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Type II Unbound Cohesive Subgrade Soil Synthetic Reference 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 cohesive subgrade soil obtained from LTPP field sites. All laboratories conducting tests for the LTPP program were required to be accredited by the AASHTO Accreditation Program (AAP). AAP includes site inspections of equipment and procedures, and participation in applicable proficiency sample testing. A few critical LTPP tests, such as the triaxial resilient modulus test, were not addressed fully by the AAP, and LTPP decided to conduct supplemental testing.

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

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

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

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

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

PART I INTRODUCTION

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

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

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

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

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

The Type II Unbound Cohesive Subgrade Soil Synthetic Reference Sample research was

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

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

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

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

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

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

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

The final comments, analyses, conclusions and recommendations resulting from the Type II Unbound Cohesive Subgrade Soil Synthetic Reference Sample Program are contained in Part III of this report.

A set of precision statements in AASHTO/ASTM format is contained in Part IV.

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PART III RESEARCH ANALYSES, OBSERVATIONS, AND CONCLUSIONS

1. Background

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

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

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

2. Design of the Experiment

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

The levels of the confining pressure were 0 and 4 psi. The levels for the deviator stress were 2, 6, and 10 psi. The tests at the six combinations of these factors were carried out in

a sequence without removing or demounting the specimen. Thus the evaluation of the effects of these levels should be more precise than it could have been if these data were from independent measured values. It should be noted, however, that this sequence is typically followed with unbound cohesive materials. The testing error is the only component of error that affects the differences in the measured M_R values. These averaged differences may then be tested by simple t tests.

3. Observations

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

- The differences among the Laboratory averages are reasonable if laboratory B is omitted for specimen TU-700 and laboratories J and L are omitted for specimen DPTU-1560. Although Laboratory A was not omitted from the further analyses it is clear that its values are large for specimens DPTU-1560 and TU-960.
- The laboratory means for specimens DPTU-1560 and TU-960 (See Figures 2 and 3) tend to follow the same pattern. This would indicate that the laboratories could be better calibrated in this range to reduce the variability among laboratories. With the exception of laboratory A, the pattern is also seen in Figure 1 for specimen TU-700.
- The average of the measured M_R for specimen TU-700 does not appear to depend upon the level of the deviator stress.
- The average of the measured M_R for specimens DPTU-1560 and TU-960 tends to increase with the level of the deviator stress.

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

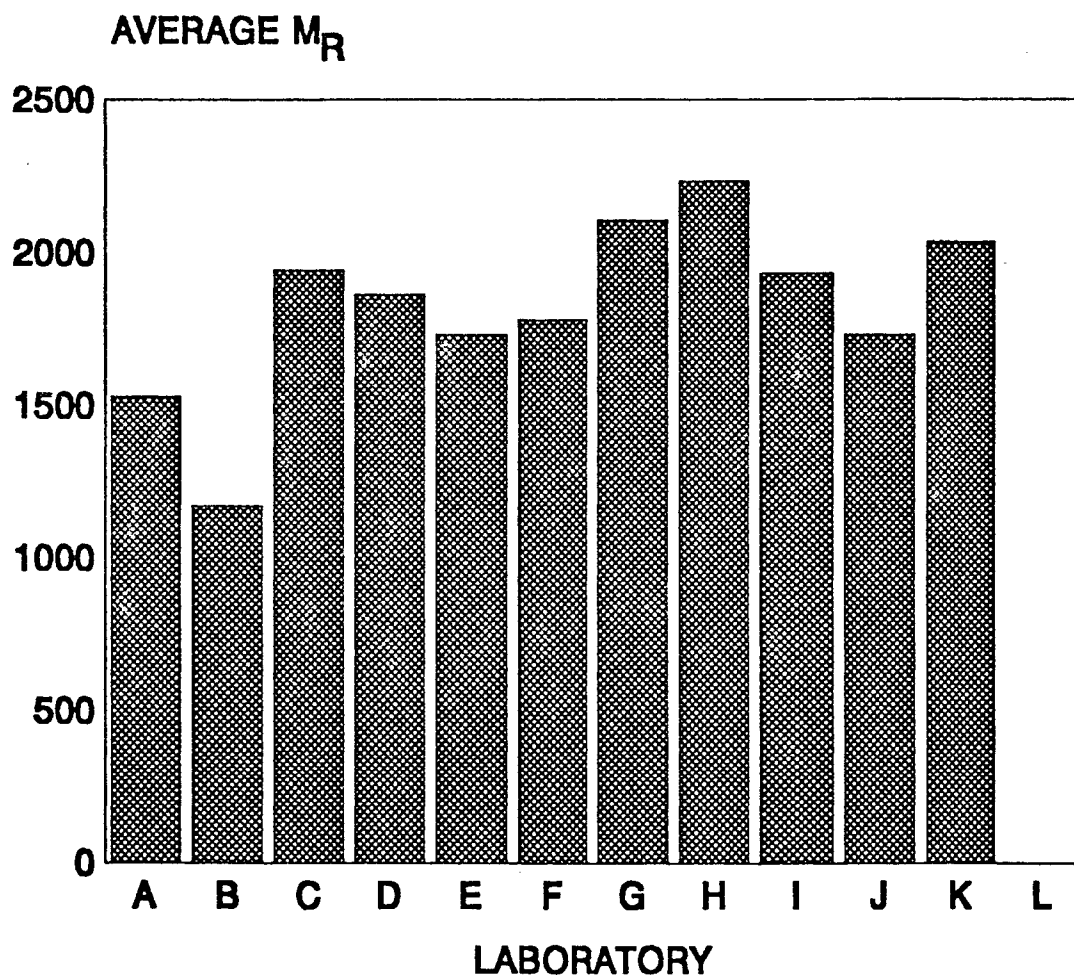


Figure 1. Laboratory Averages for Synthetic Specimen TU-700.

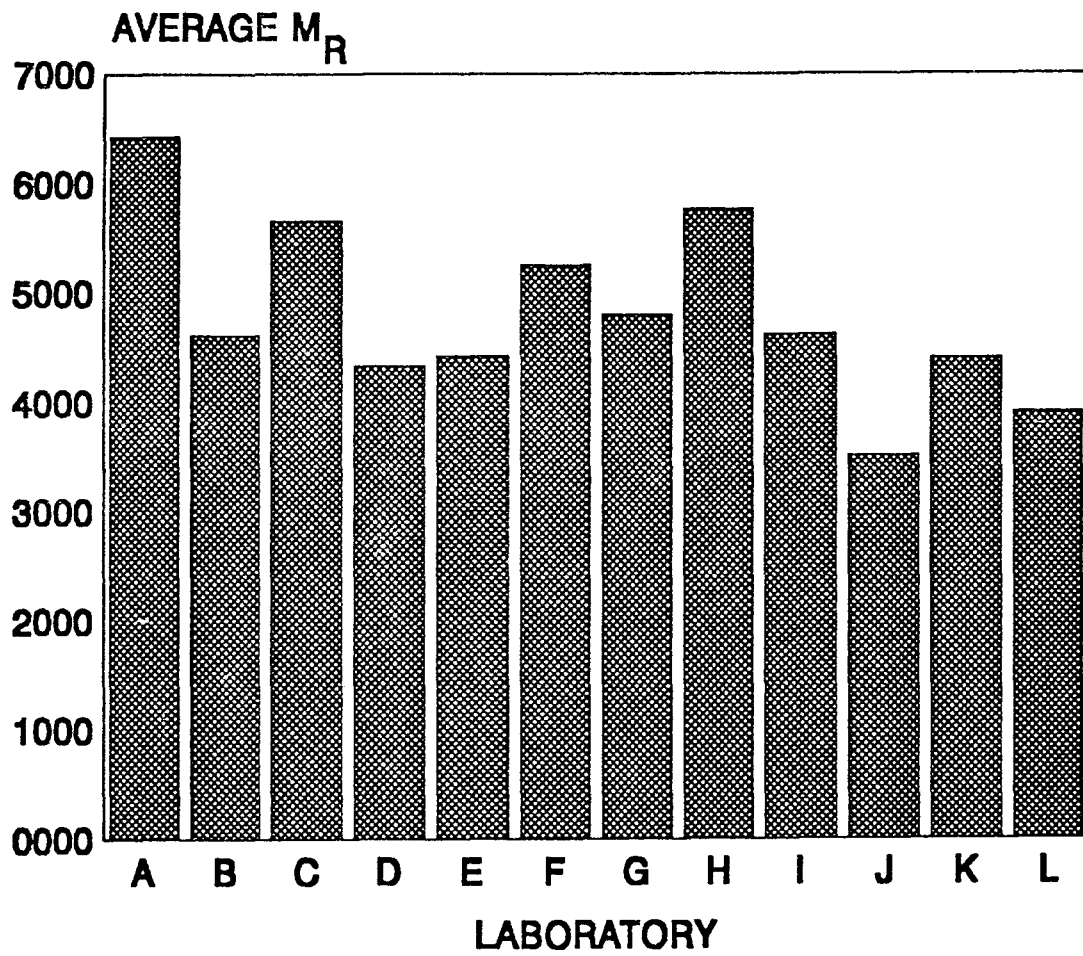


Figure 2. Laboratory Averages for Synthetic Specimen DPTU-1560.

