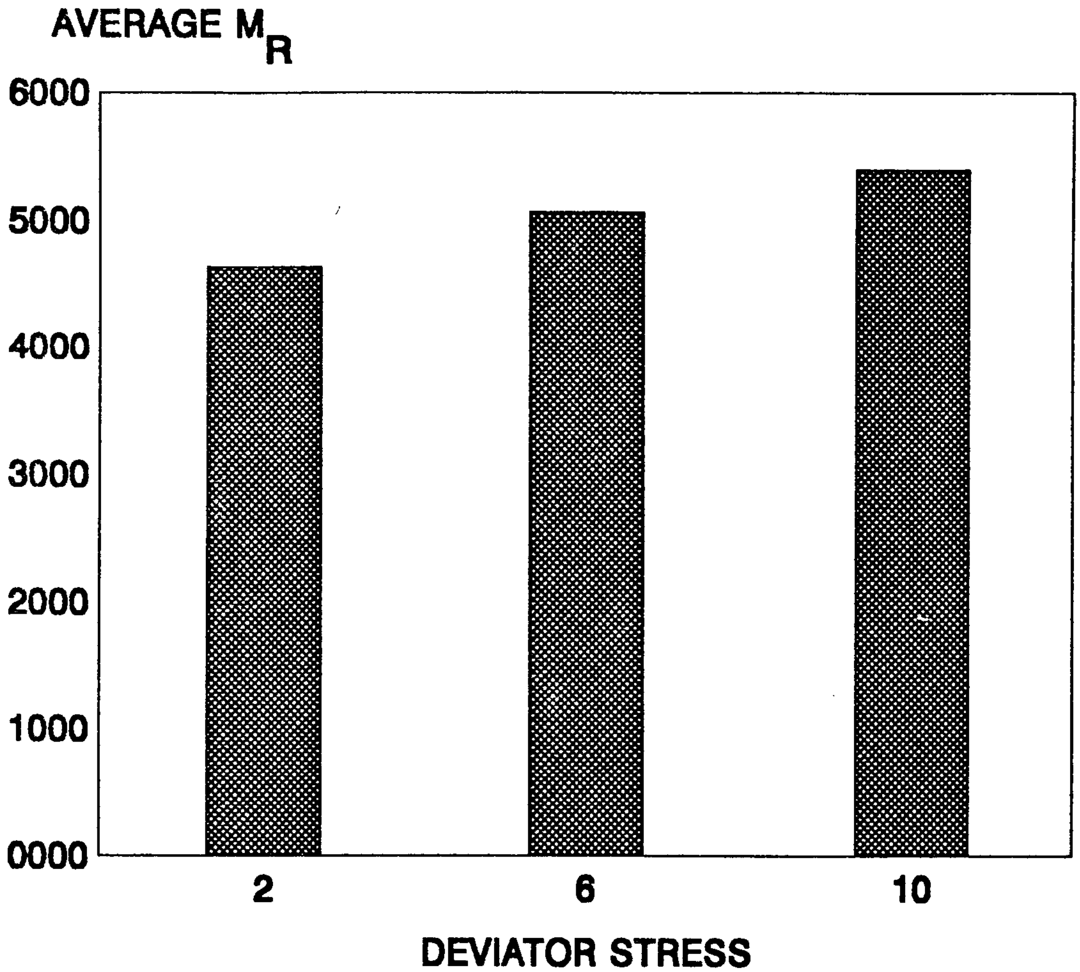


Figure 5. Average M_R by Deviator Stress for Synthetic Specimen DPTU-1560.

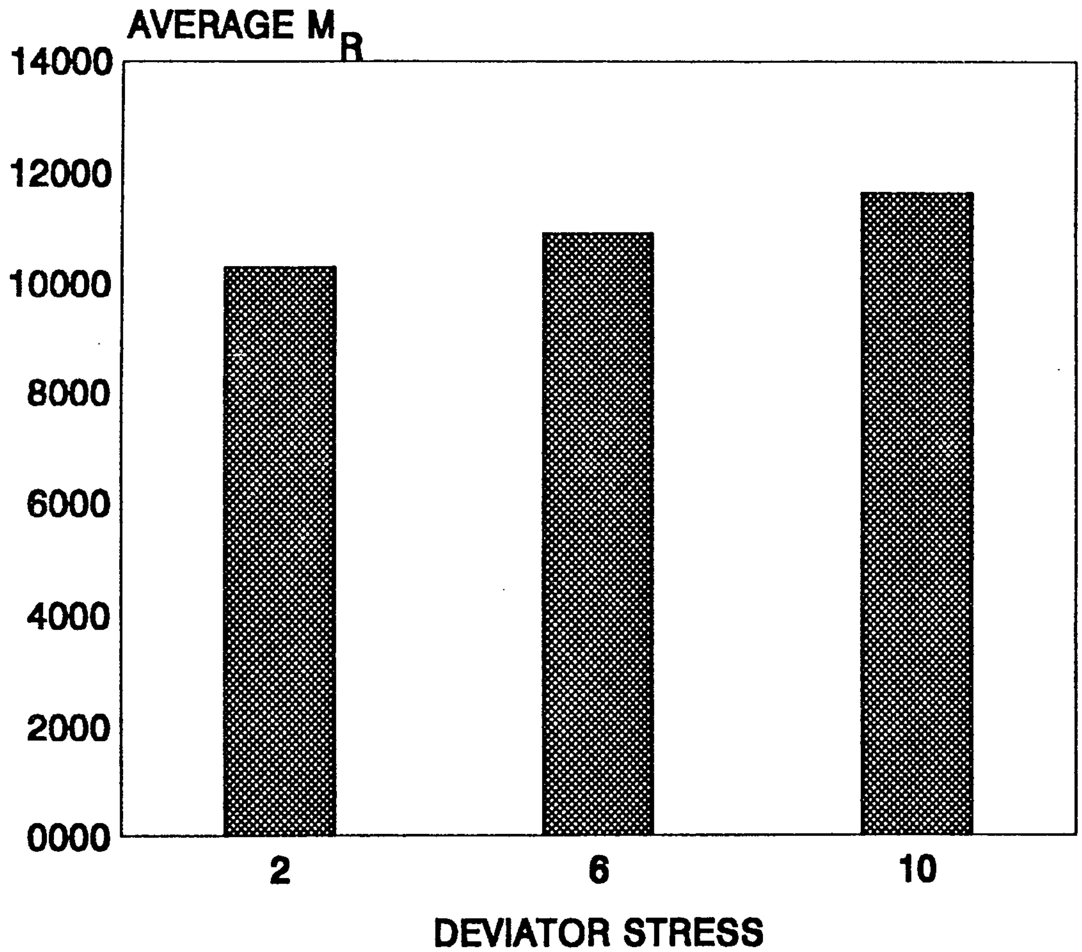


Figure 6. Average M_R by Deviator Stress for Synthetic Specimen TU-960.

4. The Statistical Analyses

The measured modulus, M_R, for a given specimen at laboratory I and for test J, may be represented as

$$M_R = MU + LAB(I) + TEST(I,J)$$

where it is assumed that MU is the true but unknown value for the modulus, LAB(I) is a normal random variable with mean of zero and standard deviation of STAND(LAB), TEST(I,J) is a normal random variable with mean of zero and standard deviation of STAND(TEST). It is the estimation of these standard deviations that is important in the analysis of the experimental data.

The estimates for these standard deviations for each of the combinations of confining pressure and deviator stress are given in Table 1. Since there was no apparent effect due to the confining pressure, these are pooled and given in Table 2. The values given in Table 2 form the basis for the values given in Part IV of this report.

It is especially useful to consider the coefficient of variation when evaluating the precision of measurements over a range of values for the measurements. This is true here and the coefficients are given in Table 3, along with their averages over the levels of the factors and specimens. It is useful to simply summarize the analysis of the components of variance by considering that the Laboratory CV is about 15% and the Test CV is about 2%. It should be noted that one laboratory was omitted from the analysis of the TU-700 data and two laboratories were omitted from the analysis of the DPTU-1560 data.

The question of the dependence of the measured M_R upon the value of the deviator stress does not have a simple answer. The measured values for specimen TU-700 clearly do not depend upon the deviator stress. This specimen had the lowest values for the modulus (about 1890 psi). However, the other two specimens did have larger values as the deviator stress increased, and a simple t test using the paired differences produced statistical significance

Table 1. Standard Deviations for the Factors in the Statistical Model.

Specimen	Confining Pressure	Deviator Stress	Standard Deviation, psi	
			Lab	Test
TU-700	0	2	347	60
TU-700	0	6	214	34
TU-700	0	10	221	21
TU-700	4	2	289	59
TU-700	4	6	227	34
TU-700	4	10	260	28
DPTU-1560	0	2	876	119
DPTU-1560	0	6	769	82
DPTU-1560	0	10	715	60
DPTU-1560	4	2	795	153
DPTU-1560	4	6	704	67
DPTU-1560	4	10	675	39
TU-960	0	2	2003	418
TU-960	0	6	1718	166
TU-960	0	10	2175	163
TU-960	4	2	1509	375
TU-960	4	6	1646	266
TU-960	4	10	2122	245

Table 2. Pooled Standard Deviation for the Factors in the Statistical Model. (Pooled over Confining Pressure)

		Standard Deviation, psi	
Specimen	Deviator Stress	Lab	Test
TU-700	2	319.3	59.5
TU-700	6	220.6	34.0
TU-700	10	241.3	24.7
DPTU-1560	2	836.5	137.1
DPTU-1560	6	737.2	74.9
DPTU-1560	10	695.3	24.7
TU-960	2	1773.3	397.1
TU-960	6	1682.4	221.7
TU-960	10	2148.7	208.1

Table 3. Coefficient of Variation Among Laboratories and Within Laboratories.

Specimen	Confining Pressure	Deviator Stress	Coefficient of Variation, percent: Among Labs	Coefficient of Variation, percent: Within Labs
TU-700	0	2	18.3	3.2
TU-700	0	4	11.3	1.8
TU-700	0	6	11.6	1.1
TU-700	4	2	15.2	3.1
TU-700	4	4	12.2	1.8
TU-700	4	6	13.9	1.5
DPTU-1560	0	2	19.1	2.6
DPTU-1560	0	4	15.1	1.6
DPTU-1560	0	6	13.3	1.1
DPTU-1560	4	2	17.0	3.3
DPTU-1560	4	4	13.9	1.3
DPTU-1560	4	6	12.5	.7
TU-960	0	2	19.6	4.1
TU-960	0	4	15.7	1.5
TU-960	0	6	18.6	1.4
TU-960	4	2	14.5	3.6
TU-960	4	4	15.2	2.5
TU-960	4	6	18.3	2.1
Averages Confining Pressure = 0			15.8	2.0
Averages Confining Pressure = 4			14.7	2.2
Averages Deviator Stress = 2			17.3	3.3
Averages Deviator Stress = 6			13.9	1.7
Averages Deviator Stress = 10			14.7	1.3
Overall Average			15.3	2.1

for 4 of the 6 comparisons at very impressive levels. The test was not very powerful, but it does clearly indicate that for these two specimens the measured M_R did increase with the level of the deviator stress. The values of the modulus for these two specimens were about 5,000 and 11,000 psi.

5. Analysis of the Nevada Data

Preliminary experiments were carried out at one of the participating laboratories and reported to Steele Engineering on May 11, 1990. These experiments provided an excellent check on the assumption that the variation in the repeated tests of the synthetic specimens as described in the Type 2 testing protocol for the synthetic specimens would be near the results when completely independent replications were carried out. These experiments included two technicians, often had five independent replications and for each replication often had two repeated tests.

Nested analysis of variance were carried out for each of the synthetic specimens with a model that accounted for all the sources of variation in an appropriate manner. The results for TU-700 and TU-960 were that the test component of variance included 75-76% of the independent replication error component of variance. There was not sufficient data to make a good comparison for the DPTU-1560 specimen, but for the two settings in which the components could be estimated the test component was 98% of the independent replication error component of variance.

The implications of these results are:

i) For the synthetic specimens the within laboratory error is composed of both the errors in setting up the equipment, mounting the specimen, and finally the testing, data acquisition and reduction. For the synthetic specimens the latter source of errors, that is the testing and data processing, constitute about 75% of the variation in the within laboratory variance.

ii) The within laboratory coefficient of variation for the synthetic specimens was estimated to be about 2% when the test component was used in the analysis. If independent replications had been carried out this number might have been near 3% which is still quite good. The results for the within laboratory variation when using the synthetic specimens are indeed very good and suggest that this should provide an excellent means for checking on the calibration of the laboratories on a regular basis.

iii) In the analysis in this report the among laboratories coefficient of variation for the synthetic specimens are ~~be~~ overestimated by a small amount since the within laboratory component of variance as estimated in this report is somewhat underestimated. The underestimation of the within laboratory coefficient of variation is underestimated because the samples were not remounted between replicate measurements, therefore neglecting the mounting effect. However, the values given for the among-laboratory standard deviation (1s) ,etc., in Part IV are very nearly correct as stated. This seems to be a somewhat large laboratory component of variance, even when some of the outliers were omitted, and this conclusion should not be in doubt.

The within laboratory means for each laboratory are shown in Table 4 where they are compared to the among laboratory means. The means in Table 4 for each (laboratory) x (specimen-type) combination were averaged for the different levels of confining pressure and deviator stress. From the data in Table 4 a picture of the consistency of the data from each laboratory emerges. Laboratories A and B both show extremes in the differences of the among laboratory means from the overall means when the different specimen types are compared. In particular, laboratory A is 16 percent low for specimens TU-700 and 34 and 33 percent high for specimens DTTU-1560 and TU-960 respectively, a range of 50 percent. Laboratory H, on the other hand, with a much smaller range in differences (11 percent) shows the same average difference [(22+20+9)/3=17 versus (-16+34+33)=17] but the variability for laboratory H is much smaller. From this one can conclude that while both laboratory A and H yield, on the average, results greater than the overall average, the testing is under much better control in laboratory A than laboratory H. Most likely some systematic error is operative in laboratory H whereas both a systematic error and relatively uncontrolled testing variability is operative in laboratory A. The focus in laboratory H should be on seeking the source of systematic errors (e.g.calibration) whereas laboratory A should address both systemic errors as well as random testing errors. Additional comments can be made regarding the other laboratories and these comparisons should be given as feedback to the participating laboratories.

Interlaboratory use of reference specimens can only address systemic errors. Although the use of interlaboratory systematic errors can be accounted for with "after the fact" reference specimens, attention should be given to correcting the source of the systematic errors. The reference specimens should not be used as a crutch to simply bring individual laboratories into agreement with each other.

Table 4. Comparision of Laboratory Means with Overall Means.

Lab	Sample TU-700 Lab Mean, psi	Sample TU-700 Difference from Overall Mean, %	Sample DPTU-1560 Lab Mean, psi	Sample DPTU-1560 Difference from Overall Mean, %	Sample TU-960 Lab Mean, psi	Sample TU-960 Difference from Overall Mean, %
A	1530	-16	6432	34	14566	33
B	1170	-36	4618	- 4	10513	- 4
C	1943	7	5660	18	11399	4
D	1864	2	4341	-10	10152	- 7
E	1734	- 5	4427	- 8	10289	- 6
F	1780	- 2	5252	9	12385	13
G	2107	16	4802	0	9987	- 9
H	2234	22	5766	20	11887	9
I	1933	6	4624	- 4	11037	1
J	1734	- 5	3517	-27	10200	- 7
K	2035	12	4403	- 9	9429	-14
L	N/A		3911	-19	9582	-13
Overall Mean	1824		4813		10952	

6. Summary and Conclusions

The objectives of this experiment were attained. Each of these three specimens were tested extensively with very little within laboratory coefficient of variation (about 2%), indicating excellent performance.

