SHRP-P-695

Round 1 Type II Unbound Cohesive Subgrade Soil Proficiency Sample Program

Garland W. Steele
Steele Engineering
Tornado, West Virginia

Charles E. Antle
Consulting Statistician
State College, Pennsylvania

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

Strategic Highway Research Program
National Research Council
Washington, DC 1994

SHRP-P-695
Product no. 5020

Program Manager: *Neil F. Hawks*
Project Manager: *Adrian Pelzner*
Program Area Secretaries: *Cynthia Baker, Francine A. Burgess*
Production Editor: *Katharyn L. Bine*

key words:

accreditation
laboratory testing
LTPP test protocol
proficiency testing
resilient modulus testing
subbase soil
unbound granular base

August 1994

Strategic Highway Research Program
National Research Council
2101 Constitution Avenue N.W.
Washington, DC 20418

(202) 334-3774

.450M/NAP/0894

Acknowledgments

The research described herein was supported by the Strategic Highway Research Program (SHRP). SHRP is a unit of the National Research Council that was authorized by section 128 of the Surface Transportation and Uniform Relocation Assistance Act of 1987.

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 subgrage 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.

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 that 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 research sample 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 by the Construction Materials Reference Laboratory (CMRL) at the National Institute of Standards and Technology (NIST), and participation in applicable proficiency sample series distributed by CMRL. However, a few critical tests in the 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. Three elements of primary importance, 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,

- 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.

- a sound estimate of the precision of laboratory resilient modulus test data generated on unbound cohesive subgrade soils during the time when LTPP field research samples were tested.

The approach taken to satisfy the needs noted in the first two elements is fully described in the final research report on "The Type II Unbound Cohesive Subgrade Soil Synthetic Reference Sample Program."

The Type II Unbound Cohesive Subgrade Soil Proficiency Sample Program research was designed, to fill the need indicated in the third element, 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 research program.

Samples for Round 1 of the Type II Unbound Cohesive Subgrade Soil Proficiency were prepared, certain laboratory tests performed, correspondence containing instructions to participating laboratories prepared, and samples shipped to participants 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 the round 1 proficiency sample research, a set of eight samples was shipped to each participant for testing in accordance with correspondence accompanying the round (see part II). The set of samples contained two different soils and participants prepared and tested two 2.8 in. diameter by 5.6 in. length test specimens from each of the eight samples. All participants were required to complete testing on the Type II synthetic reference sample set prior to testing the Round 1 proficiency samples.

Ten 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 correspondence, soil classification test data, and proficiency fabrication procedure for Round 1 is included in Appendix A of this report.

The final comments, analyses, conclusions and recommendations resulting from the Round 1 Type II Unbound Cohesive Subgrade Soil Proficiency 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

Florida Department of Transportation
Materials and Research Laboratory
PO Box 1029
Gainesville, FL 32602

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

Law Engineering
396 Plasters Avenue
Atlanta, GA 30324

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

Minnesota Department of Transportation
Materials and Research Laboratory
1400 Gervais Avenue
Maplewood, MN 55109

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

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

PART III RESEARCH ANALYSES, OBSERVATIONS, AND CONCLUSIONS

1. Background

This experiment was designed with the following objectives:

- To evaluate the capability of the participating laboratories in measuring the resilient modulus of Type II unbound subgrade soil samples.

- To evaluate the sources of variability that are due to the laboratories, sampling of materials, and the measuring process.

- To evaluate the effects of confining pressure and deviator stress on the measurements of the resilient modulus.

A total of ten laboratories participated in this program. Data from nine of these were available for analysis at the time this report was written. This allowed for comparisons of the performance of the laboratories and this was done in several analyses as well as in the descriptive statistics presented in the figures and tables. This provides the participating laboratories with an excellent means for evaluating their performance in respect to that of the group, and this is the purpose stated in the first objective.

This experiment was designed so that the sources of variation in the measured M_R values could be evaluated for the group of participating laboratories. A statistical model for the experimental data was developed in order to separate and evaluate the different sources of variation in the measured values for the M_R. The variability due to the laboratories, that is the LABORATORY component of variance, is the first source identified. The within laboratory variation is separated into three components; the first is the PAIR, the second is the SAMPLE, and the third is the MEASUREMENT. These are discussed more fully in the sections which follow.

The design of this experiment also allowed for an evaluation of the effects of the confining pressure and deviator stress on the measured values of the resilient modulus. Three levels of the confining pressure and five levels of the deviator stress were included in the experiment and this provides an excellent data base with which to evaluate the effects of these factors.

2. Design of the Experiment

As described in Part I of this report each laboratory was sent a total of eight samples for testing--four samples of material A and four samples of material B. Material A was classified as an A-5-(8) silty soil and material B as an A-7-5-(16) clay soil. At the participating laboratories, each sample was subdivided into two subsamples. A procedure for subdividing the samples and preparing the test specimens for material (A and B) was sent to each laboratory. Details of this procedure are given in Appendix A. According to the experiment design, a total of sixteen test specimens, eight for each material, were to be tested at each participating laboratory.

Each material was first subdivided into 25-lb samples at the Maryland Department of Transportation. These 25-lb samples were subsequently subdivided, again at the Maryland Department of Transportation, into 12.5-lb samples. Four of these 12.5-lb samples were randomly assigned to each participating laboratory. At the participating laboratory, each 12.5-lb sample was further subdivided into two subsamples and a test specimen was prepared from each subsample. Thus, for each material eight test specimens were prepared and components of variance were assigned as follows:

- LABORATORY--resulting from effect of laboratory
- PAIR--resulting from the effect of dividing the batch of material into 25-lb samples, performed at the Maryland Department of Transportation
- SAMP--resulting from the effect of subdividing the 25-lb samples into 12.5-lb samples, four of which were sent to the participating laboratories

- MEASUREMENT--resulting from both measurement errors in the particular participating laboratory and the effect of subdividing the 12.5-lb sample into two test specimens, performed at the participating laboratory.

The first level of division performed at the Maryland Department of Transportation was designated as PAIR (this produced the 25-lb samples). For each 25-lb sample there was a division into two samples noted as SMP in the data base (this produced the 12.5-lb samples). Thus the PAIR is nested in the LABORATORY and the SMP is nested in the PAIR. The analyses of variance was structured to take this sample splitting process into account. The final division of the 12.5-lb samples at the participating laboratory into two subsamples for testing provided two test specimens from each of the samples, thereby providing the means to evaluate the component of variance noted as the MEASUREMENT component.

A test specimen was prepared from each of the subsamples described above and tested under a set of conditions specified by the confining stress (noted as CONF hereafter) and the deviator stress (noted as DEVID hereafter) as described in Appendix B. There were three levels for CONF (2, 4, and 6 psi) and five levels for DEVID (2, 4, 6, 8, and 10 psi). These 15 combinations for the two factors were used in testing each of the specimens. These constitute the subplot treatments in the experiment.

It may be noted that the MEASUREMENT error contains the errors in the measuring process and the differences due to the real differences in the two subsamples. Perhaps it should also be noted that most of the laboratories reported CONF and DEVID as the levels noted above, but one laboratory reported measured values. These measured values were rounded to the nearest level as stated for the experiment (2, 4, etc.) and these levels were used in all of the analyses reported in this report.

3. Results for the Group of Laboratories

The apparent laboratory differences may be observed in Figures 1 and 2 where the laboratory averages (averaged over deviator stress and confining pressure) for the measurements of M_R

for materials A and B are presented. It is clear from these figures that laboratory A has values that are much higher than the other laboratories. It was suggested in an early analysis that this laboratory should be omitted from the statistical analysis and that was done. It is also questionable whether or not laboratory C should be regarded as an outlier. It will be seen later that there are other reasons for suggesting that laboratory C be omitted from the statistical analysis. Laboratory I had the lowest average values for both materials and was regarded as an outlier.

It was noted in the description of the experiment that at each laboratory there were two subsamples from each sample of material and these subsamples were tested under the same set of conditions. These may be regarded as two independent measurements and as such provide a means for the evaluation of the MEASUREMENT variability within each laboratory. A convenient measure of this variability within a laboratory is the coefficient of variation or the CV as it is abbreviated. The averages of these within laboratory CV's for the MEASUREMENT component are given in Table 1 for all of the laboratories in this experiment. This same information is presented in Figure 3. It may be seen from this figure that the variability in the measurements at laboratory C are unreasonably large. When considered with the fact that the average for the measurements was also questionable, it is clear that the data from this laboratory should not be used in the further statistical analyses.

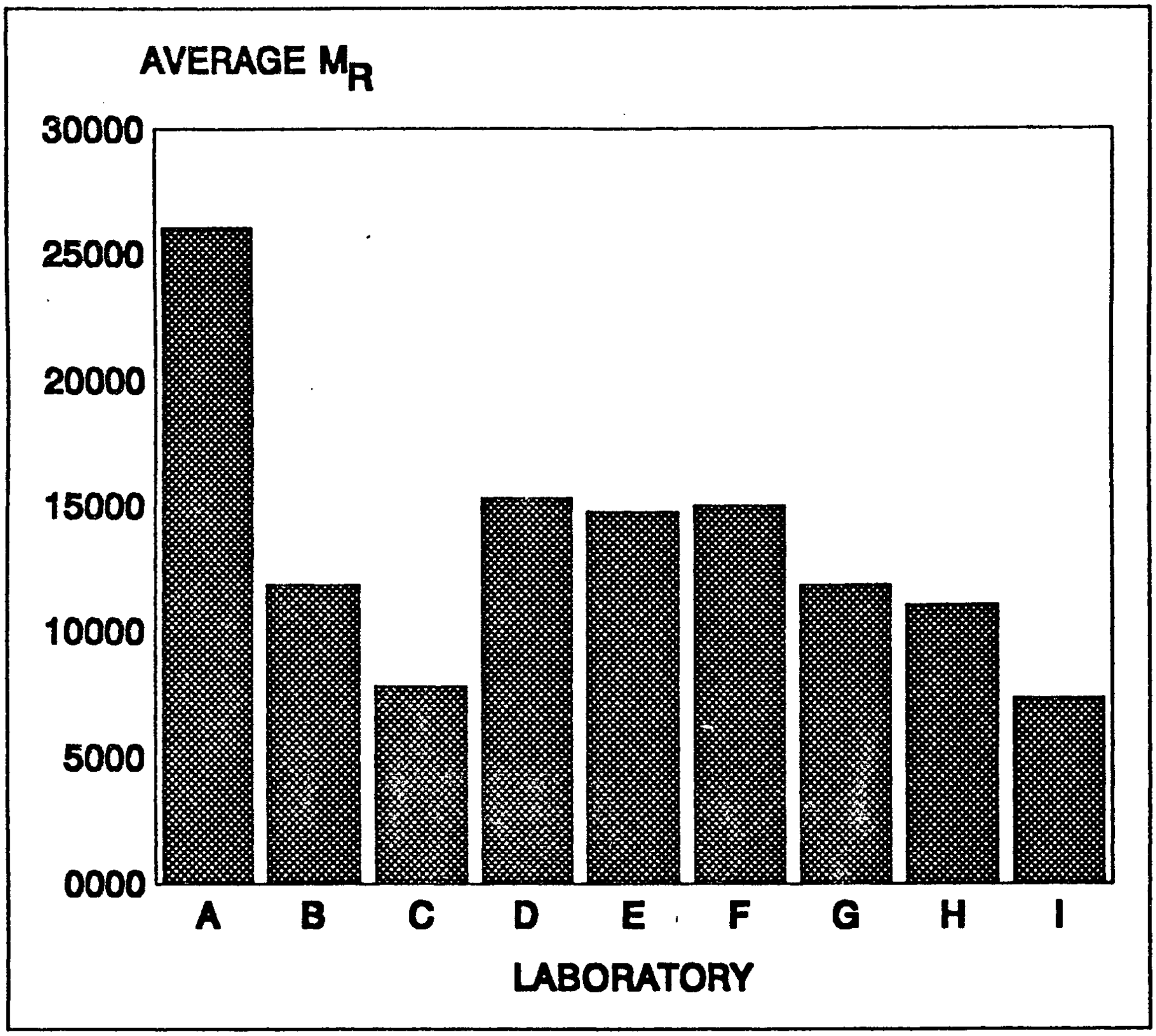


Figure 1. M_R Averages for Material A by Laboratory for Type II Soils Experiment.