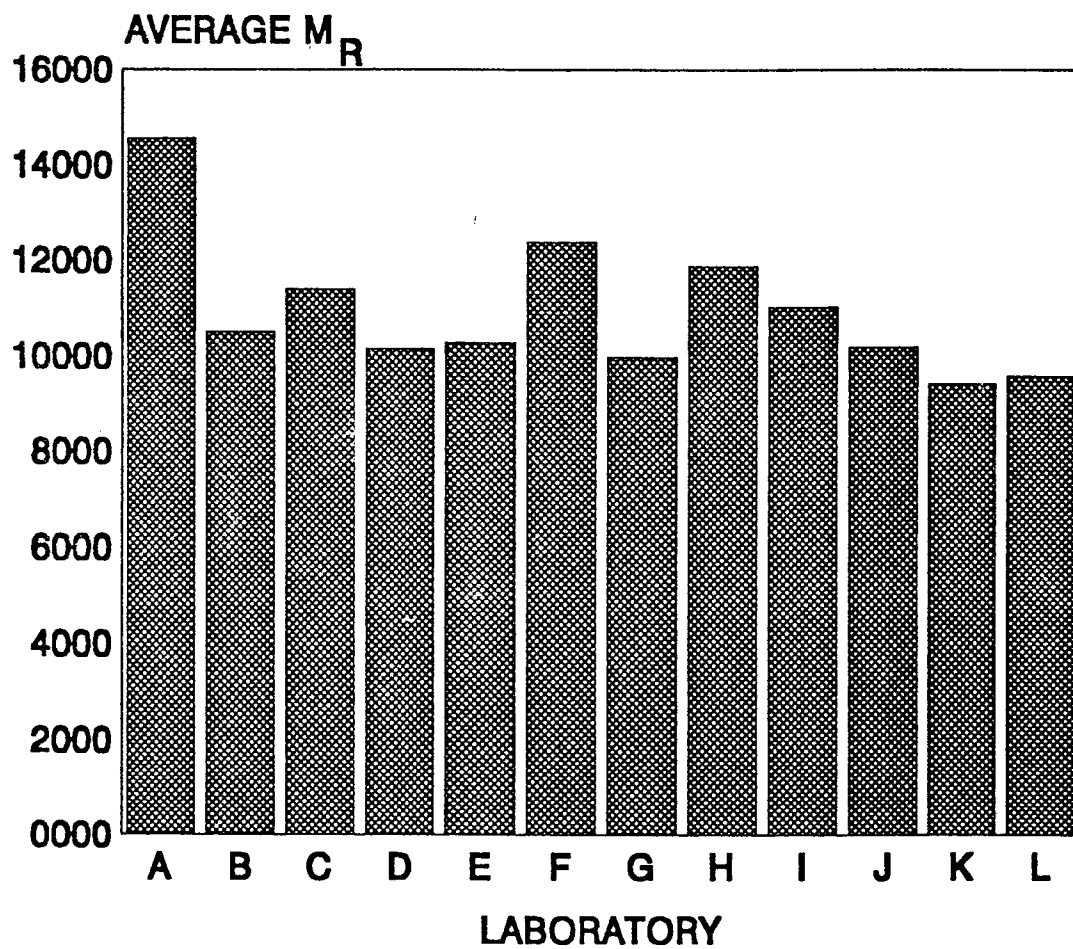


Figure 3. Laboratory Averages for Synthetic Specimen TU-960.

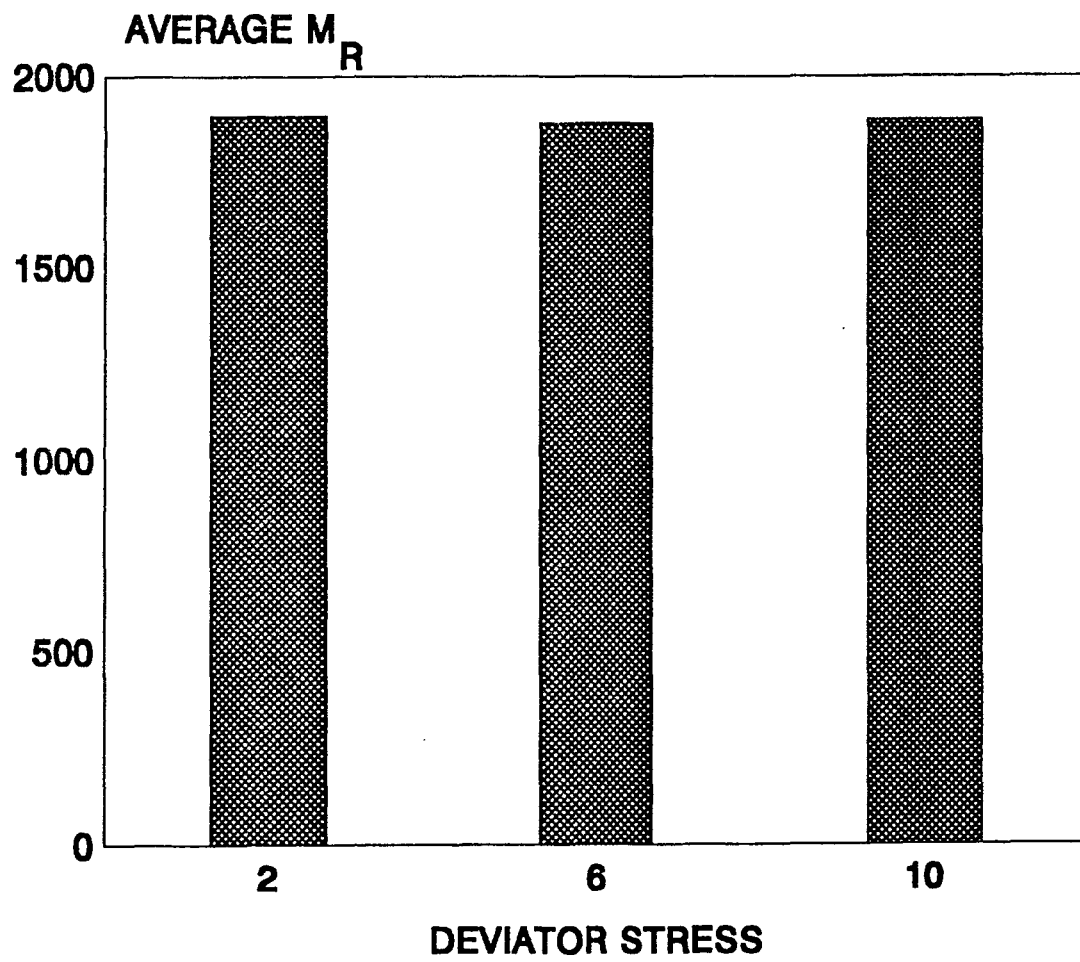


Figure 4. Average M_R by Deviator Stress for Synthetic Specimen TU-700.

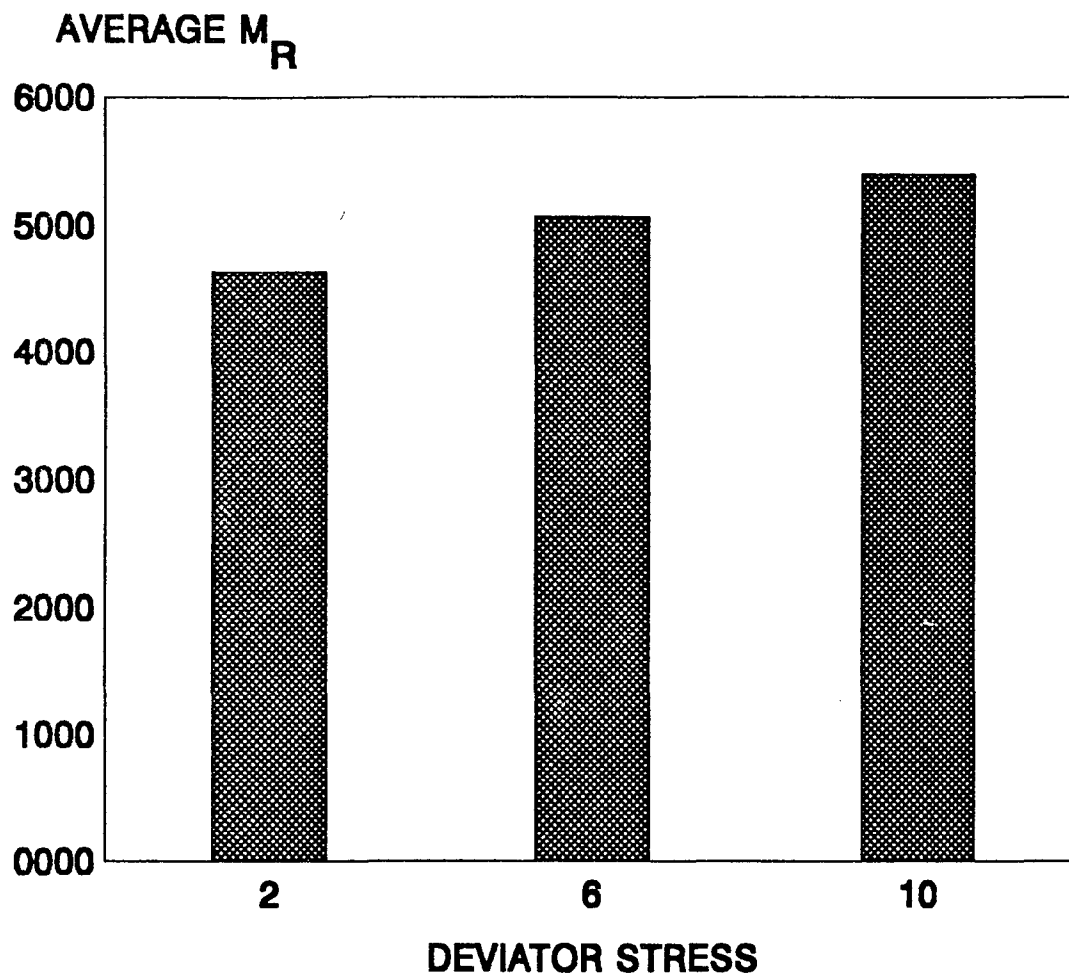


Figure 5. Average M_R by Deviator Stress for Synthetic Specimen DPTU-1560.