The conditions of the test, in particular the deviator stress, did affect the measured M_R values for two of the specimens. This would need to be a consideration when these or similar specimens are used for calibration purposes. The confining pressure had very little, if any, effect on the measurements of these synthetic specimens. Even though the confining pressure had little effect, for consistency, both the confining pressure and the deviator stress should be specified in any reference or round robin testing performed with these specimens.

The between laboratories coefficient of variation was about 15%. Thus some consideration must be given to the laboratory bias whenever measurements of the M_R from different laboratories are used in the same analysis.

The very low within laboratory coefficient of variation revealed in this research demonstrates that a carefully assembled and maintained triaxial M_R test system for 2.8 inch diameter by 5.6 inch length specimens can be stabilized and operated for limited (short) time periods with excellent repeatability.

The among laboratories coefficient of variation, which is several times that for within laboratories, shows that different carefully assembled and maintained M_R test systems for 2.8 inch diameter by 5.6 inch length specimens yield significantly varying responses on the same specimens.

One possible explanation for the relatively large difference between the within laboratory variability and the among laboratories variability is that the longer term stability of the M_R test systems is subject to much larger variations than those normally encountered during limited time periods. Such a difference might be expected in complex systems, but not, perhaps, to the degree experienced. Another possible explanation could be that a bias component exceeding the within laboratory variability is intrinsic to each of the different test systems.

In either case, the use of reference specimens on a continuous basis in an appropriately designed and operated reference system would provide the means for maintaining an excellent within laboratory variability and improving the among laboratory variability of the test studied in this research. The use of multiple reference specimens (different materials) is recommended so that participating laboratories can asses their ability to attain the among laboratory mean as well as obtain reproducible test results. Reference specimens should not, however, be used as a substitute for proper calibration of the components in the test system.

Based on the results of this research, consideration should be given to the establishment of a two tiered reference specimen program. The first tier or primary reference set(s) to be rotated on a frequent basis to all interested laboratories that are performing triaxial M_R tests on 2.8 inch diameter by 5.6 inch length specimens. Participating laboratories would be expected to verify calibration of their test system based on expected test values with a primary reference set. If expected values were not obtained, further calibration or maintenance of their test system would be performed prior to further use of the system. The second tier or secondary reference sets would be rented or loaned to participating laboratories for quality control checks of the M_R test system prior to testing each specimen. When anticipated values are obtained from a quality control test, the stability (calibration) of the test system would be verified and the laboratory would proceed with confidence in performing scheduled tests. If expected values were not obtained from a quality control test, maintenance on the test system would be performed prior to proceeding with scheduled tests.

PART IV AASHTO/ASTM FORMAT PRECISION STATEMENTS

Two concepts of precision that are described in ASTM documents are the repeatability and the reproducibility measures. The repeatability measure will indicate the within laboratory precision and will be given by the within laboratory standard deviation for the measured modulus. Alternatively, it may be given as a coefficient of variation for the within laboratory errors. The basis for the tables in Part IV for the entries regarding the within laboratory results is the estimated standard deviations as given in the tables for the within laboratory standard deviations. These within laboratory standard deviations are designated as 1s for the Single Operator Precision entries in Part IV.

The 1s% for the Single Operator Precision statements are the 1s values divided by the average value for the measurements multiplird by 100, i.e., the coefficient of variation. The d2s entries given in Part IV for the Single Operator Precision statements are 2.8 x 1s and this represents the limits (±) within which we would expect to find the difference between *two observations at the same laboratory for the same specimen* with probability of 0.95. When two such measurements differ by more than this at the same laboratory, a check should be made to determine if it is a chance event or if there has been a mistake in the measurements.

The 1s values given in the tables in Part IV for the Multi-Laboratory Precision entries are the standard deviation one would have in the measured M_R values *if a specimen is sent to a random laboratory and a measured value is reported.* Thus, this standard deviation includes the variation among laboratories and the variation within the laboratories. The d2s entries in the tables in Part IV are simply 2.8 times the value for 1s in the respective table.

The value for the 1s entries in the Multi-Laboratory Precision part of the tables are given by

$$[(STDLAB)^2 + (STDTEST^2)]^{0.5}$$

that is, the square root of the sum of the squares of the standard deviations for the

Laboratory and the Test (or Error) components of the model. The d2s limits in the Multi-Laboratory Precision entries represent the limits (±) within which the difference in the measurements of the same specimen at two different laboratories should occur with probability of 0.95. When observed differences are outside this range for the same specimen as measured at two laboratories one should make an inquiry into the correctness of the experiment and the data.

Table 5. Precision Statements for Type II Synthetic Reference Samples.

Specimen & Type of Index	Mean Total M_R (psi) at 2 psi deviator stress	1s[1]	1s%[1]	d2s[1]
Single Operator Precision				
TU-700	1898.9	59.5	3.1	168.3
DPTU-1560	4634.7	137.1	3.0	387.6
TU-960	10312.6	397.1	3.9	1123.0
Multi-laboratory Precision				
TU-700	1898.9	324.8	17.1	918.6
DPTU-1560	4634.7	847.6	18.3	2397.1
TU-960	10312.6	1817.2	17.6	5139.1

[1] These numbers represent, respectively, the (1s), (1s%), and (d2s) limits described in ASTM C670, Preparing Precision Statements for Test Methods for Construction Materials.

Table 6. Precision Statements for Type II Synthetic Reference Samples.

Specimen & Type of Index	Mean Total M_R (psi) at 6 psi deviator stress	1s[1]	1s%[1]	d2s[1]
Single Operator Precision				
TU-700	1879.3	34.0	1.8	96.1
DPTU-1560	5065.6	74.9	2.0	211.8
TU-960	10909.6	221.7	1.5	627.0
Multi-laboratory Precision				
TU-700	1879.3	223.2	11.8	631.2
DPTU-1560	5065.6	741.0	14.6	2095.6
TU-960	10909.6	1696.9	15.6	4798.9

[1] These numbers represent, respectively, the (1s), (1s%), and (d2s) limits described in ASTM C670, Preparing Precision Statements for Test Methods for Construction Materials.

Table 7. Precision Statements for Type II Synthetic Reference Samples.

Specimen & Type of Index	Mean Total M_R (psi) at 10 psi deviator stress	1s[1]	1s% [1]	d2s[1]
Single Operator Precision				
TU-700	1888.5	24.7	1.3	70.0
DPTU-1560	5396.3	50.6	.9	143.1
TU-960	11633.9	208.1	1.8	588.5
Multi-laboratory Precision				
TU-700	1888.5	242.6	12.8	686.0
DPTU-1560	5396.3	697.1	12.9	1971.5
TU-960	11633.9	2158.7	18.6	6104.8

[1] These numbers represent, respectively, the (1s), (1s%), and (d2s) limits described in ASTM C670, Preparing Precision Statements for Test Methods for Construction Materials.

APPENDIX A

Maryland Department of Transportation
State Highway Administration

Richard H. Trainor
Secretary

Hal Kassoff
Administrator

PLEASE REPLY TO:
OFFICE OF MATERIALS & RESEARCH
2323 WEST JOPPA ROAD
BROOKLANDVILLE, MARYLAND 21022

March 7, 1990

Thank you for agreeing to participate in this proficiency sample series. This series of experiments is absolutely critical to the highest and best use of the Resilient Modulus data gathered as part of the SHRP Long Term Pavement Performance (LTPP) research. As a proficiency sample cooperator, your organization will be participating in the development of data required to determine the precision of SHRP protocol P-46, the Resilient Modulus of Unbound Granular Base/Subbase Materials and Subgrade Soils.

Briefly, P-46 requires a closed-loop electro-hydraulic loading device capable of providing varying, haversine-shaped, repeated loads in fixed cycles of load and rest period. Test samples are encased in a membrane and subjected to varying confining pressure during test. Loads are measured using a load cell located inside the triaxial cell. Deformations are measured using two spring loaded LVDT's mounted outside the triaxial cell. Suitable signal excitation, conditioning and recording equipment are required for simultaneous recording of axial load and deformations. Attached is a copy of SHRP protocol P-46 further defining these equipment requirements.

The first step in assuring the reliability of the data obtained form P-46 testing is calibration of the test systems. Attached is a copy of the calibration procedure to be used for calibrating your system. We realize that not all systems are the same and some variation of this procedure may be required for your equipment. We ask that you follow this procedure as closely as possible and notify us of any deviations that you make.

My telephone number is (301) 321-3417

Teletypewriter for Impaired Hearing or Speech
383-7555 Baltimore Metro - 565-0451 D.C. Metro - 1-800-492-5062 Statewide Toll Free
707 North Calvert St., Baltimore, Maryland 21203-0717

A set of synthetic reference specimens (as indicated in the procedure) will be rotated through your laboratory on a loan basis for use in verifying your system. These specimens are to be tested after calibration of your system as set forth in the attachment and the data recorded on the form under SYNTHETIC SPECIMEN TEST DATA ON CALIBRATED EQUIPMENT.

In order to minimize the time required for equipment verification, you should call me at 301-321-3417 or Garland Steele of Steele Engineering, Inc. at 304-727-8719 to determine whether the results are in the expected range. If so the forms should be returned to my address. If not, the system should be recalibrated and the specimens tested again. It is anticipated that each laboratory will:

- Carefully unpack the reference specimens when received
- Retain the reference specimens no more than three workdays
- Cross off your address before re-enclosing the shipping list
- Repack the reference specimens in the same or equivalent packaging
- Ship to the next laboratory on the shipping list enclosed with the specimens

After a laboratory has completed the above indicated calibration and verification procedure, that laboratory may proceed with testing of the SHRP Type II Soil Proficiency samples that we will send to you along with forms and instructions. Please note that the Type II Soil Proficiency samples may arrive at your laboratory before the synthetic reference specimens. Do NOT test them before:

1) Your equipment has been calibrated and verified
2) A Notice-To-Proceed has been issued from this office.

Please let me know if you have any questions or comments.

Sincerely,

Edmund J. Oberc
Assistant Division Chief
Soils Laboratory

EJO:ds

RESILIENT MODULUS TESTING EQUIPMENT
GUIDE FOR CALIBRATION
SHRP TYPE II SOIL SAMPLES

1. SCOPE

This procedure is a guide for calibrating testing equipment to be used in measuring the resilient modulus of SHRP Type II subgrade soils. Several sources for resilient modulus test equipment are available. This procedure describes several steps that should be followed, regardless of manufacturer. Some of the adjustments mentioned in this procedure may not be available on all models. In these cases, calibration should be performed by the manufacturer, either on site or at the factory.

2. REFERENCED DOCUMENTS

SHRP (Strategic Highway Research Program) Test Protocol P-46, Resilient Modulus of Unbound Granular Base/Subbase Materials and Subgrade Soils

3. SUMMARY OF METHOD

The calibration procedure consists of the following steps:
- Measuring the laboratory temperature.
- Calibrating the LVDT's.
- Adjusting the load application timing control.
- Calibrating the load cell.
- Testing of synthetic reference specimens to verify test equipment calibration.

4. APPARATUS

4.1 Thermometer - Suitable for measuring temperatures of approximately 20-30 C with an accuracy of 0.5 C and traceable to a National Bureau of Standards calibrated thermometer.

4.2 Resilient Modulus Testing Apparatus - Suitable for performing SHRP (Strategic Highway Research Project) Protocol P-46, Resilient Modulus of Unbound Granular Base/Subbase Materials and Subgrade Soils.

4.3 LVDT Transducer Calibrator - Accurate to 0.0005 inch. May be available from the manufacturer of the resilient modulus apparatus. Should be accompanied by a calibration certificate. The device should be of a configuration such that the device and LVDT will not be held and warmed by the hand. Some configurations of resilient modulus equipment requires that the LVDT's be calibrated at the same time. These configurations will require 2 LVDT transducer calibrators.

4.4 Machinist's Gage Block (Optional) - Size to be equal to the full range of the LVDT to be calibrated, accurate to ± .0005 inches, calibration certificates required

4.5 Oscilloscope

4.6 Load cell calibration stand and weights - Stand must be suitable for applying compression loads to the load cell by use of weights. Weights shall be accurate to 0.01 lbs. and shall be accompanied by a calibration certificate. Weights must be available for the range of the load cell.

4.7 Proving Ring (Optional) - Capacity to be equal to or greater than the largest load applied during the resilient modulus test. Accurate to 0.01 pounds, calibration certificate required.

4.8 Small hand tools (screwdriver, etc.)

5. PROCEDURE

5.1 Measure and record the temperature of the sample storage and sample test rooms. The temperature of the rooms should be 25$\pm$1 C. If the temperature of the sample storage and sample test rooms is outside this range, adjust the temperature.

5.2 Calibration of the LVDT's - The resilient modulus testing equipment measures the horizontal deformation of a sample which occurs during an applied load by use of very sensitive transducers. Assuring accurate response of the transducers and the display to known deformation is a key step in calibrating the modulus test equipment.

Calibrate the LVDT's in accordance with the resilient modulus equipment manufacturer's instructions. The LVDT's must be calibrated using a standard for which calibration certificates are available.

If no procedure is available, calibrate the LVDT's in accordance with the following procedure. This procedure allows calibration of each LVDT separately. Modifications to this section may be made for equipment configurations that require simultaneous calibration.

5.2.1 Turn on the Resilient Modulus Apparatus (RMA) and allow the electronic equipment to warm up for at least 15 minutes or as directed by the manufacturer.

5.2.2 Mount one LVDT form the RMA in the LVDT transducer calibrator. Connect the LVDT to the RMA and set up the RMA for calibration.

5.2.3 Set the LVDT transducer calibrator to a convenient zero position, one that will allow the movement of the LVDT through its full linear range (the exact midpoint of the calibrator is suggested). Record the value displayed on the LVDT calibrator.

5.2.4 Position the LVDT in the LVDT transducer calibrator so that the LVDT is at its electronic center.

5.2.5 Adjust the RMA "Zero" potentiometer until the RMA readout indicates 0.000 inches.

5.2.6 Advance the LVDT calibrator the full linear range of the LVDT in the "compression" direction. The RMA readout should display the value of the full linear range of the transducer. Record the RMA readout.

5.2.7 Return the LVDT transducer calibrator to its zero position. The RMA readout should read zero.

5.2.8 Repeat steps 5.2.5 through 5.2.7 four times. Compute the average RMA readout at the full linear range of the LVDT. This should be the same as the full linear range.

5.2.9 If the average RMA readout and the LVDT calibrator display do not agree, adjust the "Gain" on the appropriate potentiometer on the RMA (see manufacturer's instructions).

5.2.10 Repeat Steps 5.2.5 through 5.2.9 until the transducer displacement is accurately indicated on the RMA.

5.2.11 Repeat for the second transducer (if required).

NOTE: An alternate acceptable method of LVDT calibration would be to use a rigid frame to hold the LVDT and move it through its full linear range by use of a machinist's gage block.

5.3 ADJUSTING THE LOAD APPLICATION TIMING CONTROL - The load application sequence must be checked for precise timing.

5.3.1 Connect an oscilloscope to the appropriate terminals on the RMA (refer to the manufacturer's manual for your RMA).

5.3.2 The trigger pulse must be set for 0.10 seconds "ON"; 0.9 seconds "OFF"; 1.00 seconds per cycle.

5.3.3 Adjust the timing if necessary. Timing controllers are usually found on a circuit board inside the RMA housing.

5.4 CALIBRATING THE LOAD CELL - An electronic load cell is used to indicate the instantaneous force which is applied onto the test specimen during the resilient modulus test. Accurate load application is important in determining the resilient modulus. The load cell must be calibrated. Calibrate the load cell in accordance with the resilient modulus equipment manufacturer's instructions. The load cell must be calibrated using a standard for which calibration certificates are available. If no procedure is available, calibrate the load cell in accordance with the following procedure.

