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Round 1 Type 1 Unbound Granular Base Course Proficiency Sample Program

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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 granular base course material obtained from LTPP field sites. All laboratories conducting tests for the LTPP program were required to be accredited by the AASHTO Accreditation Program (AAP). AAP includes site inspections of equipment and procedures, and participation in applicable proficiency sample testing. A few critical LTPP tests, such as the triaxial resilient modulus test, were not addressed fully by the AAP, and LTPP decided to conduct supplemental testing.

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

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

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

A set of eight test samples was shipped to each of nine participating laboratories together with appropriate instructions. All participants were required to complete testing of the Type I synthetic reference sample set prior to testing the Round 1 proficiency samples.

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 granular base course material 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 the 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 granular base course materials 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 I Unbound Granular Base Course Synthetic Reference Sample Program".

The Type I Unbound Granular Base Course Proficiency Sample Program research was designed, to fill the need indicated in the third element, by Virgil Anderson, #48 Oaks Place, Lago Vista, TX 78645, and Robin High, 2440 NW Rolling Green Drive, Corvallis, OR 97330, 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 I Unbound Granular Base Course Proficiency Sample Program were obtained, prepared, certain laboratory tests performed, correspondence containing instructions to participating laboratories prepared, and samples shipped to participants by the University of Nevada-Reno Laboratory under the direction of Mary Stroup-Gardiner. 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 appendix A). The set of samples contained two different aggregates, each obtained from SHRP Materials Reference Library aggregate sources in California (Pleasonton and Watsonville). Participants prepared and tested two 6 in diameter by 12 in length test specimens from each of the eight samples. All participants were required to complete testing on the Type I synthetic reference sample set prior to testing the Round 1 proficiency samples.

Fifteen laboratories initially indicated intent to participate and nine finally participated in the program. All participants made significant contributions to the success of the LTPP research effort. A list of participants completing the program is in Part II of this report.

The final comments, analyses, conclusions and recommendations resulting from the Round 1 Type I Unbound Granular Base Course Proficiency Sample Program are contained in Part III. A set of precision statements in AASHTO/ASTM format is contained in Part IV.

A copy of the initiating correspondence, soil classification test data, moisture-density data, and proficiency sample fabrication procedure for Round 1 is included in Appendix A of this report. Values of M_R reported for each material at the various levels of confining pressure and deviator stress are listed in Appendix B. Appendix C contains a report on some additional work that was conducted at Vulcan Materials.

PART II PARTICIPATING LABORATORIES

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Georgia Tech Materials Laboratory
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Atlanta, GA 30322

Law Engineering
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Atlanta, GA 30324

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Construction Materials Group
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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 to measure the resilient modulus of Type I unbound granular base course materials.
- 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 nine laboratories participated in this program. Data from seven 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 presented in this report. The results of this study provide 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 the evaluation of the effects of the confining pressure and the deviator stress on the measured values of the resilient modulus. Five levels of the confining pressure and three appropriate levels of the deviator stress for each level of confining pressure were included in the experiment. 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 P and four samples of material W. Each of these samples was subdivided at the participating laboratory, producing sixteen test specimens, eight for each material. Components of variance were assigned to each of these sampling steps as described below.

The samples sent to the participating laboratories were generated at the University of Nevada-Reno Laboratory by first dividing each lot of material (P and W) into a series of samples. This step in the sampling process was assigned a component of variance identified as PAIR. Each of these samples were subsequently divided at the University of Nevada-Reno into two subsamples, yielding a series of paired samples. This step in the sampling process was assigned a component of variance identified as SAMPLE. For each material (P and W) ~~four~~ two pairs of these subsamples were selected at random and sent to each participating laboratory for testing, resulting in the shipment of eight samples to each laboratory. At the participating laboratories, the eight samples were each divided into two subsamples and a single test specimen was prepared from each of these subsamples. The component of variance associated with this step in the sampling process was identified as MEASUREMENT.

Each specimen was tested under a set of conditions specified by the confining stress (noted as CONF hereafter) and the deviator stress (noted as DEVID hereafter). There were five levels for the CONF (3, 5, 10, 15, and 20 psi) and three appropriate levels for the DEVID. The level for DEVID depends upon the level for CONF. For example, the levels of the DEVID when the CONF is 3 psi are 3, 6, and 9 psi, and when the CONF is 20 psi the levels of the DEVID are 15, 20, and 40 psi. Thus there are 15 combinations of confining pressure and deviator stress for the two factors at which each of the specimens was tested.

For each material eight test specimens were prepared and components of variance were assigned as follows:

- LABORATORY--resulting from the effect of laboratory

- PAIR--resulting from the initial division of the lot of each material (P and W) into a series of samples--performed at the University of Nevada-Reno

- SAMPLE--resulting from the division of the initial sample into subsamples--performed at the University of Nevada-Reno

- MEASUREMENT--resulting from specimen preparation (especially compaction), from measurement and testing errors, and from the sampling effect resulting from the division of the samples shipped to each laboratory into two test specimens--all resulting from work performed at the participating laboratory.

The first level of preparation was designated as PAIR and for each of the two samples associated with PAIR there was a division into two samples noted as SAMPLE in the data base. Thus PAIR is nested in LABORATORY and SAMPLE is nested in PAIR. The analyses of variance takes this structure into account. The final division at the laboratory into two subsamples for testing provides two specimens from each of the samples which were then tested thereby providing the means to evaluate the component of variance noted as the MEASUREMENT component. It should 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.

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 levels of confining pressure and deviator stress) for materials P and W are presented. It is clear from these figures that laboratory C has values that are much higher than the other laboratories. It will be clear later, from this and other considerations, that this laboratory should be omitted from further statistical analyses of the laboratories as a group and from the precision statements in Part IV of this report. Laboratory C will be included in the additional descriptive statistics for the individual laboratories in which case it does not alter any of the group evaluations.

It was noted in the description of the experiment that there are at each laboratory eight specimens of the same material which were tested under the same set of conditions. These measured values for M_R may be regarded as eight independent measurements and as such provide an excellent means for the evaluation of the 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 each of the materials are given in Table 1. The average of these for the two materials is presented in Figure 3. It may be seen from this figure that three of the laboratories had much higher variability than the other four laboratories. Laboratory C is in the high group which, when combined with the high average values reported by this laboratory, dictated that it be omitted from the statistical analyses of the group.

Omitting laboratories A and D from the analyses might also be desirable and could be justified, although 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., A, D, E, H, I, and J, unless noted otherwise.

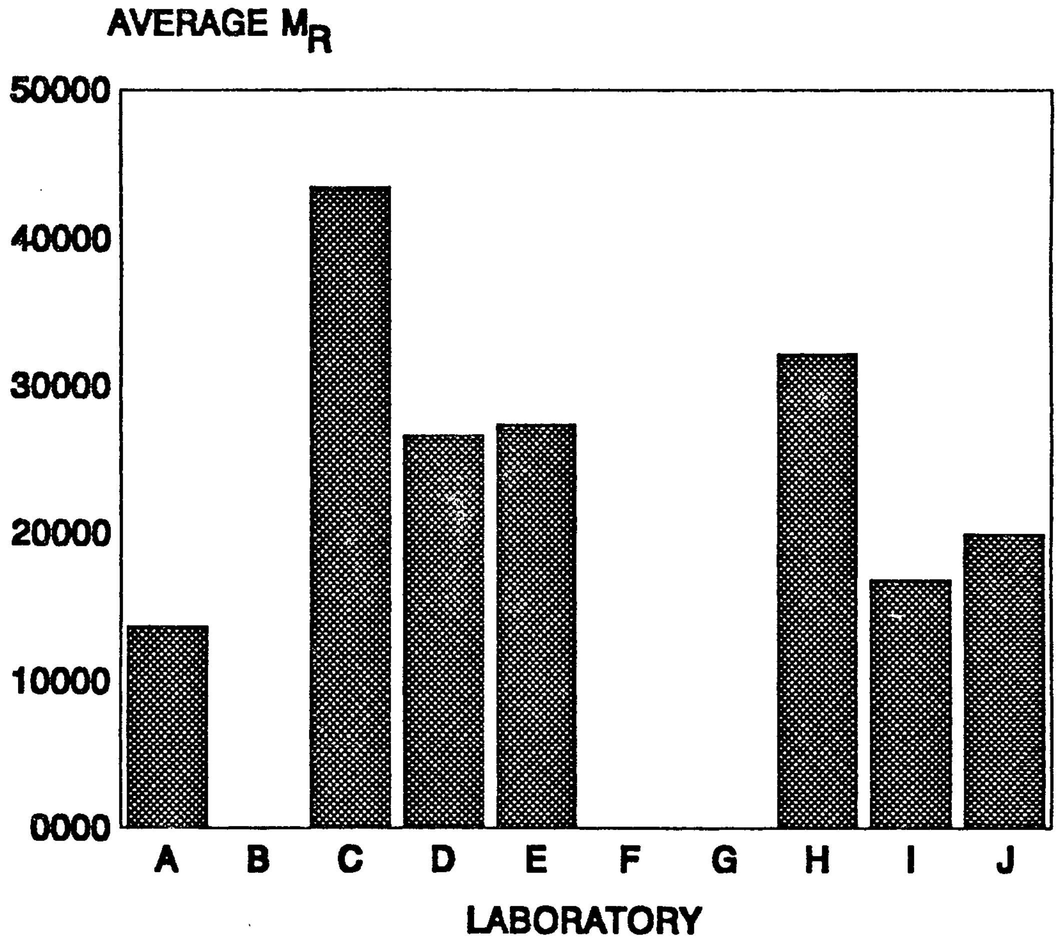


Figure 1. Laboratory Averages for M_R (psi) with Material P.

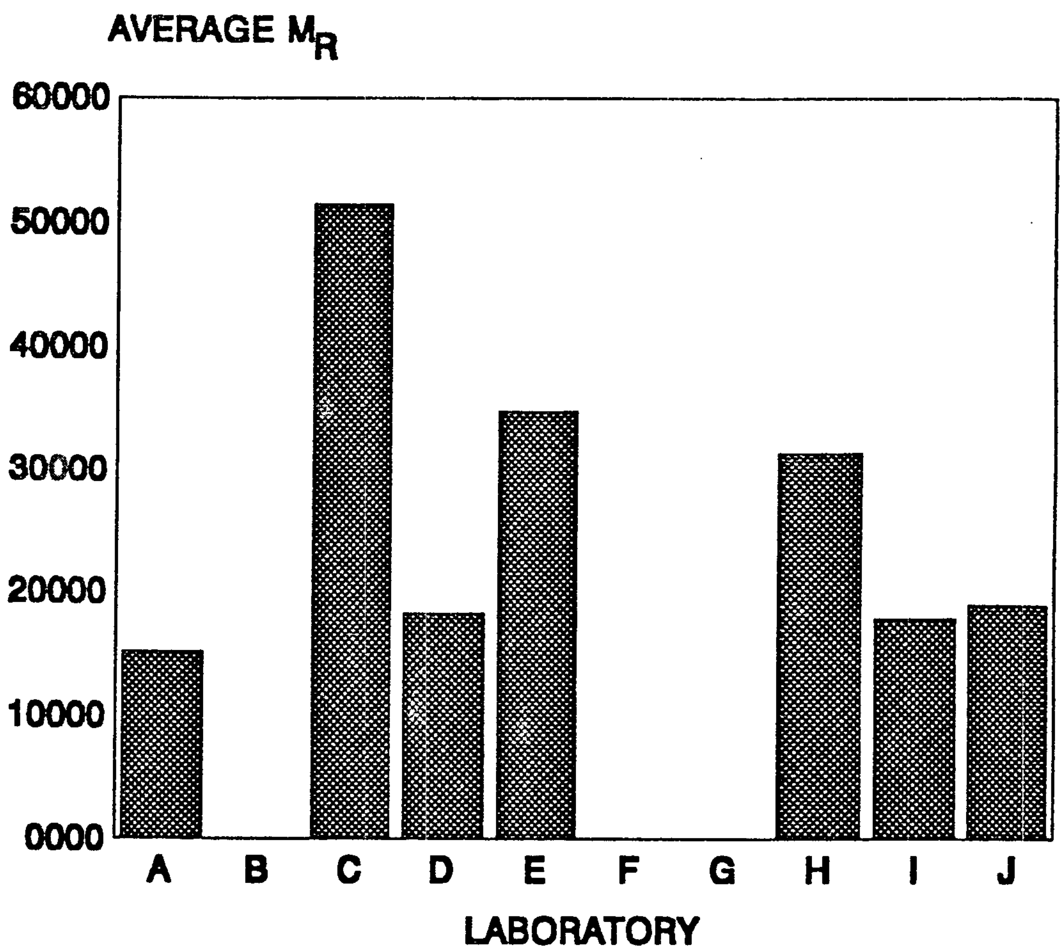


Figure 2. Laboratory Averages for M_R (psi) with Material W.

Table 1. Laboratory Averages and Coefficient of Variation for Materials P and W.

Material	Laboratory	Average M_R (psi)	Average CV (%)
P	A	13,710	19%
P	C	43,427	18%
P	D	26,616	13%
P	E	27,360	13%
P	H	32,159	7%
P	I	16,836	5%
P	J	19,938	9%
W	A	15,149	20%
W	C	51,421	15%
W	D	18,173	25%
W	E	34,661	6%
W	H	31,291	6%
W	I	17,764	6%
W	J	18,852	8%

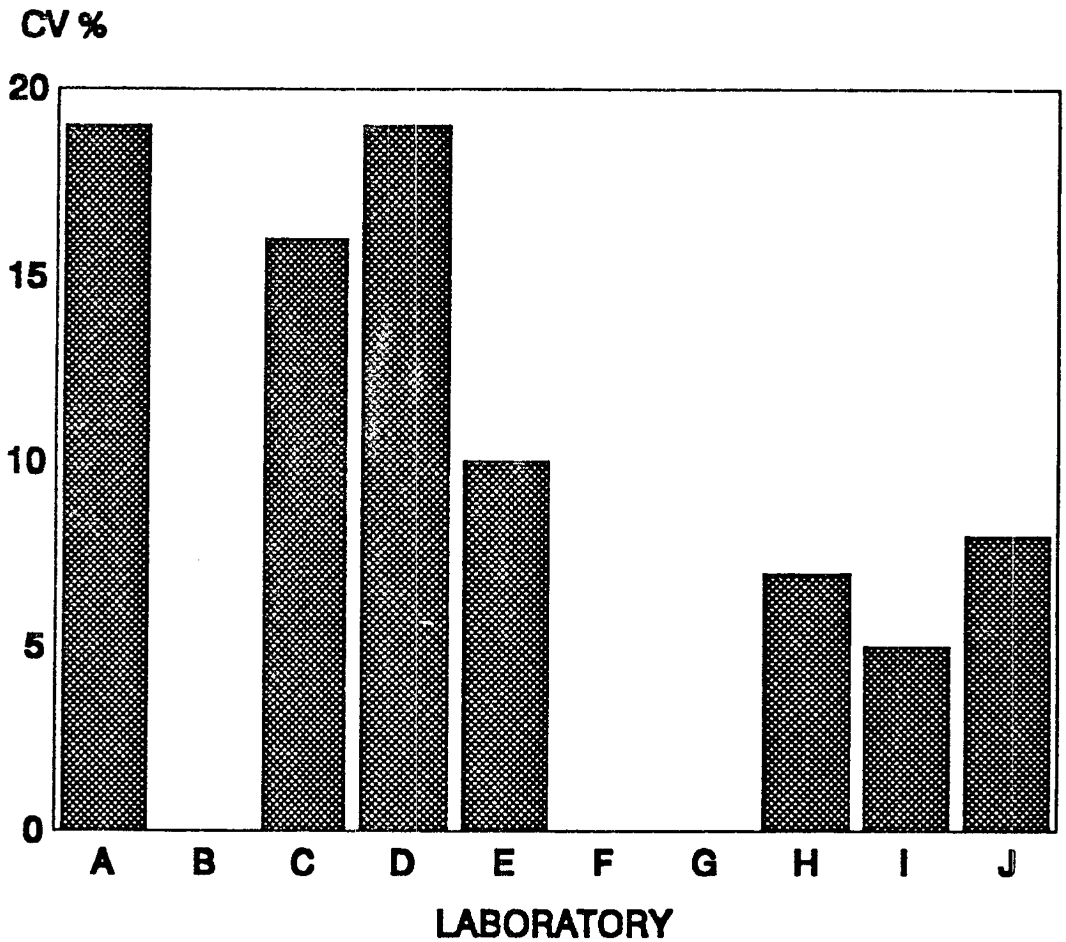


Figure 3. Average Coefficients of Variation (CV %) for the Laboratories.