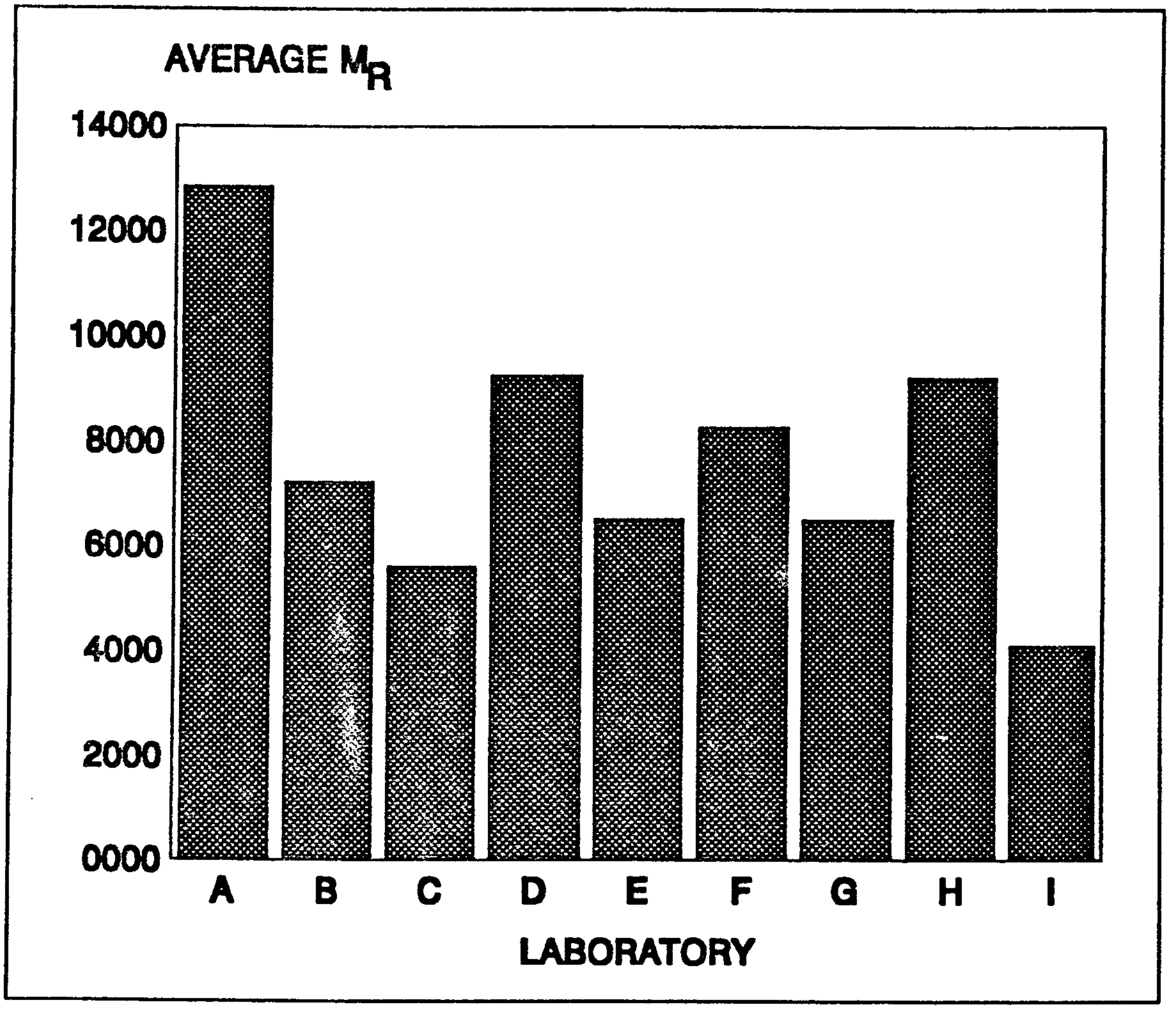


Figure 2. M_R Averages for Material B by Laboratory for Type II Soils Experiment.

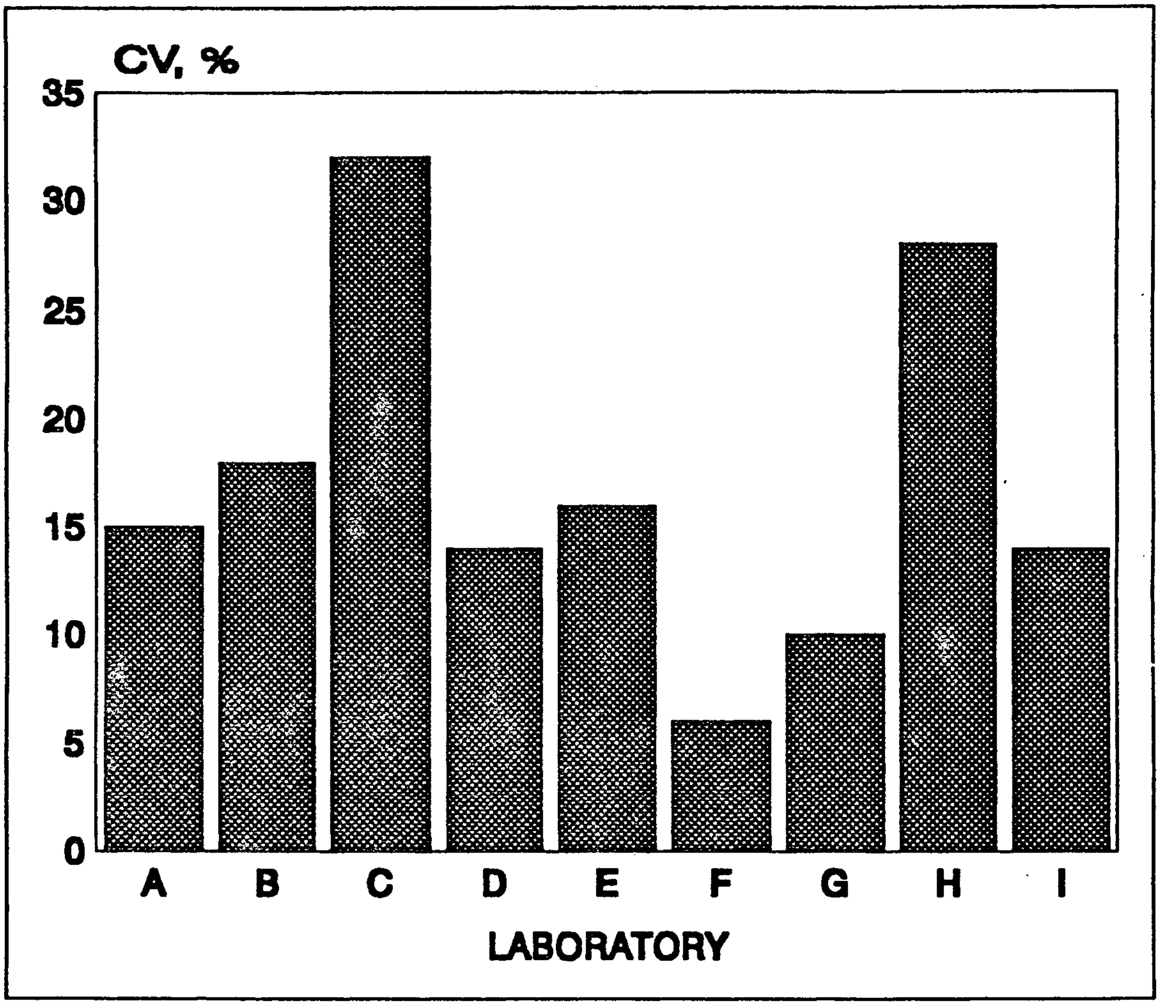


Figure 3. Averages of Within Laboratory Coefficients of Variation for M_R Tests for the Type II Soils Experiment.

Table 1. Averaged Coefficient of Variation for the Within Laboratories Pooled Standard Deviation.

Laboratory	CV, %	N
A	15%	30
B	18%	30
C	32%	30
D	14%	30
E	16%	30
F	6%	30
G	10%	30
H	28%	12

Laboratory H provided about half of the data which the other laboratories provided. There were several features in the data from laboratory H which were not observed in the other laboratories data. It will also be noted from Table 1 and Figure 3 that the measurement errors at laboratory H were second only to those at laboratory C.

It is difficult to omit data from an experiment when the number of laboratories is already less than desired. However, the influence of the outliers is clearly greater when the number of laboratories is small, so it is still important to omit the outliers. In the remainder of this report the analysis and results will be for the remaining laboratories, i.e., B, D, E, F and G, unless noted otherwise.

4. A Statistical Model for the Components of Variance

The following statistical model is useful in describing and evaluating the sources of the observed variation in the measured values for the M_r when a given specimen is subjected to given levels of the CONF and DEVID;

$$M_R(I,J,K,L) = MU + LABORATORY(I) + PAIR(I,J) + SAMPLE(I,J,K) + MEASUREMENT(I,J,K,L)$$

where each of these terms in the model is a normal random variable with respective standard deviations of SIGMA(LAB), SIGMA(PAIR), SIGMA(SAMPLE), and SIGMA(MEASUREMENT). It should be noted that each of these effects is nested in the ones that are given before it. For example, the SAMPLE(I,J,K) term is the added effect for sample K from pair J at laboratory I. For each of the two materials and each combination of the CONF and DEVID a nested analysis of variance will provide estimates for these standard deviations. It is these estimated standard deviations that provide an evaluation of the effects of the identified sources of variation in the M_R measurements. These estimated standard deviations are given in Table 2. These estimated standard deviations also provide the basis for the data given in Part IV that are required for precision statements . It will be useful to divide each of these estimated standard deviations by the estimated M_R for the material in

Table 2. Estimated Standard Deviations for the Factors in the Components of Variance Model (Laboratories B, D, E, F and G).

Material	Deviator Stress (psi)	Confining Pressure (psi)	Average M_R (psi)	Standard Deviation			
				Lab	Pair	Sample	Measurement
A	2	2	15,230	2,637	831	0	2,540
A	2	4	15,584	1,958	726	0	2,224
A	2	6	15,645	0	1,875	1,071	2,379
A	4	2	13,277	1,373	1,096	0	1,752
A	4	4	14,153	1,247	1,133	342	1,805
A	4	6	14,434	1,040	1,216	468	1,910
A	6	2	12,690	1,611	1,046	0	1,664
A	6	4	13,374	1,328	1,525	621	1,466
A	6	6	13,549	1,959	822	636	964
A	8	2	12,541	1,803	615	0	1,706
A	8	4	13,098	1,620	739	0	1,891
A	8	6	13,675	1,357	1,179	761	1,620
A	10	2	12,350	1,867	566	0	1,754
A	10	4	13,091	1,628	811	0	1,643
A	10	6	13,385	1,286	951	848	1,471
B	2	2	10,248	1,563	1,276	1,802	1,205
B	2	4	10,448	1,684	831	715	985
B	2	6	9,852	1,215	979	0	2,047
B	4	2	8,043	1,374	551	468	848
B	4	4	8,435	1,130	570	420	824
B	4	6	8,579	1,215	360	540	798
B	6	2	7,054	1,241	239	332	681
B	6	4	7,368	1,054	307	409	730
B	6	6	7,012	980	444	623	333
B	8	2	6,198	1,113	220	252	626
B	8	4	6,359	598	332	213	1,360
B	8	6	6,554	1,072	203	241	618
B	10	2	5,715	1,142	127	184	591
B	10	4	5,926	1,004	71	305	566
B	10	6	5,968	954	271	390	535

order to give more meaning to the respective components of variation and this will be done in some of the following analyses.

This experiment provides information on the variability that is accounted for by the laboratories through the added term, LABORATORY(I), for each of the laboratories. This may be regarded as the laboratory bias. This component is important in the development of inter laboratory precision statements. This experiment also provides information on the variability that is the result of the sampling from the source of the material. This is the added term, PAIR(I,J), which allows each member of a particular pair of samples to have its own effect or difference. This is a sampling component, and should not have a large effect in this experiment as care was taken to sample from a very homogeneous source for the two members of a pair. The variability that results from the division of the pair into two sets of two samples is accounted for by the component SAMPLE(I,J,K) in the model. This is also a sampling component and it also should be small as long as proper care was taken in the sample splitting process. In fact the variation due to this component was small, sometimes resulting in a negative estimate for its variance in which case it was estimated as zero. The small variability associated with the factors SAMP and PAIR is indeed a strong endorsement for the careful splitting process followed by the Maryland Department of Transportation and this process should be followed in subsequent studies.

In the development of within laboratory limits, it would seem that the only component in the model that should be considered is the MEASUREMENT ERROR(I,J,K,L). It should again be noted that this component does in fact contain the variation due to the final division of the sample into two subsamples and the measuring process on these subsamples.

It is useful to consider the coefficient of variation (CV) associated with each of the sources of variation, that is with the terms in the above model. The coefficient of variation, the standard deviation assigned to the source divided by the average of the measured M_R, is generally somewhat independent of the magnitude of the measured values. It is helpful to compare the CV's from different experiments, rather than standard deviations, in order to assess the sources of variability in the measurements. It is often reasonable and useful to average CV's. The averaged coefficients of variation for the sources of variation identified in this components of variance model are given in Table 3 for each of the materials when tested at each of the levels of the deviator stress. It will be seen in Table 3 that the variability due to the laboratories is about 13% of the measured M_R. The variability due to the measuring process is about 12% so that these two sources are contributing about equally to the variation in the measured values.

5. The Effects of the Confining Pressure and the Deviator Stress

The effect of the deviator stress level on the measured values of M_R can be clearly seen in Figure 5 for material A and in Figure 6 for material B. Appropriate tests of significance for the observed decreases in the measured M_R provide strong assurances that these decreases at these laboratories are real. The data for these figures represent the average over the confining pressure levels and over all of the specimens of the stated material. It does appear that the low values of the deviator stress (2 psi in particular) produce measurements that are inconsistent with those at the higher levels of the deviator stress for both materials. The pattern is especially true for material B as shown in Figure 5. Where the M_R appears to increase abruptly as the deviator stress is decreased from 4 to 2 psi. It should be further noted that the standard deviation appears to increase with decreasing values of confining pressure, Table 2. Taken together, these observations may imply an inherent difficulty with measurements at low confining pressures.

Table 3. Coefficient of Variation for Each Factor in the Components of Variance Model (Laboratories B, D, E, F and G).