5.4.1 Turn on the Resilient Modulus Apparatus (RMA) and allow the electronic equipment to warm up for at least 15 minutes or as directed by the manufacturer.

5.4.2 Connect the load cell to the RMA.

5.4.3 Place the load cell under a suitable stand, such as shown in Figure 2. The loading stand provides a stable platform for applying known weights onto the center of the load cell.

5.4.4 The RMA display must read 0.00 pounds for the unloaded load cell. If the display is not 0.00 pounds, then zero the readout by adjusting the appropriate potentiometer (refer to the manufacturer's instructions).

5.4.5 Lower the loading platform shaft carefully onto the center of the load cell. Record the tare weight.

5.4.6 Place known weights on the loading platform. The weights should bracket the range load which will be applied during the resilient modulus test. Record the readout on the RMA display for each applied load. The RMA display should indicate the applied load (including tare) over the full range of loads that are applied. If not, calibrate the readout by adjusting the appropriate potentiometer (see manufacturer's instructions).

5.4.7 Repeat Steps 5.4.5 and 5.4.6 until the correct loads are displayed on the RMA.

NOTE: An alternate, acceptable method of load cell calibration would be to place the load and proving ring in a load frame. The loads measured by the proving ring must equal the loads measured by the load cell and displayed by the RMA.

6. TESTING THE SYNTHETIC REFERENCE SAMPLES

Synthetic reference samples will be loaned to you for round robin testing.

6.1 Determine the resilient moduli of the synthetic reference samples in accordance with the following.

6.1.1 Make several measurements of the diameter and height of the specimen.

6.1.2 Clean the triaxial base pedestal. Center the synthetic reference specimen on the triaxial cell pedestal. Do not use porous stones or membrane.

6.1.3 Using commercially available glue (Superglue or other), attach the sample to the pedestal base using three to four spots along the sides of the pedestal base and specimen. Do not put glue between the pedestal base and the specimen, use the sides.

6.1.4 In a similar manner, attach the top cap to the sample.

6.1.5 Once the glue has set, proceed to assemble the triaxial chamber and connect all transducers and zero out the LVDT's.

6.1.6 With a confining pressure at zero, apply a static load of between 0.5 and 1.0 psi to the specimen (seating load).

6.1.7 Using a frequency of 1 Hz with a load duration of 0.1 second and a no-load duration of 0.9 second, apply a dynamic load of 2 psi.

6.1.8 Apply 50 repetitions of the 2 psi load and record the recovered deformations and loads of the last five cycles. Repeat another 50 load repetitions and record the last five recovered deformations and loads.

6.1.9 Repeat Step 6.1.8 for dynamic loads of 6 psi and 10 psi.

6.1.10 Increase the confining pressure to 4 psi and repeat Steps 6.1.8 and 6.1.9.

6.1.11 Calculate the resilient modulus for each set of measurements. Stresses and strains should be corrected based on permanent strain accumulation.

6.1.12 Record the resilient moduli on the attached form.

RESILIENT MODULUS TESTING EQUIPMENT

S.H.R.P. TYPE II SOIL

SYNTHETIC SPECIMEN TEST DATA

ON CALIBRATED EQUIPMENT

TESTING LABORATORY:______________________________

DATE:__________ TIME:________ TEMPERATURE:__________

SAMPLE NUMBER:_______ OPERATOR:______________

	CONFINING PRESSURE = 0 P.S.I.		CONFINING PRESSURE = 4 P.S.I.	
	TEST #1	TEST #2	TEST #1	TEST #2
DYNAMIC LOAD	RESILIENT MODULUS	RESILIENT MODULUS	RESILIENT MODULUS	RESILIENT MODULUS
2 P.S.I.	______	______	______	______
6 P.S.I.	______	______	______	______
10 P.S.I.	______	______	______	______

NOTE CONCERNING P46

An earlier draft of SHRP Protocol P46 supplemented by several additional procedural directions was supplied to all participants in this Program. The initiating letter with attachments and the P46 draft included in this appendix for information contains all the procedural requirements, including the supplemental procedural directions, that were conveyed to participants.

SHRP PROTOCOL: P46

For SHRP Test Designation: UG07, SS07

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

This SHRP protocol describes the laboratory testing procedure for the determination of the Resilient Modulus (M_r) of unbound granular base and subbase materials and subgrade soils. 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.

Resilient modulus testing for unbound materials shall commence only after approval by the SHRP Regional Engineer to begin testing.

Definitions

The following definitions, associated with LTPP pavement sample handling and testing, will be 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) and the 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 never 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.

(g) Subgrade: Subgrade soils are prepared and compacted before the placement of subbase and/or base layers.

(i) A treated subgrade layer (for example cement- or lime-treated soils) is considered a treated subbase layer in the GPS study of 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 GPS 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 five feet of the subgrade; and the bulk sample of the subgrade retrieved from 12 inch diameter boreholes or the test pit is considered to be representative of the subgrade soils within 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; (i) all unbound granular base and subbase material, and (ii) all untreated subgrade soils which meet the criteria of less than 70% passing the No. 10 sieve and 20% maximum passing No. 200 sieve. Testing parameters used for Type 1 unbound materials are different from those specified for Material Type 2.

(j) Material Type 2: For the purpose of this protocol (resilient modulus tests), Material Type 2 includes all untreated subgrade soils not meeting the criteria given above in (h) (ii). Generally, thin-walled tube samples of untreated subgrade soils fall in this Type 2 category.

(k) 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.

Sample Locations for GPS Pavement Sections

(a) The test shall be performed on the test specimens prepared from bulk samples of the unbound granular base and subbase materials retrieved from boreholes BA1, BA2, BA3, etc. and from the test pit (or bulk samples retrieved from boreholes BA4, BA5, BA6, etc. in the absence of the test pit samples).

(b) For the subgrade soils, the test shall be carried out on undisturbed thin-walled tube samples retrieved from boreholes A1 and A2; if available. If the thin-walled tube samples are unavailable or unsuitable for testing, or if directed by SHRP, 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 boreholes BA1, BA2, BA3, etc. and from the test pit (or bulk samples from boreholes BA4, BA5, BA6, etc. in the absence of the test pit samples).

Assignment of SHRP Laboratory Numbers

For each layer, SHRP requires a representative test sample to be taken from the bulk samples to perform the designated tests. The test results shall be reported separately for test samples obtained from the bulk samples collected at the beginning and end of the section as follows:

(a) Beginning of the Section (Stations 0-):

Bulk samples of each layer are retrieved from BA1, BA2, BA3, etc. type 12 inch diameter boreholes. These bulk samples are combined, prepared and reduced to a representative test size in accordance with AASHTO T87-86 and AASHTO T248-83. The results of each test determined from a representative portion of this bulk sample shall be assigned SHRP Laboratory Test Number '1'.

The results of each test determined from a representative portion of the thin-walled tube sample of subgrade soils from borehole A1 shall be assigned SHRP Laboratory Test Number '1'.

(b) End of the Section (Stations 5+):

If there is no test pit, then bulk samples of each layer are retrieved from one or more BA type 12 inch diameter boreholes generally designated as BA4, BA5, BA6, etc. When there is a test pit, the bulk samples are retrieved from the test pit. These bulk samples are combined, prepared and reduced to a representative test size in accordance with AASHTO T87-86 and AASHTO T248-83. The results of each test determined for the end of the section location shall be assigned SHRP Laboratory Test Number '2'.

The results of each test determined from a representative portion of the thin-walled tube sample of subgrade soils from borehole A2 shall be assigned SHRP Laboratory Test Number '2'.

Laboratory Testing Sequence of Unbound Granular Base and Subbase Materials

Bulk samples of each layer of unbound granular base and subbase materials from LTPP-GPS pavement sections shall be used for the laboratory tests in the following sequence:

- Natural Moisture Content (SHRP Test Designation UG10, Protocol P49)
- Particle Size Analysis (SHRP Test Designations UG01 and UG02, Protocol P41)
- Atterberg Limits (SHRP Test Designation UG04, Protocol P43)
- Classification and Description (SHRP Test Designation UG08, Protocol P47)
- Moisture-Density Relations (SHRP Test Designation UG05, Protocol P44)
- Resilient Modulus (SHRP Test Designation UG07, Protocol P46)

The Resilient Modulus Test shall be the last test performed in the above testing sequence. 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.

Laboratory Testing Sequence of Untreated Subgrade Soils

(a) Bulk samples of untreated subgrade soils from LTPP-GPS pavement sections shall be used for the laboratory tests in the following sequence:

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

- Resilient Modulus (SHRP Test Designation SS07, Protocol P46)

The resilient modulus test shall be the last test performed in the above testing sequence when thin-walled tube samples are unavailable or unsuitable for testing as explained in (b) below. If the available bulk sample is insufficient in size and a test sample from one test is reused for other test(s) and/or the resilient modulus test, then appropriate comment codes shall be used in reporting the test results for P46.

(b) If the thin-walled tube samples are not available, then follow the test sequence described in (a) above for the resilient modulus test. The test specimen however is reconstituted from a representative portion of the bulk sample. The comment code 89 shall be used in reporting the test results for P46.

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

- If the thin-walled tubes are available and acceptable for the resilient modulus test then no bulk sample is needed to reconstitute the test sample for Protocol P46. The "undisturbed" thin-walled tube sample is used in the resilient modulus testing (Protocol P46). The comment code 87 shall be used in reporting the test results for P46.
- The resilient modulus testing of the "undisturbed" thin-walled tube sample can be done without waiting for the entire sequence of testing shown in (a) above provided that the thin-walled tube sample is suitable for testing. The comment code 87 shall be used in reporting the test results for P46.
- If the thin-walled tube sample is not acceptable then use bulk samples as described in (a) above to reconstitute the test specimen for the resilient modulus testing (Protocol P46). The comment code 88 shall be used in reporting the test results for P46.
- If available, properly mark the untested thin-walled tube sample and store for possible future use by SHRP. The comment code 90 shall be used in reporting the test results for P46.

1. SCOPE

1.1 These methods cover procedures for preparing and testing unbound granular base/subbase materials and subgrade soils for determination of resilient modulus under specified conditions representing stress states beneath flexible and rigid pavements subjected to moving wheel loads.

1.2 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.

1.3 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.

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

2. APPLICABLE DOCUMENTS

2.1 AASHTO Standards

T88-86 Particle Size Analysis of Soils

T99-86 The Moisture-Density Relations of Soils Using a 5.5 lb. Rammer and 12-Inch Drop

T100-86 Specific Gravity of Soils

T233-86 Density of Soil-in-Place by Block, Chunk or Core Sampling

T234-85 Strength parameters of soils by Triaxial Compression

T265-86 Laboratory Determination of Moisture Content of Soils

T292-91I Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials

2.2 SHRP 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

3. SUMMARY OF TEST METHOD

3.1 A repeated axial deviator 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 deviator 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.

4. SIGNIFICANCE AND USE

4.1 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.

4.2 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 pavements subjected to moving wheel loads.

5. BASIC DEFINITIONS

5.1 S_1 is the total axial stress (major principal stress).

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

5.3 $S_d = S_1 - S_3$ is the repeated axial deviator stress for this procedure, and is the difference between the major and minor principal stresses in a triaxial test.

5.4 e_1 is the total axial deformation due to S_d.

5.5 e_r is the resilient (recovered) axial deformation due to S_d.

5.6 $M_r = S_d/e_r$ is defined as the resilient modulus.

5.7 Load duration is the time interval the specimen is subjected to a deviator stress.

5.8 Cycle duration is the time interval between successive applications of a deviator stress.

5.9 $Y_d = GY_w/[1+ (wG/S)]$

where Y_d = unit weight of dry soil, pounds per cubic foot

G = specific gravity of soil solids, dimensionless,

w = moisture content of soil, (%),

S = degree of saturation, (%), and

Y_w = unit weight of water, pounds per cubic foot and may be assumed to be 62.4 pounds per cubic foot (pcf).

NOTE 1: Both w and S must be expressed as numbers; (e.g., 20% is 20), and shall be reported as numbers for SHRP test results.

5.10 Material Definitions - For the purpose of this testing protocol unbound granular base and subbase materials and subgrade soil are categorized as one of two types using the following criteria.

5.10.1 Material Type 1 - all unbound granular base and subbase material, and all untreated subgrade soils which meet the criteria of less than 70% passing the No. 10 sieve and 20% maximum passing the No. 200 sieve.

5.10.2 Material Type 2 - all the untreated subgrade soils not meeting the criteria in 5.10.1. Generally, thin-walled samples of untreated subgrade soils fall in this Type 2 category.

5.10.3 Testing parameters used for Type 1 unbound materials are different from those specified for unbound material Type 2. Type 1 will always include AASHTO classification A-1-a soils, and Type 2 will always include A-4, A-5, A-6, and A-7 soils. A-1-b, A-2 and A-3 soils may fall into either category.

5.10.4 Use the test results of gradation tests (Protocols P41 or P51) and classification tests (Protocols P47 or P52) to establish the material category according to the above criteria.

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 triaxial chamber suitable for use in resilient testing of soils is shown in Figure 1. The deformation is measured externally with two spring loaded LVDT's as shown in Figure 1.

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

6.2 Loading Device:

6.2.1 The external loading device must be capable of providing variable magnitude of repeated loads for fixed cycles of load and rest period. A closed-loop electro-hydraulic system is required by SHRP.

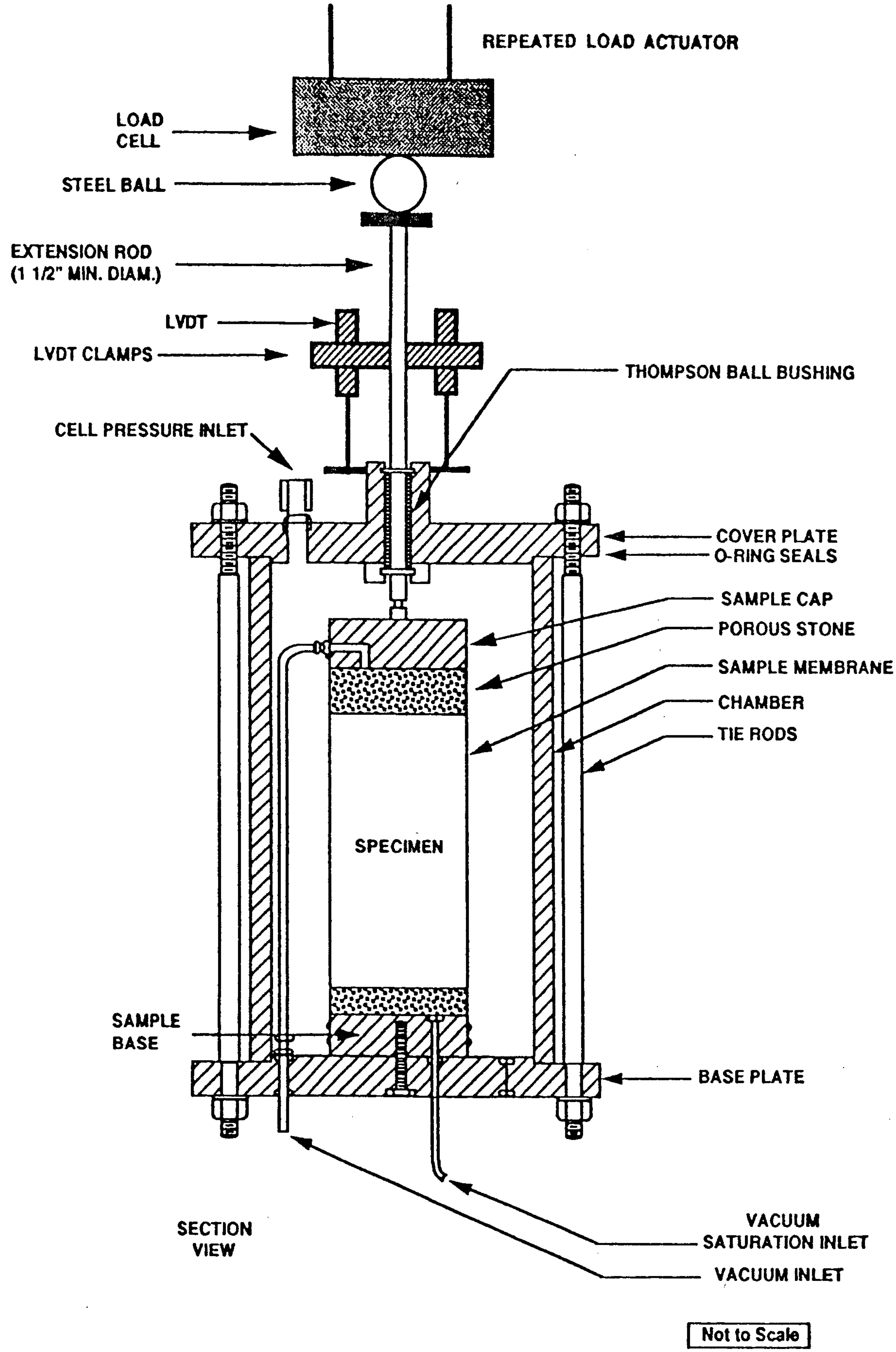


Figure 1. Triaxial chamber with external LVDT's and load cell.