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;

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

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 precision statements given in the tables in Part IV.

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 and this variability is accounted for by two terms in the model, PAIR(I,J) and SAMPLE(I,J,K). The variability that results from the division of the large sample of material into a series of samples if accounted for by the component PAIR(I,J) and the variability associated with the subdivision of these samples into two subsamples is accounted for by the component SAMPLE(I,J,K) in the model. Finally, in Table 2 the testing and measurement error is accounted for by the component MEASUREMENT(I,J,K,L). This component also includes a sampling component to the

Table 2. Estimated Standard Deviations for the Components in the Statistical Model.

Material	Deviator Stress (psi)	Confining Pressure (psi)	Average M_R	Standard Deviation			
				Lab	Pair	Sample	Error
P	3	3	14,259	1,092	267	315	571
P	6	3	13,588	1,264	356	0	475
P	9	3	13,925	1,446	297	0	427
P	5	5	16,092	1,542	277	0	625
P	10	5	16,603	1,696	347	119	415
P	15	5	17,002	1,830	356	44	510
P	10	10	21,839	2,441	685	193	652
P	20	10	23,153	2,576	389	361	555
P	30	10	24,179	2,496	401	478	559
P	10	15	24,765	2,485	645	828	777
P	15	15	25,786	2,747	393	282	700
P	30	15	28,933	2,987	612	0	799
P	15	20	30,015	3,119	656	196	866
P	20	20	31,364	3,223	857	0	1,132
P	40	20	34,957	3,483	733	0	1,012

Table 2. Estimated Standard Deviations for the Components in the Statistical Model (cont'd).

Material	Deviator Stress (psi)	Confining Pressure (psi)	Average M_R	Standard Deviation: Lab	Pair	Sample	Error
W	3	3	14,359	1,763	0	357	464
W	6	3	14,143	1,525	50	0	455
W	9	3	14,004	1,663	83	105	447
W	5	5	16,960	1,790	0	430	565
W	10	5	16,737	2,004	0	241	428
W	15	5	17,029	1,986	0	332	500
W	10	10	22,383	2,803	0	455	620
W	20	10	23,751	2,870	0	540	638
W	30	10	24,615	2,838	0	525	817
W	10	15	26,216	3,097	0	620	805
W	15	15	26,967	3,139	0	789	970
W	30	15	29,638	3,411	0	854	687
W	15	20	31,556	3,595	0	1,019	668
W	20	20	32,671	3,758	0	1,122	597
W	40	20	35,748	3,948	0	1,217	578

extent that it includes the ability of each laboratory to subdivide the samples that were shipped to them so that two test specimens could be prepared from each sample that was shipped.

The sampling component should not have a large effect in this experiment if the nature of the material is such that the sampling or dividing procedure results in truly representative sampling *and* the procedure to subdivide the samples was correctly applied. It should be noted that the granular materials being used in this experiment are highly susceptible to segregation during handling and in the event that the sampling error is high, the sampling procedure itself may need to be reviewed.

Returning to Table 2, the standard deviation for the PAIR component is very small for aggregate W, reported as 0 for 13 of the 14 laboratories. In contrast, the standard deviation is noticeably larger for the SAMPLE component. The shift in variability from PAIR to SAMPLE is most likely the result of a systematic error in the procedure that was used to prepare the samples and the cause cannot be identified by examining the reported data.

To examine the effect of each of the terms on the model it is useful to consider the coefficient of variation (CV) associated with each of the sources of variation rather than the standard deviations. The coefficient of variation is the standard deviation assigned to the source divided by the average of the measured M_R (multiplied by 100 percent). The CV is generally somewhat independent of the magnitude of the measured values because it is normalized by the means. It is often reasonable and useful to average CV's whereas it may not be reasonable to average standard deviations.

The averaged coefficients of variation for the sources of variation identified in the components of variance model are given in Table 3 for each of the materials when tested at each of the levels of the confining pressure. It will be seen in Table 3 that the variability would be very large due to the laboratories, approximately 34 percent of the measured M_R. The variability due to the measuring process is about 9 percent. It has already been noted that the within laboratory performance of these laboratories divides the laboratories into two groups, one of which is quite good and the other is not good. Thus the 9 percent CV for the measuring process is larger than should be expected on the basis of the statistical data.

The large variability due to the laboratories (34%) would be even larger if laboratory C had been included. It will be seen in the next section that there is a somewhat consistent laboratory effect over the experimental points so that it may be possible to adjust the laboratory data by means of a statistical calibration. This may reduce this effect to an acceptable level although such an adjustment should not be used an a replacement for developing a repeatable experimental procedure and proper calibration procedures in individual laboratories. Such an adjustment procedure should only be used to adjust a body of data such as in this experiment and should not be used to calibrate a laboratory for future testing.

It should be noted that the components of primary interest in this experiment are the laboratory and the measurement effects and these are estimated quite well. These are the only components used in the development of the values given in Part IV. It should again be noted that the measurement component does in fact contain the variation due to the final division of the sample into two subsamples, the preparation of the two specimens, and the measuring process on the specimens.

Table 3. Coefficient of Variation for the Components in the Statistical Model.

Material	Confining Pressure (psi)	Average M_R (psi)	Coefficient of Variation			
			Lab	Pair	Sample	Measurement
P	3	13,924	29	7	2	11
P	5	16,566	32	5	2	10
P	10	23,057	34	6	6	
P	15	26,495	33	7	4	9
P	20	32,112	32	7	2	10
W	3	14,169	37	1	3	10
W	5	16,909	36	0	6	9
W	10	23,583	38	0	7	9
W	15	27,607	37	0	9	9
W	20	33,325	36	0	11	6
Average		22,775	34	3	5	9

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

The overall effect of the confining pressure level on the measured values of M_R can be seen in Figure 4 for material P and in Figure 5 for material W. It is true that the levels of the deviator stress were larger for the larger values of the confining pressure, and thus care must be taken in assigning the increase in M_R values to the increase in confining pressure. However, by considering a fixed level of the deviator stress such as 20 psi and then observing the effect of increasing the confining pressure from 10 to 20 psi it will be seen that there is a large increase in the M_R values. The results for this example along with appropriate tests of significance for the observed increases in the measured M_R are given in Table 4. It is clear that this observed effect of the confining pressure is a real effect. The fact that a large increase occurred in every laboratory adds strength to this conclusion. The data for Table 4 are the averages over the deviator stress levels and over all of the specimens of the given material.

It has been noted in the description of the experiment that each of the eight specimens of a given material is mounted and then the tests are carried out at the different levels of the confining pressure and deviator stress. It follows that these measurements will be highly correlated, and the difference in the effects of confining pressure and deviator stress levels will be well determined. Much of the "noise" in the experiment is cancelled when these differences are considered. The information presented in Figures 4 and 5 can also be presented as graphs of the average M_R vs. confining pressure for each of the laboratories. This is done in Figures 6 and 7 where it is seen that the laboratories did give rather predictable values over the range of confining pressure levels. This also indicates that some statistical calibrations may be useful in adjusting the laboratory data in order to reduce the large laboratory effect.

The effect of the deviator stress may be observed in Table 2. As noted, care must be taken in considering this effect as the DEVID values change with the CONF values. However, if

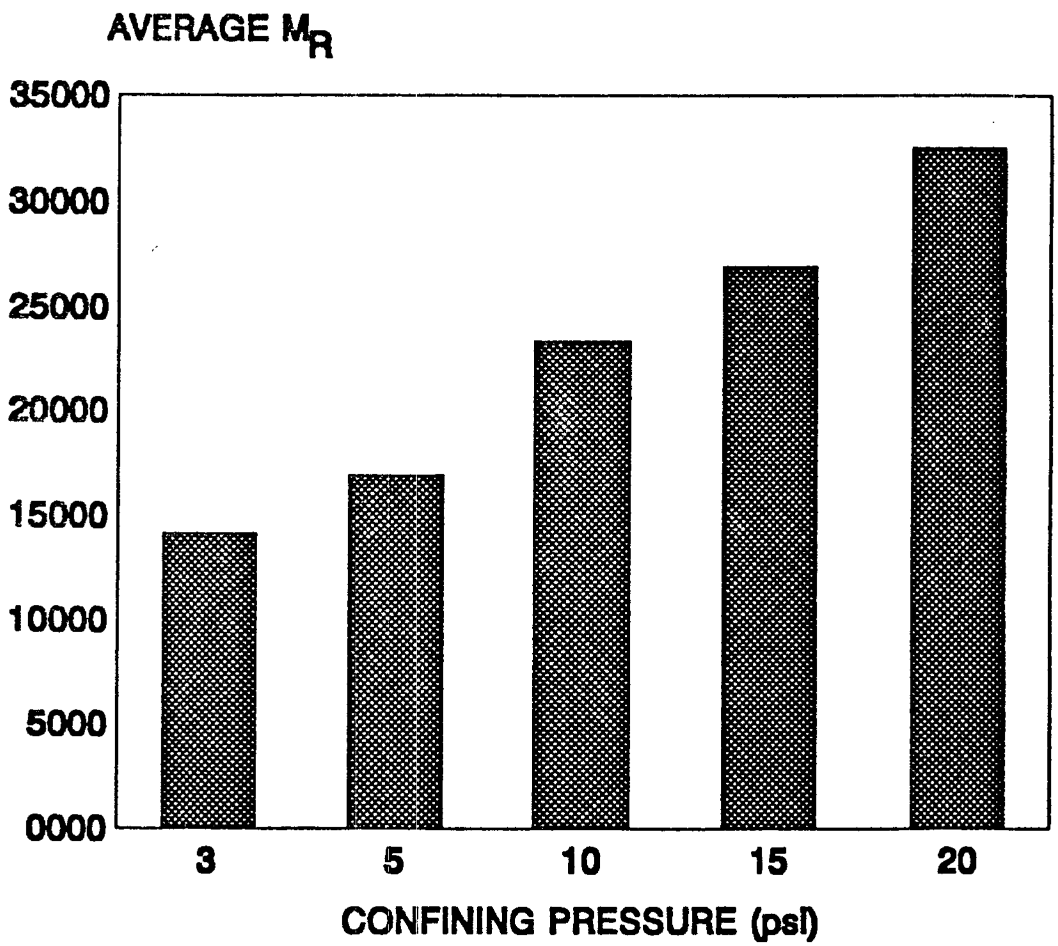


Figure 4. Average M_R (psi) by Confining Pressure for Material P.

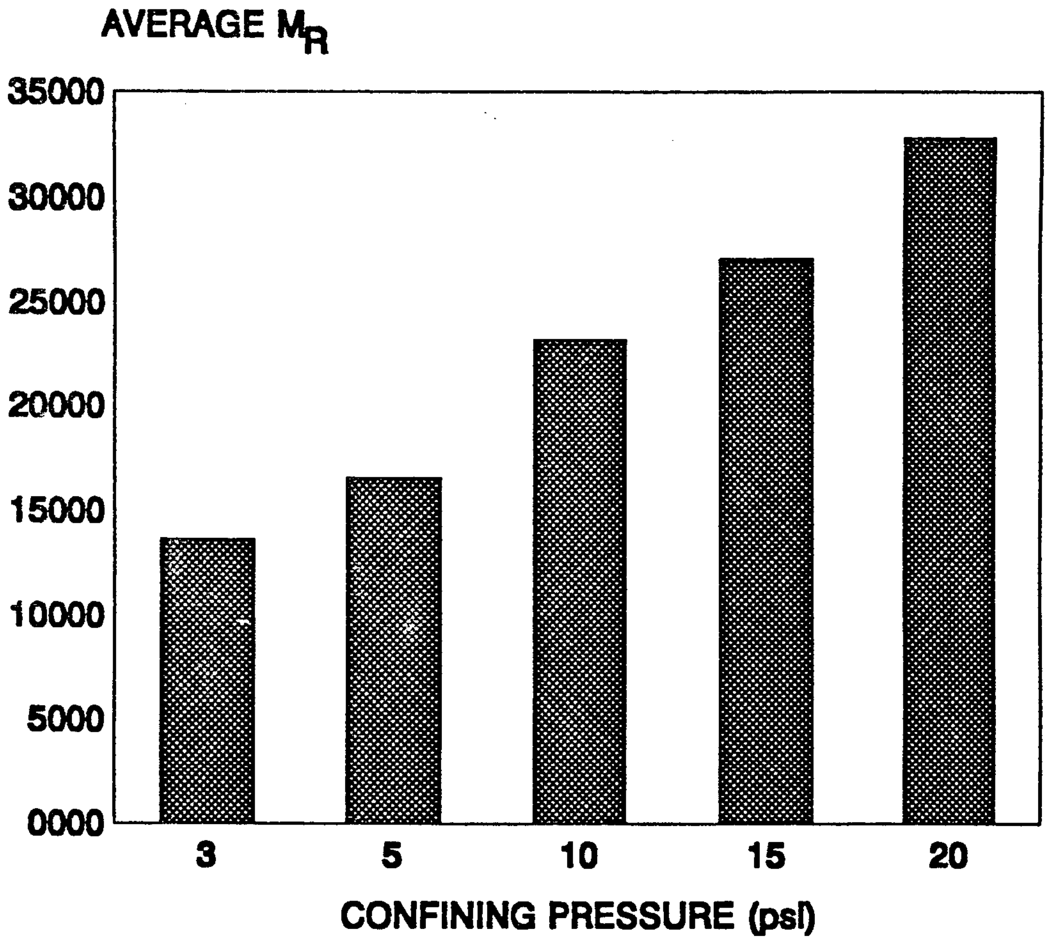


Figure 5. Average M_R (psi) by Confining Pressure for Material W.