Material	Deviator Stress	Average M_R	Coefficient of Variation, % Lab	Pair	Sample	Measurement
A	2	15,487	10	7	2	15
A	4	13,955	9	8	2	13
A	6	13,204	12	9	3	10
A	8	13,105	12	6	2	13
A	10	12,942	12	6	2	13
B	2	10,183	15	10	8	14
B	4	8,352	15	6	6	10
B	6	7,144	15	5	6	8
B	8	6,370	15	4	4	14
B	10	5,870	18	3	5	10
Average Material A		13,738	11	7	2	13
Average Material B		7,584	15	5	6	11
Overall Average		---	13	6	4	12

To demonstrate the effect of deviator stress on M_R, the differences between the M_R values measured at 2 and 10 psi are given in Table 4 where the differences are also expressed as a percentage of the M_R values averaged over all of the deviator stresses. The 2-sided P-values do indeed indicate that the deviator stress does affect the measured M_R value. Of course, based upon published data and experience in the field, the M_R is expected to vary with the deviator stress. The t test which were used in developing the P values for Tables 4 and later in Table 5 were based upon the paired data at each laboratory. This is the appropriate method for these problems since the data at the two levels of deviator stress or confining pressure are dependent data. Since there is no pooling of the standard deviation over the laboratories, the P values depend upon both the observed average differences at a laboratory and the variation of these differences at that laboratory. Hence, for example, in Table 5 an observed 13 percent difference at Laboratories A and B for material B produces different P values.

The effect of the confining pressure on the measured values of M_R may be seen in Figure 6 for material A and in Figure 7 for material B. Differences between the M_R values obtained at 6 and 2 psi confining pressure are given in Table 5, where the differences are also expressed as a percentage of the M_R values averaged over the deviator stresses. Appropriate tests of significance, P-values, indicate that the observed differences between the measurements at 6 psi and at 2 psi for material A are significant at the .01 level or lower, except for laboratories C and D. The tests of significance in the case of material B indicated reasonable significance for the observed differences except for laboratory F. However, while most of the measurements increase as the confining pressure increases, it must be noted that laboratory F reported measurements which decreased at 6 psi for the confining pressure. Nevertheless, it must be observed that the measured M_R does increase with confining pressure. These increases are not large as might be expected for a cohesive soil.

The averaged values of the measured M_R for the combinations of the confining pressure and deviator stress are given in Appendix B. The complete data base is also available for further analyses as needed.

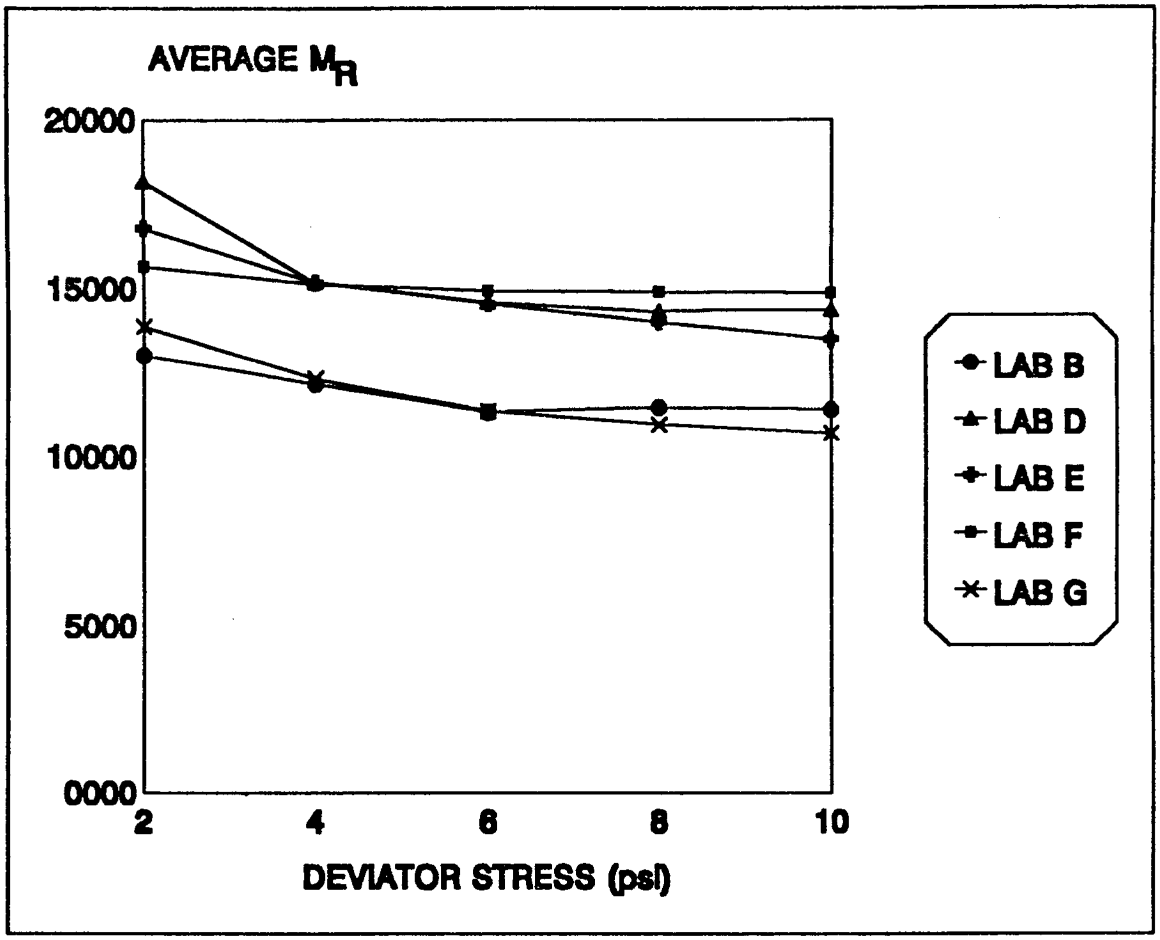


Figure 4. Average M_R Measurements by Deviator Stress Levels for Material A.

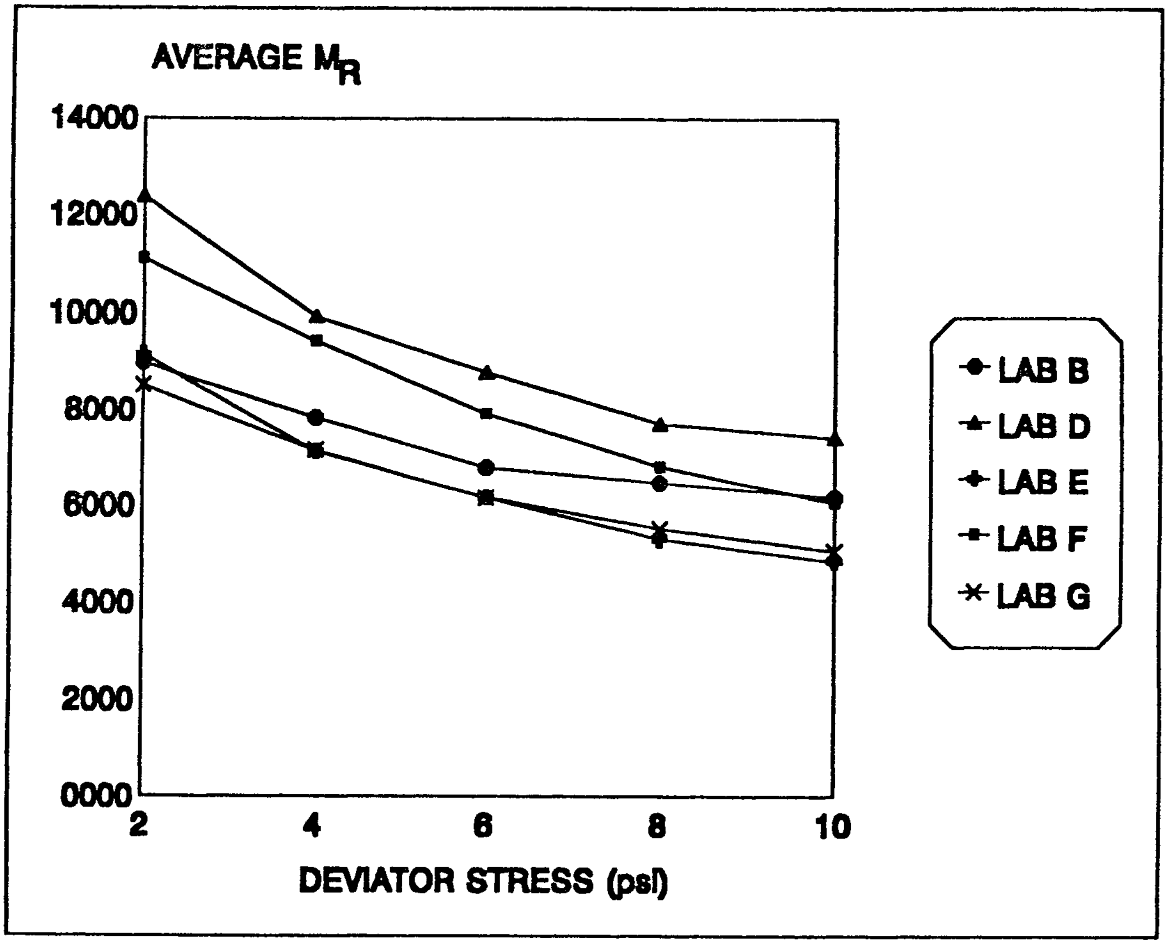


Figure 5. Average M_R Measurements by Deviator Stress Levels for Material B.

Table 4. Average Differences in M_R for Deviator Stress Levels 10 and 2 psi and the Measured Significance Level (P-Value) for the Observed Differences.

Material	Lab	Average Difference	Average M_R	Percent Difference	P-Value (2 sided)
A	A	-13,687	29,568	-46%	.001
A	B	-1,421	12,098	-12%	.005
A	C	-5,354	9,272	-58%	.009
A	D	-3,999	16,355	-24%	.001
A	E	-3,610	15,141	-24%	.000
A	F	-854	15,279	-6%	.037
A	G	-3,190	12,292	-26%	.000
A	H	12,134	10,372	117%	.000
B	A	-7,278	14,004	-52%	.000
B	B	-2,760	7,543	-37%	.000
B	C	-9,645	8,185	-118%	.055
B	D	-4,984	9,921	-50%	.000
B	E	-4,392	7,022	-63%	.000
B	F	-5,136	8,630	-60%	.000
B	G	-3,428	6,806	-50%	.000
B	H	9,157	8,610	106%	.001

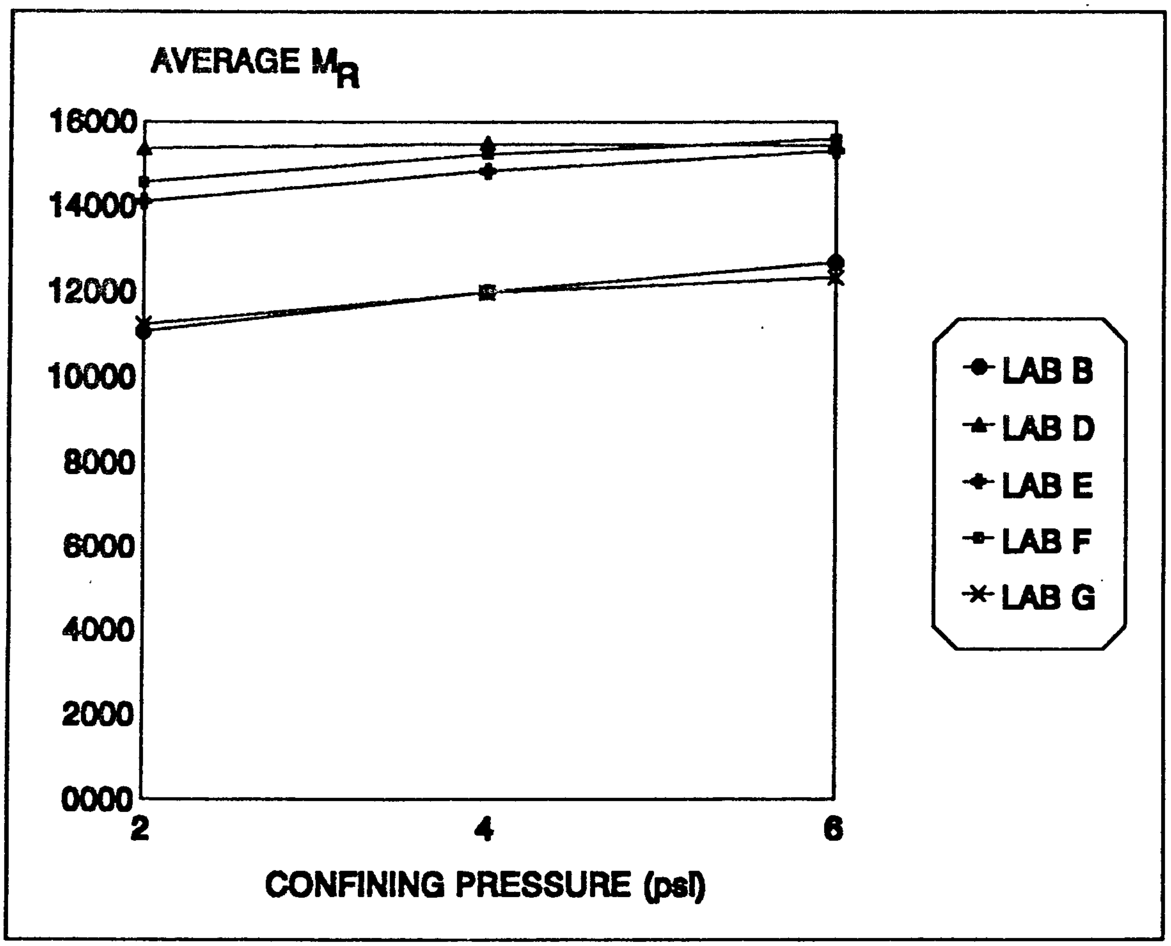


Figure 6. Average M_R Measurements by Confining Pressure Levels for Material A.