6.2.2 A load duration of 0.1 seconds and cycle duration of 1 second is required. A haversine shaped stress pulse form shall be used.

6.3 Load and Specimen Response Measuring Equipment:

6.3.1 The axial load measuring device should be an electronic load cell and will be located between the specimen cap and the loading piston as shown in Figure 1. The following load cell capacities are recommended:

Sample Diameter In Inches	Maximum Load Capacity
2.8	100 lb.
6.0	1400 lb.

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

6.3.3 Axial Deformation - Measuring equipment for all materials shall consist of 2 Linear Variable Differential Transducers (LVDT's) clamped to the piston rod outside the test chamber as shown in Figure 1. Spring-loaded LVDT's are required. The following LVDT ranges are recommended:

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

All the 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)

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 shield cables for connections). If a filter is used, it should have a frequency which cannot attenuate the signal. The LVDT's should be wired separately so each LVDT signal can be monitored independently.

6.3.5 In order to minimize errors in testing specimens, LVDT's shall be calibrated daily and load cells should be calibrated once a week using a suitable proving ring. The load cell shall be calibrated semi-annually by an external agency.

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 Attachment A and Attachment B of this procedure for specimen compaction equipment.

6.5 Equipment for trimming test specimen 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 0.02 inch), rubber membranes from 0.01 to 0.031 inch thickness, rubber O-rings, vacuum source with bubble chamber and regulator, membrane expander, porous stones, scales, moisture content cans and data sheets, as required.

6.7 System Calibration and Periodic Checks - The entire system (transducer, conditioning and recording devices) will be calibrated using synthetic samples of known modulus. Periodic checks of the system shall be performed using reference samples provided by SHRP. This is done in order to calibrate the systems used by all the laboratories participating in the SHRP material testing program.

7. PREPARATION OF TEST SPECIMENS

7.1 Specimen Size - Specimen length should not be less than two times the diameter. Minimum specimen diameter is 2.8 inches or five times the nominal particle size. (Nominal particle size is the sieve opening for which 95 percent of the material passes during the sieve analysis. See Form P41 or P51 as appropriate for the sieve analysis test results).

Unless otherwise directed by SHRP, the following guidelines, based on the sieve analysis test results (See Form T41 or T51 as appropriate), shall be used to determine the test specimen size.

7.1.1 Use the 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 (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 2.8-inch diameter molds shall be used to reconstitute Type 2 test specimens.

7.1.2 Use 6.0 inch diameter split molds to prepare 12 inch high test specimens for all Type 1 materials with nominal particle sizes 1 1/4 inch, without removing any coarse aggregate.

7.1.3 If more than 5 percent of a sample is retained on the 1 1/4-inch sieve remove the particles retained on the 1 1/4-inch sieve prior to specimen preparation. If more than 10 percent of the sample is plus 1 1/4 inch material, the specimen shall be stored and the RCOC contacted for further instructions.

7.2 Undisturbed 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. Determine the natural moisture content (w) of the tube sample following the procedure outlined in SHRP Protocol P49 (AASHTO T265-86) and record in the test report. Determine the in situ density of the subgrade soil as specified in AASHTO T233-86.

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

7.2.1 Examine the thin-walled tube samples from each end of the test section separately. For both ends of a test section, select a sample suitable for testing (see NOTE 2) 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.

NOTE 2: To be suitable for testing, a specimen of sufficient length (generally 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, edges sheared off that cannot be repaired during preparation, presence of particles much larger than that typical for the material (example, 1-inch gravel 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.

7.2.2 If a good undisturbed subgrade sample is unavailable from a particular location, a reconstituted specimen shall be prepared as described in Sections 7.3, 7.4 and 7.5. Select a sample for reconstitution, again giving priority to samples extracted near the surface of the subgrade. Determine the in situ moisture content (w) of material that is representative of the sample to be reconstituted, (about 200 grams of the sample for moisture content determination), following the procedure outlined in SHRP Protocol P49 (AASHTO T265-86), and record on the test report. Assume the in-place density measured in the test pit (for asphalt concrete pavements) as the basis for reconstitution. In the absence of a test pit and if in-place densities are not measured, select the optimum moisture content and 95 percent of the maximum dry density (determined for the same layer using SHRP Protocol P55, Moisture Density Relations of Subgrade Soils, for reconstitution of the test specimen.

The moisture content of the laboratory compacted specimen should not vary more than ± 1/2 percentage point from the in situ moisture content obtained for that layer. The dry density of the laboratory compacted specimens should not vary by more than ± 5 percent of the in-place dry density for that layer.

Where subgrade samples were not retrieved in either of the two thin-wall tubes or the thin-walled tube samples are unsuitable for testing, than a representative test sample from the bulk samples of subgrade shall be used to prepare reconstituted specimens according to Sections 7.3, 7.4 and 7.5.

7.3 Laboratory Compacted Specimens - Reconstituted test specimens shall be prepared to approximate the in situ dry density (Y_d) and moisture content (w), (see NOTE 3). 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.

NOTE 3: In general, in situ densities for unbound bases, subbases and subgrade soils are measured directly using nuclear moisture/density testing equipment in test pits near the end of a GPS section (after Station 5+00) for asphalt concrete pavements. For PCC pavements, in situ density measurements are generally not made for bases, subbases and subgrade soils because test pit excavations are usually not performed on PCC pavements. In situ moisture contents will generally be available from laboratory measurements of samples taken in the field (see Section 7.4). The same applies for subgrade samples if undisturbed thin-walled tube samples suitable for testing are not available. See Section 7.2.2 for guidance on selecting densities and moisture contents for reconstitution of subgrade materials.

7.3.1 The moisture content of the laboratory compacted specimen should not vary more than ±1/2 percentage point from the in situ moisture content obtained for that layer.

The dry density of the laboratory compacted specimens should not vary by more than ± 5 percent of the in-place dry density for that layer. The desired in-place density shall be taken from the first available option of the following: (a) the average in-place density determined in the field, or (b) from the moisture-density relations as described in Section 7.4.

7.3.2 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.

7.3.3 Determine the moisture content (w_1) of the air-dried sample. The sample for moisture content shall weigh not less than 200 g for samples with a maximum particle size smaller than the No. 4 sieve (4.75 mm) and not less than 500 g for samples with a maximum particle size greater than the No. 4 sieve (4.75 mm).

7.3.4 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. An excess of 0.5-inch (13 mm) is generally adequate for this purpose.

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

W_s (pounds) = Y_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

7.3.6 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

Y_d and moisture content w.

W_t (grams) = W_s x (1 + w/100)

7.3.7 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} (grams) = (W_s + W_{as}) x (1 + w_1/100)

7.3.8 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 (grams) = (W_s + W_{as}) x (w_1/100)

W_2 (grams) = (W_s + W_{as}) x (w/100)

W_{aw} (grams) = W_2 - W_1

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

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

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

7.3.12 After mixing and storage, weigh the wet soil and container to the nearest gram and record this value on the appropriate form (see Worksheet T46).

7.4 Compaction Methods and Equipment for Reconstituting Specimens

7.4.1 Compacting Specimens for Type 1 Materials - The general method of compaction for these soils will be those of Attachment A of this protocol.

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

7.4.3 Moisture and Density for Compaction - When the in situ density and moisture content are known from the field data (see Section 7.2.2) the sample should be compacted to this in situ dry density and moisture content.

7.4.4 Moisture and Density for Compaction when Field Data is not Available - In the absence of the test pit, the in situ density and moisture contents are not known; therefore one of the following procedures is used.

(a) Unbound Granular Base and Subbase Materials (Type 1): Use the results of the UG05 test (Protocol P44) on Form T44 to establish the maximum dry density and the optimum moisture content based on AASHTO T180-85. Select the optimum moisture content and 95 percent of the maximum dry density for sample compaction.

(b) Subgrade Soils (Type 1): Subgrade soils may be categorized as Type 1 or as Type 2 according to the criteria of Section 5.10. In the case of Type 1 subgrade soils, use the results of SS05 (Protocol P55) on Form T55 to establish the maximum dry density and the optimum moisture content based on AASHTO T99-86. Select the optimum moisture content and 95% of the maximum dry density for sample compaction.

(c) Unbound Material Type 2: Generally subgrade soils (fine-grained) are included in the unbound material Type 2 category. Select the optimum moisture content and 95% maximum dry density for sample compaction as described in Section 7.4.4.

The sample dry density and moisture content should not differ by more than 3 percent of the in situ dry density and 1 percentage point of the in situ moisture content respectively for Type 1 materials, and 2 percent of the in situ dry density and 1/2% of the in situ moisture content for Type 2 materials respectively (See NOTE 4). If the remolded sample does not meet this criteria, it should be discarded.

NOTE 4: Example: if the desired dry density is 120 pcf and desired moisture content is 8.0 percent for a Type 1 soil, a dry density between 116.4 and 123.6 pcf and a moisture content between 7.2 and 8.8 percent would be acceptable.

7.4.5 The specimen should be protected from moisture change and tested the same day it is compacted.

7.5 Specific Gravity - Determine the specific gravity of solids following AASHTO T100-86.

8. TEST PROCEDURE

8.1 Resilient Modulus Test for Type 2 Soils - The procedure described in this section is used for undisturbed or laboratory compacted specimens of Type 2 soils as defined in Section 5.10.2. Compacted specimens should be tested on the same day after preparation.

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 the triaxial chamber base assembly on a table close to the loading frame. If the chamber has a removable bottom platen (sample base) tighten it firmly to obtain an air tight seal.

8.1.1.2 Place a porous stone on the top of the pedestal or bottom and plate of the triaxial chamber.

8.1.1.3 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.

8.1.1.4 Place the top platen (with load cell included) on the specimen, fold up the membrane, and seal it to the top platen with an O-ring or some pressure seal.

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

8.1.1.6 Connect the specimen's bottom drainage line to the vacuum source through the medium of a bubble chamber. Apply a vacuum of 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.

8.1.1.7 When leakage has been eliminated, disconnect the vacuum supply and place the chamber on the base plate, the load cell on the porous stone, 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.

8.1.1.8 Slide the assembly apparatus into position under the axial loading device. Bring the loading device down and couple it to the triaxial chamber piston and apply a seating pressure to the sample of 2 psi in order to obtain full contact of the piston with the top platen.

8.1.2 Conduct the Resilient Modulus Test - The following steps are required to conduct the resilient modulus test on a specimen of Type 2 soil which has been installed in the triaxial chamber and placed under the loading frame.

8.1.2.1 Open all drainage valves loading into the specimen.

8.1.2.2 If it is not already connected, connect the air pressure supply line to the triaxial chamber and apply a confining pressure of 6 psi to the test specimen. A contact load of 10% (±.5 lbs.) (.1S_d) of the maximum applied load during each sequence number shall be maintained during all repeated load applications.

8.1.2.3 Conducting - Begin the test by applying 1000 repetitions of a deviator stress of 4 psi using a haversine shaped load pulse consisting of a 0.1 second load followed by a 0.9 second rest period. 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 end platens and the test specimen.

8.1.2.4 Testing Specimen - The testing is performed following the loading sequence shown in Table 1. Begin by decreasing the deviator stress to 2 psi (Sequence No. 1, Table 1). Apply 100 repetitions of deviator stress using a haversine shaped load pulse consisting of a 0.1 second load followed by a 0.9 second rest period and record the average of the recovered deformations of the last five cycles on Worksheet T46.

Sequence No.	Confining Pressure S_3 psi.	Dev. Stress S_d psi.	Contact Load $.1S_d$ psi.	Number of Load Applications
0 (preconditioning)	6	4		1000
1	6	2		100
2	6	4		100
3	6	6		100
4	6	8		100
5	6	10		100
6	4	2		100
7	4	4		100
8	4	6		100
9	4	8		100
10	4	10		100
11	2	2		100
12	2	4		100
13	2	6		100
14	2	8		100
15	2	10		100

Table 1. Testing Sequence for Type 2 Soils.

8.1.2.5 Increase the deviator stress to 4 psi (Sequence No. 3) and repeat step 8.1.2.4 at this new stress level.

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

8.1.2.7 Continue the test for the remaining load sequences in Table 1 (4 to 15) recording the vertical recovered deformation. If at any time the permanent strain of the sample exceeds 5 percent, stop the test and report the result on the appropriate worksheet (See Worksheet T46).

8.1.2.8 After completion of the resilient modulus test procedure, check the total vertical permanent strain that the specimen was subjected to during the resilient modulus portion of the test procedure. If the total vertical permanent strain did not exceed 5 percent, continue with the quick shear test procedure. (Section 8.1.2.9 - 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.

8.1.2.9 Apply a confining pressure of 4 psi. to the specimen. Apply a load so as to produce an axial strain at a rate of 1 percent per minute. Continue loading until (1) the load values decrease with increasing strain, (2) 5 percent strain is reached, or (3) the capacity of the load cell is reached. The internally mounted deformation transducer in the actuator shaft shall be used to monitor specimen deformation.

8.1.2.10 Plot the stress-strain curve for the specimen for the quick shear test procedure.

8.1.2.11 At the completion of the loading sequences, disassemble the triaxial cell.

8.1.2.12 Remove the membrane from the specimen and use the entire specimen to determine moisture content. Record this value on the appropriate form (See Worksheet T46).

8.2 Resilient Modulus Test for Type 1 Materials - The procedure described in this section applies to all unbound granular base and subbase materials and all unbound subgrade soils which meet the following criteria.

Less than 70% passing the #10 sieve and a
maximum of 20% passing the #200 sieve

8.2.1 Assembly of the Triaxial Chamber - Follow Steps 8.1.1.1 through 8.1.1.8. When compaction is completed, place the porous stone and top sample cap on the 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.

8.2.1.1 through 8.2.1.8 are the same as steps 8.1.1.1 through 8.1.1.8.

8.2.1.9 Connect the chamber pressure supply line and apply a confining pressure of 15 psi.

8.2.1.10 Remove the vacuum supply from the vacuum saturation inlet and close this line.

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. This can be done by applying a seating pressure of 2 psi. A minimum contact load of 10 percent ($.1S_d$) of the maximum applied load shall be maintained during all repeated load determination.

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

8.2.2.3 Set the confining pressure to 15 psi and apply 1000 repetitions of an axial deviator stress of 15 psi using a haversine shaped load pulse consisting of a 0.1 second load followed by a 0.9 second rest period. The drainage valve should be open throughout the resilient testing. This stress sequence constitutes the sample conditioning.