Table 4. Average Difference for M_R at Confining Pressures of 20 psi vs. 10 psi When Deviator Stress is 20 psi.

Material	Lab	Average M_R (20) - M_R (10)	P-Value	N
P	A	7,136	.002	8
P	C	20,172	.000	8
P	D	9,082	.000	4
P	E	8,294	.000	8
P	H	12,224	.000	8
P	I	3,671	.000	8
P	J	9,292	.000	8
W	A	6,269	.000	8
W	C	27,237	.000	8
W	D	5,933	.124	4
W	E	12,052	.000	8
W	H	12,590	.000	8
W	I	4,859	.000	8
W	J	10,321	.000	8

attention is given to the case where the confining pressure is a constant, for example 20 psi, and the differences in the M_R for deviator stress levels of 20 and 40 are averaged at each laboratory as shown in Table 5, then it will be seen that there is a real effect due to the increase in the deviator stress level. This effect is smaller than the effect of increasing the confining pressure, and thus it seems reasonable to regard the graphs in Figures 6 and 7 as representing primarily the increase in the measured M_R values that is due to the increase in the confining pressure.

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.

6. Conclusions

Based on the analysis of the data a number of findings and conclusions are warranted. These findings and conclusions are valid for the materials that were tested and the laboratories that participated in the program. Caution should be used in extrapolating the findings and conclusions to all granular base course materials and to laboratories in general.

The resilient modulus test can be performed on granular materials with acceptable levels of repeatability within a given laboratory. It was observed that the measurement errors at some of the laboratories were quite small (about 7% for the CV) and this value would be further reduced if the poorly performing laboratories were removed from the estimation of the CV. The laboratories with considerably larger values (about 19%) could benefit from studying the procedures in place at the better performing laboratories.

The interlaboratory reproducibility (approximately 34% for the CV) was considered unacceptable. Activities that could possibly reduce this variability include: further refinement of the procedure; better training of the technicians; and improved calibration of the test equipment. Sample preparation, which was not studied in this experiment, should

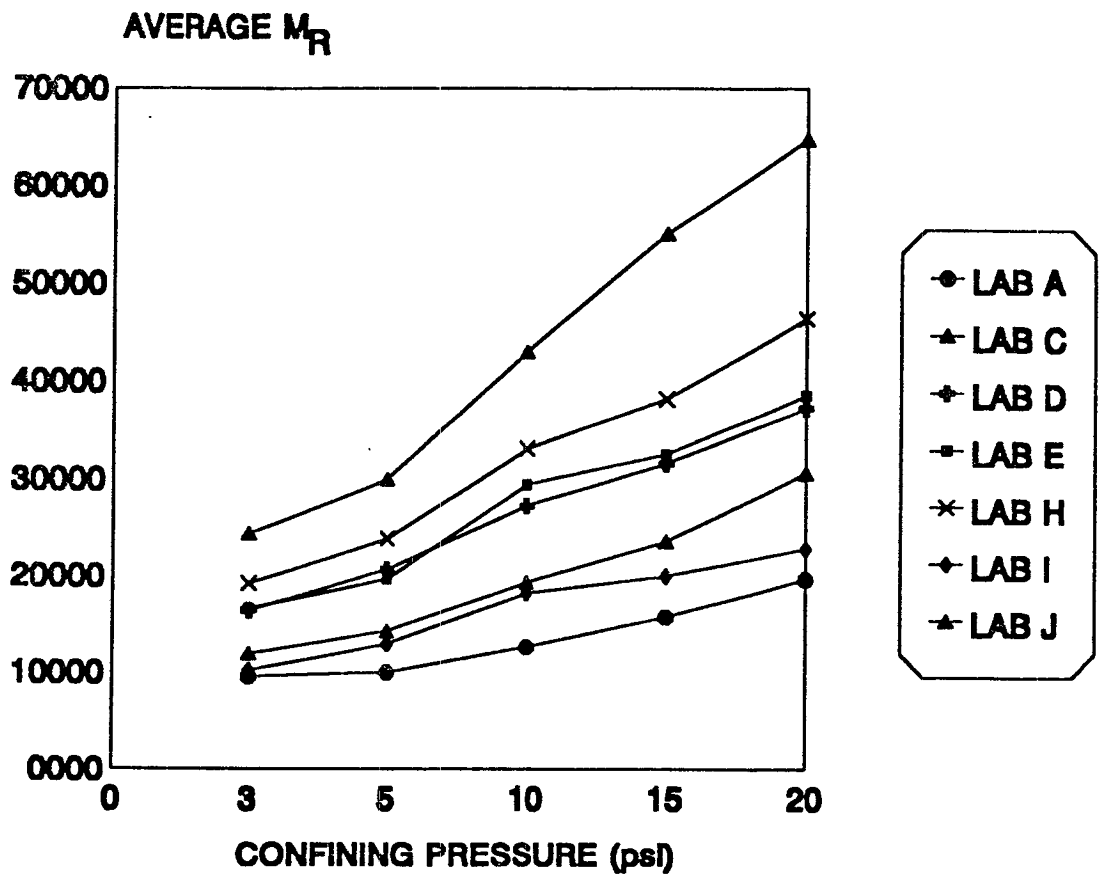


Figure 6. Average M_R by Confining Pressure for the Laboratories for Material P.

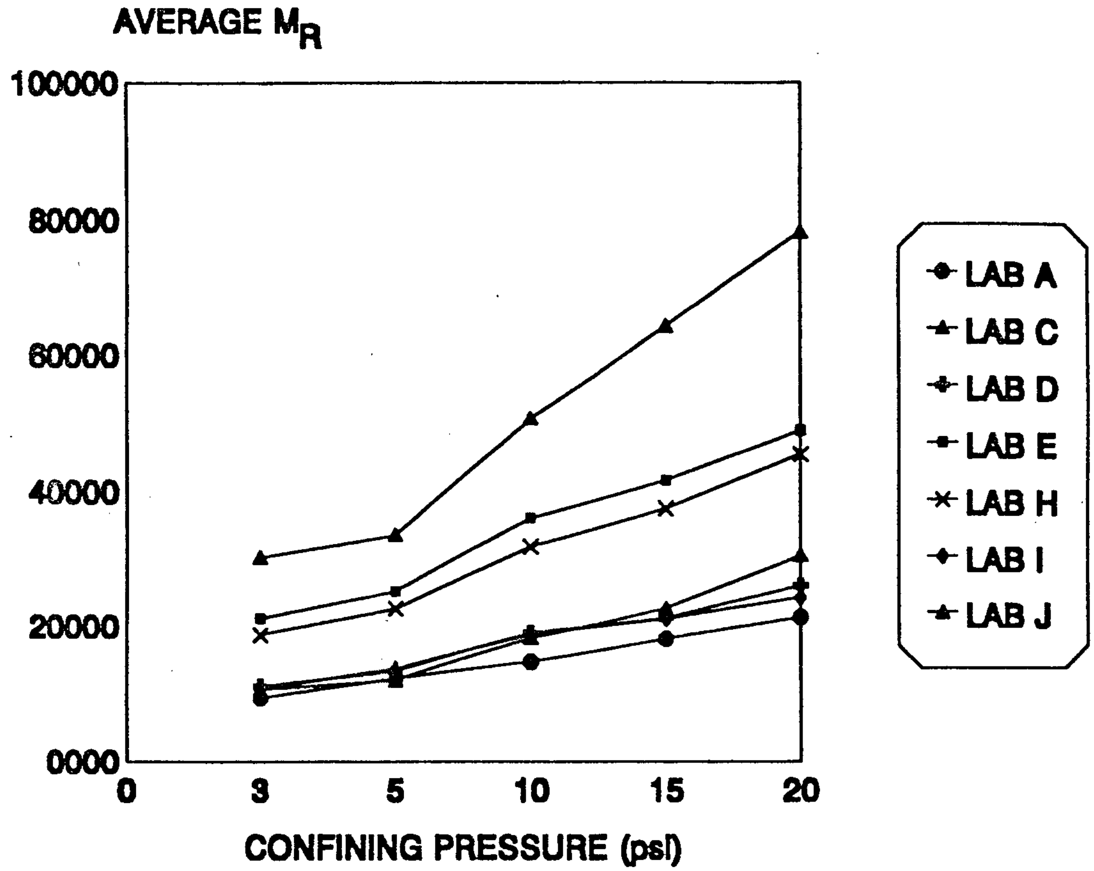


Figure 7. Average M_R by Confining Pressure for the Laboratories for Material W.

Table 5. Average Difference for M_R at Deviator Stress of 40 psi vs. 20 psi When Confining Pressure is 20 psi.

Material	Lab	Average M_R (40) - M_R (20)	P-Value	N
P	A	1,707	.020	8
P	C	988	.391	8
P	D	3,875	.028	4
P	E	4,244	.000	8
P	H	3,825	.000	8
P	I	2,731	.000	8
P	J	5,320	.013	8
W	A	1,828	.001	9
W	C	-2,428	.456	8
W	D	2,902	.029	4
W	E	3,031	.000	8
W	H	3,717	.000	8
W	I	1,399	.027	8
W	J	7,331	.000	8

also be investigated as a possible source of variability. Inability to reproduce test specimensfrom one laboratory to another may be the cause of a significant portion of interlaboratory variability.

The values for M_R varied with the deviator stress and confining pressure as expected for granular soils (base course aggregates). It is clear that there is a large effect due to the confining pressure--the measured M_R increased with increasing levels of confining pressure. There was also an effect due to deviator stress--the measured M_R increased with increasing levels of deviator stress, even when the confining pressure was constant.

It was observed that the measured M_R values depended much more on the laboratory that conducted the testing and the confining pressure and deviator stress than they did upon the source of material. If the two materials tested are representative of the range of base course materials expected in the field, this indicates that well graded, high quality base course materials may be expected to yield similar M_R values, even when the materials are from geologically different sources. Such an indication lends significant support to the common practice of accepting different types of base materials as equal alternates. In future rounds, aggregates from additional sources and with different gradations should be included in the testing program.

The large estimated values for the laboratory component of variance (about 34% for the between laboratory CV) will require continued monitoring of the performance of the laboratories when testing unbound granular base course materials. The interlaboratory variability associated with the reference specimens was much less (about 20% for the between laboratory CV)[1] indicating that a considerable portion of the variability is associated with the sample preparation and problems associated with the testing of unbound granular materials as opposed to the test itself.

---

[1]Steele, G. W., C. A. Antle, and D. A. Anderson, "Final Research Report on the Type I Unbound Granular Base Synthetic Reference Sample Program, Final Research Report Prepared for Pavement Consultancy Services, FHWA Contract No. DTFH-61-92-C-00134, October, 1993

Consideration should be given to the establishment of an appropriately designed and operated reference program for laboratories performing triaxial M_R tests on 6-inch diameter by 12-inch length base course specimens. Such a program should aid in reducing the among-laboratory variability revealed in the research results presented in this report. Specific recommendations for such a program are given in the report cited in footnote 1.

The testing of synthetic reference specimens alone will not be sufficient to reduce or identify the cause the high between laboratory variability associated with the testing of granular base course materials because much of the variability is apparently associated with sample preparation and problems associated with the handling and testing of unbound granular materials as opposed to the M_R test itself. Therefore, it is especially important that appropriately designed proficiency sample rounds be regularly scheduled for distribution to laboratories performing this test on unbound granular base course materials, particularly those laboratories involved in the LTPP research.

Proficiency sample rounds will provide participants in the program the data base necessary to further refine their test procedure and sample preparation techniques so that the between laboratory variability can be reduced to acceptable levels. Such proficiency sample rounds would also provide participants in this research the data base necessary for statistical calibration of the laboratories involved in this research, thus allowing a more reliable comparison of data generated in triaxial M_R testson 6-inch diameter by 12-inch length specimens in 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 I Proficiency Samples, 3 psi.

Material Source, P or W; Type of Index; Deviator Stress	Mean Total M_R (psi) at 3 psi confining pressure	s[1]	s%[1]	d2s[1]
Single Operator Precision				
deviator stress				
3 psi P	14,259	1,805	13%	5,054
3 psi W	14,359	1,466	10%	4,105
6 psi P	13,588	1,502	11%	4,206
6 psi W	14,143	1,438	10%	4,026
9 psi P	13,925	1,350	10%	3,780
9 psi W	14,004	1,413	10%	3,956
Among-laboratories Precision				
deviator stress				
3 psi P	14,259	3,896	27%	10,910
3 psi W	14,359	5,765	40%	16,141
6 psi P	13,588	4,266	31%	11,945
6 psi W	14,143	5,033	36%	14,092
9 psi P	13,925	4,760	34%	13,329
9 psi W	14,005	5,446	39%	15,250

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

Material source - P = Pleasonton; W = Watsonville

Table 7. Precision Statements for Round 1 Type I Proficiency Samples, 5 psi.

Material Source, P or W; Type of Index; Deviator Stress	Mean Total M_R (psi) at 5 psi confining pressure	s[1]	s%[1]	d2s[1]
Single Operator Precision				
deviator stress				
5 psi P	16,092	1,977	12%	5,536
5 psi W	16,960	1,786	11%	5,001
10 psi P	16,603	1,313	8%	3,676
10 psi W	16,737	1,354	8%	3,791
15 psi P	17,002	1,614	9%	4,519
15 psi W	17,029	1,582	9%	4,430
Among-laboratories Precision				
deviator stress				
5 psi P	16,092	5,263	33%	14,738
5 psi W	16,960	5,935	35%	16,618
10 psi P	16,603	5,529	33%	15,482
10 psi W	16,737	6,481	39%	18,147
15 psi P	17,002	6,008	35%	16,822
15 psi W	17,029	6,475	38%	18,131

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

Material source - P = Pleasonton; W = Watsonville

Table 8. Precision Statements for Round 1 Type I Proficiency Samples, 10 psi.

Material Source, P or W; Type of Index; Deviator Stress	Mean Total M_R (psi) at 10 psi confining pressure	s[1]	s%[1]	d2s[1]
Single Operator Precision				
deviator stress				
10 psi P	21,839	2,063	9%	5,776
10 psi W	22,383	1,961	9%	5,491
20 psi P	23,153	1,756	8%	4,917
20 psi W	23,751	2,018	8%	5,650
30 psi P	24,179	1,768	7%	4,950
30 psi W	24,615	2,583	10%	7,232
Among-laboratories Precision				
deviator stress				
10 psi P	21,839	7,988	37%	22,366
10 psi W	22,383	9,077	41%	25,417
20 psi P	23,153	8,328	36%	23,319
20 psi W	23,751	9,299	39%	26,036
30 psi P	24,179	8,083	33%	22,634
30 psi W	24,615	9,338	38%	26,147

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

Material source - P = Pleasonton; W = Watsonville

Table 9. Precision Statements for Round 1 Type I Proficiency Samples, 15 psi.