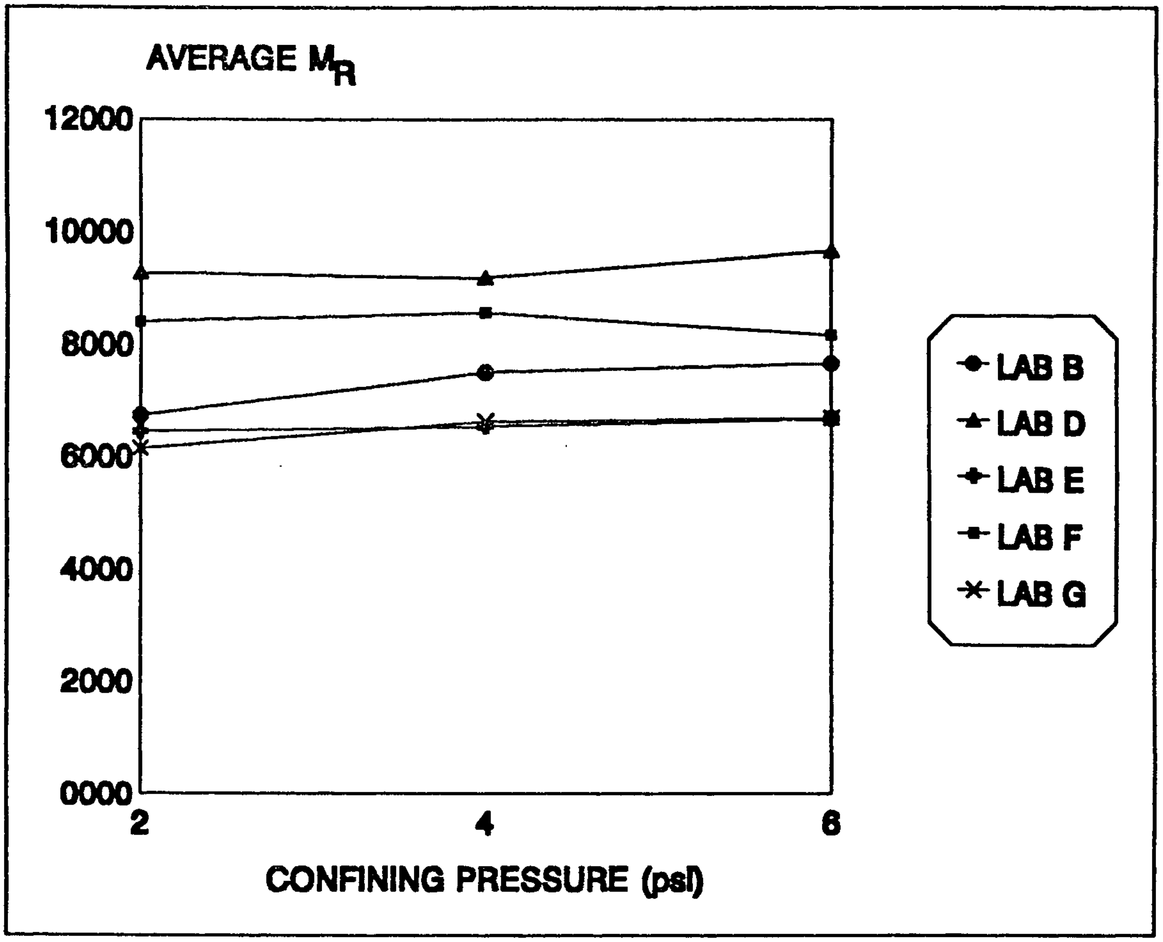


Figure 7. Average M_R Measurements by Confining Pressure Levels for Material B.

Table 5. Averaged Difference in Measured M_R for Confining Pressure Levels 6 and 2 psi and Significance Level (P-Value) for the Observed Differences.

Material	Lab	Average Difference	Average M_R	Percent Difference	P-Value (2 sided)
A	A	5,740	26,351	22%	.000
A	B	1,608	11,867	14%	.000
A	C	-23	7,736	-0%	.946
A	D	73	15,404	0%	.896
A	E	1,203	14,707	8%	.004
A	F	1,022	15,069	7%	.003
A	G	1,091	11,779	9%	.000
B	A	1,703	12,762	13%	.001
B	B	930	7,201	13%	.018
B	C	1,226	5,526	22%	.118
B	D	394	9,466	4%	.035
B	E	236	6,570	4%	.264
B	F	-224	8,288	-3%	.030
B	G	506	6,451	8%	.032

6. Conclusions

The values for the coefficient of variation for the laboratories, for the sampling components (PAIR and SAMPLE), and for the measurements as given in the tables and figures appear to be reasonable. However, it must be noted that these were developed using data from only five of the eight laboratories which provided data. It must be observed that the performance of the 8 laboratories was not uniformly good, but some are indeed much better than others in the group. The findings and conclusions stated in this report are most probably not applicable to the general population of laboratories performing triaxial test on cohesive soils. The between and within laboratory variability for the general population would most likely be considerably greater that reported for the selected laboratories in this study.

The performance of laboratory F should receive more attention. The within laboratory precision at this laboratory was quite outstanding as noted by the coefficient of variation (about 6%, see Figure 3). Furthermore it will be observed that the values reported from this laboratory are near the middle for the group of laboratories, both for material A and B (See Figures 1 and 2). The observed outstanding performance at this laboratory most likely reflects excellent quality control and not mere chance. A detailed inspection of the operating procedures and level, of technician skill at his laboratory may provide information that can be used to enhance the overall test procedure.

The differences among laboratories as indicated by the coefficient of variation for the laboratory component of variance can be addressed in three ways. First, the laboratories could be asked to reevaluate their procedures and equipment calibration and repeat the testing with the synthetic specimens to make an attempt to bring their laboratory into better conformance with the other laboratories. This is the preferred approach.

Second, a physical calibration using synthetic specimens of known M_R could be done on a regular basis. This would seem to be an acceptable, although not preferred alternative, as the laboratory component of variance is about the same value as the within laboratory component of variance. Thirdly, the data in this study should provide the means for a statistical calibration for the participating laboratories. There is little promise for the three (A, C and H) in this regard due to the manner in which their data were not generally consistent in any respect. The question of whether a statistical calibration will be dependent upon the source of the materials, i.e. how wide a range of materials, values, etc., will require some further evaluation. Any use of a statistical "correction" should be used with great caution because it is analogous to treating the symptoms of a disease rather than the disease itself.

Consideration should be given to the establishment of an appropriately designed and operated reference specimen program for laboratories performing triaxial M_R tests on 2.8 inch diameter by 5.6 inch length soil specimens. Such a program should aid in reducing the among-laboratory variability revealed in this research.

It is clear that there is an effect due to the confining pressure. Generally the measured M_R increased with increasing levels of confining pressure. There may be a small decrease in the variation of the data with increasing levels of the confining pressure.

It is also clear that there is an effect due to the deviator stress. Generally the measured M_R decreased with increasing levels of deviator stress. There is a considerable decrease in the variation of the data with increasing levels of the deviator stress. The results as given in Part IV should be useful in considering the choice of deviator stress to be recommended in practice. It is clear that the variability as reported in Part IV for deviator stress levels of 2 psi are much higher than the variability with higher levels of deviator stress and the desirability of using 2 psi in future testing should be questioned.

It may be concluded that the laboratory component of variance and the measurement component are of about the same magnitude. Both are about 12-13% when averaged over all levels of the deviator stress and the confining pressure. The variance resulting from the different levels of sampling was quite low and justifies the careful sample splitting procedure followed in this study.

Appropriately designed rounds of proficiency sample testing should be regularly scheduled for distribution to laboratories performing this test on subgrade soils, particularly those involved in the LTPP research. Such proficiency sample rounds would provide participants in this research the data base necessary for statistical calibration, if needed, of the laboratories involved during the time tests are performed, thus allowing a more reliable comparison of data generated in triaxial M_R tests on 2.8 inch diameter by 5.6 inch length specimens for all phases of the research.

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 multiplied 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 6. Precision Statements for Round 1 Type II Proficiency Samples.
Material A

Specimen & Type of Index	Mean Total M_R (psi) at 2 psi deviator stress	1s[1]	1s%[1]	d2s[1]
Single Operator Precision				
confining pressure				
2 psi	15,230	2,540	17%	7,183
4 psi	15,584	2,224	14%	6,289
6 psi	15,645	2,379	15%	6,728
Among-laboratories Precision				
confining pressure				
2 psi	15,230	3,661	24%	10,354
4 psi	15,584	2,963	19%	8,380
6 psi	15,645	2,379	15%	6,728

[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 Round 1 Type II Proficiency Samples.
Material A

Specimen & Type of Index	Mean Total M_R (psi) at 4 psi deviator stress	1s[1]	1s%[1]	d2s[1]
Single Operator Precision				
confining pressure				
2 psi	13,277	1,752	13%	4,955
4 psi	14,153	1,805	13%	5,105
6 psi	14,434	1,910	13%	5,401
Among-laboratories Precision				
confining pressure				
2 psi	13,277	2,226	17%	6,295
4 psi	14,153	2,194	16%	6,204
6 psi	14,434	2,175	15%	6,150

[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 8. Precision Statements for Round 1 Type II Proficiency Samples.
Material A

Specimen & Type of Index	Mean Total M_R (psi) at 6 psi deviator stress	1s[1]	1s%[1]	d2s[1]
Single Operator Precision				
confining pressure				
2 psi	12,690	1,664	13%	4,706
4 psi	13,374	1,466	11%	4,146
6 psi	13,549	964	7%	2,726
Among-laboratories Precision				
confining pressure				
2 psi	12,690	2,316	18%	6,550
4 psi	13,374	1,978	15%	5,594
6 psi	13,549	2,183	16%	6,174

[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 9. Precision Statements for Round 1 Type II Proficiency Samples.
Material A

Specimen & Type of Index	Mean Total M_R (psi) at 8 psi deviator stress	1s[1]	1s%[1]	d2s[1]
Single Operator Precision				
confining pressure				
2 psi	12,541	1,706	14%	4,825
4 psi	13,098	1,891	14%	5,348
6 psi	13,675	1,620	12%	4,581
Among-laboratories Precision				
confining pressure				
2 psi	12,541	2,482	20%	7,020
4 psi	13,098	2,490	19%	7,042
6 psi	13,675	2,113	15%	5,976

[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 10. Precision Statements for Round 1 Type II Proficiency Samples.
Material A

Specimen & Type of Index	Mean Total M_R (psi) at 10 psi deviator stress	1s[1]	1s%[1]	d2s[1]
Single Operator Precision				
confining pressure				
2 psi	12,350	1,754	14%	4,960
4 psi	13,091	1,643	13%	4,646
6 psi	13,385	1,471	11%	4,160
Among-laboratories Precision				
confining pressure				
2 psi	12,350	2,562	21%	7,244
4 psi	13,091	2,313	18%	6,541
6 psi	13,385	1,953	15%	5,526

[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 11. Precision Statements for Round 1 Type II Proficiency Samples. Material B

Specimen & Type of Index	Mean Total M_R (psi) at 2 psi deviator stress	1s[1]	1s%[1]	d2s[1]
Single Operator Precision				
confining pressure				
2 psi	10,248	1,205	12%	3,408
4 psi	10,448	985	9%	2,786
6 psi	9,852	2,047	21%	5,789
Among-laboratories Precision				
confining pressure				
2 psi	10,248	1,974	19%	5,581
4 psi	10,448	1,951	19%	5,517
6 psi	9,852	2,380	24%	6,732

[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 12. Precision Statements for Round 1 Type II Proficiency Samples.
Material B

Specimen & Type of Index	Mean Total M_R (psi) at 4 psi deviator stress	1s[1]	1s%[1]	d2s[1]
Single Operator Precision				
confining pressure				
2 psi	8,043	848	11%	2,398
4 psi	8,435	824	10%	2,330
6 psi	8,579	798	9%	2,257
Among-laboratories Precision				
confining pressure				
2 psi	8,043	1,615	20%	4,566
4 psi	8,435	1,399	17%	3,955
6 psi	8,579	1,454	17%	4,111

[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 13. Precision Statements for Round 1 Type II Proficiency Samples. Material B

Specimen & Type of Index	Mean Total M_R (psi) at 6 psi deviator stress	1s[1]	1s%[1]	d2s[1]
Single Operator Precision				
confining pressure				
2 psi	7,054	681	10%	1,926
4 psi	7,368	730	10%	2,064
6 psi	7,012	333	5%	942
Among-laboratories Precision				
confining pressure				
2 psi	7,054	1,416	20%	4,003
4 psi	7,368	1,282	17%	3,626
6 psi	7,012	1,035	15%	2,927

[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 14. Precision Statements for Round 1 Type II Proficiency Samples. Material B

Specimen & Type of Index	Mean Total M_R (psi) at 8 psi deviator stress	1s[1]	1s%[1]	d2s[1]
Single Operator Precision				
confining pressure				
2 psi	6,198	626	10%	1,770
4 psi	6,359	1,360	21%	3,846
6 psi	6,554	618	9%	1,748
Among-laboratories Precision				
confining pressure				
2 psi	6,198	1,277	21%	3,611
4 psi	6,359	1,486	23%	4,201
6 psi	6,554	1,237	19%	3,499

[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 15. Precision Statements for Round 1 Type II Proficiency Samples.
Material B

Specimen & Type of Index	Mean Total M_R (psi) at 10 psi deviator stress	1s[1]	1s%[1]	d2s[1]
Single Operator Precision				
confining pressure				
2 psi	5,715	591	10%	1,671
4 psi	5,926	566	10%	1,601
6 psi	5,968	535	9%	1,513
Among-laboratories Precision				
confining pressure				
2 psi	5,715	1,286	22%	3,636
4 psi	5,926	1,153	19%	3,259
6 psi	5,968	1,094	18%	3,093

[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

July 24, 1990

Dear

Enclosed is Round I of the S.H.R.P. Type II Soil Proficiency Samples. This round consists of eight samples. This material has been randomly selected and shipped to your lab for testing as part of the S.H.R.P. Long Term Pavement Performance (L.T.P.P.) on the Resilient Modulus of Unbound Subgrade Materials (S.H.R.P. Protocol P-46, Type II Soil).