8.2.2.4 Testing the Sample. The testing is performed following the loading sequences in Table 2 using a haversine shaped load pulse consisting of a 0.1 second load followed by a 0.9 second rest period. Decrease the deviator stress to 3 psi and set the confining pressure to 3 psi (Sequence No. 1, Table 2). Apply 100 repetitions of deviator stress and record the average of the deformations of the last five load cycles on the appropriate testing form as shown on Worksheet T46.

8.2.2.5 Continue with Sequence No. 2 increasing the deviator stress to 6 psi and repeat 8.2.2.4 at this new stress level.

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

8.2.2.7 After completion of the resilient modulus test procedure, check the total vertical permanent strain that the specimen was subjected to during the resilient modulus portion of the test procedure. If the total vertical permanent strain did not exceed 5 percent, continue with the quick shear test procedure (Section 8.2.2.8 - 8.2.2.9). If the total vertical permanent strain exceeds 5 percent, the test is completed. No additional testing is to be conducted on the specimen.

8.2.2.8 Apply the load so as to produce an axial strain at a rate of 1 percent per minute. Continue loading until (1) the load values decrease with increasing strain, (2) 5 percent strain is reached, or (3) the capacity of the load cell is reached. The internally mounted deformation transducer in the actuator shaft shall be used to monitor specimen deformation.

8.2.2.9 Plot the stress-strain curve for the specimen for the quick shear test procedure.

8.2.2.10 At the completion of the quick shear test, reduce the confining pressure to zero and disassemble the triaxial cell.

8.2.2.11 Remove the membrane from the specimen and use the entire sample to determine the moisture content. Record this value on the form shown in Worksheet T46.

Sequence No.	Confining Pressure S_3 psi.	Dev. Stress S_d psi.	Contact Load $.1S_d$ psi.	Number of Load Applications
0 (preconditioning)	15	15		1000
1	3	3		100
2	3	6		100
3	3	9		100
4	5	5		100
5	5	10		100
6	5	15		100
7	10	10		100
8	10	20		100
9	10	30		100
10	15	10		100
11	15	15		100
12	15	30		100
13	20	15		100
14	20	20		100
15	20	40		100

Table 2. Testing Sequence for Type 1 Soils.

9. CALCULATIONS

9.1 Perform calculations using the tabular arrangement shown on Worksheet T46.

9.1.1 Calculate the mean and standard deviation of the load and recoverable deformation. The mean values are used to calculate the deviator stress and the resilient strain.

10. REPORT

The following information is to be recorded on Form T46.

10.1 The specimen identification shall include: Laboratory Identification Code, State Code, SHRP Section ID, Layer Number, Field Set Number, Sample Location Number and SHRP Sample Number.

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

10.3 Test Results

(a) Worksheet: Record the test data for each specimen on Worksheet T46 and attach with Form T46.

(b) M_r Relationships and Plots: Plot Log M_r versus Log S_d and attach the appropriate plots to Form T46. Determine the appropriate coefficients (k_1 and k_2 and k_5) using least squares regression.

- Simple relationship for Type 1 Material (Figure T46A)

  $M_r = k_1(1 + S_3)k_2(S_d)^{k5}$

  Where S_d = deviator stress and

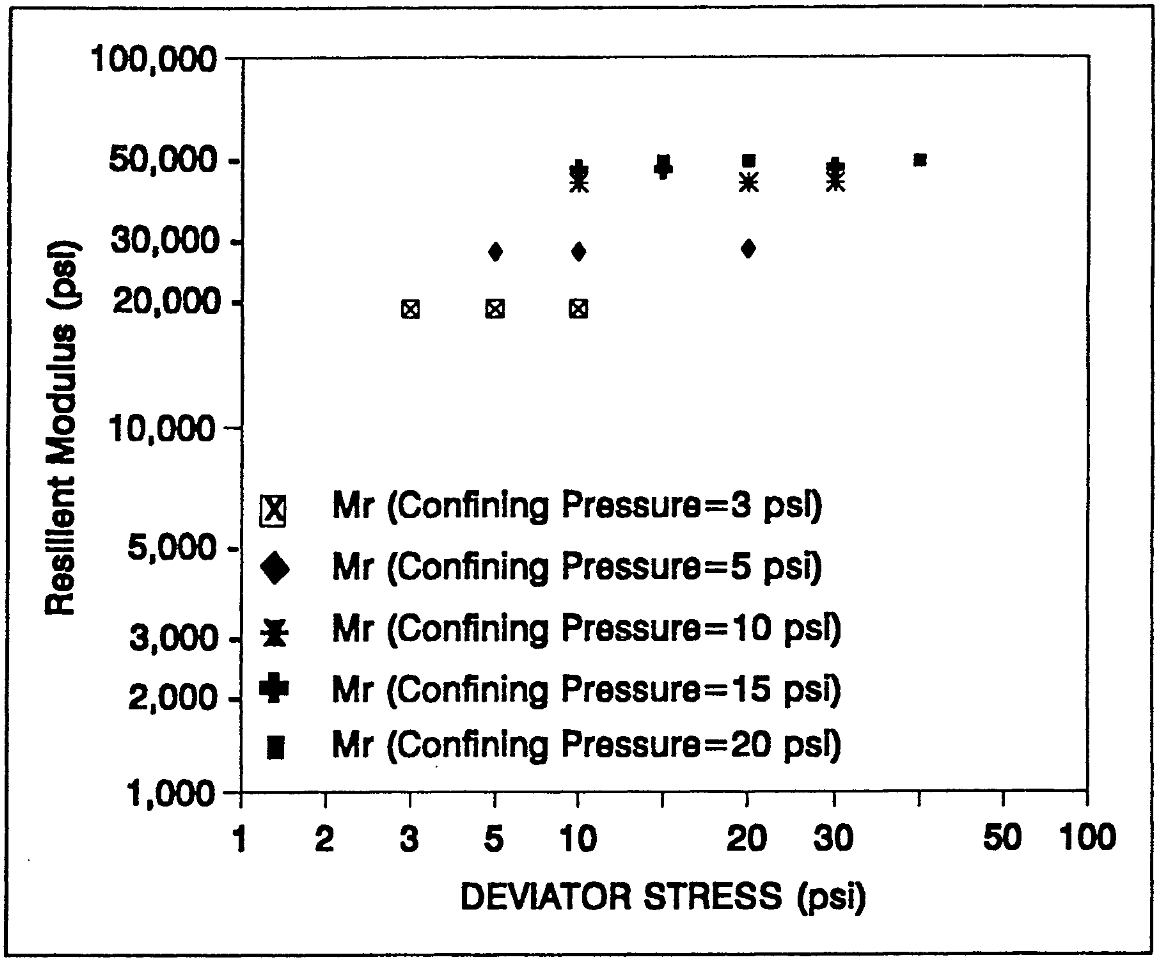
  S_3 = confining pressure

- Simple relationship for Type 2 Material (Figure T46B)

  $M_r = k_1 (S_d)^{k2}(1 + S_3)^{k5}$

  Where S_d = deviator stress and

  S_3 = confining pressure

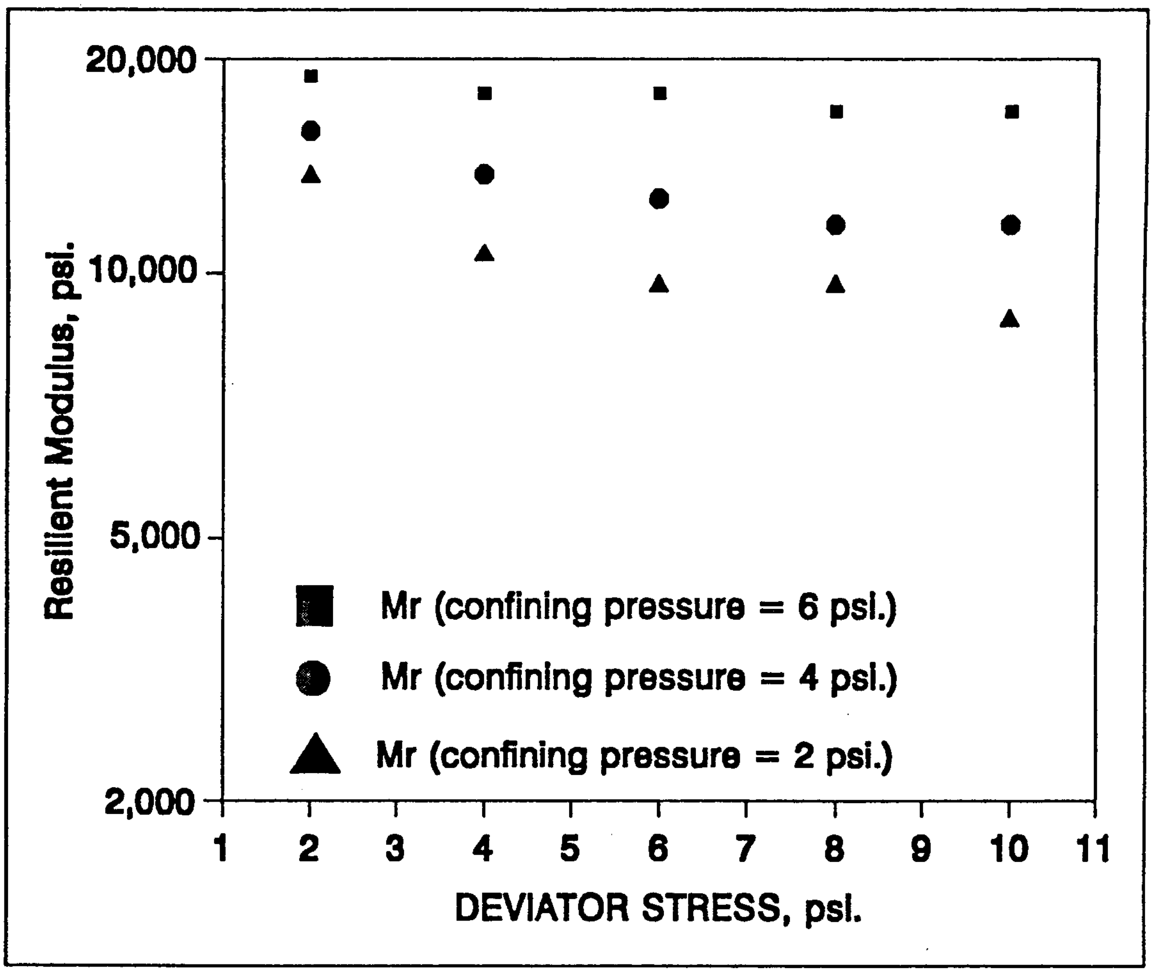


$M_r = K_1 (1+S_3)^{K}2(S_d)^{K}5$

$M_r = 12542 (1+S_3)^{.4098} (S_d)^{.0628}$

$R^2 = .988$

Figure T46A. Logarithmic plot of resilient modulus vs. deviator stress for type 1 materials.



$$Mr = K_1 (S_d)^{K2} (1+S_3)^{K5}$$
$$= 14071 \ (S_d)^{-.151} (1+S_3)^{.200}$$
$$R^2 = .977$$

Figure T46B. Logarithmic plot of resilient modulus vs. deviator stress for type 2 materials.

(c) Specimen Data: moisture content (After the test), w, % Dry Density, Y_d, pcf

(d) Constants for M_r Relationships: Values of regression constants and related stress parameters used in the M_r relationship.

(e) M_r for Material Type 1 at a confining pressure of 15 psi and deviator stress of 15 psi.

(f) M_r for Material Type 2 at a confining pressure of 6 psi and deviator stress of 4 psi.

10.4 Comments shall include SHRP standard comment code(s), as shown on Page E.1-3 of the SHRP 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 SHRP.
81	A separate test sample was used for classification and description tests (Protocol P47 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 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 for 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). This test sample was reused for other designated tests and the remnant of the samples was saved and stored for possible future use by SHRP.

87 The "undisturbed" thin-walled tube sample was used for the resilient modulus testing (Protocol P46).

88 The thin-walled tube sample was not suitable, therefore, a reconstituted sample from the bulk samples was used for the resilient modulus testing.

89 The thin-walled tube sample was not available. The test sample for the resilient modulus testing (Protocol P46) was reconstituted from the bulk sample.

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

94 The test was not performed because of the oversize aggregates; sample was stored until further instructions from SHRP.

10.5 Use Form T46, Worksheet T46 and Figure T46A or T46B to report the results of the resilient modulus test to the SHRP Regional Engineer.

NOTE 5: Item 5(d) of Form T46 contains six constants for the M_r relationship, k_1, k_2, k_3, k_4, k_5 and k_6. Constants k_3 and k_4 and k_6 are for future use and will not be required at this time. In addition, stress parameters S_4, S_5 and S_6 are for future use and will not be required at this time.

ATTACHMENT A TO SHRP PROTOCOL P46

COMPACTION OF TYPE 1 SOILS

Type 1 soils will be recompacted using a 6.0 inch split mold and vibratory compaction. Six inch diameter split molds shall be used to prepare 12 inch high test samples for all Type 1 materials with nominal particle sizes less than or equal to 1 1/4 inches. If samples contain more than 5 percent by volume of plus 1 1/4 inch material, the plus 1 1/4 inch material shall be removed prior to sample preparation and this condition shall be noted in the data reporting for this test.

Cohesionless soils are compacted readily by use of a split mold mounted on the base of the triaxial cell as shown in Figure 2. Compaction forces are generated by a small hand-held air hammer.

1. SCOPE

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

2. APPARATUS

2.1 Six inch diameter split mold.

2.2 Vibratory compaction device.

3. PROCEDURE

3.1 Tighten the bottom platen into place on the triaxial cell base. It is essential that an airtight seal is obtained.

3.2 Place the two 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 0.01 inch.

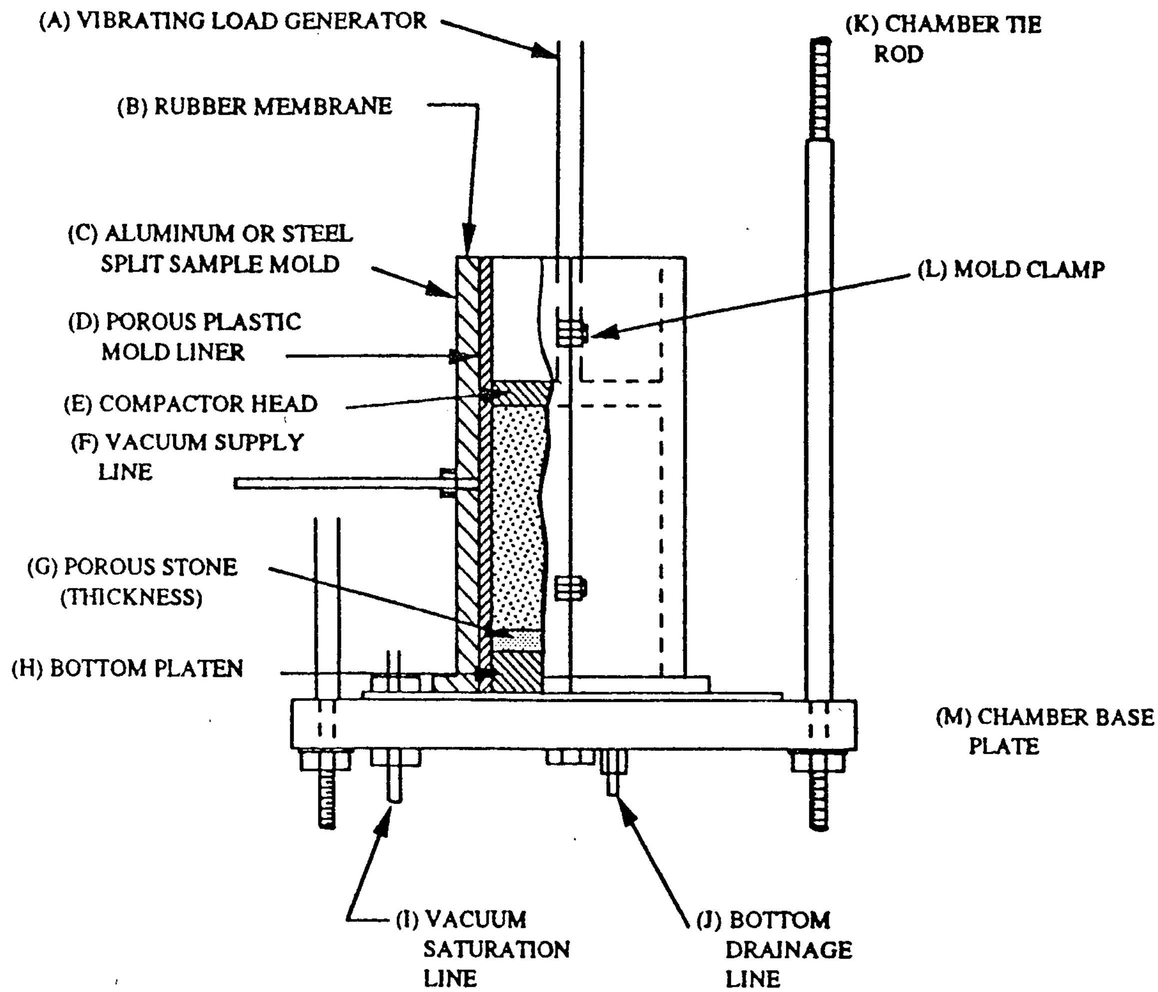


TABLE OF MEASUREMENTS (TYPICAL)

DIMENSION	A	B	D	C	E	F	G	H	I	J	K	L	M
METRIC, mm	Note 1	Note 2	Note 2	Note 2	Note 3	6.4	6.4	38.1	6.4	6.4	12.7	Note 1	25.4
ENGLISH, in.						0.25	0.25	1.50	0.25	0.25	0.50		1.00

NOTE:

1. Dimension varies with manufacturer
2. Dimension varies with specimen size
3. Diameter should be 0.25 ± 0.02 inch (6.35 ± 0.5 mm) smaller then specimen diameter

Figure 2. Apparatus for vibratory compaction of Type 1 unbound materials.