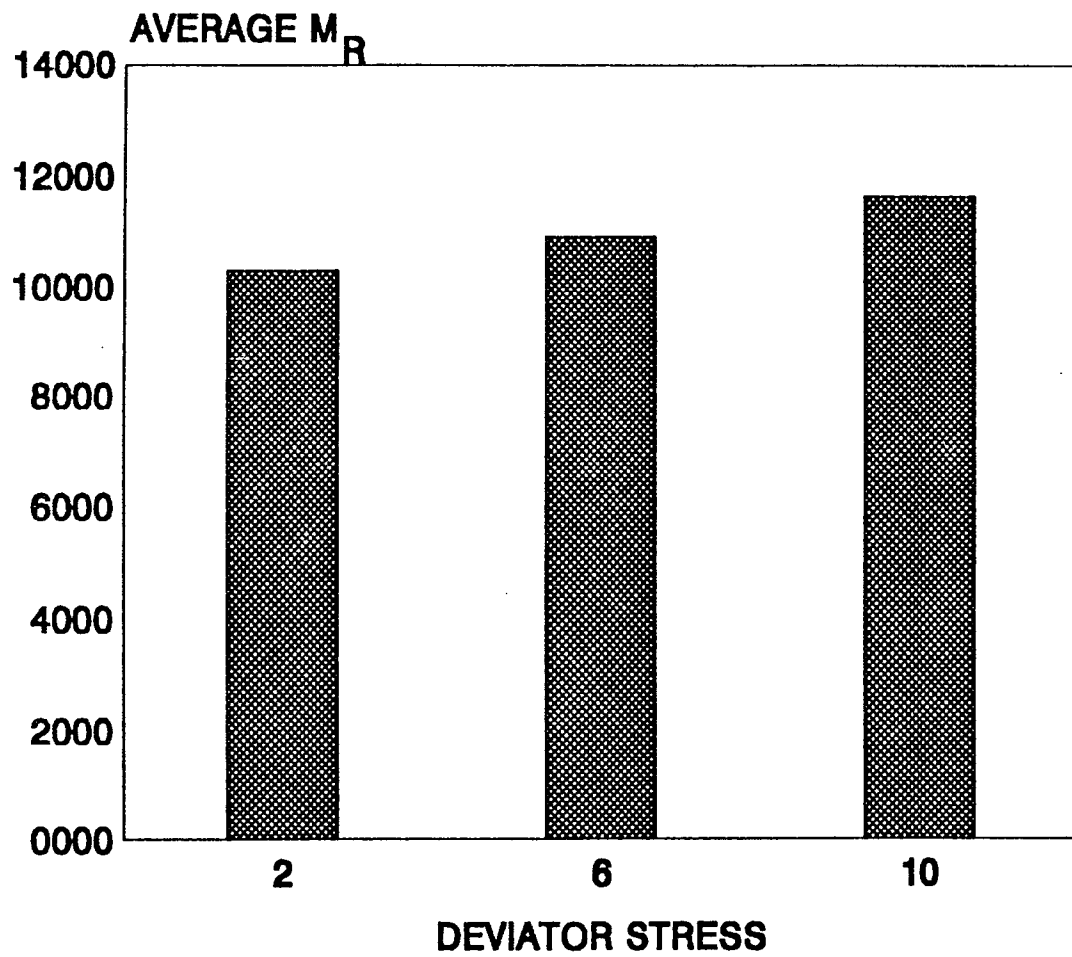


Figure 6. Average M_R by Deviator Stress for Synthetic Specimen TU-960.

4. The Statistical Analyses

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

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

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

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

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

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

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

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

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

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

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

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

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

5. Analysis of the Nevada Data

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

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

The implications of these results are:

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

- ii) The within laboratory coefficient of variation for the synthetic specimens was estimated to be about 2% when the test component was used in the analysis. If independent replications had been carried out this number might have been near 3% which is still quite good. The results for the within laboratory variation when using the synthetic specimens are indeed very good and suggest that this should provide an excellent means for checking on the calibration of the laboratories on a regular basis.
- iii) In the analysis in this report the among laboratories coefficient of variation for the synthetic specimens are ~~5%~~ overestimated by a small amount since the within laboratory component of variance as estimated in this report is somewhat underestimated. The underestimation of the within laboratory coefficient of variation is underestimated because the samples were not remounted between replicate measurements, therefore neglecting the mounting effect. However, the values given for the among-laboratory standard deviation (1s) ,etc., in Part IV are very nearly correct as stated. This seems to be a somewhat large laboratory component of variance, even when some of the outliers were omitted, and this conclusion should not be in doubt.

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

testing variability is operative in laboratory A. The focus in laboratory H should be on seeking the source of systematic errors (e.g. calibration) whereas laboratory A should address both systemic errors as well as random testing errors. Additional comments can be made regarding the other laboratories and these comparisons should be given as feedback to the participating laboratories.

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

Table 4. Comparison of Laboratory Means with Overall Means.

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

6. Summary and Conclusions

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

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

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

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

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

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

perhaps, to the degree experienced. Another possible explanation could be that a bias component exceeding the within laboratory variability is intrinsic to each of the different test systems.

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

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

PART IV AASHTO/ASTM FORMAT PRECISION STATEMENTS

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

The 1s% for the Single Operator Precision statements are the 1s values divided by the average value for the measurements multiplied by 100, i.e., the coefficient of variation. The d2s entries given in Part IV for the Single Operator Precision statements are $2.8 \times 1s$ and this represents the limits (\pm) 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

$$[(STD_{LAB})^2 + (STD_{TEST}^2)]^{0.5}$$

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 (\pm) within which the difference in the measurements of the same specimen at two different laboratories should occur with probability of 0.95. When observed differences are outside this range for the same specimen as measured at two laboratories one should make an inquiry into the correctness of the experiment and the data.

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

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

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

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

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

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

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

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

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

APPENDIX A

Maryland Department of Transportation
State Highway Administration

Richard H. Trainor
Secretary

Hal Kassoff
Administrator

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

March 7, 1990

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

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

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

My telephone number is (301) 321-3417

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

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

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

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

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

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

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

Sincerely,

Edmund J. Oberc
Assistant Division Chief
Soils Laboratory

EJO:ds

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

1. SCOPE

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

2. REFERENCED DOCUMENTS

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

3. SUMMARY OF METHOD

The calibration procedure consists of the following steps:

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

4. APPARATUS

- 4.1 Thermometer - Suitable for measuring temperatures of approximately 20-30 C with an accuracy of 0.5 C and traceable to a National Bureau of Standards calibrated thermometer.
- 4.2 Resilient Modulus Testing Apparatus - Suitable for performing SHRP (Strategic Highway Research Project) Protocol P-46, Resilient Modulus of Unbound Granular Base/Subbase Materials and Subgrade Soils.
- 4.3 LVDT Transducer Calibrator - Accurate to 0.0005 inch. May be available from the manufacturer of the resilient modulus apparatus. Should be accompanied by a calibration certificate. The device should be of a configuration such that the device and LVDT will not be held and warmed by the hand. Some configurations of resilient modulus equipment requires that the LVDT's be calibrated at the same time. These configurations will require 2 LVDT transducer calibrators.
- 4.4 Machinist's Gage Block (Optional) - Size to be equal to the full range of the LVDT to be calibrated, accurate to $\pm .0005$ inches, calibration certificates required
- 4.5 Oscilloscope

- 4.6 Load cell calibration stand and weights - Stand must be suitable for applying compression loads to the load cell by use of weights. Weights shall be accurate to 0.01 lbs. and shall be accompanied by a calibration certificate. Weights must be available for the range of the load cell.
- 4.7 Proving Ring (Optional) - Capacity to be equal to or greater than the largest load applied during the resilient modulus test. Accurate to 0.01 pounds, calibration certificate required.
- 4.8 Small hand tools (screwdriver, etc.)

5. PROCEDURE

- 5.1 Measure and record the temperature of the sample storage and sample test rooms. The temperature of the rooms should be 25 ± 1 C. If the temperature of the sample storage and sample test rooms is outside this range, adjust the temperature.
- 5.2 Calibration of the LVDT's - The resilient modulus testing equipment measures the horizontal deformation of a sample which occurs during an applied load by use of very sensitive transducers. Assuring accurate response of the transducers and the display to known deformation is a key step in calibrating the modulus test equipment.