Care should be taken during the testing to maintain the identity of each sample as a Components of Variance Analysis will be performed on the data obtained at the completion of Round I.

Two specimens (2.8 in. diameter by 5.6 in. high) from each of the eight samples should be made and tested in accordance with S.H.R.P. Protocol P-46, except that the molding procedure shall be as follows:

1) Each specimen shall be molded at its optimum moisture content to 95% of its maximum dry density.
2) Air dry the material.
3) Calculate the amount of soil and water required to form a specimen 5.6 in. in height by 2.8 in. in diameter.
4) Weigh out the exact amount of soil and water required for each specimen and combine. Keep the material for each specimen in a separate container.
5) After mixing the soil and water, allow the material to cure in a sealed container for at least 24 hours.
6) Mold the 2.8 in. by 5.6 in. specimens using static compaction by the double plunger method similar to the method outlined in A.S.T.M. D1632-87, Section 9.0. The specimen shall be compacted to the exact height desired.
7) Remove the specimen from the mold by suitable means that do not change its density or moisture content. The surface of the specimen shall be free of voids or other defects.

continued Page Two

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

The optimum moisture content and maximum dry density of the samples are:

Sample	Max. Dry Density	Optimum Moisture Content
4 samples with prefix "A"	86.0 pcf	30.0%
4 samples with prefix "B"	81.5 pcf	31.8%

Do not test this material until you have verified the calibration your equipment using the synthetic verification samples now in circulation and have received notice to proceed from Mr. Garland Steele. Record all data on copies of the attached data sheet and return to me as soon as the tests are complete.

If you have any questions, please call me at 1-301-321-3417 or Mr. Garland Steele at 1-304-727-8719.

Sincerely,

Edmund J. Oberc

EJO:mlm

Procedure Used for Fabricating and Distribution of Type II Proficiency Samples

- Obtain sufficient material from each source to provide the total required mass.
- Air dry the material until friable and pass through a ½ inch sieve.
- Discard any + ½ in. material.
- Thoroughly blend the - ½ in. material.
- Split the blended material into equal portions of about 25 pounds and bag the portions.
- Arrange the 25 lb. portions in an array that simplifies implementation of a random selection procedure.
- Randomly select two 25 lb. bagged portions from each material for each laboratory.
- Split each 25 lb. bagged portion into two samples of about 12.5 lbs. each and bag the two samples.
- Carefully maintain the identity of each of the pairs of bagged samples for the master identification (key) sheets.
- Assign each 12.5 lb. bagged sample a random number for shipment, again maintaining the identity and source of each on the master identification sheet.
- Thus, each participating laboratory will receive four 12.5 lb. 1- bag samples from each of the two materials, or a total of eight 1-bag samples, all identified with a random number traceable through the key sheet to the original randomly selected, paired and split materials.

- Send instructions with each set of eight samples.

Instructions will include directions to 1) carefully maintain the assigned sample identification number, 2) prepare and test two 2.8 in. by 5.6 in. test specimens from each of the eight samples, 3) mold specimens at the target moisture and density value for each material as indicated in the instructions (in lieu of field values), 4) test in accordance with P46, and 5) return the test data on forms prescribed therein.

Round 1 - Sample B

MATERIALS AND RESEARCH

Laboratory Worksheet

COMBINED HYDROMETER, SIEVE ANALYSIS AND TEST DATA SHEET

LOG NO. SHRP RED CONTRACT: ______ FIELD CLASS: ______

LOCATION - STA: ______ DEPTH: ______

EST. MOIST.: ______ OPT. MOIST. DATE: ______ CUT ☐ FILL ☐ NC/NF ☐

OPERATOR ______ DATE ______ CHECKED BY ______ DATE ______

TEST DATA

CLASSIFICATION : MSMT A-5 AASHO A-7-5 (16) EST. C.B.R. VALUE ______

LIQUID LIMIT ☐ : 61 SHRINKAGE LIMIT : 26 SHRINKAGE 95% T-180 ______

PLASTICITY INDEX : 26 SHRINKAGE RATIO : 1.44 ☐ FACTOR 98% T-99 ______

MOISTURE DENSITY RELATIONS ☐ T-180 ______ MAX DEN. = 86.0 pcf OPT. MOIST. = 30.0 %

☐ T-99 ______ MAX DEN. = ______ pcf OPT. MOIST. = ______ %

GRADATION (PERCENT PASSING by WEIGHT)

Sieve	%	Sieve	%	Sieve	%
2½"		½"	98	#40	85
2"		⅜"		#60	79
1½"		#4	97	#100	72
1"		#10	92	#200	63
¾"	100	#30	87	#270	61

PERCENT OF SOIL MORTAR

*COARSE SAND: (2.0 - 0.42 mm)	8	31
≠FINE SAND: (0.42 - 0.075 mm)	23	
SILT: (0.075 - 0.005 mm)		37
▲CLAY: (0.005 - 0.001 mm)		32
COLLOIDS: (0.001mm Minus		

MOISTURE AT ______ ( )= ______ %( ) MOISTURE AT ______ ( )= ______ % ( )

☐ ORGANIC TEST : ______ %, ☐ P.H. ______, ☐ OTHER TESTS SP. GR. 2.85

☐ COLOR ______ ☐ C.B.R. ______ %, ( ), ☐ VOL. CHANGE ______ %

REMARKS: ______

☐ 24 Hr. Bath ☐ MSMT ☐ #40 Wash ☐ #200 Wash ☐ No Bath Required

MECHANICAL ANALYSIS DATA

CALCULATIONS

HYGRO

(W_a) 24.13

(W_o) 22.04

(W_w) 2.09 x 100 ÷ W_o = 9.5 % HYGRO

TEST SAMPLE

W_a X 100 ÷ (% HYGRO + 100) = W_s

W_a = 50.88 W_s = 46.47

BATH

SEDIMENTATION START MIN.	TEMP °F	H	+ C	= R	(R/W$_s$)X100 % CLAY ▲	EST. MAX. GRAIN SIZE mm
						.005

*COARSE SAND P_p 10 - p_p 40 = 8

≠FINE SAND P_p 40 - p_p 200 = 23

FINE SIEVE ANALYSIS

WHERE: P_p = W_p / W_s X 100 P_p 10–100

SIEVE	W_s = 46.47	P_p X	S/100	% TOTAL SAMPLE PASS.	MAX. GRAIN SIZE mm
#30	W_r = 2.20 W_p 44.27	95.27 ≠ 95		87	0.60
#40	W_r = 1.53 W_p 42.74	91.97 ≠ 92	.92	85	0.425
#60	W_r = 3.00 W_p 39.74	85.52 ≠ 86		79	0.250
#100	W_r = 3.27 W_p 36.47	78.48 ≠ 78		72	0.150
#200	W_r = 4.42 W_p 32.05	68.92 ≠ 69	.11	63	0.075
#270	W_r = 1.45 W_p 30.60	65.85 ≠ 66		61	0.053

NOMENCLATURE

WHERE:

W_a = Air Dry (gm)

W_o = Oven Dry (gm)

W_w = Water Wt. (gm)

H = Hydrometer Reading

C = Temp. Correction Factor

R = Corrected Hydrom. Reading

P_r = % Samp. Retained on Sieve

P_p = % Sample Passing Sieve

W_r = Wt. Retained on Sieve (gm)

S = % Total Sample Passing #10 Sieve

W_p = Wt. Passing Sieve (gm)

LOG NO. SHRP RED	24 HOUR HYDROMETER ANALYSIS

FORMULA

$P = \frac{Ra}{W_s} \times 100$

$d = d_1 \times K_L \times K_G \times K_a$

WHERE:
- P = % Soil in Suspension
- R = Corrected Hydrometer Reading
- a = Constant - Depending on Specific Gravity
- W_s = Oven Dry Weight of Test Sample
- H = Hydrometer Reading, Uncorrected
- C = Correction Factor for Temperature
- S = % Total Sample Passing #10 Sieve
- S_1 = % Total Sample Passing

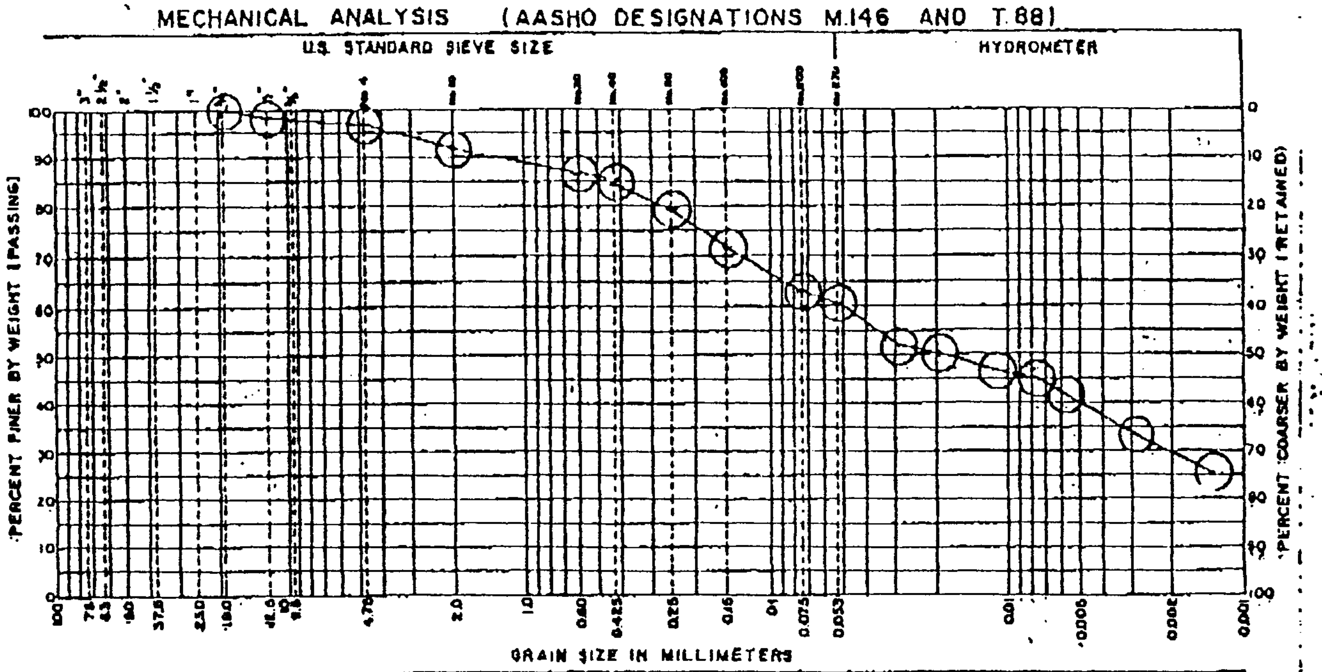
WHERE:
- d = Corrected Grain Diameter
- d_1 = Max. Grain Dia. Under Assumed Conditions
- K_L = Correction for Elevation of Hydrometer (H)
- K_G = Correction for Variation of Specific Gravity
- K_a = Correction for Variation of Viscosity of Suspending Medium

CALCULATIONS

a = 0.960 W_s = 46.47 % Total Sample Passing #10(S) 92 Sp.Gr. 2.85

TEMP. °F	(H+	C =	R) x	100a/W_s =	P x S/100 =	S_1	OBS. TIME	T MIN.	d_1 x	K_L x	K_G x	K_a	= d	
		.						30 sec	.081					
		.						1	.057					
78	32.0	-4.7	27.3	2.066	56.4	52		2	.040	.828		.0356	.029	
78	31.0	-4.7	26.3	2.066	54.3	50		5	.026	.834		.0231	.019	
		.												
78	29.5	-4.7	24.8	2.066	51.2	47		15	.015	.845		.0134	.011	
78	28.5	-4.7	23.8	2.066	49.2	45		30	.010	.849		.0089	.0076	
78	27.0	-4.7	22.3	2.066	46.1	42		60	.0074	.858		.0066	.0057	
77	22.5	-4.9	17.6	2.066	36.4	33		250	.0036	.885		.0032	.0028	
		.												
76	19.0	-5.2	13.8	2.066	28.5	26		1440	.0015	.955		.0014	.0013	

MECHANICAL ANALYSIS (AASHO DESIGNATIONS M.146 AND T.88)



GRAVEL			SAND		SILT	CLAY
COARSE	MEDIUM	FINE	COARSE	FINE		

% SOIL MORTAR • READING FROM CURVE ÷ S/100 REMARKS: 0.002 = 29.8 ÷ .92 = 32.4 ≈ 32

MATERIALS AND RESEARCH

Laboratory Worksheet

COMBINED HYDROMETER, SIEVE ANALYSIS AND TEST DATA SHEET

LOG NO. ______ CONTRACT: ______ FIELD CLASS: ______

LOCATION - STA: ______ DEPTH: ______

EST. MOIST.: ______ OPT. MOIST. DATE: ______ CUT ☐ FILL ☐ NC/NF ☐

OPERATOR ______ DATE ______ CHECKED BY ______ DATE ______

TEST DATA

CLASSIFICATION : MSMT A-5 AASHO A-5 (8) EST. C.B.R. VALUE 1

LIQUID LIMIT ☐ : 56 SHRINKAGE LIMIT : 32 SHRINKAGE 95% T-180 ______

PLASTICITY INDEX : 11 SHRINKAGE RATIO : 1.38 ☐ FACTOR 98% T-99 ______

MOISTURE DENSITY RELATIONS ☐ T-180 6 MAX DEN. = 81.5 pcf OPT. MOIST. = 31.8 %

☐ T-99 ______ MAX DEN. = ______ pcf OPT. MOIST. = ______ %

GRADATION (PERCENT PASSING by WEIGHT) — PERCENT OF SOIL MORTAR

Sieve		Sieve		Sieve				
2½"		½"		#40	91	*COARSE SAND: (2.0 - 0.42 mm)	9	38
2"		⅜"		#60	83	≠FINE SAND: (0.42 - 0.075 mm)	29	
1½"		#4		#100	75	SILT: (0.075 - 0.005 mm)		45
1"		#10	100	#200	62	▲CLAY: (0.005 - 0.001 mm)		17
¾"		#30		#270		COLLOIDS: (0.001mm Minus		