3.3 Remove the top platen and upper porous stone if used. Measure the thickness of the rubber membrane with a micrometer.

3.4 Place the rubber membrane over the bottom platen and lower porous stone. 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 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 line 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 0.01 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 5.6 inches and the height measured in step 3.7.

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

3.10 For six inch diameter specimens (specimen height of 12 inches) 5 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 mass of soil, 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. 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 fine surface shall be a smooth horizontal plane.

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. The moisture content of this sample shall be using SHRP Protocol P49.

Proceed with section 8.2 of this protocol.

ATTACHMENT B TO SHRP PROTOCOL P46

COMPACTION OF TYPE 2 SOILS

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

Specimens shall be recompacted in a 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 2.8 inches in diameter and 5.6 inches in height). A typical mold assembly is shown in Figure 3. Several steps are required for static compaction as follows in the Procedures section of this attachment.

1. SCOPE

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

2. APPARATUS

   As shown in Figure 3.

3. PROCEDURE

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

   3.2 Place one of the loading rams into the specimen mold.

   3.3 Place the mass 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.

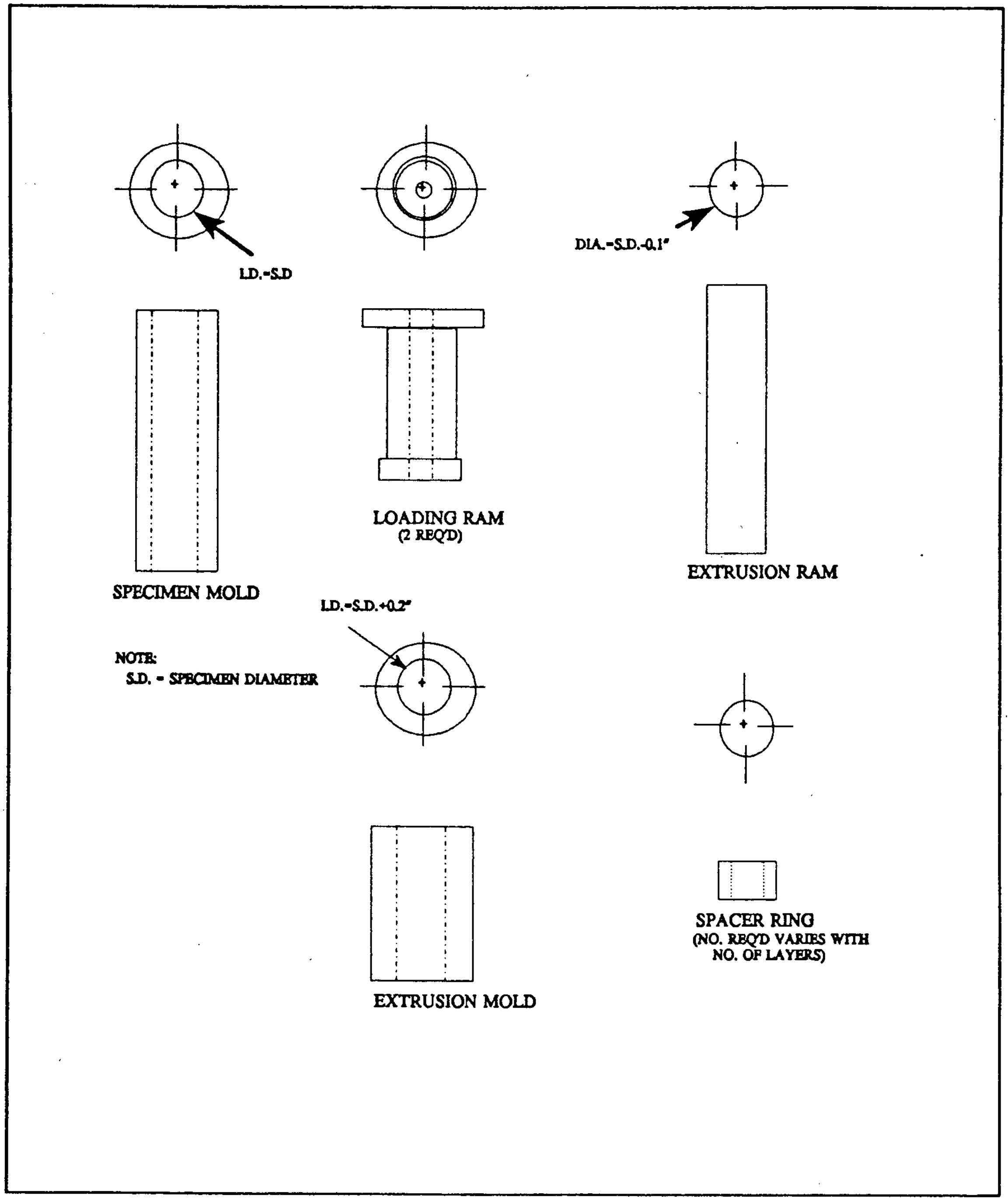


Figure 3. Apparatus for static compaction of Type 2 unbound materials.

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

3.5 Slowly increase the load until the loading caps rest firmly against the mold. 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. NOTE 6: 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.

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

3.7 Remove the loading ram. Scarify the surfaces of the compacted layer and put the weight of wet soil W_L for the second layer in place and form a mound. Add a spacer ring and insert the loading ram.

3.8 Invert the assembly and repeat step 3.7.

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

3.10 Repeat steps 3.7, 3.8 and 3.9 to compact the remaining two layers.

3.11 After completion is completed, determine the moisture content of the remaining soil using SHRP Protocol P49. Record this value on SHRP Worksheet T46.

3.12 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.

3.13 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 0.5 in. (13 mm.). Platens shall be of a material which will not absorb soil moisture.

3.14 Determine the weight of the compacted specimen to the nearest gram. Measure the height and diameter to the nearest 0.01 inch. Record these values on Worksheet T46.

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

3.16 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.

LABORATORY MATERIAL HANDLING AND TESTING
LABORATORY MATERIAL TEST DATA
RESILIENT MODULUS OF UNBOUND GRANULAR BASE/SUBBASE
WORKSHEET T46 - PAGE 1

SHEET NO __ OF __

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

LABORATORY PERFORMING TEST: ____________________
LABORATORY IDENTIFICATION CODE: ___ ___ ___ ___

STATE CODE: ___ ___
SHRP SECTION ID.: ___ ___ ___ ___ ___ ___
FIELD SET NO.: ___

1. LAYER NUMBER (FROM LAB SHEET L04) ___

2. SHRP LABORATORY TEST NUMBER ___

3. LOCATION NUMBER (enter an asterisk as the third digit if the specimen is recompacted from a combined bulk sample) ___ ___ ___

4. SHRP SAMPLE NUMBER (enter an asterisk as the third and fourth digit if the specimen is recompacted from a combined bulk sample) ___ ___ ___ ___

5. MATERIAL TYPE (TYPE 1 OR TYPE 2) ___

6. SPECIMEN INFORMATION:
   SPECIFIC GRAVITY ___ . ___ ___ ___
   SPECIMEN DIAMETER, inches
   TOP ___ . ___ ___
   MIDDLE ___ . ___ ___
   BOTTOM ___ . ___ ___
   AVERAGE ___ . ___ ___
   MEMBRANE THICKNESS, inches ___ . ___ ___
   NET DIAMETER, inches ___ . ___ ___
   HEIGHT OF SPEC. + CAP + BASE, inches ___ ___ . ___ ___
   HEIGHT OF CAP + BASE, inches ___ ___ . ___ ___
   INITIAL LENGTH, L_o, inches ___ ___ . ___ ___
   INSIDE DIAMETER OF MOLD, inches ___ . ___ ___

7. 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 * ___ ___ ___ ___ ___ . ___ ___

8. SOIL SPECIMEN VOLUME:
   INITIAL AREA, A_o, in.^{2} ___ ___ . ___ ___
   INITIAL VOLUME, $A_o * L_o$, in.^{3} ___ ___ ___ . ___ ___

9. SOIL PROPERTIES:
   WET DENSITY, pcf. ___ ___ ___ . ___
   COMPACTION MOISTURE CONTENT ___ ___ . ___
   SATURATION, S, % ___ ___ . ___
   DRY DENSITY, Y_d, pcf. ___ ___ ___ . ___
   MOISTURE CONTENT AFTER M_r TESTING, % ___ ___ ___ . ___

10. COMMENTS (20 characters or less)
____
____
____

Notes: * If a thin-walled tube is used for resilient modulus testing, these items do not need to be reported.
** If a thin-walled tube is used for resilient modulus testing, record the moisture content of the pavement layer being tested.

LABORATORY MATERIAL HANDLING AND TESTING
LABORATORY MATERIAL TEST DATA
RESILIENT MODULUS OF UNBOUND GRANULAR BASE/SUBBASE
MATERIALS AND SUBGRADE SOILS
LAB DATA SHEET T46

SHEET NO __ OF __

UNBOUND GRANULAR BASE, SUBBASE 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)
   LAYER MATERIAL (CIRCLE ONE): BASE/SUBBASE/SUBGRADE
2. SHRP LABORATORY TEST NUMBER . . . . ____
3. LOCATION NUMBER (Enter an asterisk as the third digit) . . . . ____ ____ ____
4. SHRP SAMPLE NUMBER (Enter an asterisk as third and fourth digit) . . . . ____ ____ ____ ____
5. MATERIAL TYPE — TYPE ____
6. TEST RESULTS (Section 10.3 of Protocol P46)
   (a) PLOTS (FIGURE T46A or T46B).: (Record the attached Figure No.) — T46 ____
   (b) CONSTANTS FOR Mr RELATIONSHIP

k^2 = __ . __ __ __ __ __

k_1 __ __ __ __ __ __ . k_2 __ . __ __ __ __ __
k_3 __ __ __ __ __ __ . k_4 __ . __ __ __ __ __
k_5 __ __ __ __ __ __ . k_6 __ . __ __ __ __ __

STRESS PARAMETERS (Specify one or more from Sd, S4, S5, S6)

__ __ __ . __ __ __ . __ __ __ . __ __
S_d S_4 S_5 S_6

   (c) Mr FOR MATERIAL TYPE 1;
      AT CONFINING (CHAMBER) PRESSURE = 15 psi, DEVIATOR STRESS = 15 psi __ __ __ __ __ __ .
   (d) Mr FOR MATERIAL TYPE 2;
      AT CONFINING (CHAMBER) PRESSURE = 6 psi, DEVIATOR STRESS = 4 psi __ __ __ __ __ __ .

7. STRESS-STRAIN PLOT ATTACHED (YES OR NO) ____ ____ ____

8. COMMENTS (Section 10.4 of Protocol P46)
   (a) CODE __ __ __ __ __ __
   (b) NOTE __ __ __ __ __ __

9. TEST DATE __ __ . __ __ . __ __

NOTE: * RESULTS OF CLASSIFICATION AND DESCRIPTION (FORM T47 FOR UNBOUND BASE/SUBBASE OR FORM T52 FOR SUBGRADE) SHALL BE USED TO CATEGORIZE MATERIAL TYPE 1 OR 2.

GENERAL REMARKS:______________________________

SUBMITTED BY, DATE

____
LABORATORY CHIEF
Affiliation __________

CHECKED AND APPROVED, DATE

____
Affiliation __________

Form T46, March 1992

SHRP SECTION NUMBER ________
SHRP SAMPLE NUMBER ________
SHRP LABORATORY TEST NUMBER __
LAYER NUMBER ____________
MATERIAL TYPE ____________
10. RESILIENT MODULUS TESTING.

A Chamber Confining Pressure, S_3 (psi)	B Nominal Deviator Stress, S_d (psi)	C Mean Deviator Load (lb)*	D Standard Deviation of Load (lb)*	E Mean Applied Dev. Stress (psi)*	F Mean Applied Contact Stress (psi)*	G Mean Recov. Def. LVDT #1 Reading (in.)*	H Mean Recov. Def. LVDT #2 Reading (in.)*	I Mean Recoverable Deformation (in.)*	J Std. Dev. of Recoverable Deformation (in.)*	K Mean of Resilient Strain (in/in.)*	L Mean of M_r (psi.)*	M Standard Dev. of M_r (psi.)*

* obtained from the last five load cycles

SUBMITTED BY, DATE

____
LABORATORY CHIEF
Affiliation ________

CHECKED AND APPROVED, DATE

____
Affiliation ______________

APPENDIX B

DATA FROM THE TYPE II SYNTHETIC REFERENCE SAMPLES AS REPORTED FROM PARTICIPANTS. SEPTEMBER 1993.