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

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

 - 5.2.1 Turn on the Resilient Modulus Apparatus (RMA) and allow the electronic equipment to warm up for at least 15 minutes or as directed by the manufacturer.
 - 5.2.2 Mount one LVDT from the RMA in the LVDT transducer calibrator. Connect the LVDT to the RMA and set up the RMA for calibration.
 - 5.2.3 Set the LVDT transducer calibrator to a convenient zero position, one that will allow the movement of the LVDT through its full linear range (the exact midpoint of the calibrator is suggested). Record the value displayed on the LVDT calibrator.
 - 5.2.4 Position the LVDT in the LVDT transducer calibrator so that the LVDT is at its electronic center.
 - 5.2.5 Adjust the RMA "Zero" potentiometer until the RMA readout indicates 0.000 inches.

- 5.2.6 Advance the LVDT calibrator the full linear range of the LVDT in the "compression" direction. The RMA readout should display the value of the full linear range of the transducer. Record the RMA readout.
- 5.2.7 Return the LVDT transducer calibrator to its zero position. The RMA readout should read zero.
- 5.2.8 Repeat steps 5.2.5 through 5.2.7 four times. Compute the average RMA readout at the full linear range of the LVDT. This should be the same as the full linear range.
- 5.2.9 If the average RMA readout and the LVDT calibrator display do not agree, adjust the "Gain" on the appropriate potentiometer on the RMA (see manufacturer's instructions).
- 5.2.10 Repeat Steps 5.2.5 through 5.2.9 until the transducer displacement is accurately indicated on the RMA.
- 5.2.11 Repeat for the second transducer (if required).

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

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

- 5.3.1 Connect an oscilloscope to the appropriate terminals on the RMA (refer to the manufacturer's manual for your RMA).
- 5.3.2 The trigger pulse must be set for 0.10 seconds "ON"; 0.9 seconds "OFF"; 1.00 seconds per cycle.
- 5.3.3 Adjust the timing if necessary. Timing controllers are usually found on a circuit board inside the RMA housing.

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

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

- 5.4.3 Place the load cell under a suitable stand, such as shown in Figure 2. The loading stand provides a stable platform for applying known weights onto the center of the load cell.
- 5.4.4 The RMA display must read 0.00 pounds for the unloaded load cell. If the display is not 0.00 pounds, then zero the readout by adjusting the appropriate potentiometer (refer to the manufacturer's instructions).
- 5.4.5 Lower the loading platform shaft carefully onto the center of the load cell. Record the tare weight.
- 5.4.6 Place known weights on the loading platform. The weights should bracket the range load which will be applied during the resilient modulus test. Record the readout on the RMA display for each applied load. The RMA display should indicate the applied load (including tare) over the full range of loads that are applied. If not, calibrate the readout by adjusting the appropriate potentiometer (see manufacturer's instructions).
- 5.4.7 Repeat Steps 5.4.5 and 5.4.6 until the correct loads are displayed on the RMA.

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

6. TESTING THE SYNTHETIC REFERENCE SAMPLES

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

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

- 6.1.1 Make several measurements of the diameter and height of the specimen.
- 6.1.2 Clean the triaxial base pedestal. Center the synthetic reference specimen on the triaxial cell pedestal. Do not use porous stones or membrane.
- 6.1.3 Using commercially available glue (Superglue or other), attach the sample to the pedestal base using three to four spots along the sides of the pedestal base and specimen. Do not put glue between the pedestal base and the specimen, use the sides.
- 6.1.4 In a similar manner, attach the top cap to the sample.
- 6.1.5 Once the glue has set, proceed to assemble the triaxial chamber and connect all transducers and zero out the LVDT's.

- 6.1.6 With a confining pressure at zero, apply a static load of between 0.5 and 1.0 psi to the specimen (seating load).
- 6.1.7 Using a frequency of 1 Hz with a load duration of 0.1 second and a no-load duration of 0.9 second, apply a dynamic load of 2 psi.
- 6.1.8 Apply 50 repetitions of the 2 psi load and record the recovered deformations and loads of the last five cycles. Repeat another 50 load repetitions and record the last five recovered deformations and loads.
- 6.1.9 Repeat Step 6.1.8 for dynamic loads of 6 psi and 10 psi.
- 6.1.10 Increase the confining pressure to 4 psi and repeat Steps 6.1.8 and 6.1.9.
- 6.1.11 Calculate the resilient modulus for each set of measurements. Stresses and strains should be corrected based on permanent strain accumulation.
- 6.1.12 Record the resilient moduli on the attached form.

RESILIENT MODULUS TESTING EQUIPMENT

S.H.R.P. TYPE II SOIL

SYNTHETIC SPECIMEN TEST DATA

ON CALIBRATED EQUIPMENT

TESTING LABORATORY: _____

DATE: _____ TIME: _____ TEMPERATURE: _____

SAMPLE NUMBER: _____ OPERATOR: _____

CONFINING PRESSURE =
0 P.S.I.

CONFINING PRESSURE =
4 P.S.I.

| | TEST #1 | TEST #2 | TEST #1 | TEST #2 |
|-------------------------|------------------------------|------------------------------|------------------------------|------------------------------|
| <u>DYNAMIC LOAD</u> | <u>RESILIENT MODULUS</u> | <u>RESILIENT MODULUS</u> | <u>RESILIENT MODULUS</u> | <u>RESILIENT MODULUS</u> |
| 2 P.S.I. | _____ | _____ | _____ | _____ |
| 6 P.S.I. | _____ | _____ | _____ | _____ |
| 10 P.S.I. | _____ | _____ | _____ | _____ |

NOTE CONCERNING P46

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

SHRP PROTOCOL: P46

For SHRP Test Designation: UG07, SS07

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

This SHRP protocol describes the laboratory testing procedure for the determination of the Resilient Modulus (M_r) of unbound granular base and subbase materials and subgrade soils. This protocol is based partially on the test standard AASHTO T292-91I, Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials. The test shall be carried out in accordance with the following protocol procedure.

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

Definitions

The following definitions, associated with LTPP pavement sample handling and testing, will be used throughout this protocol:

- (a) Layer: That part of the pavement produced with similar material and placed with similar equipment and techniques. The material within a particular layer is assumed to be homogeneous. The layer thickness of unbound granular base and subbase materials is determined from field exploration logs (borehole logs and/or test pit log).
- (b) Sample: A representative portion of material from one or more pavement layers received from the field. A sample can be a core, block, chunk, pieces, bulk, thin-walled tube or jar sample.
- (c) Bulk Sample: That part of the pavement material that is removed from an unbound base or subbase layer or from the subgrade. Bulk samples are retrieved from the borehole(s) and the test pit at the designated locations. The bulk sample of each layer is shipped in one or more bag(s) to the Regional Laboratory Material Testing Contractor. The material from one layer should never be mixed with the material from another layer - even if there is less than the desired amount to perform the specified tests.

- (d) **Test Sample:** That part of the bulk sample of an unbound base or subbase layer or subgrade which is prepared and used for the specified test. The quantity of the test sample may be the same but will usually be less than the bulk sample.
- (e) **Test Specimen:** For the purpose of this protocol, a test specimen is defined as (i) that part of the thin-walled tube sample of the subgrade which is used for the specified tests and (ii) that part of the test sample of unbound granular base or subbase materials or untreated subgrade soils which is remolded to the specified moisture and density condition by recompaction in the laboratory.
- (f) **Unbound Granular Base and Subbase Materials:** These include soil-aggregate mixtures and naturally occurring materials used in each layer of base or subbase. No binding or stabilizing agent is used to prepare unbound granular base or subbase layers.
- (g) **Subgrade:** Subgrade soils are prepared and compacted before the placement of subbase and/or base layers.
 - (i) A treated subgrade layer (for example cement- or lime-treated soils) is considered a treated subbase layer in the GPS study of the LTPP program. Treated subgrade materials and bound or stabilized layers of subgrade soils are considered treated subbase materials and should be tested using Protocol P31.
 - (ii) Untreated subgrade soils include all cohesive and non-cohesive (granular) soils present in the sampling zone.

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

- (h) Material Type 1: For the purposes of this protocol (resilient modulus tests), Material Type 1 includes; (i) all unbound granular base and subbase material, and (ii) all untreated subgrade soils which meet the criteria of less than 70% passing the No. 10 sieve and 20% maximum passing No. 200 sieve. Testing parameters used for Type 1 unbound materials are different from those specified for Material Type 2.
- (j) Material Type 2: For the purpose of this protocol (resilient modulus tests), Material Type 2 includes all untreated subgrade soils not meeting the criteria given above in (h) (ii). Generally, thin-walled tube samples of untreated subgrade soils fall in this Type 2 category.
- (k) Resilient Modulus of Unbound Materials: The modulus of an unbound material is determined by repeated load triaxial compression tests on test specimens of the unbound material samples. Resilient modulus (M_r) is the ratio of the amplitude of the repeated axial stress to the amplitude of the resultant recoverable axial strain.

Sample Locations for GPS Pavement Sections

- (a) The test shall be performed on the test specimens prepared from bulk samples of the unbound granular base and subbase materials retrieved from boreholes BA1, BA2, BA3, etc. and from the test pit (or bulk samples retrieved from boreholes BA4, BA5, BA6, etc. in the absence of the test pit samples).
- (b) For the subgrade soils, the test shall be carried out on undisturbed thin-walled tube samples retrieved from boreholes A1 and A2; if available. If the thin-walled tube samples are unavailable or unsuitable for testing, or if directed by SHRP, then bulk samples of subgrade soils shall be used to remold test specimens for resilient modulus tests. Bulk samples of subgrade soils are retrieved from boreholes BA1, BA2, BA3, etc. and from the test pit (or bulk samples from boreholes BA4, BA5, BA6, etc. in the absence of the test pit samples).