MOISTURE AT ______ ( )= ______ %( ) MOISTURE AT ______ ( )= ______ % ( )

☐ ORGANIC TEST : ______ %, ☐ P.H. ______, ☐ OTHER TESTS SP. GR. 2.73

☐ COLOR ______ ☐ C.B.R. ______ %, ( ), ☐ VOL. CHANGE ______ %

REMARKS: ______

☒ 24 Hr. Bath ☐ MSMT ☐ #40 Wash ☐ #200 Wash ☐ No Bath Required

MECHANICAL ANALYSIS DATA

CALCULATIONS

HYGRO

(W_a) 26.39
(W_o) 25.65
(W_w) .74 x 100 ÷ W_o = 29 % HYGRO

TEST SAMPLE

W_a X 100 ÷ (% HYGRO + 100) = W_s

W_a = 55.41 W_s = 53.85

BATH

SEDIMENTATION START MIN.	TEMP °F	H	+ C	= R	(R/W_s)X100 % CLAY ▲	EST. MAX. GRAIN SIZE mm	
							*COARSE SAND P_p 10 - p_p 40 = 9
							≠FINE SAND P_p 40 - p_p 200 = 29
						.005	

FINE SIEVE ANALYSIS

WHERE: P_r = W_r / W_s X 100 P_p 10=100

SIEVE	W_s = 53.85	P_p X	S/100	% TOTAL SAMPLE PASS.	MAX. GRAIN SIZE mm
#30	W_r = ___ / W_p				0.60
#40	W_r = 4.76 / W_p 49.09	91.16 ≑ 91	1.0	91	0.425
#60	W_r = 4.31 / W_p 44.78	83.16 ≑ 83	1.0	83	0.250
#100	W_r = 4.50 / W_p 40.28	74.80 ≑ 75	1.0	75	0.150
#200	W_r = 6.91 / W_p 33.37	61.97 ≑ 62	1.0	62	0.075
#270	W_r = ___ / W_p				0.053

NOMENCLATURE
WHERE:
W_a - Air Dry (gm)
W_o - Oven Dry (gm)
W_w - Water Wt. (gm)
H - Hydrometer Reading
C - Temp. Correction Factor
R - Corrected Hydrom. Reading
P_r - % Samp. Retained on Sieve
P_p - % Sample Passing Sieve
W_r - Wt. Retained on Sieve (gm)
S - % Total Sample Passing #10 Sieve
W_p - Wt. Passing Sieve (gm)

Round 1 Sample A

LOG NO. MTS #47 — 24 HOUR HYDROMETER ANALYSIS

FORMULA

$P = \frac{Ra}{W_s} \times 100$

$d = d_1 \times K_L \times K_G \times K_n$

WHERE:
- P = % Soil in Suspension
- R = Corrected Hydrometer Reading
- a = Constant - Depending on Specific Gravity
- W_s = Oven Dry Weight of Test Sample
- H = Hydrometer Reading, Uncorrected
- C = Correction Factor for Temperature
- S = % Total Sample Passing #10 Sieve
- S_1 = % Total Sample Passing

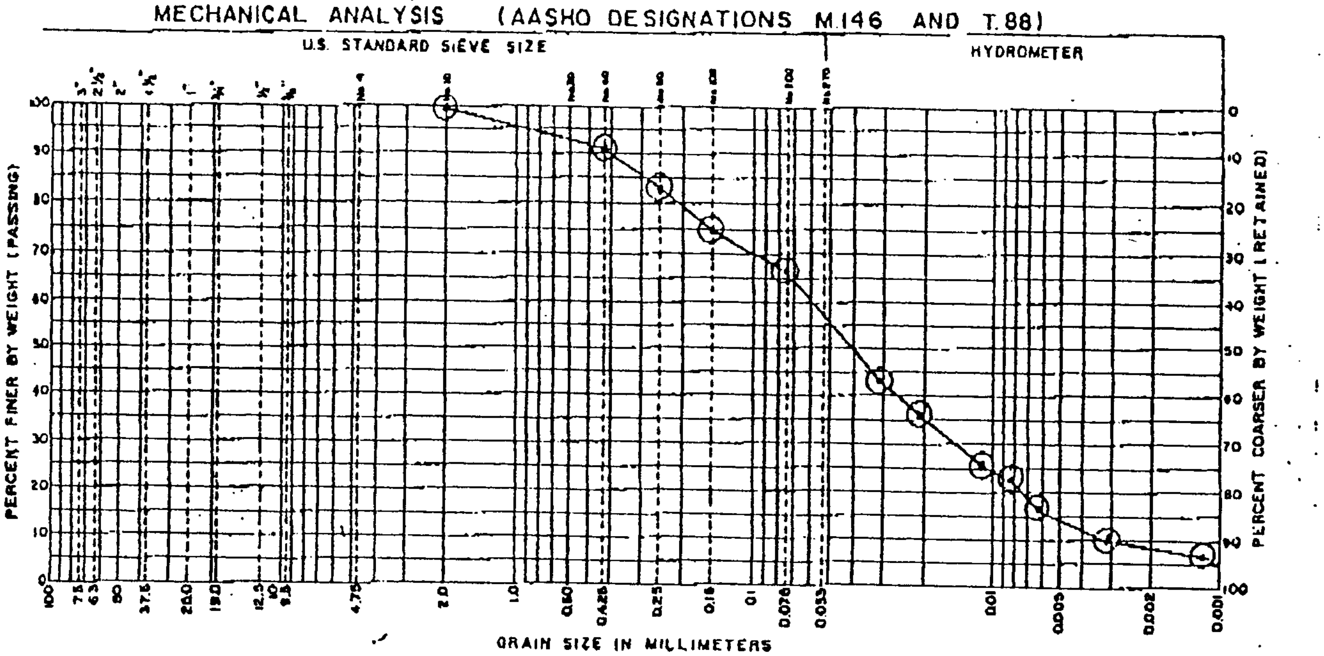
WHERE:
- d = Corrected Grain Diameter
- d_1 = Max. Grain Dia. Under Assumed Conditions
- K_L = Correction for Elevation of Hydrometer (H)
- K_G = Correction for Variation of Specific Gravity
- K_n = Correction for Variation of Viscosity of Suspending Medium

CALCULATIONS

a = 0.982 W_s = 53.85 % Total Sample Passing #10(S) 100 Sp.Gr. 2.73

TEMP. °F	(H+	C =	R) x	100a/W_s =	P x S/100 = S_1		OBS. TIME	T MIN.	d_1 X K_L X K_G X K_n = d					
		.						30 sec	.081					
		.						1	.057					
79	28.0	-4.5	23.5	1.824	42.9	43		2	.040	.852		.0564	.051	
79	24.0	-4.5	19.5	1.824	35.6	36		5	.026	.876		.0237	.021	
		.												
79	19.0	-4.5	14.5	1.824	26.4	26		15	.015	.905		.0137	.012	
79	17.0	-4.5	12.5	1.824	22.8	23		30	.010	.915		.0091	.0083	
79	14.0	-4.5	9.5	1.824	17.3	17		60	.0074	.930		.0067	.0062	
80	10.0	-4.3	5.7	1.824	10.4	10		250	.0036	.950		.0053	.0051	
		.												
77	9.0	-4.9	4.1	1.824	7.4	7		1440	.0015	.955		.0014	.0013	

MECHANICAL ANALYSIS (AASHO DESIGNATIONS M.146 AND T.88)



GRAVEL			SAND		SILT	CLAY
COARSE	MEDIUM	FINE	COARSE	FINE		

% SOIL MORTAR = READING FROM CURVE ÷ S/100 REMARKS: 0.005 = 16.8 ÷ 1.0 ≈ 17

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. Further, the 'quick shear test' was not used in this Program.

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.

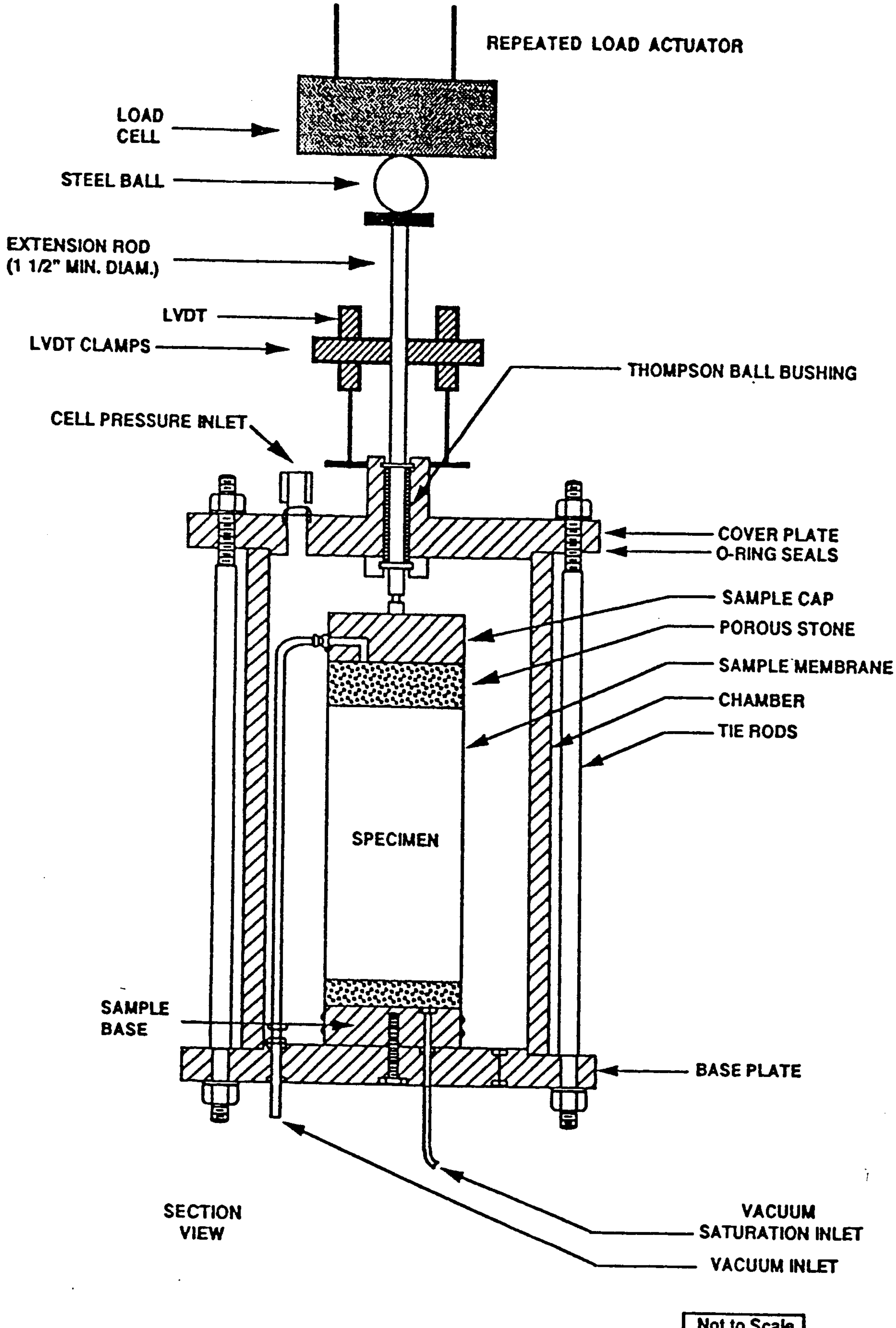


Figure 1. Triaxial chamber with external LVDT's and load cell.

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 Typc 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_{sd}), with the moisture content (w_1), required to obtain W_s, including an additional amount W_{sm} of at least 500 grams to provide material for the determination of moisture content at the time of compaction.