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	LABORATORY CODE	TEST NO	MR
1	TU-700	0	2	A	1	1494
2	TU-700	0	2	A	2	1498
3	TU-700	0	2	B	1	1091
4	TU-700	0	2	B	2	1102
5	TU-700	0	2	C	1	1944
6	TU-700	0	2	C	2	1955
7	TU-700	0	2	D	1	1737
8	TU-700	0	2	D	2	1897
9	TU-700	0	2	E	1	1477
10	TU-700	0	2	E	2	1483
11	TU-700	0	2	F	1	1664
12	TU-700	0	2	F	2	1665
13	TU-700	0	2	G	1	2668
14	TU-700	0	2	G	2	2622
15	TU-700	0	2	H	1	2109
16	TU-700	0	2	H	2	2092
17	TU-700	0	2	I	1	1953
18	TU-700	0	2	I	2	1986
19	TU-700	0	2	J	1	2100
20	TU-700	0	2	K	1	1862
21	TU-700	0	2	K	2	1673
22	TU-700	0	6	A	1	1547
23	TU-700	0	6	A	2	1549
24	TU-700	0	6	B	1	1165
25	TU-700	0	6	B	2	1169
26	TU-700	0	6	C	1	1939
27	TU-700	0	6	C	2	1942
28	TU-700	0	6	D	1	1891
29	TU-700	0	6	D	2	1805
30	TU-700	0	6	E	1	1800
31	TU-700	0	6	E	2	1802
32	TU-700	0	6	F	1	1803
33	TU-700	0	6	F	2	1803
34	TU-700	0	6	G	1	2092
35	TU-700	0	6	G	2	2058
36	TU-700	0	6	H	1	2263
37	TU-700	0	6	H	2	2245
38	TU-700	0	6	I	1	1830
39	TU-700	0	6	I	2	1849
40	TU-700	0	6	J	1	1700

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	LABORATORY CODE	TEST NO	MR
41	TU-700	0	6	K	1	2212
42	TU-700	0	6	K	2	2107
43	TU-700	0	0	A	1	1559
44	TU-700	0	0	A	2	1560
45	TU-700	0	0	B	1	1230
46	TU-700	0	0	B	2	1232
47	TU-700	0	0	C	1	1942
48	TU-700	0	0	C	2	1950
49	TU-700	0	0	D	1	1957
50	TU-700	0	0	D	2	1917
51	TU-700	0	0	E	1	1869
52	TU-700	0	0	E	2	1882
53	TU-700	0	0	F	1	1898
54	TU-700	0	10	F	2	1899
55	TU-700	0	10	G	1	1872
56	TU-700	0	10	G	2	1832
57	TU-700	0	10	H	1	2359
58	TU-700	0	10	H	2	2356
59	TU-700	0	10	I	1	1899
60	TU-700	0	10	I	2	1937
61	TU-700	0	10	J	1	1600
62	TU-700	0	10	K	1	2139
63	TU-700	0	10	K	2	2086
64	TU-700	4	2	A	1	1479
65	TU-700	4	2	A	2	1476
66	TU-700	4	2	B	1	1122
67	TU-700	4	2	B	2	1116
68	TU-700	4	2	C	1	1933
69	TU-700	4	2	C	2	1935
70	TU-700	4	2	D	1	1897
71	TU-700	4	2	D	2	1737
72	TU-700	4	2	E	1	1593
73	TU-700	4	2	E	2	1585
74	TU-700	4	2	F	1	1621
75	TU-700	4	2	F	2	1624
76	TU-700	4	2	G	1	2349
77	TU-700	4	2	G	2	2507
78	TU-700	4	2	H	1	2109
79	TU-700	4	2	H	2	2071
80	TU-700	4	2	I	1	1953
81	TU-700	4	2	I	2	2003
82	TU-700	4	2	J	1	2200
83	TU-700	4	2	K	1	1806

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	LABORATORY CODE	TEST NO	MR
84	TU-700	4	2	K	2	1897
85	TU-700	4	6	A	1	1538
86	TU-700	4	6	A	2	1538
87	TU-700	4	6	B	1	1167
88	TU-700	4	6	B	2	1173
89	TU-700	4	6	C	1	1941
90	TU-700	4	6	C	2	1943
91	TU-700	4	6	D	1	1805
92	TU-700	4	6	D	2	1873
93	TU-700	4	6	E	1	1777
94	TU-700	4	6	E	2	1802
95	TU-700	4	6	F	1	1798
96	TU-700	4	6	F	2	1801
97	TU-700	4	6	G	1	1850
98	TU-700	4	6	G	2	1910
99	TU-700	4	6	H	1	2274
100	TU-700	4	6	H	2	2236
101	TU-700	4	6	I	1	1879
102	TU-700	4	6	I	2	1895
103	TU-700	4	6	J	1	1500
104	TU-700	4	6	K	1	2238
105	TU-700	4	6	K	2	2138
106	TU-700	4	10	A	1	1555
107	TU-700	4	10	A	2	1556
108	TU-700	4	10	B	1	1234
109	TU-700	4	10	B	2	1236
110	TU-700	4	10	C	1	1946
111	TU-700	4	10	C	2	1939
112	TU-700	4	10	D	1	1866
113	TU-700	4	10	D	2	1984
114	TU-700	4	10	E	1	1869
115	TU-700	4	10	E	2	1869
116	TU-700	4	10	F	1	1883
117	TU-700	4	10	F	2	1893
118	TU-700	4	10	G	1	1759
119	TU-700	4	10	G	2	1759
120	TU-700	4	10	H	1	2346
121	TU-700	4	10	H	2	2342
122	TU-700	4	10	I	1	2003
123	TU-700	4	10	I	2	2000
124	TU-700	4	10	J	1	1300
125	TU-700	4	10	K	1	2119
126	TU-700	4	10	K	2	2139

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	LABORATORY CODE	TEST NO	MR
127	DPTU1560	0	2	A	1	6289
128	DPTU1560	0	2	A	2	6368
129	DPTU1560	0	2	B	1	4707
130	DPTU1560	0	2	B	2	4805
131	DPTU1560	0	2	C	1	5348
132	DPTU1560	0	2	C	2	5450
133	DPTU1560	0	2	D	1	4273
134	DPTU1560	0	2	D	2	3884
135	DPTU1560	0	2	E	1	3541
136	DPTU1560	0	2	E	2	3560
137	DPTU1560	0	2	F	1	4533
138	DPTU1560	0	2	F	2	4700
139	DPTU1560	0	2	G	1	4313
140	DPTU1560	0	2	G	2	4568
141	DPTU1560	0	2	H	1	5256
142	DPTU1560	0	2	H	2	5213
143	DPTU1560	0	2	I	1	4107
144	DPTU1560	0	2	I	2	4182
145	DPTU1560	0	2	J	1	3100
146	DPTU1560	0	2	K	1	3487
147	DPTU1560	0	2	K	2	3418
148	DPTU1560	0	2	L	1	5803
149	DPTU1560	0	6	A	1	6529
150	DPTU1560	0	6	A	2	6543
151	DPTU1560	0	6	B	1	4495
152	DPTU1560	0	6	B	2	4544
153	DPTU1560	0	6	C	1	5817
154	DPTU1560	0	6	C	2	5882
155	DPTU1560	0	6	D	1	4183
156	DPTU1560	0	6	D	2	4415
157	DPTU1560	0	6	E	1	4358
158	DPTU1560	0	6	E	2	4393
159	DPTU1560	0	6	F	1	5292
160	DPTU1560	0	6	F	2	5367
161	DPTU1560	0	6	G	1	4834
162	DPTU1560	0	6	G	2	4901
163	DPTU1560	0	6	H	1	5766
164	DPTU1560	0	6	H	2	5879
165	DPTU1560	0	6	I	1	4510
166	DPTU1560	0	6	I	2	4395
167	DPTU1560	0	6	J	1	3000
168	DPTU1560	0	6	K	1	4769
169	DPTU1560	0	6	K	2	4576

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	LABORATORY CODE	TEST NO	MR
170	DPTU1560	0	6	L	1	3315
171	DPTU1560	0	10	A	1	6546
172	DPTU1560	0	10	A	2	6551
173	DPTU1560	0	10	B	1	4467
174	DPTU1560	0	10	B	2	4469
175	DPTU1560	0	10	C	1	5854
176	DPTU1560	0	10	C	2	5811
177	DPTU1560	0	10	D	1	4443
178	DPTU1560	0	10	D	2	4608
179	DPTU1560	0	10	E	1	5085
180	DPTU1560	0	10	E	2	5025
181	DPTU1560	0	10	F	1	5958
182	DPTU1560	0	10	F	2	6042
183	DPTU1560	0	10	G	1	5234
184	DPTU1560	0	10	G	2	5076
185	DPTU1560	0	10	H	1	6196
186	DPTU1560	0	10	H	2	6254
187	DPTU1560	0	10	I	1	4957
188	DPTU1560	0	10	I	2	4978
189	DPTU1560	0	10	J	1	3300
190	DPTU1560	0	10	K	1	5157
191	DPTU1560	0	10	K	2	5092
192	DPTU1560	0	10	L	1	2702
193	DPTU1560	4	2	A	1	6187
194	DPTU1560	4	2	A	2	6237
195	DPTU1560	4	2	B	1	4901
196	DPTU1560	4	2	B	2	4905
197	DPTU1560	4	2	C	1	5348
198	DPTU1560	4	2	C	2	5399
199	DPTU1560	4	2	D	1	3944
200	DPTU1560	4	2	D	2	4382
201	DPTU1560	4	2	E	1	3666
202	DPTU1560	4	2	E	2	3600
203	DPTU1560	4	2	F	1	4470
204	DPTU1560	4	2	F	2	4530
205	DPTU1560	4	2	G	1	4573
206	DPTU1560	4	2	G	2	4384
207	DPTU1560	4	2	H	1	5256
208	DPTU1560	4	2	H	2	5256
209	DPTU1560	4	2	I	1	4600
210	DPTU1560	4	2	I	2	4510
211	DPTU1560	4	2	J	1	5200
212	DPTU1560	4	2	K	1	3383

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	LABORATORY CODE	TEST NO	MR
213	DPTU1560	4	2	K	2	3853
214	DPTU1560	4	2	L	1	5801
215	DPTU1560	4	6	A	1	6444
216	DPTU1560	4	6	A	2	6437
217	DPTU1560	4	6	B	1	4596
218	DPTU1560	4	6	B	2	4555
219	DPTU1560	4	6	C	1	5719
220	DPTU1560	4	6	C	2	5710
221	DPTU1560	4	6	D	1	4519
222	DPTU1560	4	6	D	2	4253
223	DPTU1560	4	6	E	1	4641
224	DPTU1560	4	6	E	2	4649
225	DPTU1560	4	6	F	1	5188
226	DPTU1560	4	6	F	2	5193
227	DPTU1560	4	6	G	1	4704
228	DPTU1560	4	6	G	2	4704
229	DPTU1560	4	6	H	1	5781
230	DPTU1560	4	6	H	2	5895
231	DPTU1560	4	6	I	1	4631
232	DPTU1560	4	6	I	2	4570
233	DPTU1560	4	6	J	1	3200
234	DPTU1560	4	6	K	1	4496
235	DPTU1560	4	6	K	2	4489
236	DPTU1560	4	6	L	1	3144
237	DPTU1560	4	10	A	1	6523
238	DPTU1560	4	10	A	2	6521
239	DPTU1560	4	10	B	1	4484
240	DPTU1560	4	10	B	2	4490
241	DPTU1560	4	10	C	1	5806
242	DPTU1560	4	10	C	2	5773
243	DPTU1560	4	10	D	1	4527
244	DPTU1560	4	10	D	2	4659
245	DPTU1560	4	10	E	1	5299
246	DPTU1560	4	10	E	2	5302
247	DPTU1560	4	10	F	1	5881
248	DPTU1560	4	10	F	2	5867
249	DPTU1560	4	10	G	1	5177
250	DPTU1560	4	10	G	2	5155
251	DPTU1560	4	10	H	1	6186
252	DPTU1560	4	10	H	2	6243
253	DPTU1560	4	10	I	1	5000
254	DPTU1560	4	10	I	2	5044
255	DPTU1560	4	10	J	1	3300

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	LABORATORY CODE	TEST NO	MR
256	DPTU1560	4	10	K	1	5092
257	DPTU1560	4	10	K	2	5018
258	DPTU1560	4	10	L	1	2702
259	TU-960	0	2	A	1	13004
260	TU-960	0	2	A	2	13357
261	TU-960	0	2	B	1	13762
262	TU-960	0	2	B	2	15144
263	TU-960	0	2	C	1	10686
264	TU-960	0	2	C	2	10686
265	TU-960	0	2	D	1	10688
266	TU-960	0	2	D	2	9798
267	TU-960	0	2	E	1	8458
268	TU-960	0	2	E	2	8525
269	TU-960	0	2	F	1	11435
270	TU-960	0	2	F	2	11283
271	TU-960	0	2	G	1	9717
272	TU-960	0	2	G	2	10098
273	TU-960	0	2	H	1	10481
274	TU-960	0	2	H	2	10397
275	TU-960	0	2	I	1	9420
276	TU-960	0	2	I	2	9043
277	TU-960	0	2	J	1	6200
278	TU-960	0	2	K	1	8783
279	TU-960	0	2	K	2	9372
280	TU-960	0	2	L	1	9649
281	TU-960	0	6	A	1	14889
282	TU-960	0	6	A	2	14886
283	TU-960	0	6	B	1	9073
284	TU-960	0	6	B	2	9035
285	TU-960	0	6	C	1	11545
286	TU-960	0	6	C	2	11416
287	TU-960	0	6	D	1	9797
288	TU-960	0	6	D	2	10233
289	TU-960	0	6	E	1	10143
290	TU-960	0	6	E	2	10095
291	TU-960	0	6	F	1	12774
292	TU-960	0	6	F	2	12636
293	TU-960	0	6	G	1	10135
294	TU-960	0	6	G	2	10287
295	TU-960	0	6	H	1	11896
296	TU-960	0	6	H	2	12353
297	TU-960	0	6	I	1	11119
298	TU-960	0	6	I	2	11119

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	LABORATORY CODE	TEST NO	MR
299	TU-960	0	6	J	1	11000
300	TU-960	0	6	K	1	9348
301	TU-960	0	6	K	2	9046
302	TU-960	0	6	L	1	9668
303	TU-960	0	10	A	1	16526
304	TU-960	0	10	A	2	16431
305	TU-960	0	0	B	1	8807
306	TU-960	0	0	B	2	8800
307	TU-960	0	10	C	1	12011
308	TU-960	0	10	C	2	12080
309	TU-960	0	10	D	1	10243
310	TU-960	0	10	D	2	10633
311	TU-960	0	10	E	1	11835
312	TU-960	0	10	E	2	11903
313	TU-960	0	10	F	1	13734
314	TU-960	0	10	F	2	13734
315	TU-960	0	10	G	1	10318
316	TU-960	0	10	G	2	10318
317	TU-960	0	10	H	1	13059
318	TU-960	0	10	H	2	13038
319	TU-960	0	10	I	1	12560
320	TU-960	0	10	I	2	13144
321	TU-960	0	10	J	1	11000
322	TU-960	0	10	K	1	10542
323	TU-960	0	10	K	2	10673
324	TU-960	0	10	L	1	8789
325	TU-960	4	2	A	1	12702
326	TU-960	4	2	A	2	12588
327	TU-960	4	2	B	1	12386
328	TU-960	4	2	B	2	13026
329	TU-960	4	2	C	1	11090
330	TU-960	4	2	C	2	11033
331	TU-960	4	2	D	1	9144
332	TU-960	4	2	D	2	10614
333	TU-960	4	2	E	1	8945
334	TU-960	4	2	E	2	8945
335	TU-960	4	2	F	1	10790
336	TU-960	4	2	F	2	10804
337	TU-960	4	2	G	1	10098
338	TU-960	4	2	G	2	10564
339	TU-960	4	2	H	1	10481
340	TU-960	4	2	H	2	10566
341	TU-960	4	2	I	1	9420

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	LABORATORY CODE	TEST NO	MR
342	TU-960	4	2	I	2	9420
343	TU-960	4	2	J	1	7800
344	TU-960	4	2	K	1	8304
345	TU-960	4	2	K	2	8304
346	TU-960	4	2	L	1	12172
347	TU-960	4	6	A	1	14250
348	TU-960	4	6	A	2	14259
349	TU-960	4	6	B	1	8923
350	TU-960	4	6	B	2	9290
351	TU-960	4	6	C	1	11270
352	TU-960	4	6	C	2	11241
353	TU-960	4	6	D	1	9481
354	TU-960	4	6	D	2	10264
355	TU-960	4	6	E	1	10189
356	TU-960	4	6	E	2	10150
357	TU-960	4	6	F	1	12432
358	TU-960	4	6	F	2	12435
359	TU-960	4	6	G	1	9567
360	TU-960	4	6	G	2	9576
361	TU-960	4	6	H	1	11927
362	TU-960	4	6	H	2	12386
363	TU-960	4	6	I	1	11119
364	TU-960	4	6	I	2	10939
365	TU-960	4	6	J	1	12300
366	TU-960	4	6	K	1	9650
367	TU-960	4	6	K	2	8999
368	TU-960	4	6	L	1	8776
369	TU-960	4	10	A	1	15958
370	TU-960	4	10	A	2	15938
371	TU-960	4	10	B	1	8671
372	TU-960	4	10	B	2	9241
373	TU-960	4	10	C	1	11863
374	TU-960	4	10	C	2	11863
375	TU-960	4	10	D	1	10688
376	TU-960	4	10	D	2	10243
377	TU-960	4	10	E	1	12146
378	TU-960	4	10	E	2	12133
379	TU-960	4	10	F	1	13283
380	TU-960	4	10	F	2	13283
381	TU-960	4	10	G	1	9544
382	TU-960	4	10	G	2	9620
383	TU-960	4	10	H	1	13038
384	TU-960	4	10	H	2	13017

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	LABORATORY CODE	TEST NO	MR
385	TU-960	4	10	I	1	12845
386	TU-960	4	10	I	2	12287
387	TU-960	4	10	J	1	12900
388	TU-960	4	10	K	1	10362
389	TU-960	4	10	K	2	9759
390	TU-960	4	10	L	1	8438

APPENDIX C

DATA BASE from the UNIVERSITY OF NEVADA-RENO
as provided by M. Stroup-Gardiner May 11, 1990 to Steele Engineering, Inc.
Data are for the synthetic specimens in the Type 2 experiment.