Assignment of SHRP Laboratory Numbers

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

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

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

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

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

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

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

Laboratory Testing Sequence of Unbound Granular Base and Subbase Materials

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

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

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

Laboratory Testing Sequence of Untreated Subgrade Soils

- (a) Bulk samples of untreated subgrade soils from LTPP-GPS pavement sections shall be used for the laboratory tests in the following sequence:
- Natural Moisture Content (SHRP Test Designation SS09, Protocol P49)
 - Sieve Analysis (SHRP Test Designation SS01, Protocol P51)
 - Hydrometer Analysis (SHRP Test Designation SS02, Protocol P42)
 - Atterberg Limits (SHRP Test Designation SS03, Protocol P43)
 - Classification and Description (SHRP Test Designation SS04, Protocol P52)
 - Moisture-Density Relations (SHRP Test Designation SS05, Protocol P55)

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

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

- (b) If the thin-walled tube samples are not available, then follow the test sequence described in (a) above for the resilient modulus test. The test specimen however is reconstituted from a representative portion of the bulk sample. The comment code 89 shall be used in reporting the test results for P46.
- (c) Instructions for undisturbed thin-walled tube samples of subgrade soils:
 - If the thin-walled tubes are available and acceptable for the resilient modulus test then no bulk sample is needed to reconstitute the test sample for Protocol P46. The "undisturbed" thin-walled tube sample is used in the resilient modulus testing (Protocol P46). The comment code 87 shall be used in reporting the test results for P46.
 - The resilient modulus testing of the "undisturbed" thin-walled tube sample can be done without waiting for the entire sequence of testing shown in (a) above provided that the thin-walled tube sample is suitable for testing. The comment code 87 shall be used in reporting the test results for P46.
 - If the thin-walled tube sample is not acceptable then use bulk samples as described in (a) above to reconstitute the test specimen for the resilient modulus testing (Protocol P46). The comment code 88 shall be used in reporting the test results for P46.
 - If available, properly mark the untested thin-walled tube sample and store for possible future use by SHRP. The comment code 90 shall be used in reporting the test results for P46.

1. SCOPE

- 1.1 These methods cover procedures for preparing and testing unbound granular base/subbase materials and subgrade soils for determination of resilient modulus under specified conditions representing stress states beneath flexible and rigid pavements subjected to moving wheel loads.
- 1.2 The methods described are applicable to: undisturbed samples of natural and compacted subgrade soils, and to disturbed samples of unbound base and subbase and subgrade soils prepared for testing by compaction in the laboratory.
- 1.3 The value of resilient modulus (M_r) determined from this protocol procedure is a measure of the elastic modulus of unbound base and subbase materials and subgrade soils recognizing certain nonlinear characteristics.
- 1.4 Resilient modulus (M_r) values can be used with structural response analysis models to calculate pavement structural response to wheel loads, and with pavement design procedures to design pavement structures.

2. APPLICABLE DOCUMENTS

2.1 AASHTO Standards

- T88-86 Particle Size Analysis of Soils
- T99-86 The Moisture-Density Relations of Soils Using a 5.5 lb. Rammer and 12-Inch Drop
- T100-86 Specific Gravity of Soils
- T233-86 Density of Soil-in-Place by Block, Chunk or Core Sampling
- T234-85 Strength parameters of soils by Triaxial Compression
- T265-86 Laboratory Determination of Moisture Content of Soils
- T292-91I Resilient Modulus of Subgrade Soils and Untreated Base/Subbase Materials

2.2 SHRP Protocols

P41 - Gradation of Unbound Granular Base and Subbase Materials

P42 - Hydrometer Analysis of Subgrade Soils

P43 - Determination of Atterberg Limits of Unbound Granular Base and Subbase Materials and Subgrade Soils

P44 - Moisture-Density Relations of Unbound Granular Base and Subbase Materials

P47 - Classification and Description of Unbound Granular Base and Subbase Materials

P49 - Determination of Natural Moisture Content

P51 - Sieve Analysis of Subgrade Soils

P52 - Classification and Description of Subgrade Soils

P55 - Moisture-Density Relations of Subgrade Soils

3. SUMMARY OF TEST METHOD

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

4. SIGNIFICANCE AND USE

- 4.1 The resilient modulus test provides a basic constitutive relationship between stress and deformation of pavement construction materials for use in structural analysis of layered pavement systems.
- 4.2 The resilient modulus test provides a means of characterizing pavement construction materials, including subgrade soils under a variety of conditions (i.e. moisture, density, etc.) and stress states that simulate the conditions in pavements subjected to moving wheel loads.

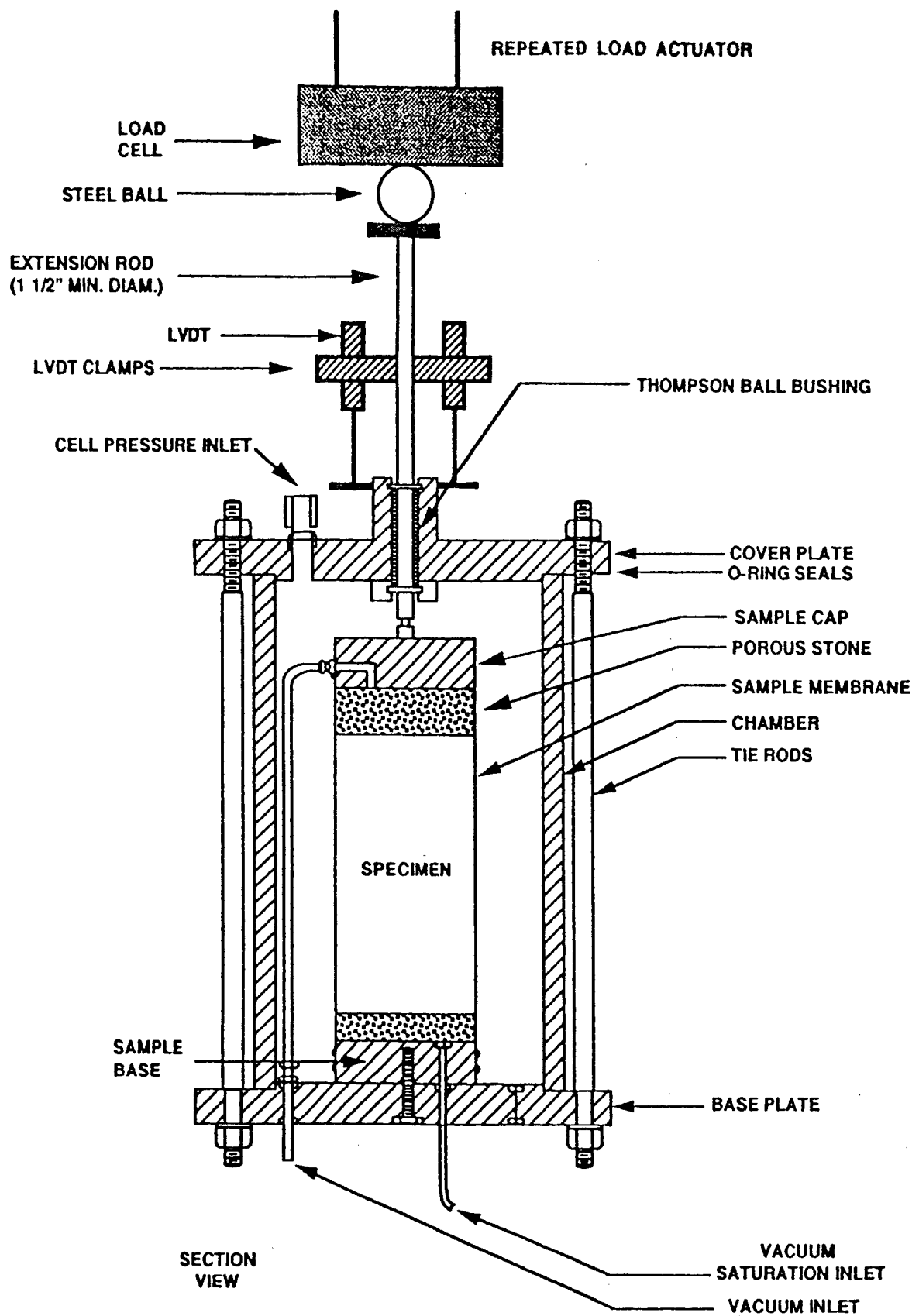
5. BASIC DEFINITIONS

- 5.1 S_1 is the total axial stress (major principal stress).
- 5.2 S_3 is the total radial stress; that is, the applied confining pressure in the triaxial chamber (minor principal stress).
- 5.3 $S_d = S_1 - S_3$ is the repeated axial deviator stress for this procedure, and is the difference between the major and minor principal stresses in a triaxial test.
- 5.4 e_1 is the total axial deformation due to S_d .
- 5.5 e_r is the resilient (recovered) axial deformation due to S_d .
- 5.6 $M_r = S_d/e_r$ is defined as the resilient modulus.
- 5.7 Load duration is the time interval the specimen is subjected to a deviator stress.
- 5.8 Cycle duration is the time interval between successive applications of a deviator stress.
- 5.9 $Y_d = GY_w/[1 + (wG/S)]$
where Y_d = unit weight of dry soil, pounds per cubic foot
 G = specific gravity of soil solids, dimensionless,
 w = moisture content of soil, (%),
 S = degree of saturation, (%), and
 Y_w = unit weight of water, pounds per cubic foot and may be assumed to be 62.4 pounds per cubic foot (pcf).
NOTE 1: Both w and S must be expressed as numbers; (e.g., 20% is 20), and shall be reported as numbers for SHRP test results.
- 5.10 Material Definitions - For the purpose of this testing protocol unbound granular base and subbase materials and subgrade soil are categorized as one of two types using the following criteria.