W_{sd} (grams) = (W_s + W_{sm}) 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_{sm}) x (w_1/100)

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

W_{aw} (grams) = W_2 - W_1

7.3.9 Place the mass of the sample (W_{sd}) 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) <u>M_r Relationships and Plots:</u> 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

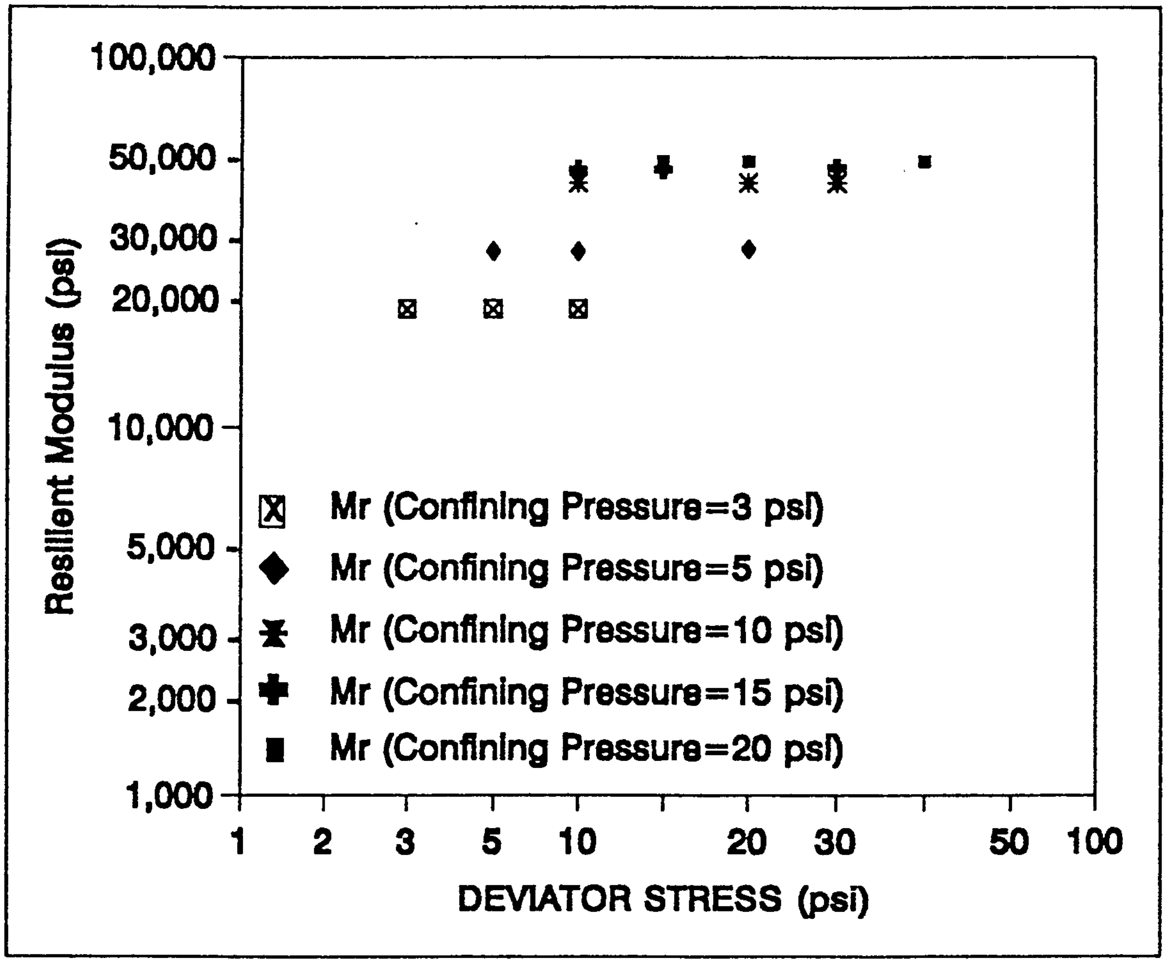
  S_3 = confining pressure

- 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

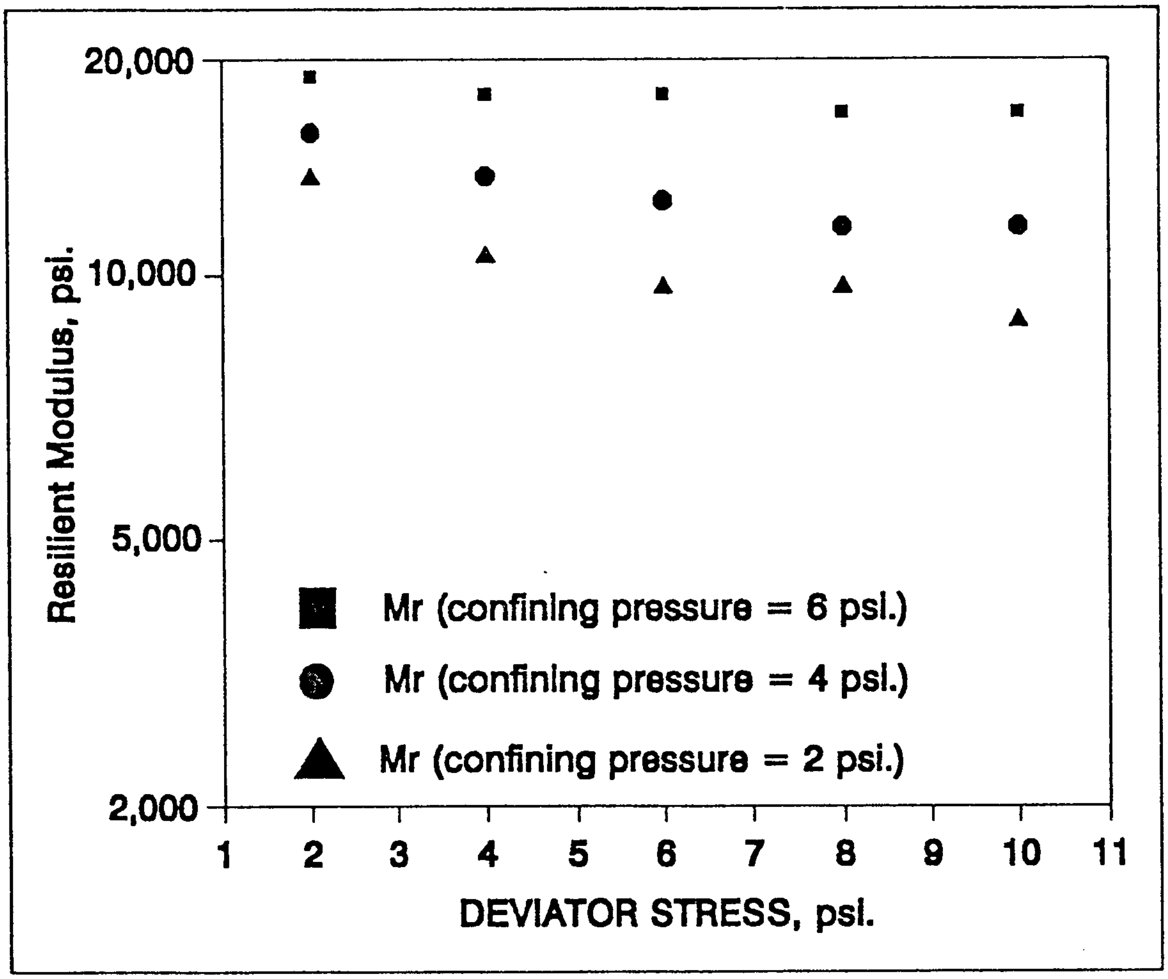


$M_r = K_1 (1+S_3)^{K_2} (S_d)^{K_5}$

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

$R^2 = .988$

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.

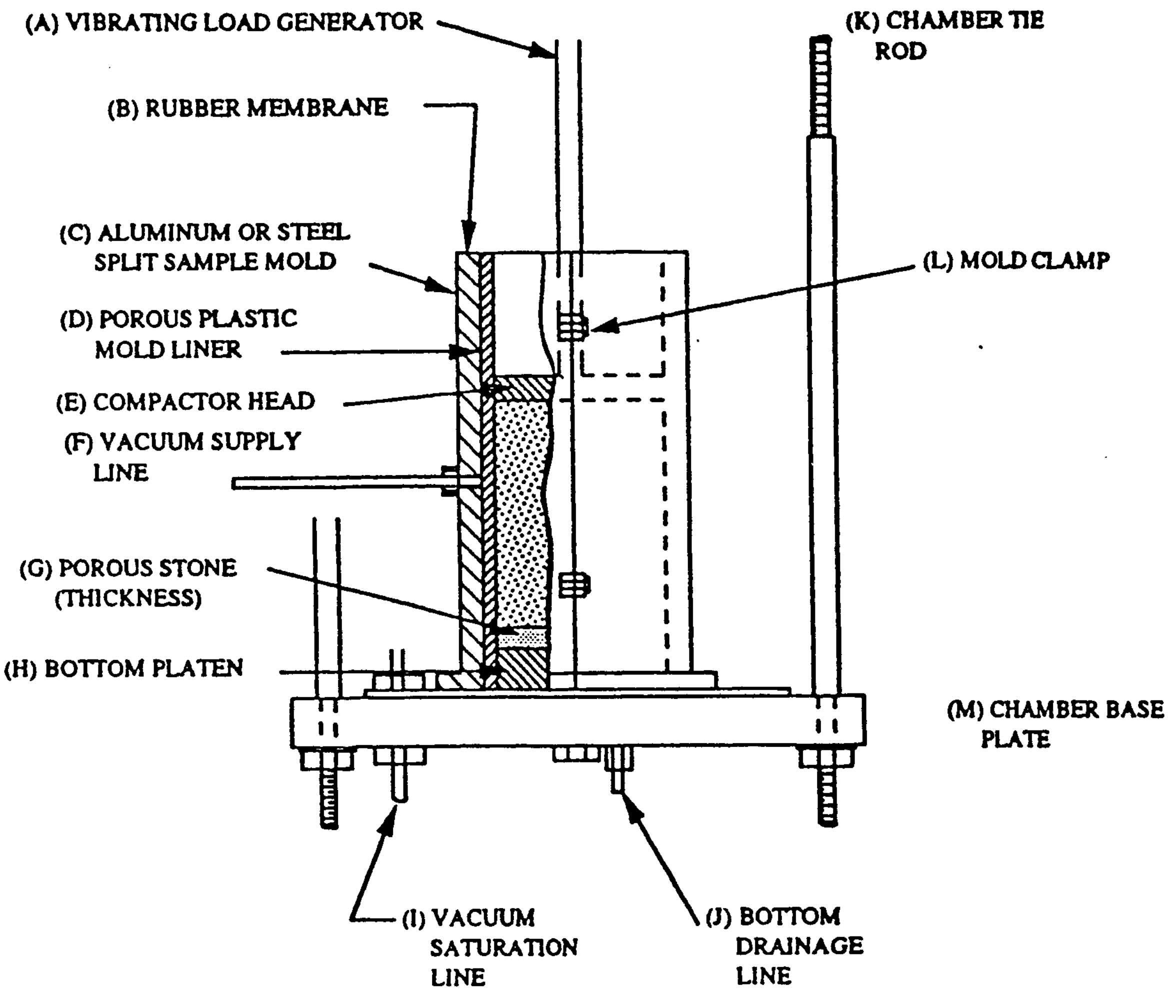


TABLE OF MEASUREMENTS (TYPICAL)

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.

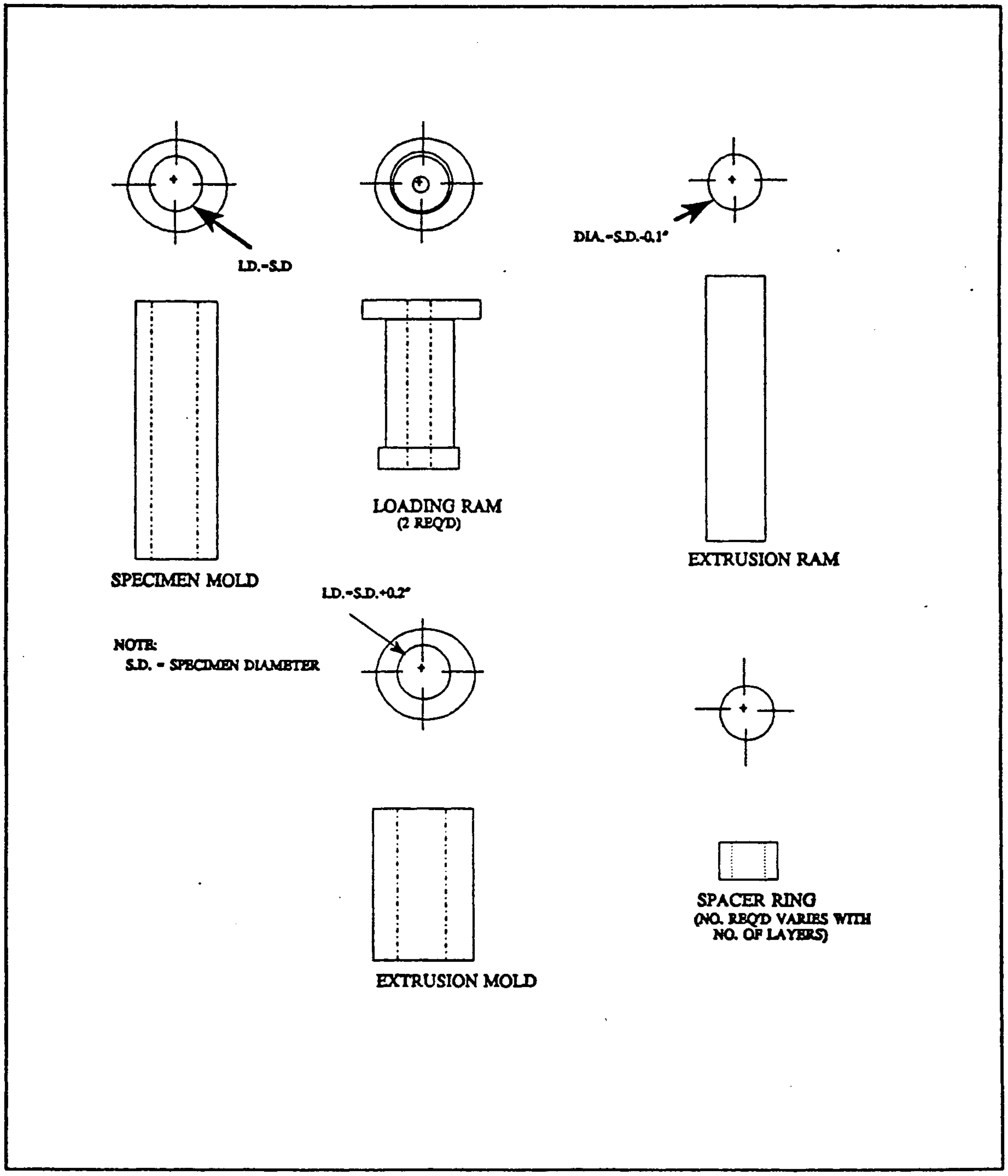


Figure 3. Apparatus for static compaction of Type 2 unbound materials.