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	TECHNICIAN	REP	TEST	MR
1	TU-700	0	2	1	1	1	1717
2	TU-700	0	2	1	1	2	1799
3	TU-700	0	2	1	2	1	1824
4	TU-700	0	2	1	2	2	1769
5	TU-700	0	2	1	3	1	1818
6	TU-700	0	2	1	3	2	1801
7	TU-700	0	2	1	4	1	1766
8	TU-700	0	2	1	4	2	1824
9	TU-700	0	2	1	5	2	1833
10	TU-700	0	2	2	1	1	1796
11	TU-700	0	2	2	1	2	1728
12	TU-700	0	2	2	2	1	1749
13	TU-700	0	2	2	2	2	1858
14	TU-700	0	2	2	3	1	1867
15	TU-700	0	2	2	3	2	1781
16	TU-700	0	2	2	4	1	1767
17	TU-700	0	2	2	4	2	1850
18	TU-700	0	2	2	5	1	1871
19	TU-700	0	2	2	5	2	1861
20	TU-700	4	2	1	1	1	1862
21	TU-700	4	2	1	1	2	1831
22	TU-700	4	2	1	2	1	1826
23	TU-700	4	2	1	2	2	1758
24	TU-700	4	2	1	3	1	1727
25	TU-700	4	2	1	3	2	1750
26	TU-700	4	2	1	4	1	1832
27	TU-700	4	2	1	4	2	1961
28	TU-700	4	2	1	5	1	1799
29	TU-700	4	2	1	5	2	1799
30	TU-700	4	2	2	1	1	1809
31	TU-700	4	2	2	1	2	1811
32	TU-700	4	2	2	2	1	1835
33	TU-700	4	2	2	2	2	1826
34	TU-700	4	2	2	3	1	1845
35	TU-700	4	2	2	3	2	1842
36	TU-700	4	2	2	4	2	1842
37	TU-700	4	2	2	5	1	1871
38	TU-700	4	2	2	5	2	1834
39	TU-700	0	6	1	1	1	1880

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	TECHNICIAN	REP	TEST	MR
40	TU-700	0	6	1	2	1	1900
41	TU-700	0	6	1	2	2	1909
42	TU-700	0	6	1	3	1	1919
43	TU-700	0	6	1	4	1	1910
44	TU-700	0	6	1	5	1	1898
45	TU-700	0	6	2	1	1	1884
46	TU-700	0	6	2	1	2	1880
47	TU-700	0	6	2	2	1	1868
48	TU-700	0	6	2	2	2	1882
49	TU-700	0	6	2	3	1	1885
50	TU-700	0	6	2	3	2	1881
51	TU-700	0	6	2	4	1	1884
52	TU-700	0	6	2	4	2	1871
53	TU-700	0	6	2	5	1	1890
54	TU-700	0	6	2	5	2	1882
55	TU-700	4	6	1	1	1	1899
56	TU-700	4	6	1	2	1	1890
57	TU-700	4	6	1	2	2	1901
58	TU-700	4	6	1	3	1	1883
59	TU-700	4	6	1	3	2	1885
60	TU-700	4	6	1	4	1	1891
61	TU-700	4	6	1	5	1	1879
62	TU-700	4	6	1	5	2	1865
63	TU-700	4	6	2	1	1	1901
64	TU-700	4	6	2	1	2	1880
65	TU-700	4	6	2	2	1	1887
66	TU-700	4	6	2	2	2	1892
67	TU-700	4	6	2	3	1	1878
68	TU-700	4	6	2	3	2	1874
69	TU-700	4	6	2	4	1	1878
70	TU-700	4	6	2	4	2	1881
71	TU-700	4	6	2	5	1	1884
72	TU-700	4	6	2	5	2	1885
73	TU-700	0	10	1	1	1	1962
74	TU-700	0	10	1	1	2	1955
75	TU-700	0	10	1	2	1	1954
76	TU-700	0	10	1	2	2	1972
77	TU-700	0	10	1	3	1	1960
78	TU-700	0	10	1	3	2	1859
79	TU-700	0	10	1	4	1	1957
80	TU-700	0	10	1	4	2	1959
81	TU-700	0	10	1	5	1	1946
82	TU-700	0	10	1	5	2	1948

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	TECHNICIAN	REP	TEST	MR
83	TU-700	0	10	2	1	1	1936
84	TU-700	0	10	2	1	2	1945
85	TU-700	0	10	2	2	1	1936
86	TU-700	0	10	2	2	2	1969
87	TU-700	0	10	2	3	1	1949
88	TU-700	0	10	2	3	2	1952
89	TU-700	0	10	2	4	1	1942
90	TU-700	0	10	2	4	2	1937
91	TU-700	0	10	2	5	1	1962
92	TU-700	0	10	2	5	2	1940
93	TU-700	4	10	1	1	1	1947
94	TU-700	4	10	1	1	2	1954
95	TU-700	4	10	1	2	1	1959
96	TU-700	4	10	1	2	2	1959
97	TU-700	4	10	1	3	1	1949
98	TU-700	4	10	1	3	2	1847
99	TU-700	4	10	1	4	1	1945
100	TU-700	4	10	1	4	2	1945
101	TU-700	4	10	1	5	2	1943
102	TU-700	4	10	2	1	1	1957
103	TU-700	4	10	2	2	1	1977
104	TU-700	4	10	2	3	1	1977
105	TU-700	4	10	2	4	1	1971
106	TU-700	4	10	2	5	1	1966
107	DPTU1560	0	2	1	1	1	4248
108	DPTU1560	0	2	1	1	2	4311
109	DPTU1560	0	2	1	2	1	3864
110	DPTU1560	0	2	1	2	2	4346
111	DPTU1560	0	2	1	3	1	4061
112	DPTU1560	0	2	1	3	2	4200
113	DPTU1560	0	2	1	4	1	4013
114	DPTU1560	0	2	1	4	2	3852
115	DPTU1560	0	2	1	5	1	4063
116	DPTU1560	0	2	1	5	2	4169
117	DPTU1560	4	2	1	1	1	3981
118	DPTU1560	4	2	1	1	2	3962
119	DPTU1560	4	2	1	2	1	4017
120	DPTU1560	4	2	1	2	2	4216
121	DPTU1560	4	2	1	3	1	4176
122	DPTU1560	4	2	1	3	2	3824
123	DPTU1560	4	2	1	4	1	4262
124	DPTU1560	4	2	1	4	2	4061
125	DPTU1560	4	2	1	5	1	4175

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	TECHNICIAN	REP	TEST	MR
126	DPTU1560	4	2	1	5	2	4250
127	DPTU1560	0	6	1	1	1	4279
128	DPTU1560	0	6	1	2	1	4354
129	DPTU1560	0	6	1	3	1	4411
130	DPTU1560	0	6	1	5	1	4334
131	DPTU1560	4	6	1	1	1	4417
132	DPTU1560	4	6	1	1	2	4326
133	DPTU1560	4	6	1	2	1	4334
134	DPTU1560	4	6	1	2	2	4326
135	DPTU1560	4	6	1	3	1	4319
136	DPTU1560	4	6	1	3	2	4417
137	DPTU1560	4	6	1	4	1	4219
138	DPTU1560	4	6	1	4	2	4334
139	DPTU1560	4	6	1	5	1	4206
140	DPTU1560	4	6	1	5	2	4350
141	DPTU1560	4	10	1	1	1	4630
142	DPTU1560	4	10	1	1	2	4602
143	DPTU1560	4	10	1	2	1	4584
144	DPTU1560	4	10	1	2	2	4622
145	DPTU1560	4	10	1	3	1	4609
146	DPTU1560	4	10	1	3	2	4581
147	DPTU1560	4	10	1	4	1	4604
148	DPTU1560	4	10	1	4	2	4577
149	DPTU1560	4	10	1	5	1	4609
150	DPTU1560	4	10	1	5	2	4573
151	DPTU1560	0	10	1	1	1	4571
152	DPTU1560	0	10	1	1	2	4590
153	DPTU1560	0	10	1	2	1	4577
154	DPTU1560	0	10	1	3	1	4615
155	DPTU1560	0	10	1	3	2	4545
156	DPTU1560	0	10	1	4	1	4630
157	DPTU1560	0	10	1	4	2	4556
158	DPTU1560	0	10	1	5	1	4545
159	DPTU1560	0	10	1	5	2	4624
160	TU-960	0	2	1	1	1	9857
161	TU-960	0	2	1	1	2	9022
162	TU-960	0	2	1	2	1	9626
163	TU-960	0	2	1	2	2	9474
164	TU-960	0	2	1	3	1	9475
165	TU-960	0	2	1	3	2	9295
166	TU-960	0	2	1	4	1	9857
167	TU-960	0	2	1	4	2	9546
168	TU-960	0	2	1	5	1	10369

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	TECHNICIAN	REP	TEST	MR
169	TU-960	0	2	1	5	2	9017
170	TU-960	0	2	2	1	1	10757
171	TU-960	0	2	2	1	2	10263
172	TU-960	0	2	2	2	1	11416
173	TU-960	0	2	2	2	2	10723
174	TU-960	0	2	2	3	1	10746
175	TU-960	0	2	2	3	2	10974
176	TU-960	0	2	2	4	1	11194
177	TU-960	0	2	2	4	2	11172
178	TU-960	0	2	2	5	1	10728
179	TU-960	0	2	2	5	2	10753
180	TU-960	4	2	1	1	1	10955
181	TU-960	4	2	1	1	2	10589
182	TU-960	4	2	1	2	1	11011
183	TU-960	4	2	1	2	2	9634
184	TU-960	4	2	1	3	1	9773
185	TU-960	4	2	1	3	2	10523
186	TU-960	4	2	1	4	1	9467
187	TU-960	4	2	1	4	2	9956
188	TU-960	4	2	1	5	1	10343
189	TU-960	4	2	1	5	2	10390
190	TU-960	4	2	2	1	1	10840
191	TU-960	4	2	2	1	2	10975
192	TU-960	4	2	2	2	1	10358
193	TU-960	4	2	2	2	2	10390
194	TU-960	4	2	2	3	1	8857
195	TU-960	4	2	2	3	2	9105
196	TU-960	4	2	2	4	1	9078
197	TU-960	4	2	2	4	2	9258
198	TU-960	4	2	2	5	1	8836
199	TU-960	4	2	2	5	2	9738
200	TU-960	0	6	1	1	1	10219
201	TU-960	0	6	1	1	2	10326
202	TU-960	0	6	1	2	1	10025
203	TU-960	0	6	1	2	2	10349
204	TU-960	0	6	1	3	2	10481
205	TU-960	0	6	1	4	1	10142
206	TU-960	0	6	1	4	2	10268
207	TU-960	0	6	1	5	1	10366
208	TU-960	0	6	1	5	2	10258
209	TU-960	0	6	2	1	1	10088
210	TU-960	0	6	2	1	2	10338
211	TU-960	0	6	2	2	1	9567

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	TECHNICIAN	REP	TEST	MR
212	TU-960	0	6	2	2	2	10257
213	TU-960	0	6	2	3	1	10119
214	TU-960	0	6	2	3	2	10216
215	TU-960	0	6	2	4	1	10255
216	TU-960	0	6	2	4	2	10399
217	TU-960	0	6	2	5	1	10396
218	TU-960	0	6	2	5	2	10145
219	TU-960	4	6	1	1	1	10145
220	TU-960	4	6	1	1	2	10276
221	TU-960	4	6	1	2	1	10505
222	TU-960	4	6	1	2	2	10335
223	TU-960	4	6	1	3	1	10237
224	TU-960	4	6	1	3	2	10362
225	TU-960	4	6	1	4	1	10571
226	TU-960	4	6	1	4	2	10782
227	TU-960	4	6	1	5	1	10435
228	TU-960	4	6	1	5	2	10281
229	TU-960	4	6	2	1	1	9985
230	TU-960	4	6	2	1	2	10084
231	TU-960	4	6	2	2	1	9567
232	TU-960	4	6	2	2	2	9968
233	TU-960	4	6	2	3	1	10174
234	TU-960	4	6	2	3	2	10031
235	TU-960	4	6	2	4	1	9771
236	TU-960	4	6	2	4	2	9930
237	TU-960	4	6	2	5	1	10272
238	TU-960	4	6	2	5	2	10073
239	TU-960	0	10	1	1	1	10498
240	TU-960	0	10	1	1	2	10472
241	TU-960	0	10	1	2	1	10508
242	TU-960	0	10	1	2	2	10684
243	TU-960	0	10	1	3	1	10626
244	TU-960	0	10	1	3	2	10618
245	TU-960	0	10	1	4	1	10453
246	TU-960	0	10	1	4	2	10551
247	TU-960	0	10	1	5	2	10610
248	TU-960	0	10	2	1	1	10462
249	TU-960	0	10	2	1	2	10630
250	TU-960	0	10	2	2	2	10441
251	TU-960	0	10	2	3	1	10598
252	TU-960	0	10	2	3	2	10630
253	TU-960	0	10	2	4	1	10481
254	TU-960	0	10	2	4	2	10592

OBS	SPECIMEN	CONFINING PRESSURE	DEVIATOR STRESS	TECHNICIAN	REP	TEST	MR
255	TU-960	0	10	2	5	1	10608
256	TU-960	0	10	2	5	2	10563
257	TU-960	4	10	1	1	1	10620
258	TU-960	4	10	1	1	2	10634
259	TU-960	4	10	1	2	1	10709
260	TU-960	4	10	1	2	2	10692
261	TU-960	4	10	1	3	2	10418
262	TU-960	4	10	1	4	1	10454
263	TU-960	4	10	1	4	2	10759
264	TU-960	4	10	1	5	1	10659
265	TU-960	4	10	1	5	2	10547
266	TU-960	4	10	2	1	1	10285
267	TU-960	4	10	2	2	1	10330
268	TU-960	4	10	2	3	1	10521
269	TU-960	4	10	2	3	2	10326
270	TU-960	4	10	2	4	1	10362
271	TU-960	4	10	2	4	2	10315
272	TU-960	4	10	2	5	1	10509
273	TU-960	4	10	2	5	2	10505