- 5.10.1 Material Type 1 - all unbound granular base and subbase material, and all untreated subgrade soils which meet the criteria of less than 70% passing the No. 10 sieve and 20% maximum passing the No. 200 sieve.
- 5.10.2 Material Type 2 - all the untreated subgrade soils not meeting the criteria in 5.10.1. Generally, thin-walled samples of untreated subgrade soils fall in this Type 2 category.
- 5.10.3 Testing parameters used for Type 1 unbound materials are different from those specified for unbound material Type 2. Type 1 will always include AASHTO classification A-1-a soils, and Type 2 will always include A-4, A-5, A-6, and A-7 soils. A-1-b, A-2 and A-3 soils may fall into either category.
- 5.10.4 Use the test results of gradation tests (Protocols P41 or P51) and classification tests (Protocols P47 or P52) to establish the material category according to the above criteria.

6. APPARATUS

- 6.1 Triaxial Pressure Chamber - The pressure chamber is used to contain the test specimen and the confining fluid during the test. A triaxial chamber suitable for use in resilient testing of soils is shown in Figure 1. The deformation is measured externally with two spring loaded LVDT's as shown in Figure 1.
 - 6.1.1 Air shall be used in the triaxial chamber as the confining fluid for all SHRP testing.
- 6.2 Loading Device:
 - 6.2.1 The external loading device must be capable of providing variable magnitude of repeated loads for fixed cycles of load and rest period. A closed-loop electro-hydraulic system is required by SHRP.



Not to Scale

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 | $\pm 25\%$ of full scale |
| Repeatability | $\pm 1\%$ 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 $1 \frac{1}{4}$ inch, without removing any coarse aggregate.
- 7.1.3 If more than 5 percent of a sample is retained on the $1 \frac{1}{4}$ -inch sieve remove the particles retained on the $1 \frac{1}{4}$ -inch sieve prior to specimen preparation. If more than 10 percent of the sample is plus $1 \frac{1}{4}$ 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 $\pm 1/2$ 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 $\pm 1/2$ 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:
$$W_s \text{ (pounds)} = Y_d \text{ (pounds per cubic foot)} \times V \text{ (cubic feet)}$$
$$W_s \text{ (grams)} = W_s \text{ (pounds)} \times 454$$
$$W_w \text{ (pounds)} = W_s \text{ (pounds)} \times w \text{ (\%/100)}$$
$$W_w \text{ (grams)} = W_w \text{ (pounds)} \times 454$$
- 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 .

$$W_1 (\text{grams}) = W_s \times (1 + w/100)$$

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

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

- 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).

$$W_1 (\text{grams}) = (W_s + W_{ms}) \times (w_1/100)$$

$$W_2 (\text{grams}) = (W_s + W_{ms}) \times (w/100)$$

$$W_{aw} (\text{grams}) = W_2 - W_1$$

- 7.3.9 Place the mass of the sample (W_{sd}) determined in 7.3.7 into a mixing pan.
- 7.3.10 Add the water (W_{aw}) to the sample in small amounts and mix thoroughly after each addition.
- 7.3.11 Place the mixture in a plastic bag. Seal the bag and place it in a second bag and seal it.
- 7.3.12 After mixing and storage, weigh the wet soil and container to the nearest gram and record this value on the appropriate form (see Worksheet T46).

7.4 Compaction Methods and Equipment for Reconstituting Specimens

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

- 7.4.2 Compacting Specimens for Type 2 Materials - The general method of compaction for Type 2 materials will be that of Attachment B of this protocol.
- 7.4.3 Moisture and Density for Compaction - When the in situ density and moisture content are known from the field data (see Section 7.2.2) the sample should be compacted to this in situ dry density and moisture content.
- 7.4.4 Moisture and Density for Compaction when Field Data is not Available - In the absence of the test pit, the in situ density and moisture contents are not known; therefore one of the following procedures is used.
- (a) Unbound Granular Base and Subbase Materials (Type 1): Use the results of the UG05 test (Protocol P44) on Form T44 to establish the maximum dry density and the optimum moisture content based on AASHTO T180-85. Select the optimum moisture content and 95 percent of the maximum dry density for sample compaction.
 - (b) Subgrade Soils (Type 1): Subgrade soils may be categorized as Type 1 or as Type 2 according to the criteria of Section 5.10. In the case of Type 1 subgrade soils, use the results of SS05 (Protocol P55) on Form T55 to establish the maximum dry density and the optimum moisture content based on AASHTO T99-86. Select the optimum moisture content and 95% of the maximum dry density for sample compaction.
 - (c) Unbound Material Type 2: Generally subgrade soils (fine-grained) are included in the unbound material Type 2 category. Select the optimum moisture content and 95% maximum dry density for sample compaction as described in Section 7.4.4.
- The sample dry density and moisture content should not differ by more than 3 percent of the in situ dry density and 1 percentage point of the in situ moisture content respectively for Type 1 materials, and 2 percent of the in situ dry density and 1/2% of the

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

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

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

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

8. TEST PROCEDURE

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

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

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

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

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

- 8.1.1.4 Place the top platen (with load cell included) on the specimen, fold up the membrane, and seal it to the top platen with an O-ring or some pressure seal.
- 8.1.1.5 If the specimen has been compacted inside a rubber membrane and the porous stones and sample are already attached to the rubber membrane in place, steps 8.1.1.2, 8.1.1.3, and 8.1.1.4 are omitted. Instead, the "specimen assembly" is placed on the top of the pedestal or bottom end plate of the triaxial chamber.
- 8.1.1.6 Connect the specimen's bottom drainage line to the vacuum source through the medium of a bubble chamber. Apply a vacuum of 1 psi. If bubbles are present, check for leakage caused by poor connections, holes in the membrane, or imperfect seals at the cap and base. The existence of an airtight seal ensures that the membrane will remain firmly in contact with the specimen. Leakage through holes in the membrane can frequently be eliminated by coating the surface of the membrane with liquid rubber latex or by using a second membrane.
- 8.1.1.7 When leakage has been eliminated, disconnect the vacuum supply and place the chamber on the base plate, the load cell on the porous stone, and the cover plate on the chamber. Insert the loading piston and obtain a firm connection with the load cell. Tighten the chamber tie rods firmly.
- 8.1.1.8 Slide the assembly apparatus into position under the axial loading device. Bring the loading device down and couple it to the triaxial chamber piston and apply a seating pressure to the sample of 2 psi in order to obtain full contact of the piston with the top platen.

- 8.1.2 Conduct the Resilient Modulus Test - The following steps are required to conduct the resilient modulus test on a specimen of Type 2 soil which has been installed in the triaxial chamber and placed under the loading frame.
- 8.1.2.1 Open all drainage valves loading into the specimen.
 - 8.1.2.2 If it is not already connected, connect the air pressure supply line to the triaxial chamber and apply a confining pressure of 6 psi to the test specimen. A contact load of 10% (± 0.5 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 .1 S_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 .1 S_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 (k₁ and k₂ and k₃) using least squares regression.

- Simple relationship for Type 1 Material (Figure T46A)