Material Source, P or W; Type of Index; Deviator Stress	Mean Total M_R (psi) at 15 psi confining pressure	s[1]	s%[1]	d2s[1]
Single Operator Precision				
deviator stress				
10 psi P	24,765	2,458	10%	6,882
10 psi W	26,216	2,547	10%	7,132
15 psi P	25,786	2,213	9%	6,196
15 psi W	26,967	3,067	11%	8,588
30 psi P	28,933	2,528	9%	7,078
30 psi W	29,638	2,173	7%	6,084
Among-laboratories Precision				
deviator stress				
10 psi P	24,765	8,167	33%	22,867
10 psi W	26,216	10,119	39%	28,333
15 psi P	25,786	8,948	35%	25,054
15 psi W	26,967	10,391	39%	29,095
30 psi P	28,933	9,769	34%	27,353
30 psi W	29,638	11,003	37%	30,808

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

Material source - P = Pleasonton; W = Watsonville

Table 10. Precision Statements for Round 1 Type I Proficiency Samples, 20 psi.

Material Source, P or W; Type of Index; Deviator Stress	Mean Total M_R (psi) at 20 psi confining pressure	s[1]	s%[1]	d2s[1]
Single Operator Precision				
deviator stress				
15 psi P	30,015	2,739	9%	7,669
15 psi W	31,556	2,112	7%	5,914
20 psi P	31,364	3,579	11%	10,021
20 psi W	32,671	1,887	6%	5,284
40 psi P	34,957	3,199	9%	8,957
40 psi W	35,748	1,828	5%	5,118
Among-laboratories Precision				
deviator stress				
15 psi P	30,015	10,223	34%	28,624
15 psi W	31,556	11,563	37%	32,375
20 psi P	31,364	10,788	34%	30,206
20 psi W	32,671	12,033	37%	33,692
40 psi P	34,957	11,482	33%	32,149
40 psi W	35,748	12,619	35%	35,333

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

Material source - P = Pleasonton; W = Watsonville

Table 11. Precision Statements for Round 1 Type I Proficiency Samples.

Material Source, P or W; Type of Index; All Deviator Stresses and Confining Pressure	Mean Total M_R (psi)	s%[1]
Single Operator Precision		
pooled P	22,431	10%
pooled W	23,118	9%
Among-laboratories Precision		
pooled P	22,431	34%
pooled W	23,118	38%

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

Material source - P = Pleasonton; W = Watsonville

APPENDIX A

UNIVERSITY OF NEVADA-RENO

Department of Civil Engineering
College of Engineering
University of Nevada-Reno
Reno, Nevada 89557-0030
(702) 784-6937

To Participating Laboratories

June 12, 1990

Dear Participant:

The University of Nevada, Reno has been contracted to provide your laboratory with SHRP proficiency samples for Type I soils. You will soon be receiving by freight the first of two rounds of SHRP proficiency samples for Type I soils. If you have not received and tested the synthetic specimens, and have not received on "OK" to begin testing Round 1 of the Type I soil samples from Mr. Garland Steele of Steele Engineering, please contact him at (304) 727-8719. Please store these containers, UNOPENED, until you are authorized by Mr. Steele to proceed. Once you have been authorized to proceed, please complete the testing and return the data forms within a maximum of four weeks.

The first round of Type I proficiency samples consists of a total of 8 randomly numbered 5-gal. buckets. The steps for testing each bucket are as follows:

1. Calibrate your equipment according to the same protocol used prior to testing the synthetic proficiency samples.

2. Pour the contents of one bucket through a riffle splitter four consecutive times. This will ensure that any batching or shipping-induced segregation is eliminated. **DO NOT COMBINE THE CONTENTS OF DIFFERENT BUCKETS.**

3. Once the contents of each bucket have been thoroughly mixed, split the material into two equal portions in order to prepare 6-inch diameter by 12-inch high samples. Do not scrap or discard any material prior to preparing the 6-inch by 12-inch specimens.

4. Label each sample with a "-a" or "-b" after the sample number for the first and second portions, respectively.

5. Prepare one sample from each portion according to SHRP protocol P46 (Resilient Modulus of Unbound Granular Base/Subbase Materials and Subgrade Soils).

6. Report the data on the attached forms and graphs. If more forms are needed, please make copies of the attached forms.

A copy of the SHRP sample preparation and testing protocol are included for your convenience. Please complete the data sheets and return to:

Mary Stroup-Gardiner
University of Nevada, Reno
Civil Engineering Department
Mail Stop 258
Reno, Nevada 89557

If you have any questions, please call either Mary at (702) 784-6858 or Mr. Steele at (304) 727-8719.

Sincerely,

M. Stroup-Gardiner

DATA SHEETS FOR PROFICIENCY SAMPLES FOR

TYPE I SOILS

General Information

Laboratory: ____

____

____

____

Technician: ____

Date: ____

SHRP Contract No. (If applicable): ______________________________

Equipment (P46 Sect 6.3):

Load Cell Capacity: ______________________

Manufacturer: ______________________

LVDT Range: ______________________

Manufacturer: ______________________

DATA SHEETS FOR PROFICIENCY SAMPLES FOR

TYPE I SOILS

Pre-Test Calculations

Calculations for Sample Numbers ____________, ______________

Field Moisture Content ________________ %

Field Density __________________________ PCF

Volume of Compacted Specimen to be Prepared (Sect. 7.3.4) :

V: ____________________ inches __________________ mm

Weight of Oven Dry Soil Solids (Sect. 7.3.5) :

W_s : ____________________ lbs __________________ grams

W_c : ____________________ lbs __________________ grams

Total Weight of Prepared Material for Desired Volume (Sect. 7.3.6) :

W_t : ____________________ grams

Total Weight of Dried Soil Sample for Resilient Modulus Sample and a Moisture Content Determination Sample (Sect. 7.3.7) :

W_{ad} : ____________________ grams

Total Weight of Water to be Added to Achieve Desired Field Moisture (Sect. 7.3.8) :

W_1 : ____________________ grams

W_2 : ____________________ grams

W_{aw} : ____________________ grams

DATA SHEETS FOR PROFICIENCY SAMPLES FOR TYPE I SOILS

Sample Preparation Calculations

Bucket Number : ________________________________

Field Moisture Content : ________________________________

Field Density : ________________________________

Sample Identification :	________ A	________ B
Number of Lifts Used for Compaction	________	________
Weight of Soil per Lift	________ grams	________ grams
Verification of Lift Thickness		
Circle One: Inches / MM		
Lift 1 :	________	________
Lift 2 :	________	________
Lift 3 :	________	________
Verification of Moisture Content After Compaction is Complete :	________ %	________ %

*******USE ATTACHED SHRP DATA SHEETS FOR******
REPORTING THE ACTUAL TEST RESULTS

Resilient Modulus (Mr) Test for Material Type 1

SHRP Section ID _ _ _ _ Field Set No. ____

State Code _ _ Location _ _ _ SHRP Sample No. __

SHRP Lab Test No. ______ Layer No. ______

Specific Gravity ____________

Soil Specimen Measurements:

Top ____________

Middle ____________

Diameter Bottom ____________

Average ____________

Membrane Thickness ____________

Net Diameter ____________

t Specimen + Cap + Base ____________

Ht Cap + Base ____________

Initial Length, Lo, inches ____________

Inside Diameter of Mold ____________

SHRP-LTPP
LABORATORY MATERIAL
HANDLING AND TESTING

Soil Specimen Weight:

Initial Weight of Container

*Wet Soil gms ____________

Final Weight of Container

*Wet Soil gms ____________

Weight Wet Soil Used ____________

Soil Specimen Volume:

Initial Area, Ao

in2 (cm2) ____________

Initial Volume, Ao Lo

in3 (cm3) ____________

Wet Density, pcf (kN/m3) ____________

Compaction Water Content, w% ____________

Saturation, S% ____________

Dry Density (YD), pcf (kn/m3) ____________

SHRP PROTOCOL: P46

Test date ________ Sheet ___ of ___

Compaction Method ____________

Constants

Vertical LVDT ____________

Load Cell ____________

Water Content After

Mr Testing, % ____________

Comments ____________

____

____

____

1 Chamber Confining Pressure, S3 (psi)	2 Nominal Deviator Stress, Sd (psi)	3 Load Cell Reading	4 Deviator Load (lb)	5 Mean Deviator Load (lb)	6 Standard Deviation Stress (psi)	7 Applied Deviator Stress (psi)	8 Recoverable Deformation LVDT Reading	9 Recoverable Deformation (inches)	10 Mean Recoverable Deformation (inches)	11 Std. Dev. of Recoverable Deformation (inches)	12 Resilient Strain (inch/inch)	13 Mr (psi)	14 Bulk Stress Sb (psi)

Worksheet T46A. Form for Resilient Modulus Test on Material Type 1 (Issued 17 August 89)

SHRP-LTPP

LABORATORY MATERIAL

HANDLING AND TESTING

Resilient Modulus (Mr) Test for Material Type 1 SHRP PROTOCOL: P46

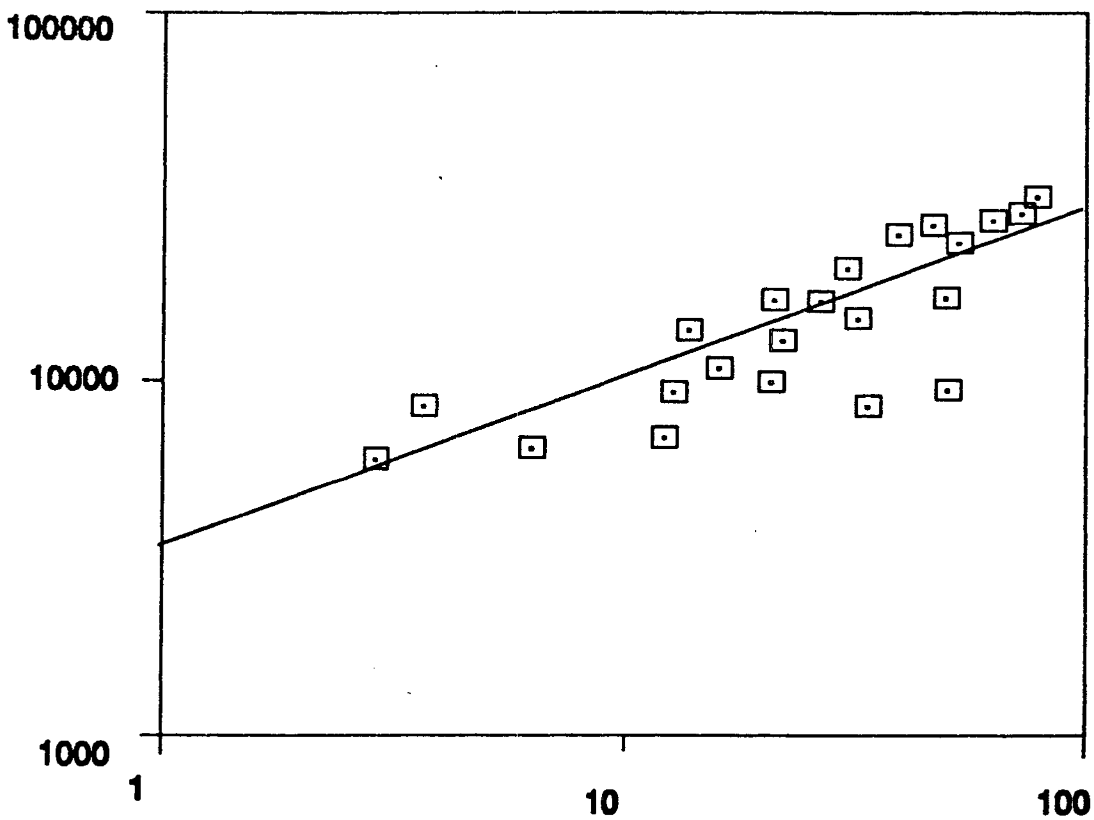
SHRP Section ID _ _ _ _ _ _ Field Set No. ____________

State Code _ _ Location _ _ _ SHRP Sample No. _ _ _

SHRP Lab Test No. ____________ Layer No. ________

$Mr = K3(Sb)^{K4} = 4301.9(Sb)^{(1408)8}$

$R^2 = 0.826$



EXAMPLE OF REQUIRED GRAPH

Figure T46A. Logarithmic plot of Resilient Modulus, (Mr) vs Bulk Stress. (Sb) for Type 1 Materials

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_t is the total axial deformation due to S_d.

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

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

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

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

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

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

G = specific gravity of soil solids, dimensionless,

w = moisture content of soil, (%),

S = degree of saturation, (%), and

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

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

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

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

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

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

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

6. APPARATUS

6.1 Triaxial Pressure Chamber - The pressure chamber is used to contain the test specimen and the confining fluid during the test. A triaxial chamber suitable for use in resilient testing of soils is shown in Figure 1. The deformation is measured externally with two spring loaded LVDT's as shown in Figure 1.

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

6.2 Loading Device:

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

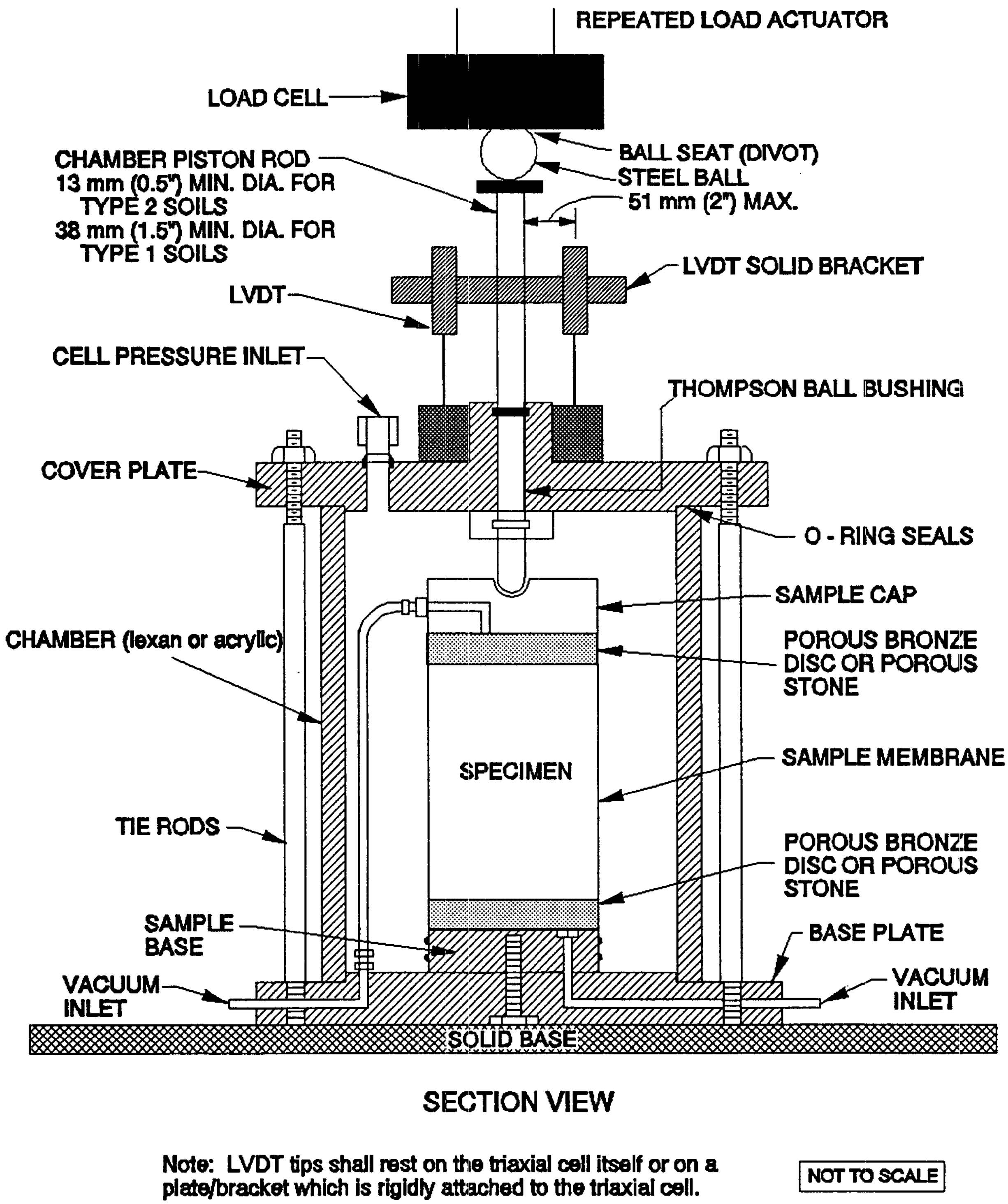


Figure 1. Triaxial chamber with external LVDT's and load cell.