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 ____________

Worksheet T46 - Page 2, March 1992

APPENDIX B

LABORATORY AVERAGES AND WITHIN LABORATORY STANDARD DEVIATIONS
AND COEFFICIENT OF VARIATION BY CONFINING PRESSURE
AND DEVIATOR STRESS LEVELS

OBS	MAT	LAB	CONFPR	DEVID	AVMR	STD	CV	NSAMP
1	A	A	2	2	31015	11492	37	8
2	A	A	2	4	22366	3001	13	8
3	A	A	2	6	21810	2878	13	8
4	A	A	2	8	21217	2739	13	8
5	A	A	2	10	21000	2550	12	8
6	A	A	4	2	33917	11738	35	8
7	A	A	4	4	23637	3911	17	8
8	A	A	4	6	23622	3200	14	8
9	A	A	4	8	23419	3694	16	8
10	A	A	4	10	22516	2328	10	8
11	A	A	6	2	44302	6121	14	8
12	A	A	6	4	27279	4051	15	8
13	A	A	6	6	25932	3703	14	8
14	A	A	6	8	23936	3231	13	8
15	A	A	6	10	24658	3722	15	8
16	A	B	2	2	12218	2717	22	8
17	A	B	2	4	11346	2383	21	8
18	A	B	2	6	10839	2366	22	8
19	A	B	2	8	10489	2123	20	8
20	A	B	2	10	10424	2003	19	8
21	A	B	4	2	13036	2639	20	8
22	A	B	4	4	12228	2332	19	8
23	A	B	4	6	11682	2177	19	8
24	A	B	4	8	11466	2258	20	8
25	A	B	4	10	11489	2131	19	8
26	A	B	6	2	13701	2139	16	10
27	A	B	6	4	12985	2550	20	8
28	A	B	6	6	11485	1292	11	6
29	A	B	6	8	12386	1931	16	8
30	A	B	6	10	12247	1849	15	8
31	A	C	2	2	11582	4371	38	8
32	A	C	2	4	7295	1907	26	7
33	A	C	2	6	6735	1527	23	8
34	A	C	2	8	6722	1341	20	6
35	A	C	2	10	6541	1112	17	11
36	A	C	4	2	11946	5849	49	8
37	A	C	4	4	7767	2477	32	8
38	A	C	4	6	7273	1839	25	7
39	A	C	4	8	6790	1542	23	7

OBS	MAT	LAB	CONFPR	DEVID	AVMR	STD	CV	NSAMP
40	A	C	4	10	6555	1305	20	10
41	A	C	6	2	10516	2494	24	8
42	A	C	6	4	7924	2127	27	7
43	A	C	6	6	7118	1576	22	7
44	A	C	6	8	6633	1272	19	8
45	A	C	6	10	6247	1322	21	9
46	A	D	2	2	19460	2972	15	7
47	A	D	2	4	14890	2178	15	7
48	A	D	2	6	14324	2056	14	7
49	A	D	2	8	14068	2229	16	7
50	A	D	2	10	14093	2259	16	7
51	A	D	4	2	18611	2730	15	7
52	A	D	4	4	15460	2813	18	7
53	A	D	4	6	14769	2535	17	7
54	A	D	4	8	14257	2719	19	7
55	A	D	4	10	14334	2569	18	7
56	A	D	6	2	17019	4099	24	10
57	A	D	6	4	15240	3342	22	7
58	A	D	6	6	14703	1343	9	4
59	A	D	6	8	14606	3283	22	7
60	A	D	6	10	14640	3146	21	7
61	A	E	2	2	16562	3120	19	8
62	A	E	2	4	14315	2136	15	7
63	A	E	2	6	13655	2100	15	6
64	A	E	2	8	13400	1570	12	10
65	A	E	2	10	12841	1609	13	9
66	A	E	4	2	16573	2320	14	8
67	A	E	4	4	15483	2048	13	8
68	A	E	4	6	14655	2645	18	5
69	A	E	4	8	13950	1793	13	8
70	A	E	4	10	13782	1561	11	11
71	A	E	6	2	17240	4204	24	9
72	A	E	6	4	15712	1883	12	7
73	A	E	6	6	15495	1650	11	5
74	A	E	6	8	15010	1869	12	6
75	A	E	6	10	13687	1492	11	12
76	A	F	2	2	15254	984	6	8
77	A	F	2	4	14472	865	6	8
78	A	F	2	6	14331	897	6	8
79	A	F	2	8	14353	958	7	8
80	A	F	2	10	14380	969	7	8

OBS	MAT	LAB	CONFPR	DEVID	AVMR	STD	CV	NSAMP
81	A	F	4	2	15983	927	6	8
82	A	F	4	4	15144	817	5	8
83	A	F	4	6	14984	867	6	8
84	A	F	4	8	14993	936	6	8
85	A	F	4	10	15005	939	6	8
86	A	F	6	2	15779	1124	7	11
87	A	F	6	4	15795	894	6	8
88	A	F	6	6	15837	703	4	5
89	A	F	6	8	15337	888	6	8
90	A	F	6	10	15172	940	6	8
91	A	G	2	2	13186	1847	14	8
92	A	G	2	4	11696	1694	14	8
93	A	G	2	6	10747	1450	13	8
94	A	G	2	8	10371	1326	13	8
95	A	G	2	10	10168	1263	12	8
96	A	G	4	2	14096	1851	13	8
97	A	G	4	4	12616	1669	13	8
98	A	G	4	6	11437	1387	12	8
99	A	G	4	8	10969	1292	12	8
100	A	G	4	10	10741	1249	12	8
101	A	G	6	2	14381	1715	12	8
102	A	G	6	4	12697	1464	12	8
103	A	G	6	6	11872	1321	11	8
104	A	G	6	8	11488	1258	11	8
105	A	G	6	10	11184	1225	11	8
106	A	H	2	2	3902	777	20	8
107	A	H	2	6	11039	2834	26	8
108	A	H	2	10	18809	5548	29	8
109	A	H	4	2	4922	273	6	7
110	A	H	4	6	12568	2326	19	8
111	A	H	4	10	14069	4209	30	8
112	A	I	2	2	7621	1205	16	8
113	A	I	2	4	7392	918	12	8
114	A	I	2	6	6812	958	14	8
115	A	I	2	8	6599	904	14	8
116	A	I	2	10	6342	852	13	8
117	A	I	4	2	8530	2722	32	8
118	A	I	4	4	7323	959	13	8
119	A	I	4	6	7066	1133	16	8

OBS	MAT	LAB	CONFPR	DEVID	AVMR	STD	CV	NSAMP
120	A	I	4	8	6753	1015	15	8
121	A	I	4	10	6907	884	13	8
122	A	I	6	2	9021	3881	43	8
123	A	I	6	4	8066	1274	16	8
124	A	I	6	6	7178	880	12	8
125	A	I	6	8	7101	784	11	8
126	A	I	6	10	7040	653	9	8
127	B	A	2	2	15410	2348	15	8
128	B	A	2	4	12470	1283	10	8
129	B	A	2	6	11439	1272	11	8
130	B	A	2	8	10350	1323	13	8
131	B	A	2	10	9886	1226	12	8
132	B	A	4	2	18045	3334	18	8
133	B	A	4	4	13305	1304	10	8
134	B	A	4	6	12201	1654	14	8
135	B	A	4	8	10985	1524	14	8
136	B	A	4	10	10527	1521	14	8
137	B	A	6	2	19474	2629	13	8
138	B	A	6	4	14300	1764	12	8
139	B	A	6	6	12290	1667	14	8
140	B	A	6	8	11324	1695	15	8
141	B	A	6	10	10681	1665	16	8
142	B	B	2	2	8333	1343	16	6
143	B	B	2	4	7203	1295	18	6
144	B	B	2	6	6465	1197	19	6
145	B	B	2	8	5987	1238	21	6
146	B	B	2	10	5692	1259	22	6
147	B	B	4	2	9408	1350	14	6
148	B	B	4	4	8067	1298	16	6
149	B	B	4	6	7195	1295	18	6
150	B	B	4	8	6593	1314	20	6
151	B	B	4	10	6288	1261	20	6
152	B	B	6	2	9153	1240	14	8
153	B	B	6	4	8267	1565	19	6
154	B	B	6	6	6705	1285	19	4
155	B	B	6	8	6882	1372	20	6
156	B	B	6	10	6510	1363	21	6
157	B	C	2	2	7325	1850	25	5
158	B	C	2	4	5868	2938	50	8
159	B	C	2	6	4374	1314	30	9

OBS	MAT	LAB	CONFPR	DEVID	AVMR	STD	CV	NSAMP
160	B	C	2	8	3865	1047	27	8
161	B	C	2	10	3468	874	25	7
162	B	C	4	2	11696	9426	81	6
163	B	C	4	4	6191	3309	53	8
164	B	C	4	6	4478	1562	35	9
165	B	C	4	8	3871	969	25	8
166	B	C	4	10	3479	791	23	7
167	B	C	6	2	12401	9441	76	8
168	B	C	6	4	6003	2780	46	7
169	B	C	6	6	4612	1577	34	9
170	B	C	6	8	3929	1132	29	8
171	B	C	6	10	3492	875	25	7
172	B	D	2	2	12631	2233	18	8
173	B	D	2	4	9715	1136	12	8
174	B	D	2	6	8746	559	6	8
175	B	D	2	8	7822	391	5	8
176	B	D	2	10	7432	278	4	8
177	B	D	4	2	12754	1647	13	8
178	B	D	4	4	9789	1066	11	8
179	B	D	4	6	8768	489	6	8
180	B	D	4	8	7196	2618	36	8
181	B	D	4	10	7397	266	4	8
182	B	D	6	2	11984	2842	24	12
183	B	D	6	4	10319	848	8	8
184	B	D	6	6	8873	413	5	4
185	B	D	6	8	8126	420	5	8
186	B	D	6	10	7457	288	4	8
187	B	E	2	2	10023	3949	39	8
188	B	E	2	4	6706	1380	21	7
189	B	E	2	6	6040	922	15	7
190	B	E	2	8	5181	772	15	9
191	B	E	2	10	4672	654	14	9
192	B	E	4	2	9223	1674	18	8
193	B	E	4	4	7196	1328	18	8
194	B	E	4	6	6228	1212	19	7
195	B	E	4	8	5430	872	16	8
196	B	E	4	10	4864	697	14	9
197	B	E	6	2	8528	1932	23	12
198	B	E	6	4	7532	1335	18	7
199	B	E	6	6	6283	1234	20	4
200	B	E	6	8	5338	715	13	7

OBS	MAT	LAB	CONFPR	DEVID	AVMR	STD	CV	NSAMP
201	B	E	6	10	4998	783	16	10
202	B	F	2	2	11841	1005	8	8
203	B	F	2	4	9374	551	6	8
204	B	F	2	6	7882	505	6	8
205	B	F	2	8	6837	398	6	8
206	B	F	2	10	6067	291	5	8
207	B	F	4	2	11939	795	7	8
208	B	F	4	4	9632	547	6	8
209	B	F	4	6	8112	497	6	8
210	B	F	4	8	6999	370	5	8
211	B	F	4	10	6153	246	4	8
212	B	F	6	2	10098	1846	18	12
213	B	F	6	4	9298	346	4	8
214	B	F	6	6	7651	270	4	4
215	B	F	6	8	6641	199	3	8
216	B	F	6	10	5966	168	3	8
217	B	G	2	2	7934	1136	14	8
218	B	G	2	4	6838	702	10	8
219	B	G	2	6	5862	610	10	8
220	B	G	2	8	5236	455	9	8
221	B	G	2	10	4712	223	5	7
222	B	G	4	2	8654	1003	12	8
223	B	G	4	4	7397	611	8	8
224	B	G	4	6	6349	621	10	8
225	B	G	4	8	5635	459	8	8
226	B	G	4	10	5152	357	7	8
227	B	G	6	2	8973	771	9	8
228	B	G	6	4	7270	509	7	8
229	B	G	6	6	6280	363	6	8
230	B	G	6	8	5710	289	5	8
231	B	G	6	10	5288	226	4	8
232	B	H	2	2	3918	938	24	8
233	B	H	2	6	11144	3278	29	8
234	B	H	2	10	12509	5326	43	8
235	B	H	4	2	4145	1272	31	8
236	B	H	4	6	10442	4049	39	8
237	B	H	4	10	13868	6126	44	8
238	B	I	2	2	4338	791	18	8
239	B	I	2	4	3946	600	15	8

OBS	MAT	LAB	CONFPR	DEVID	AVMR	STD	CV	NSAMP
240	B	I	2	6	3174	388	12	8
241	B	I	2	8	2800	290	10	7
242	B	I	2	10	2607	100	4	5
243	B	I	4	2	5433	1805	33	3
244	B	I	4	4	5258	880	17	3
245	B	I	4	6	4429	336	8	3
246	B	I	4	8	3840	339	9	3
247	B	I	4	10	3570	266	7	3
248	B	I	6	2	6516	1070	16	3
249	B	I	6	4	5338	596	11	3
250	B	I	6	6	4945	430	9	3
251	B	I	6	8	4371	304	7	3
252	B	I	6	10	3954	306	8	3