$$M_r = k_1(1 + S_3)k_2(S_d)^{k_3}$$

Where S_d = deviator stress and

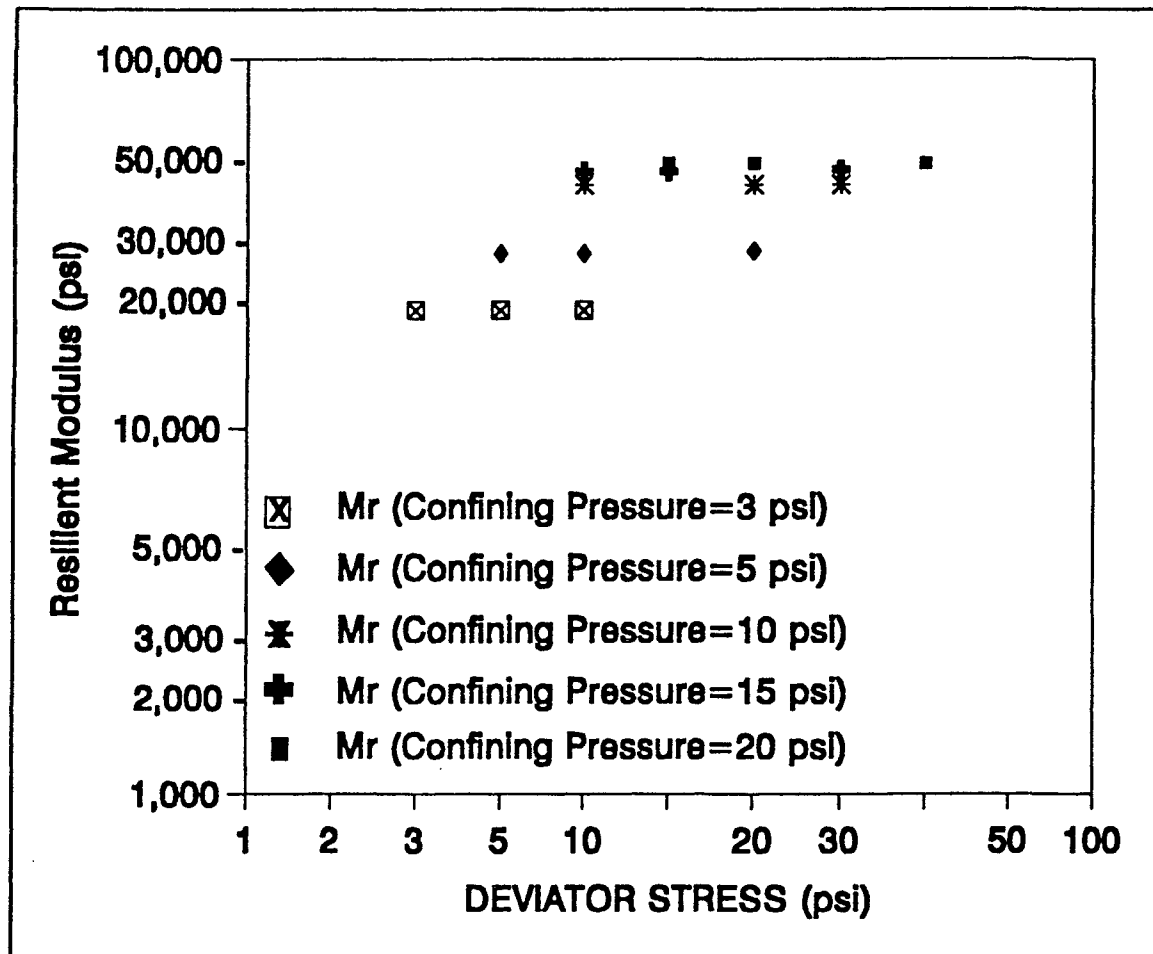
S₃ = confining pressure

- Simple relationship for Type 2 Material (Figure T46B)

$$M_r = k_1 (S_d)^{k_2}(1 + S_3)^{k_3}$$

Where S_d = deviator stress and

S₃ = confining pressure

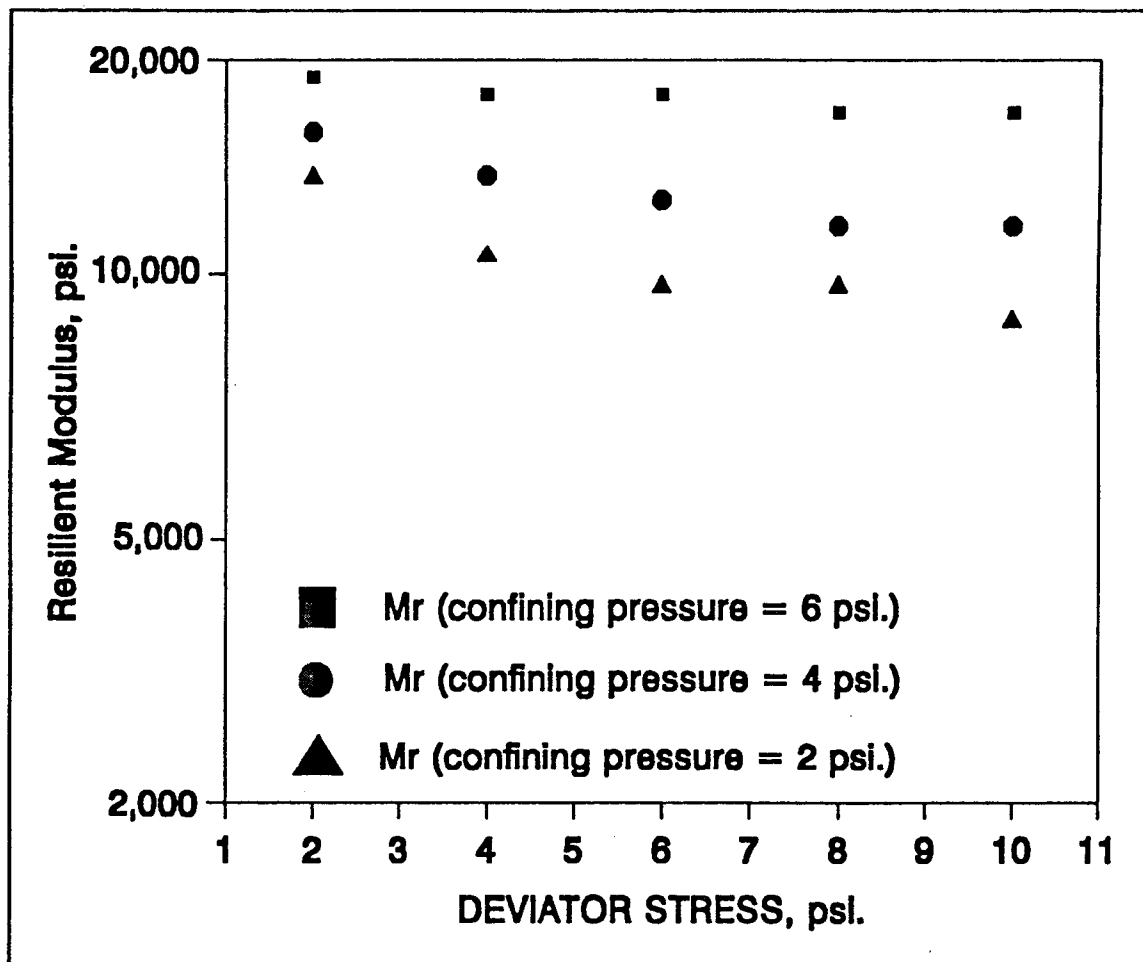


$$M_r = K_1 (1+S_3)^{K_2} (S_d)^{K_5}$$

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

$$R^2 = .988$$

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



$$\begin{aligned}
 M_r &= K_1 (S_d)^{K_2} (1+S_3)^{K_3} \\
 &= 14071 (S_d)^{-0.151} (1+S_3)^{0.200} \\
 R^2 &= .977
 \end{aligned}$$

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

- (c) Specimen Data: moisture content (After the test), w , % Dry Density, Y_d , pcf
- (d) Constants for M_r Relationships: Values of regression constants and related stress parameters used in the M_r relationship.
- (e) M_r for Material Type 1 at a confining pressure of 15 psi and deviator stress of 15 psi.
- (f) M_r for Material Type 2 at a confining pressure of 6 psi and deviator stress of 4 psi.

10.4 Comments shall include SHRP standard comment code(s), as shown on Page E.1-3 of the SHRP Laboratory Material Testing Guide and any other note as needed. Additional codes associated with resilient modulus testing are:

Code Comment

- 80 Due to the insufficient size of the bulk sample, the test sample used for the last test (Protocol P46, if the sample was reconstituted) was saved and stored for possible future use by SHRP.
- 81 A separate test sample was used for classification and description tests (Protocol P47 or P52).
- 82 Due to the insufficient size of the bulk sample, the test sample for the gradation test (Protocol P41 or P51) was also used to complete the classification and description tests (Protocol P47 or P52).
- 83 Due to the insufficient size of the bulk sample, the test sample for the moisture-density test (Protocol P44 or P55) was saved after the test and reused for the resilient modulus testing (Protocol P46).
- 85 Due to the insufficient size of the bulk sample, only dry sieving was used for the gradation test (Protocol P41 or P51). The test sample after the gradation test was saved and reused to reconstitute the test sample for the resilient modulus testing (Protocol P46).

- 86 Due to the insufficient size of the bulk sample, only dry sieving was used for the gradation test (Protocol P41 or P51). This test sample was reused for other designated tests and the remnant of the samples was saved and stored for possible future use by SHRP.
- 87 The "undisturbed" thin-walled tube sample was used for the resilient modulus testing (Protocol P46).
- 88 The thin-walled tube sample was not suitable, therefore, a reconstituted sample from the bulk samples was used for the resilient modulus testing.
- 89 The thin-walled tube sample was not available. The test sample for the resilient modulus testing (Protocol P46) was reconstituted from the bulk sample.
- 90 An excess portion of the thin-walled tube sample was saved and stored for possible future use by SHRP.
- 94 The test was not performed because of the oversize aggregates; sample was stored until further instructions from SHRP.
- 10.5 Use Form T46, Worksheet T46 and Figure T46A or T46B to report the results of the resilient modulus test to the SHRP Regional Engineer.
- NOTE 5: Item 5(d) of Form T46 contains six constants for the M_r relationship, k_1 , k_2 , k_3 , k_4 , k_5 and k_6 . Constants k_3 and k_4 and k_6 are for future use and will not be required at this time. In addition, stress parameters S_4 , S_5 and S_6 are for future use and will not be required at this time.

ATTACHMENT A TO SHRP PROTOCOL P46

COMPACTION OF TYPE 1 SOILS

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

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

1. SCOPE

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

2. APPARATUS

- 2.1 Six inch diameter split mold.
- 2.2 Vibratory compaction device.

3. PROCEDURE

- 3.1 Tighten the bottom platen into place on the triaxial cell base. It is essential that an airtight seal is obtained.
- 3.2 Place the two porous stones and the top platen on the bottom platen.
Determine the total height of the top and bottom platens and stones to the nearest 0.01 inch.