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

6.3 Load and Specimen Response Measuring Equipment:

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

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

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

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

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

All the LVDT's shall meet the following specifications:

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

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

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

6.4 Specimen Preparation Equipment - A variety of equipment is required to prepare undisturbed samples for testing and to obtain compacted specimens that are representative of field conditions. Use of different materials and different methods of compaction in the field requires the use of varying compaction techniques in the laboratory. See Attachment A and Attachment B of this procedure for specimen compaction equipment.

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

6.6 Miscellaneous Apparatus - This includes calipers, micrometer gauge, steel rule (calibrated to 0.02 inch), rubber membranes from 0.01 to 0.031 inch thickness, rubber O-rings, vacuum source with bubble chamber and regulator, membrane expander, porous stones, scales, moisture content cans and data sheets, as required.

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

7. PREPARATION OF TEST SPECIMENS

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

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

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

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

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

7.2 Undisturbed Specimens - Undisturbed subgrade soil specimens are trimmed and prepared as described in AASHTO T234-85, Strength Parameters of Soils by Triaxial Compression, using the thin-walled tube samples of the subgrade soil. Determine the natural moisture content (w) of the tube sample following the procedure outlined in SHRP Protocol P49 (AASHTO T265-86) and record in the test report. Determine the in situ density of the subgrade soil as specified in AASHTO T233-86.

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

7.2.1 Examine the thin-walled tube samples from each end of the test section separately. For both ends of a test section, select a sample suitable for testing (see NOTE 2) giving priority to samples extracted near the surface of the subgrade. That is, the sample should be taken from the top of the first tube pushed, if it is suitable for testing. If not, examine samples from increasing depths in the subgrade, selecting the first sample suitable for testing.

NOTE 2: To be suitable for testing, a specimen of sufficient length (generally twice the diameter of the specimen after preparation) must be cut from the tube sample, and must be free from defects that would result in unacceptable or biased test results. Such defects include cracks in the specimen, edges sheared off that cannot be repaired during preparation, presence of particles much larger than that typical for the material (example, 1-inch gravel in a fine-grained soil), presence of "foreign objects" such as large roots, wood particles, organic material and gouges due to gravel hanging on the edge of the tube.

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

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

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

7.3 Laboratory Compacted Specimens - Reconstituted test specimens shall be prepared to approximate the in situ dry density (Y_d) and moisture content (w), (see NOTE 3). These laboratory compacted specimens shall be prepared for all unbound granular base and subbase material and for all subgrade soils for which undisturbed tube specimens could not be obtained.

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

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

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

7.3.2 If the sample is damp when received from the field, dry it until it becomes friable. Drying may be in air or by use of a drying apparatus such that the temperature does not exceed 60°C (140°F). Then thoroughly break up the aggregations in such a manner as to avoid reducing the natural size of individual particles.

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

7.3.4 Determine the appropriate total volume (V) of the compacted specimen to be prepared. The total volume must be based on a height of the compacted specimen slightly greater than that required for resilient testing to allow for trimming of the specimen ends. An excess of 0.5-inch (13 mm) is generally adequate for this purpose.

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

W_s (pounds) = Y_d (pounds per cubic foot) x V (cubic feet)

W_s (grams) = W_s (pounds) x 454

W_w (pounds) = W_s (pounds) x w (%/100)

W_w (grams) = W_w (pounds) x 454

7.3.6 Determine the total weight of the prepared material sample (W_t) required to obtain W_s to produce the desired specimen of volume V at dry density

Y_d and moisture content w.

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

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

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

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

W_1 (grams) = (W_s + W_{as}) x (w_1/100)

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

W_{aw} (grams) = W_2 - W_1

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

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

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

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

7.4 Compaction Methods and Equipment for Reconstituting Specimens

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

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

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

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

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

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

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

The sample dry density and moisture content should not differ by more than 3 percent of the in situ dry density and 1 percentage point of the in situ moisture content respectively for Type 1 materials, and 2 percent of the in situ dry density and 1/2% of the

in situ moisture content for Type 2 materials respectively (See NOTE 4). If the remolded sample does not meet this criteria, it should be discarded.

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

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

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

8. TEST PROCEDURE

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

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

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

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

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

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

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

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

8.1.1.7 When leakage has been eliminated, disconnect the vacuum supply and place the chamber on the base plate, the load cell on the porous stone, and the cover plate on the chamber. Insert the loading piston and obtain a firm connection with the load cell. Tighten the chamber tie rods firmly.

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

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

8.1.2.1 Open all drainage valves loading into the specimen.

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

8.1.2.3 Conducting - Begin the test by applying 1000 repetitions of a deviator stress of 4 psi using a haversine shaped load pulse consisting of a 0.1 second load followed by a 0.9 second rest period. The foregoing stress sequence constitutes sample conditioning, that is, the elimination of the effects of the interval between compaction and loading and the elimination of initial loading versus reloading. This conditioning also aids in minimizing the effects of initially imperfect contact between the end platens and the test specimen.

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

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

Table 1. Testing Sequence for Type 2 Soils.

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

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

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

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

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

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

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

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

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

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

8.2.1 Assembly of the Triaxial Chamber - Follow Steps 8.1.1.1 through 8.1.1.8. When compaction is completed, place the porous stone and top sample cap on the surface of the specimen. Roll the rubber membrane off the rim of the mold and over the sample cap. If the sample cap projects above the rim of the mold, the membrane should be sealed tightly against the cap with the O-ring seal. If it does not, the seal can be applied later.

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

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

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

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

8.2.2.1 If not already done, adjust the position of the axial loading device or triaxial chamber base support as necessary to couple the load-generation device piston and the triaxial chamber piston. The triaxial chamber piston should bear firmly on the load cell. This can be done by applying a seating pressure of 2 psi. A minimum contact load of 10 percent ($.1S_d$) of the maximum applied load shall be maintained during all repeated load determination.

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

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

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

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

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

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

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

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

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

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

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

Table 2. Testing Sequence for Type 1 Soils.

9. CALCULATIONS

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

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

10. REPORT

The following information is to be recorded on Form T46.

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

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

10.3 Test Results

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

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

- Simple relationship for Type 1 Material (Figure T46A)

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

  Where S_d = deviator stress and

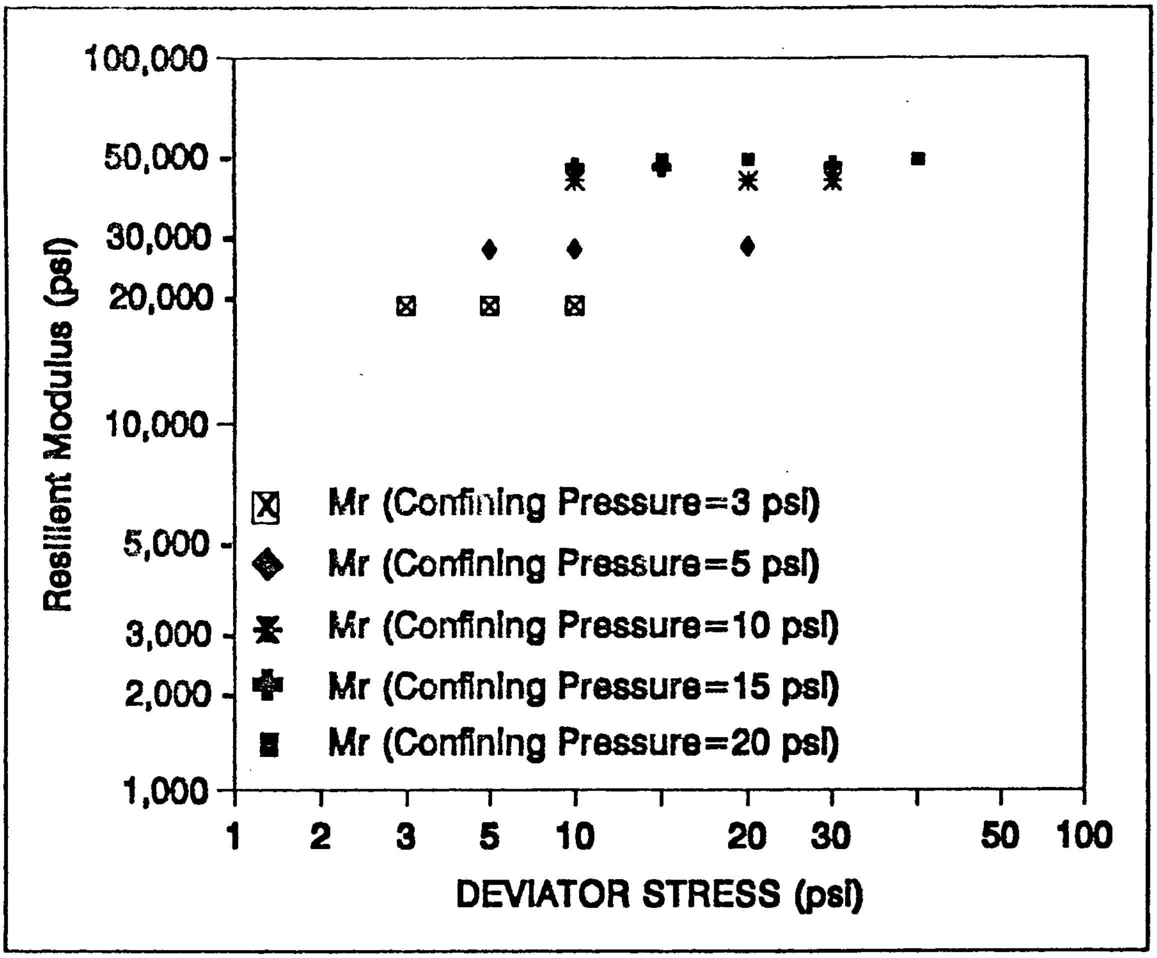
  S_3 = confining pressure

- Simple relationship for Type 2 Material (Figure T46B)

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

  Where S_d = deviator stress and

  S_3 = confining pressure

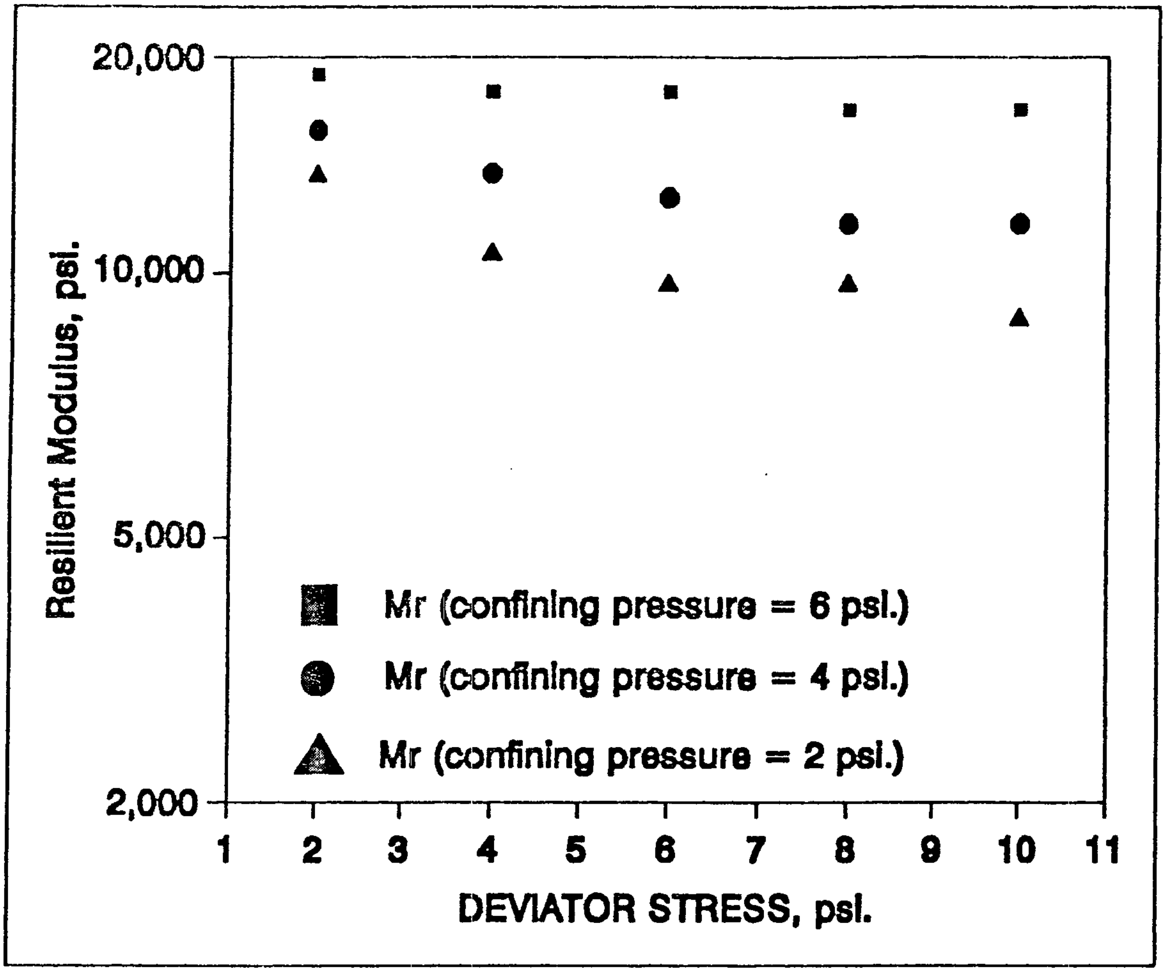


$$M_r = K_1 (1+S_3)^{K_2} (S_d)^{K_5}$$

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

$$R^2 = .988$$

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



$$Mr = K_1 (S_d)^{K2} (1+S_3)^{K3}$$
$$= 14071 \ (S_d)^{-.151} (1+S_3)^{.200}$$
$$R^2 = .977$$

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, γ_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

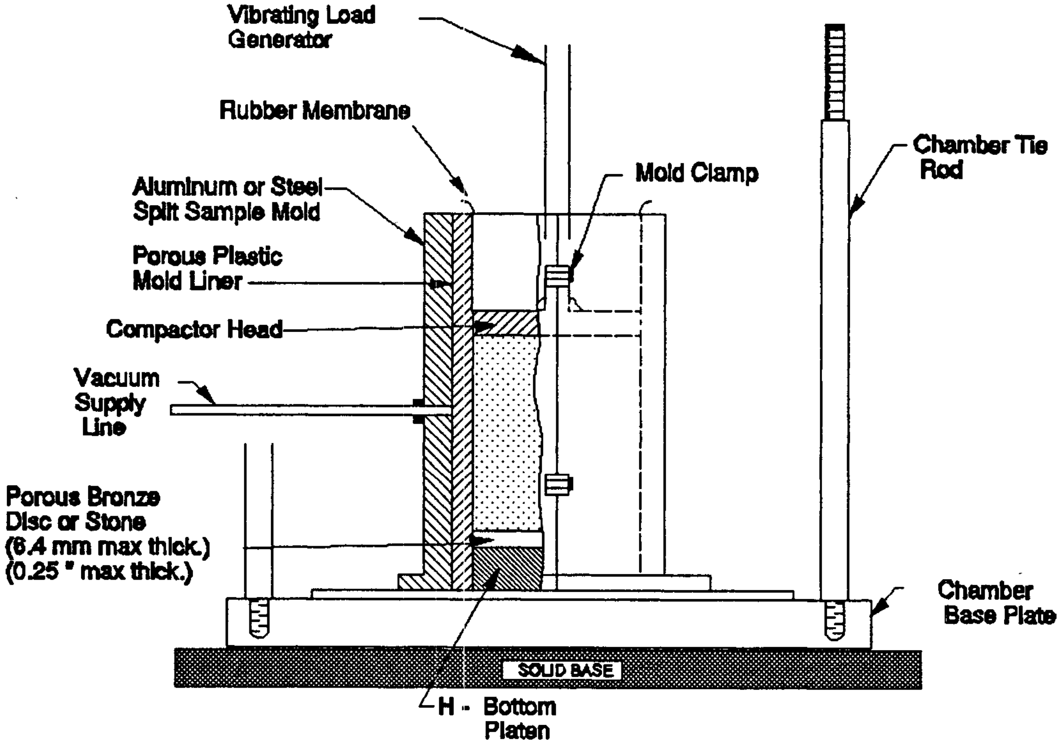
2.1 Six inch diameter split mold.

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.



Note 1: Compactor head should be 6.35 ± 0.5 mm (0.25 ± 0.02") smaller than 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_{sd} into a mixing pan. Add the required amount of water, W_{iw} 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.

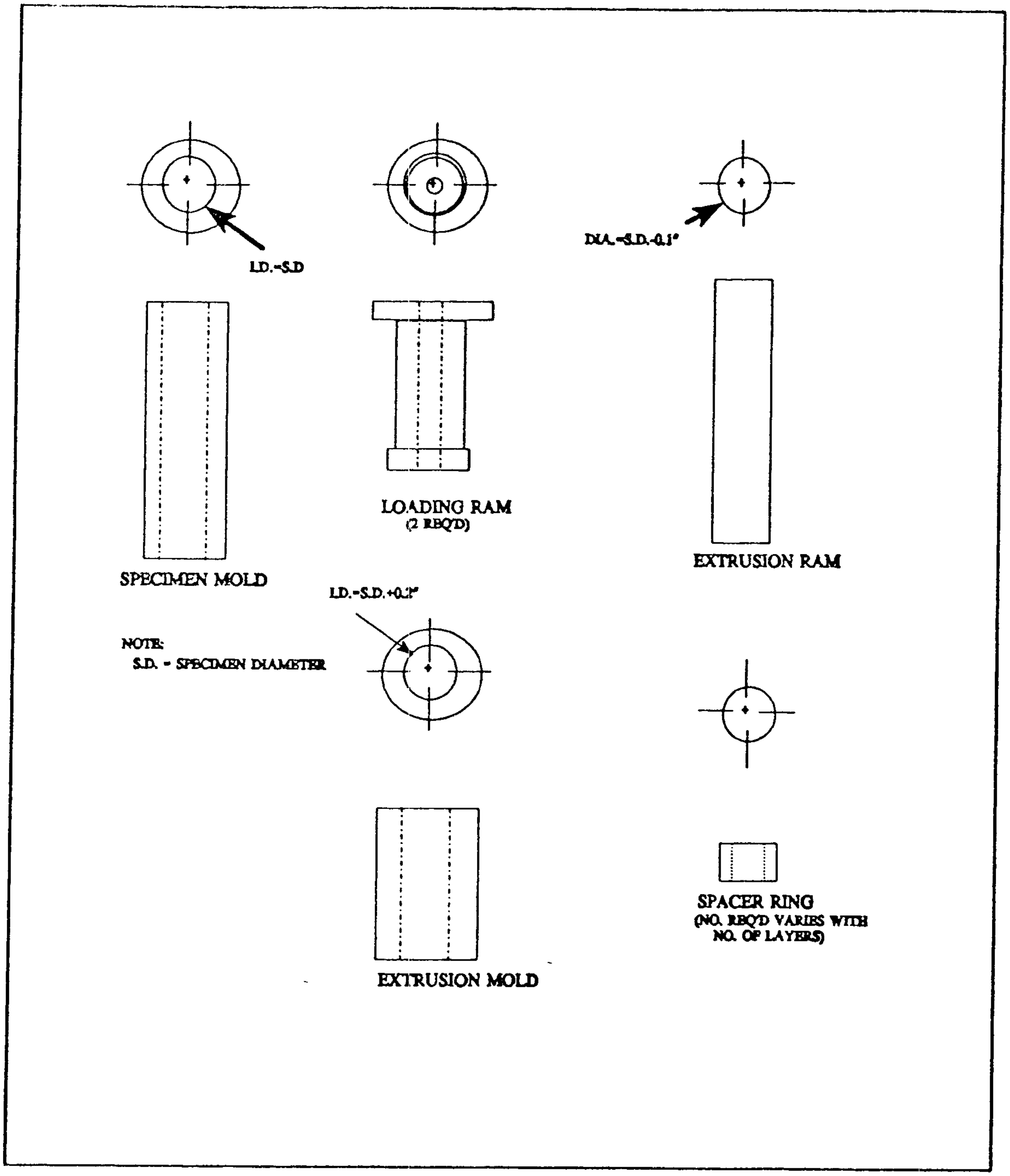


Figure 3. Apparatus for static compaction of Type 2 unbound materials.

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

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_1 _ _ _ _ _ _ . k_2 _ . _ _ _ _ _ _
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. Del. LVDT #1 Reading (in.)*	H Mean Recov. Del. 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 ____________

SHRP PROFICIENCY SAMPLES
FOR RESILIENT MODULUS TESTING
OF UNBOUND MATERIAL
(Gradation)

Sieve Size	Total % Passing
1.5"	100
1"	82
3/4"	73
1/2"	61
3/8"	52
#4	39
#8	27
#16	21
#30	15
#50	10
#100	8
#200	6

AASHTO Soil Classification	Unified Soil Classification
A-1-a	GW-GM

PLASTIC INDEX
np

Material Identification	Specific Gravity of Material Passing #4	Specific Gravity of Material Retained on #4
Watsonville	2.777	2.865
Pleasonton	2.713	2.748

Field Moisture-Density Target

Source	Dry Density	Moisture
Watsonville	133.6 #/ft^3	8.0%
Pleasonton	138.6 #/ft^3	6.0%

Note: The field moisture content and the field density were entered by the University of Nevada-Reno Laboratory on the pretest calculations sheets supplied for the 8 samples to each participant. Each of the 8 samples were identified by number only.

Fabrication Procedure
for
Type I Round 1 Proficiency Samples

- Obtain the total mass of aggregate needed from each of 2 SHRP Reference Library aggregate sources.
- Process each of the 2 sources separately.
- Screen the total mass of aggregate from each source and store each sieve fraction separately.
- Recombine the separate sieve fractions from one source by mass to yield the target gradation in a mass of aggregate sufficient for eventual fabrication of 4 test specimens (6"d x 12"l). Identify this material with a number.
- Pass the above mass of aggregate through a splitter one time and store each split in a separate five gallon plastic bucket. Identify 1 bucket with the number previously assigned followed with an A. Identify the other bucket with the number previously assigned followed by the letter B.
- Repeat the two preceding steps until the required number of pairs of buckets have been prepared.
- Array the pairs of buckets from 1 source and randomly select 2 pairs of buckets for shipment to each participant. Assign a random sample number to each of the 4 buckets, mark the buckets accordingly, and maintain a key sheet that traces the identity of all buckets shipped to each participant.
- Repeat the four preceding steps for the other source.
- Ship 8 randomly numbered buckets to each participant, 4 from one source and 4 from the other.

APPENDIX B

LABORATORY STATISTICS FOR THE TYPE I RM TESTS ON GRANULAR SOILS

OBS	MATERIAL	LAB	CONFPR	DEVID	AVMR	STD	CV	NS
1	P	A	3	3	13437	3294	25	3
2	P	A	3	6	9391	1625	17	8
3	P	A	3	9	8391	1216	14	8
4	P	A	5	5	10551	1689	16	8
5	P	A	5	10	9982	1918	19	8
6	P	A	5	15	9593	1805	19	8
7	P	A	10	10	11863	2546	21	8
8	P	A	10	20	12333	1893	15	8
9	P	A	10	30	13895	2554	18	7
10	P	A	15	10	14727	2224	15	8
11	P	A	15	15	15077	1934	13	8
12	P	A	15	30	17439	3816	22	8
13	P	A	20	15	18329	3326	18	8
14	P	A	20	20	19469	4254	22	8
15	P	A	20	40	21176	5323	25	8
16	P	C	3	3	25660	12584	49	8
17	P	C	3	6	22963	7171	31	8
18	P	C	3	9	24599	3669	15	8
19	P	C	5	5	30633	5602	18	8
20	P	C	5	10	29211	3815	13	8
21	P	C	5	15	29978	4249	14	8
22	P	C	10	10	42477	6867	16	8
23	P	C	10	20	42790	6067	14	8
24	P	C	10	30	43674	6427	15	8
25	P	C	15	10	56016	9292	17	8
26	P	C	15	15	54190	9584	18	8
27	P	C	15	30	54820	8492	15	8
28	P	C	20	15	67486	10069	15	8
29	P	C	20	20	62963	10243	16	8
30	P	C	20	40	63950	8625	13	8
31	P	D	3	3	16730	3798	23	3
32	P	D	3	6	16050	2729	17	3
33	P	D	3	9	16565	2456	15	3
34	P	D	5	5	20700	1740	8	4
35	P	D	5	10	20400	2255	11	4
36	P	D	5	15	20818	1984	10	4
37	P	D	10	10	25381	4129	16	4
38	P	D	10	20	27610	2567	9	4
39	P	D	10	30	28622	3513	12	4

OBS	MATERIAL	LAB	CONFPR	DEVID	AVMR	STD	CV	NS
40	P	D	15	10	30067	5610	19	4
41	P	D	15	15	30210	3565	12	4
42	P	D	15	30	34333	3688	11	4
43	P	D	20	15	34500	3752	11	4
44	P	D	20	20	36692	3450	9	4
45	P	D	20	40	40566	3686	9	4
46	P	E	3	3	16355	2081	13	8
47	P	E	3	6	16499	2598	16	8
48	P	E	3	9	17053	2367	14	8
49	P	E	5	5	18444	2502	14	8
50	P	E	5	10	19854	1973	10	8
51	P	E	5	15	20662	2911	14	8
52	P	E	10	10	28506	4203	15	8
53	P	E	10	20	29485	3626	12	8
54	P	E	10	30	30287	3608	12	8
55	P	E	15	10	29365	7129	24	8
56	P	E	15	15	32788	3951	12	8
57	P	E	15	30	35482	2991	8	8
58	P	E	20	15	35821	4867	14	8
59	P	E	20	20	37778	5061	13	8
60	P	E	20	40	42022	4970	12	8
61	P	H	3	3	18337	1651	9	8
62	P	H	3	6	19165	1395	7	8
63	P	H	3	9	20239	1476	7	8
64	P	H	5	5	22651	1608	7	8
65	P	H	5	10	23995	1774	7	8
66	P	H	5	15	24910	2042	8	8
67	P	H	10	10	31638	2383	8	8
68	P	H	10	20	33530	2640	8	8
69	P	H	10	30	34220	2682	8	8
70	P	H	15	10	35708	2527	7	8
71	P	H	15	15	36999	2715	7	8
72	P	H	15	30	41774	3029	7	8
73	P	H	20	15	43882	3137	7	8
74	P	H	20	20	45755	3147	7	8
75	P	H	20	40	49579	2961	6	8
76	P	I	3	3	9472	694	7	8
77	P	I	3	6	10200	513	5	8
78	P	I	3	9	11112	504	5	8
79	P	I	5	5	11756	663	6	8

OBS	MATERIAL	LAB	CONFPR	DEVID	AVMR	STD	CV	NS
80	P	I	5	10	13031	571	4	8
81	P	I	5	15	14097	460	3	8
82	P	I	10	10	16442	1218	7	8
83	P	I	10	20	18660	461	2	8
84	P	I	10	30	19540	430	2	8
85	P	I	15	10	18263	974	5	8
86	P	I	15	15	19563	729	4	8
87	P	I	15	30	22076	607	3	8
88	P	I	20	15	20943	1663	8	8
89	P	I	20	20	22331	1025	5	8
90	P	I	20	40	25062	888	4	8
91	P	J	3	3	12251	2400	20	8
92	P	J	3	6	11764	1055	9	8
93	P	J	3	9	11837	854	7	8
94	P	J	5	5	14753	1948	13	8
95	P	J	5	10	14254	966	7	8
96	P	J	5	15	13839	889	6	8
97	P	J	10	10	18973	1521	8	8
98	P	J	10	20	19530	1160	6	8
99	P	J	10	30	19449	1015	5	8
100	P	J	15	10	23110	1682	7	8
101	P	J	15	15	22294	1709	8	8
102	P	J	15	30	25195	1245	5	8
103	P	J	20	15	28856	1975	7	8
104	P	J	20	20	28822	4534	16	8
105	P	J	20	40	34143	1334	4	8
106	W	A	3	3	7958	1375	17	2
107	W	A	3	6	10343	1998	19	7
108	W	A	3	9	9066	2053	23	8
109	W	A	5	5	14960	3515	23	8
110	W	A	5	10	11278	1949	17	8
111	W	A	5	15	10815	2496	23	8
112	W	A	10	10	13744	2991	22	8
113	W	A	10	20	14663	3025	21	8
114	W	A	10	30	15869	4029	25	8
115	W	A	15	10	17297	3758	22	8
116	W	A	15	15	18355	5846	32	8
117	W	A	15	30	18807	3173	17	8
118	W	A	20	15	20582	2847	14	8
119	W	A	20	20	20931	2501	12	8
120	W	A	20	40	22575	2395	11	9