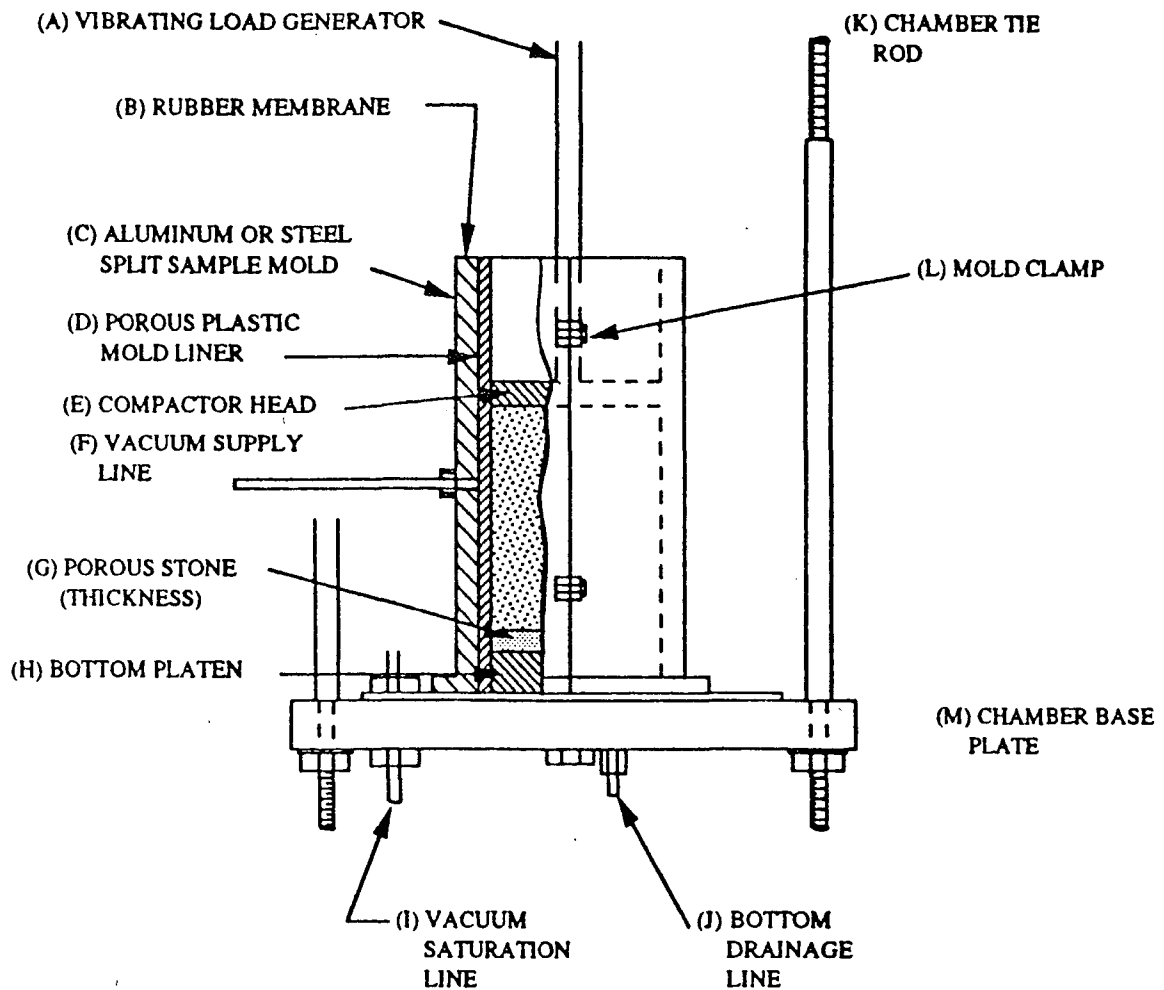


TABLE OF MEASUREMENTS (TYPICAL)

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

NOTE:

1. Dimension varies with manufacturer
2. Dimension varies with specimen size
3. Diameter should be 0.25 ± 0.02 inch (6.35 ± 0.5 mm) smaller 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_{ad} into a mixing pan. Add the required amount of water, W_{aw} and mix thoroughly.
- 3.12 Determine the weight of wet soil and the mixing pan.
- 3.13 Place the amount of wet soil, W_L , into the mold. Avoid spillage. Using a spatula, draw soil away from the inside edge of the mold to form a small mound at the center.
- 3.14 Insert the vibrator head and vibrate the soil until the distance from the surface of the compacted layer to the rim of the mold is equal to the distance measured in step 3.7 minus the thickness of the layer selected in step 3.10. This may require removal and reinsertion of the vibrator several times until experience is gained in gaging the vibration time which is required.
- 3.15 Repeat steps 3.13 and 3.14 for each new layer. The measured distance from the surface of the compacted layer to the rim of the mold is successively reduced by the layer thickness selected in step 3.10. The final 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.

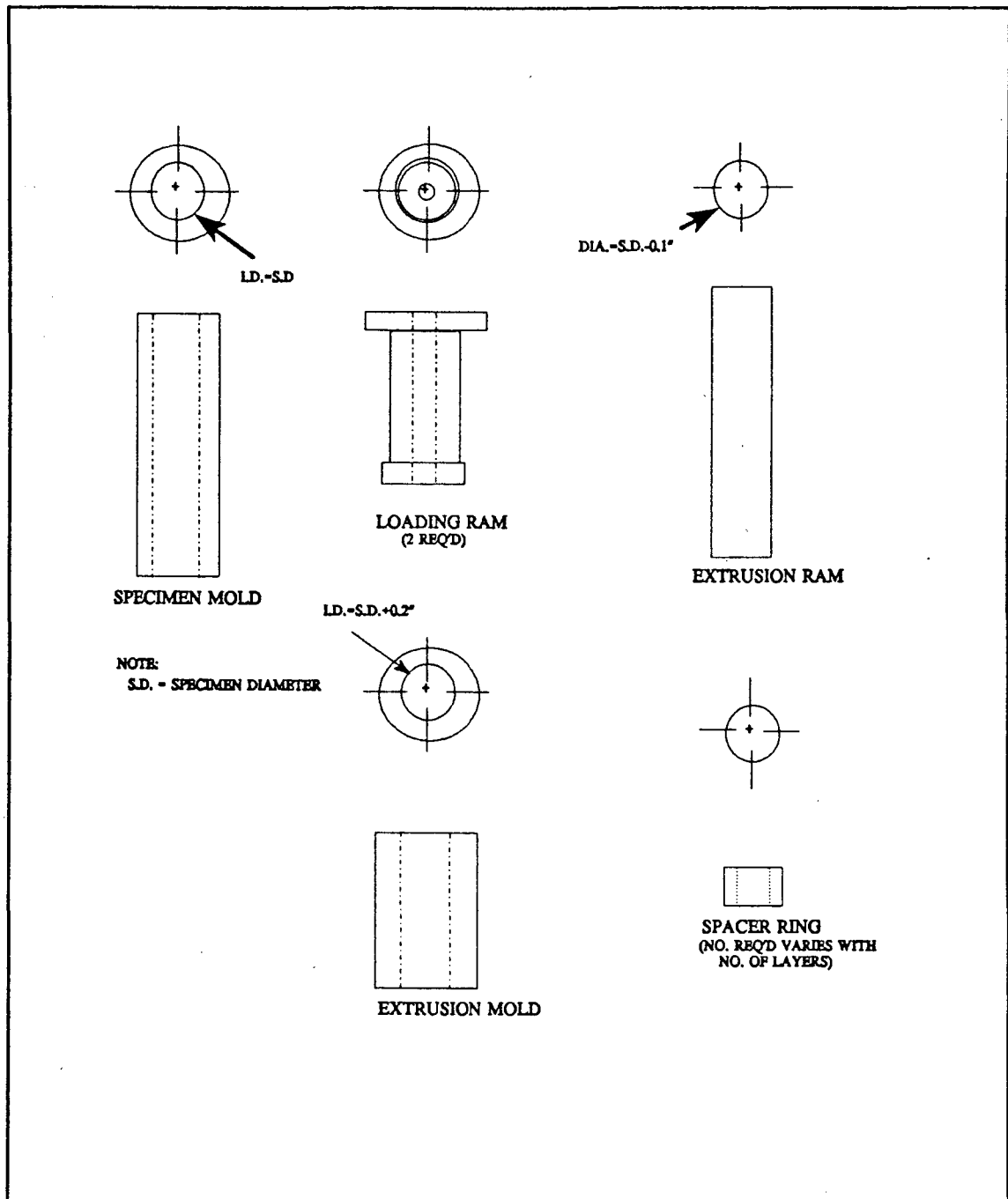


Figure 3. Apparatus for static compaction of Type 2 unbound materials.

- 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.

SHEET NO. OF

A-53

SHRP SECTION NUMBER _____

SHRP SAMPLE NUMBER _____

SHRP LABORATORY TEST NUMBER

LAYER NUMBER

MATERIAL TYPE

10. RESILIENT MODULUS TESTING.

[illegible]

* obtained from the last five load cycles

SUBMITTED BY, DATE

LABORATORY CHIEF

Affiliation

CHECKED AND APPROVED, DATE

Affiliation

APPENDIX B

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

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

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

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

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

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

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

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

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

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

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

APPENDIX C

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

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

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

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

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

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

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

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