OBS	MATERIAL	LAB	CONFPR	DEVID	AVMR	STD	CV	NS
121	W	C	3	3	34368	7016	20	8
122	W	C	3	6	28709	3549	12	8
123	W	C	3	9	27956	3390	12	8
124	W	C	5	5	33945	7734	23	8
125	W	C	5	10	32571	5914	18	8
126	W	C	5	15	34351	5048	15	8
127	W	C	10	10	48436	9730	20	8
128	W	C	10	20	52175	9274	18	8
129	W	C	10	30	51639	8495	16	8
130	W	C	15	10	67009	13426	20	8
131	W	C	15	15	62775	9860	16	8
132	W	C	15	30	63211	7712	12	8
133	W	C	20	15	77953	12420	16	7
134	W	C	20	20	79412	13142	17	8
135	W	C	20	40	76984	11410	15	8
136	W	D	3	3	10492	380	4	4
137	W	D	3	6	11704	524	4	4
138	W	D	3	9	11458	1028	9	4
139	W	D	5	5	13317	1679	13	3
140	W	D	5	10	12761	1419	11	3
141	W	D	5	15	13811	2497	18	4
142	W	D	10	10	18581	4396	24	4
143	W	D	10	20	19447	5512	28	4
144	W	D	10	30	19076	5781	30	4
145	W	D	15	10	20206	6392	32	4
146	W	D	15	15	20275	7538	37	4
147	W	D	15	30	23211	8801	38	4
148	W	D	20	15	24600	10219	42	4
149	W	D	20	20	25380	11068	44	4
150	W	D	20	40	28281	12178	43	4
151	W	E	3	3	21724	2307	11	8
152	W	E	3	6	20838	1425	7	8
153	W	E	3	9	21099	1596	8	8
154	W	E	5	5	25119	1780	7	8
155	W	E	5	10	25239	1243	5	8
156	W	E	5	15	25415	1210	5	8
157	W	E	10	10	35048	1835	5	8
158	W	E	10	20	36471	1438	4	8
159	W	E	10	30	36928	1569	4	8
160	W	E	15	10	40009	2291	6	8

OBS	MATERIAL	LAB	CONFPR	DEVID	AVMR	STD	CV	NS
161	W	E	15	15	40903	1817	4	8
162	W	E	15	30	44213	1881	4	8
163	W	E	20	15	46838	2577	6	8
164	W	E	20	20	48523	2361	5	8
165	W	E	20	40	51553	2677	5	8
166	W	H	3	3	18384	1969	11	8
167	W	H	3	6	18738	1553	8	8
168	W	H	3	9	19332	1693	9	8
169	W	H	5	5	21626	1766	8	8
170	W	H	5	10	22924	1745	8	8
171	W	H	5	15	23392	2097	9	8
172	W	H	10	10	30427	1647	5	8
173	W	H	10	20	32278	2015	6	8
174	W	H	10	30	33077	2107	6	8
175	W	H	15	10	35544	1876	5	8
176	W	H	15	15	36626	1882	5	8
177	W	H	15	30	40467	1943	5	8
178	W	H	20	15	43104	1646	4	8
179	W	H	20	20	44868	1828	4	8
180	W	H	20	40	48584	1734	4	8
181	W	I	3	3	9569	1272	13	8
182	W	I	3	6	10954	647	6	8
183	W	I	3	9	11761	697	6	8
184	W	I	5	5	12678	806	6	8
185	W	I	5	10	13865	711	5	8
186	W	I	5	15	14591	704	5	8
187	W	I	10	10	17671	894	5	8
188	W	I	10	20	19330	963	5	8
189	W	I	10	30	19681	1348	7	7
190	W	I	15	10	19844	1258	6	8
191	W	I	15	15	20815	1091	5	8
192	W	I	15	30	22702	1156	5	8
193	W	I	20	15	23224	1199	5	8
194	W	I	20	20	24188	1014	4	8
195	W	I	20	40	25587	1392	5	8
196	W	J	3	3	11291	1274	11	8
197	W	J	3	6	10585	1201	11	8
198	W	J	3	9	10035	903	9	8
199	W	J	5	5	11783	922	8	8
200	W	J	5	10	11869	1193	10	8

OBS	MATERIAL	LAB	CONFPR	DEVID	AVMR	STD	CV	NS
201	W	J	5	15	12542	1292	10	8
202	W	J	10	10	16925	1605	9	8
203	W	J	10	20	18169	1433	8	8
204	W	J	10	30	19675	1780	9	8
205	W	J	15	10	21391	1914	9	8
206	W	J	15	15	21484	1205	6	8
207	W	J	15	30	25217	1244	5	8
208	W	J	20	15	27508	1731	6	8
209	W	J	20	20	28490	1903	7	8
210	W	J	20	40	35821	2026	6	8

APPENDIX C

RESILIENT MODULUS TESTING OF

SHRP LTPP TYPE I, ROUND 1 UNBOUND BASE SAMPLES

SEPTEMBER 1993

Vulcan Materials Company
Construction Materials Group
Research and Development Laboratory
Birmingham, Alabama

INTRODUCTION

The SHRP LTPP TYPE I, ROUND I samples were tested by the Vulcan Materials Company Research and Development Laboratory in early 1992 according to the test procedure as outlined in the SHRP LTPP P-46 protocol (August 1989 Version). The eight bulk unbound base samples were oven dried to remove any remaining moisture, divided into equal portions (A and B) using a sample splitter, then remixed to the appropriate optimum moisture content (6% or 8%) as specified from the data supplied for the field conditions. The base samples were compacted to field specified maximum dry density (138.6 or 133.6 pcf) in a 6" diameter by 12" high split mold using a hand-held vibratory type compactor adapted with a 4 inch diameter plate. Compaction was accomplished in three lifts by weighing the appropriate amount of base material then compacting to a depth of four inches (as measured from the inside of the mold). Moisture contents were verified by oven drying a representative portion of the base material taken prior to compaction.

The resilient modulus testing on the TYPE I, ROUND I samples was conducted using the small triaxial cell with the 6" diameter platen as shown in Figure 1 and detailed on page 4. All test data was collected at the confining pressures of 3, 5, 10, 15, or 20 psi and target deviator stresses of 3, 5, 6, 9, 10, 15, 20, 30 or 40 psi after a seat load of 0.5 to 1.0 psi had been applied to the molded unbound base sample. Due to the differences between testing organizations in the interpretation of the SHRP TYPE I *synthetic specimen* test protocol, involving the calculation of the deviator stress used to determine resilient modulus, the data for each SHRP TYPE I, ROUND I sample tested is presented in three different formats. The actual testing protocol as used by the VMC R&D Lab is described and sample calculations for each of the three methods are detailed.

SMALL TRIAXIAL CELL CONFIGURATION
(6 Inch Diameter Platen)

Figure 1 is a diagram of the VMC R&D Lab small triaxial cell equipment which became available for use in the SHRP TYPE I, ROUND I sample study. All testing was accomplished using this triaxial cell which accommodates a sample 6 inches in diameter and 12 inches high. Both the load cell and load piston were located external to the triaxial cell. The load piston contacted the ball bearing which transferred the load through the rod to the platen. In this configuration, the mass of the 6" diameter platen, the rod and the steel ball bearing rested on the sample. The load cell was zeroed and a seat load (L_s = 15 to 30 lb), was applied to the specimen. The LVDTs were zeroed and testing was conducted by cycling between the applied seat load stress (σ_s = 0.5 to 1.0 psi) and the target deviator stresses (σ_d) as specified by the P-46 protocol. The platen was a static load (L_p = 10.7 lb) and exerted an axial stress (σ_p = 0.38 psi) on the specimen. When the confining pressure was introduced to the triaxial chamber, it forced the rod and ball bearing upward off the platen and against the load piston. The rod and ball bearing moved dynamically with the load piston and the zeroing of the load cell served to counteract any load indicated by this contact (σ_u = 0 psi).

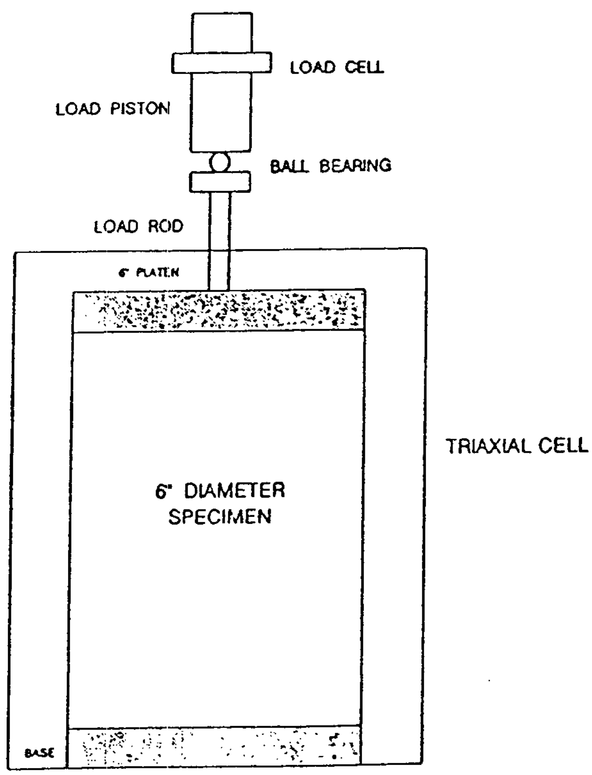


FIGURE 1. Vulcan Materials Company, R&D Lab, Small Triaxial Cell Configuration

DEFINITIONS

H_s = Specimen height (in)
H_r = Specimen recoverable deformation (in)
D_s = Specimen diameter (in)
D_r = Rod diameter (in)
A_s = Cross-sectional area of specimen (in^2)
A_r = Cross-sectional area of rod (in^2)

$L = L_{dyn} + L_s + L_p$ = Axial load (lb)
- L_{dyn} = Dynamic load (lb)
- L_s = Applied static seat load (lb)
- L_p = Static load due to mass of platen, rod, and/or ball bearing (lb)

$\sigma_d = \sigma_1 - \sigma_3$ = Deviator stress (psi)
- $\sigma_1 = \sigma_{dyn} + \sigma_s + \sigma_p + \sigma_u + \sigma_3$ = Total axial stress (psi)
  - $\sigma_{dyn} = L_{dyn}/A_s$ = Axial stress from dynamic portion of deviator stress (psi)
  - $\sigma_s = L_s/A_s$ = Axial stress from static seat load (psi)
  - $\sigma_p = L_p/A_s$ = Axial stress from static load of platen, rod, and/or ball bearing (psi)
  - $\sigma_u = A_r\sigma_3/A_s$ = Upward axial stress on load rod due to confining pressure (psi)
- σ_3 = Confining stress (psi)

$\varepsilon_r = H_r/H_s$ = Recoverable strain (in/in)

$M_r = \sigma_d/\varepsilon_r$ = Resilient modulus (psi)

DEVIATOR STRESS INTERPRETATION

Method 1: $\sigma_{d1} = \sigma_{dyn}$
Method 2: $\sigma_{d2} = \sigma_{dyn} + \sigma_s$
Method 3: $\sigma_{d3} = \sigma_{dyn} + \sigma_s + \sigma_p$

STANDARD DEVIATION

The standard deviation of population as presented for the M_r data contained in this report was calculated by the formula as defined in LOTUS SYMPHONY 2.2 whereby:

@STD = @SQRT [Σ(v$_i$ - @AVG)^2/(n-1)]

or

@STD = @SQRT[@VAR*(n)/(n-1)]

DEVIATOR STRESS CALCULATION - METHOD #1

This interpretation of the SHRP ROUND I specimen test protocol for Method #1 is based on the assumption that the deviator stress, σ_{d1}, is the dynamic or cycled stress only, σ_{dyn}. In the M_r testing conducted on the ROUND I samples in all sessions, the dynamic load was cycled between the applied seat load of either 0.5 or 1.0 psi and the target deviator loads (3, 5, 6, 9, 10, 15, 20, 30, or 40 psi). Therefore, the dynamic stresses, as defined by Method #1, were 2.5, 4.5, 5.5, 8.5, 9.5, 14.5, 19.5, 29.5, or 39.5 psi for an applied seat load of 0.5 psi. The axial stress due to the mass of the platen, ball bearing and/or rod, σ_p, was not taken into consideration in this calculation method nor was the upward lift of the rod, σ_u, from the introduction of the confining pressures to the triaxial chamber, σ_3. If the Method #1 interpretation of the test protocol was the desired interpretation by the SHRP LTPP personnel, then testing should have been accomplished by cycling the dynamic load between the 0.5 psi applied seat load and 3.5, 5.5, 6.5, 9.5 psi, etc. in order to achieve dynamic stresses equal to those targeted. The sample calculation for Method #1 for testing conducted in the small triaxial cell at any confining pressure is outlined below.

<u>Method #1 Sample Calculation:</u> $\sigma_{d1} = \sigma_{dyn}$

All Test Sessions, Small Triaxial Cell
σ_3 = 3, 5, 10, 15 or 20 psi

H_s = Specimen height (in)	12.0 in
H_r = Specimen recoverable deformation (in)	0.005 in
D_s = Specimen diameter (in)	6.0 in
A_s = Cross-sectional area of specimen (in^2)	28.27 in^2
L_{dyn} = Dynamic load (lb)	70 lb
$\sigma_{dyn} = L_{dyn}/A_s$ = Dynamic axial stress (psi)	2.5 psi
$\sigma_{d1} = \sigma_{dyn}$ = Deviator Stress (psi)	2.5 psi
σ_3 = Confining stress (psi)	all psi
$\varepsilon_r = H_r/H_s$ = Recoverable strain (in/in)	0.00042 in/in
$M_r = \sigma_d/\varepsilon_r$ = Resilient modulus (psi)	5952 psi

DEVIATOR STRESS CALCULATION - METHOD #2

This method for the calculation of the deviator stress, used to determine the resilient modulus of the SHRP TYPE I, ROUND I samples was the method used by the VMC R&D Lab during actual testing. The interpretation of the SHRP TYPE I, ROUND I specimen test protocol for Method #2 is based on the assumption that the applied seat load, σ_s, is a component of the deviator stress, σ_{d2}, along with the dynamic or cycled stress, σ_{dyn}. The basis for this assumption was the equipment configuration. Due to the inherent design of our particular instrumentation, the load cell was not re-zeroed after the application of the seat load because of zero drift (i.e. control and accuracy is maintained when the electronics are reading a load, in this case 15 to 30 lbs [0.5 to 1.0 psi], versus a reading of zero load). After the static seat load had been applied and the LVDTs zeroed, dynamic loading could then not be accomplished (without electronic interference) by cycling between loads or stresses less than the applied seat load stress and the target deviator stress. To have cycled between (or back to) zero load and the target deviator load, rather than between the applied seat load and the target deviator load, would have "removed" then "re-applied" the seat load (*Other laboratories may have referred to this effect as "clattering" or "chattering" of the ball bearing if they attempted to run the test in this manner*). Since dynamic loading could only be conducted in this manner, by cycling the instrument between the applied seat stress and the target deviator stress (3, 5, 6, 9, 10, 15, 20, 30, or 40 psi) it lead to the assumption that the seat load was to be treated as a component of the deviator load. The axial stress due to the mass of the platen, ball bearing and/or rod, σ_p, was not considered in this calculation method nor was the upward lift of the rod, σ_u, from the introduction of the confining pressures to the triaxial chamber, σ_3. The sample calculation Method #2 for TYPE I testing accomplished using the small triaxial cell at any confining pressure is outlined below.

Method #2 Sample Calculation: $\sigma_{d2} = \sigma_{dyn} + \sigma_s$

All Test Sessions, Small Triaxial Cell
σ_3 = 3, 5, 10, 15 or 20 psi

H_s = Specimen height (in)	12.0 in
H_r = Specimen recoverable deformation (in)	0.005 in
D_s = Specimen diameter (in)	6.0 in
A_s = Cross-sectional area of specimen (in^2)	28.27 in^2

L_{dyn} = Dynamic load (lb)	70 lb
L_s = Applied static seat load (lb)	15 lb
$L = L_{dyn} + L_s$ = Axial load (lb)	85 lb

$\sigma_{dyn} = L_{dyn}/A_s$ = Axial stress from dynamic portion of deviator stress (psi)	2.5 psi
$\sigma_s = L_s/A_s$ = Axial stress from static seat load (psi)	0.5 psi

$\sigma_{d2} = \sigma_{dyn} + \sigma_s$ = Deviator Stress (psi)	3.0 psi
σ_3 = Confining stress (psi)	all psi
$\varepsilon_r = H_r/H_s$ = Recoverable strain (in/in)	0.00042 in/in
$M_r = \sigma_d/\varepsilon_r$ = Resilient modulus (psi)	7143 psi

DEVIATOR STRESS CALCULATION - METHOD #3

The interpretation of the SHRP TYPE I, ROUND I specimen test protocol for Method #3 is based on the assumption that the seat load is defined as the sum of the applied seat load, L_s, and the load due to the mass of the platen, ball bearing and/or rod, L_p. The axial stress that this static load exerts on the specimen is in turn a component of the deviator stress, σ_{d3}, along with the dynamic or cycled stress, σ_{dyn}. The rational behind this assumption was again due to the equipment configuration. The axial stress due to the mass of the platen, ball bearing and/or rod, σ_p, was accounted for in this method as was the upward lift of the rod, σ_u, from the introduction of the confining pressure to the triaxial chamber, σ_3. Therefore, sample calculations for Method #3 are dependent upon the triaxial cell (large vs. small) and confining pressures (3, 5, 10, 15 or 20 psi) used during testing.

Method #3 Sample Calculation: $\sigma_{d3} = \sigma_{dyn} + \sigma_s + \sigma_p$

All Test Sessions, Small Triaxial Cell
σ_3 = 3, 5, 10, 15 or 20 psi

H_s = Specimen height (in)	12.0 in
H_r = Specimen recoverable deformation (in)	0.005 in
D_s = Specimen diameter (in)	6.0 in
A_s = Cross-sectional area of specimen (in^2)	28.27 in^2

L_{dyn} = Dynamic load (lb)	70 lb
L_s = Applied static seat load (lb)	15 lb
L_p = Static load due to mass of platen, rod, and/or ball bearing (lb)	10.7 lb
$L = L_{dyn} + L_s + L_p$ = Axial load (lb)	95.7 lb

$\sigma_{dyn} = L_{dyn}/A_s$ = Axial stress from dynamic portion of deviator stress (psi)2.5 psi	
$\sigma_s = L_s/A_s$ = Axial stress from static seat load (psi)	0.5 psi
$\sigma_p = L_p/A_s$ = Axial stress from static load of platen, rod, and/or ball bearing (psi)	0.38 psi
$\sigma_u = A_r\sigma_3/A_s$ = Upward axial stress on load rod due to confining pressure (psi)	0 psi
$\sigma_{d3} = \sigma_{dyn} + \sigma_s + \sigma_p$ = Deviator Stress (psi)	3.38 psi
σ_3 = Confining stress (psi)	all psi

$\varepsilon_r = H_r/H_s$ = Recoverable strain (in/in)	0.00042 in/in
$M_r = \sigma_d/\varepsilon_r$ = Resilient modulus (psi)	8048 psi

SHRP LTPP TYPE I, ROUND I Samples

(Stored as LOTUS SYMPHONY *.WR1 Files)

DISK #	SAMPLE I.D.	FILE NAME	FIELD DENSITY	FIELD MOISTURE
1	SHRP 12-A	SHRP12A.WR1	138.6	6.0
1	SHRP 12-B	SHRP12B.WR1	138.6	6.0
1	SHRP 35-A	SHRP35A.WR1	138.6	6.0
1	SHRP 35-B	SHRP35B.WR1	138.6	6.0
1	SHRP 58-A	SHRP58A.WR1	138.6	6.0
1	SHRP 58-B	SHRP58B.WR1	138.6	6.0
1	SHRP 71-A	SHRP71A.WR1	138.6	6.0
1	SHRP 71-B	SHRP71B.WR1	138.6	6.0
2	SHRP 89-A	SHRP89A.WR1	133.6	8.0
2	SHRP 89-B	SHRP89B.WR1	133.6	8.0
2	SHRP 109-A	SHRP109A.WR1	133.6	8.0
2	SHRP 109-B	SHRP109B.WR1	133.6	8.0
2	SHRP 128-A	SHRP128A.WR1	133.6	8.0
2	SHRP 128-B	SHRP128B.WR1	133.6	8.0
2	SHRP 134-A	SHRP134A.WR1	133.6	8.0
2	SHRP 134-B	SHRP134B.WR1	133.6	8.0

DISK #	FILE NAME	CONTENTS
1	RD1SUM1.WR1	SUMMARY OF METHOD #1 DATA
1	RD1SUM2.WR1	SUMMARY OF METHOD #2 DATA
1	RD1SUM3.WR1	SUMMARY OF METHOD #3 DATA
1	TYPE1RD1.RPT	REPORT (WORD-PERFECT FILE)

VULCAN MATERIALS COMPANY
CONSTRUCTION MATERIALS GROUP
RESEARCH & DEVELOPMENT LABORATORY

SHRP LTPP TYPE I, ROUND I UNBOUND BASE - RESILIENT MODULUS

METHOD #1

TEST SEQUENCE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CONFINING PSI	3	3	3	5	5	5	10	10	10	15	15	15	20	20	20
DEVIATOR PSI =	3	6	9	5	10	15	10	20	30	10	15	30	15	20	40
BULK PSI =	12	15	18	20	25	30	40	50	60	55	60	75	75	80	100
SPECIMEN ID															
12-A	13529	12382	13785	14677	15962	17712	21148	24334	26022	24866	25721	29999	29712	29787	36067
12-B	16236	17198	18055	18965	20071	21392	24211	27450	29287	27882	29429	34831	33628	35621	41429
35-A	13087	12861	13672	16147	18249	17809	21850	23717	24880	25147	34361	29798	29605	31074	35493
35-B	11236	12102	14480	15869	15869	17382	22470	23968	25429	24917	26831	30290	31669	31948	36613
58-A	13382	13252	14137	14488	16371	17936	19929	23001	24607	24593	24633	30033	27438	30015	35029
58-B	11449	12778	13223	15565	16441	17437	20040	21688	24089	22202	24133	28710	27941	30183	34055
71-A	20606	20195	20752	15466	19088	22100	21785	26210	29428	25197	27276	33308	27077	31032	38351
71-B	22013	19898	20449	22687	23261	23721	22910	32938	30897	26465	29811	35270	31914	33232	41229
AVERAGE:	15192	15083	16069	16733	18164	19436	21793	25413	26830	25159	27774	31530	29873	31612	37283
STD DEV:	4089	3455	3171	2771	2585	2546	1440	3530	2624	1618	3354	2539	2362	1977	2791
89-A	15829	14927	16422	17718	18861	19713	26019	27686	29413	32653	32020	36393	36992	38382	42298
89-B	14995	15707	16314	19489	20385	20808	25907	28131	29550	31258	31811	35726	36009	38484	42961
109-A	15403	15467	16703	17464	19372	20091	25138	28322	29838	30624	32716	37177	37712	39888	45423
109-B	16686	15662	16458	17903	19045	20122	23495	28453	30755	28091	30353	36255	33273	36451	42487
128-A	17474	15225	16498	17619	18227	20151	22279	26135	28725	24988	27273	32908	31030	32791	38982
128-B	21128	16838	16873	21783	20609	21683	25809	27925	30944	33266	34630	37751	38755	40668	44413
134-A	20742	19094	17839	19882	20532	22625	29007	31047	33082	33294	32912	38053	38297	40180	46889
134-B	21585	16187	16008	20214	20046	20354	25526	28040	30110	31837	33105	37147	38392	39380	44719
AVERAGE:	17980	16138	16639	19009	19635	20693	25398	28217	30302	30751	31853	36426	36308	38278	43522
STD DEV:	2742	1331	548	1574	885	984	1974	1353	1333	2882	2217	1621	2774	2581	2410

VULCAN MATERIALS COMPANY
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RESEARCH & DEVELOPMENT LABORATORY

SHRP LTPP TYPE I, ROUND I UNBOUND BASE - RESILIENT MODULUS

METHOD #2

TEST SEQUENCE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CONFINING PSI	3	3	3	5	5	5	10	10	10	15	15	15	20	20	20
DEVIATOR PSI =	3	6	9	5	10	15	10	20	30	10	15	30	15	20	40
BULK PSI =	12	15	18	20	25	30	40	50	60	55	60	75	75	80	100
SPECIMEN ID															
12-A	15246	13620	14530	15896	16596	18366	22425	24918	26656	26383	26662	30630	30721	31044	36846
12-B	20139	18649	19320	21414	20971	22085	25972	28450	30055	29292	30591	35610	35020	30881	42400
35-A	15225	13769	14446	17834	19026	18390	22937	24216	25322	26544	35477	30226	30560	32016	35917
35-B	12808	13095	15075	16861	16861	17801	23824	24401	25711	25518	27485	30470	32433	32819	36939
58-A	15494	13873	15008	16182	17063	18510	21029	23552	25366	25935	25441	30507	28798	30729	35444
58-B	13028	13316	13974	16665	17257	18066	21017	22349	24371	23878	25116	29281	29077	31087	34510
71-A	23259	21826	21855	16849	19826	22725	22718	26852	30015	26748	28389	33838	27994	31968	38923
71-B	26478	21610	21704	25045	24296	24703	24381	33939	31515	28251	31017	36150	33067	34445	41969
AVERAGE:	17710	16220	16989	18343	18987	20081	23038	26085	27376	26569	28772	32089	30959	31874	37869
STD DEV:	5024	3833	3392	3218	2666	2670	1675	3702	2722	1650	3465	2687	2400	1261	2960
89-A	18491	15934	17238	19517	19788	20356	27298	28523	29878	35102	33331	37121	38508	39551	43056
89-B	17418	16846	17224	22583	21184	21308	26843	28636	30019	32802	32834	36182	37473	39650	43472
109-A	17478	16515	17741	19111	20334	20739	26390	29005	30552	32519	34608	38070	39231	41351	46235
109-B	19619	16858	17296	18161	20479	20863	24821	29479	31311	29652	31466	36905	34470	33785	43058
128-A	20251	16006	17056	18889	18860	20558	22955	27085	29238	25289	28373	33297	31775	32791	39564
128-B	24949	18030	17804	23738	21737	22476	27065	28776	31688	35107	35747	38431	40164	41781	45209
134-A	24119	21104	18976	21689	21398	23344	30422	31988	33617	34750	34255	38811	39681	41278	47515
134-B	24257	17195	17016	21730	20782	20847	26939	28887	30650	33574	34440	37937	40264	40819	45386
AVERAGE:	20823	17311	17544	20677	20570	21311	26592	29047	30869	32349	33132	37094	37696	38876	44187
STD DEV:	3155	1672	647	2016	931	1050	2137	1375	1359	3376	2316	1760	3051	3548	2455

VULCAN MATERIALS COMPANY
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SHRP LTPP TYPE I, ROUND I UNBOUND BASE - RESILIENT MODULUS

METHOD #3

TEST SEQUENCE	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
CONFINING PSI	3	3	3	5	5	5	10	10	10	15	15	15	20	20	20
DEVIATOR PSI =	3	6	9	5	10	15	10	20	30	10	15	30	15	20	40
BULK PSI =	12	15	18	20	25	30	40	50	60	55	60	75	75	80	100
SPECIMEN ID															
12-A	17157	14480	15134	17104	17212	18823	23263	25382	26995	27356	27333	31016	31493	31465	37193
12-B	22644	19799	20133	22987	21780	22640	26916	28983	30428	30402	31368	36060	35878	37470	42799
35-A	17186	14626	15052	19215	19739	18857	23809	24173	25638	27540	36372	30608	31326	33440	36257
35-B	14490	13892	15712	18134	17497	18250	24693	24865	26034	26481	28185	30855	33249	31303	37288
58-A	17430	14759	15630	17390	17696	18971	21814	23995	25691	26892	26089	30889	29526	30588	35776
58-B	14706	14179	14577	17927	17912	18525	21819	22773	24672	24774	25747	29647	29806	31667	34835
71-A	26097	23186	22774	18118	20578	23299	23574	27366	30393	27744	29103	34263	28695	32569	39291
71-B	29851	22983	22620	26938	25219	25334	25307	34582	31912	29313	31791	36605	33890	35093	42364
AVERAGE:	19945	17238	17704	19727	19704	20587	23899	26515	27720	27563	29499	32493	31733	32949	38225
STD DEV:	5634	4072	3535	3456	2773	2739	1728	3812	2756	1715	3551	2722	2454	2316	2988
89-A	20800	16945	17966	20999	20532	20873	28324	29060	30250	36413	34172	37589	39481	40301	43461
89-B	19640	17891	17953	22717	21992	21842	27845	29177	30396	34041	33655	36639	38412	40399	43883
109-A	19697	17551	18482	20580	21107	21259	27395	29552	30934	33736	35476	38548	40205	42135	46669
109-B	22097	17916	18043	21598	21246	21391	25767	30027	31708	30765	32260	37368	35324	38145	43465
128-A	22813	17009	17771	20345	19586	21080	23823	27594	29604	26857	29079	33714	32572	34423	39181
128-B	28045	19170	18551	25531	22560	23042	28072	29322	32086	36413	36643	38916	41169	42575	39937
134-A	27216	22394	19787	23347	22192	23920	31911	32592	34040	36086	35117	39297	40668	42061	47962
134-B	27298	18273	17734	23352	21571	21374	27947	29431	31035	34812	35297	38414	41266	41588	45815
AVERAGE:	23451	18394	18286	22309	21348	21848	27636	29594	31257	33640	33962	37561	38637	40203	43797
STD DEV:	3545	1766	677	1764	962	1072	2304	1401	1377	3321	2375	1782	3127	2737	3073