SHRP-P-691

Round 1 Hot Mix Asphalt Laboratory Molded Proficiency Sample Program

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

Charles E. Antle
Consulting Statistician
State College, Pennsylvania

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

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

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2101 Constitution Avenue N.W.
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(202) 334-3774

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Abstract

All laboratories conducting tests for the Long-Term Pavement Performance (LTPP) program were required to be accredited by the American Association of State Highway and Transportation Official (AASHTO's) Accreditation Program (AAP). AAP includes site inspections of equipment and procedures, and partici[ation in applicable proficiency sample testing. A few critical LTPP tests were not addressed fully by the AAP, and LTPP staff decided to conduct supplemental testing. The Hot Mix Asphalt (HMA) Laboratory Molded Proficiency Sample Program is one of those supplemental tests.

Round 1 testing provided within- and among-laboratory diametral resilient modulus data for tests performed in accordance with SHRP Test Protocol P07. The objectives included drafting single operator and multi-laboratory test precision statements in testing proficiency status for SHRP laboratories, and preserving test sample information for future analysis.

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

PART I INTRODUCTION

One element of Quality Assurance (QA) for laboratory testing that was deemed to be of key importance to the long term pavement performance (LTPP) research, as a result of Expert Task Group (ETG) recommendations, is the American Association of State Highway and Transportation Officials (AASHTO) accreditation program (AAP) for laboratories. All laboratories providing LTPP testing services were required to be accredited by AAP. Most of the laboratory tests used for the LTPP field samples were addressed by the AAP. The AAP accreditation program 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 diametral resilient modulus test, were not fully addressed by AAP. After extensive consultation and careful study, it was determined that supplemental programs should be designed to provide assurance of quality test data for these tests in a manner similar to that provided by the AAP for other tests. The Hot Mix Asphalt (HMA) Laboratory Molded Proficiency Sample Program was among the supplemental programs approved for implementation.

Participation in the AC Synthetic Reference Sample Program[1], which had been designed to verify calibration and stability of diametral resilient modulus test systems, was a prerequisite for laboratories participating in Round 1 of the HMA Laboratory Molded Proficiency Sample Program. The Round 1 HMA Laboratory Molded Proficiency Sample Program was designed to provide within laboratory and among laboratories precision data for diametral resilient modulus tests performed in accordance with SHRP test protocol P07. The objectives included drafting single operator and multilaboratory diametral resilient modulus test

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[1]In the Synthetic Reference Sample Program, a set of four SHRP reference specimens was rotated to all laboratories participating in this program for testing in accordance with certain specified parameters. The initial reference specimen testing was conducted blind, that is, the participant did not know the moduli values for the reference specimens. In subsequent testing each participant was supplied with the acceptable reference moduli values. The intent of this procedure was to provide participants with an opportunity to verify the calibration of their diametral resilient modulus testing system by testing the set of four synthetic specimens. A response outside the anticipated range indicated the need for recalibration or other maintenance of the testing system and corrective action was required. When response was within the recommended range, authorization was given to proceed with the Hot-Mix Asphalt Laboratory Molded Sample Proficiency Sample Program.

precision statements in AASHTO/ASTM format for laboratory molded specimens, determining testing proficiency status for SHRP contract laboratories during the time period when testing of LTPP field samples was in progress, and preserving SHRP contract laboratory proficiency sample information (in the LTPP data base) for access by researchers who use test data generated by SHRP contract laboratories from LTPP field samples. In the Round 1 AC Laboratory Molded Proficiency Sample Program, each participating laboratory received two quarts of AC-10, two quarts of AC-30, and four bags of aggregate. Instructions accompanied each shipment which provided directions for each participant concerning the details for processing and testing the Round 1 samples.

Ten laboratories participated in the program. A list of participants is given in Table 1 of this report. A copy of the initiating letter and worksheets, pertinent excerpts from memoranda concerning the experimental design for this program, and certain test parameters provided to the participants are also included in Appendix A. The final comments, analyses, and conclusions for the HMA Laboratory Molded Proficiency Sample Program are contained in Part II of this report. A complete set of proficiency sample statements in AASHTO/ASTM format is contained in Part III of this report and supporting data are given in Appendix B.

Table 1. Participating Laboratories

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

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

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

State Materials & Research Engineer
Florida Department of Transportation
PO Box 1029
Gainesville, FL 32602

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

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

Oregon Department of Transportation
State Highway Division
800 Airport Road SE
Salem, OR 97310

South Western Laboratories
222 Cavalcade Street
PO Box 8768
Houston, TX 77249

US Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180

Wyoming Department of Transportation
5300 Bishop Boulevard
Cheyenne, WY 82003

PART II RESEARCH ANALYSES, OBSERVATIONS, AND CONCLUSIONS

1. Background

This experiment was designed with the following objectives:

- To evaluate the capability of participating laboratories in the fabrication and subsequent diametral resilient modulus testing of hot mix asphalt test specimens.

- To evaluate the effect of two grades of asphalt binder, AC 10 and AC 30, on the resilient modulus (M_R) of hot mix asphalt test specimens.

- To evaluate the sources of variability that are due to the laboratories, batches of materials fabricated *and* tested at the same laboratory, specimens fabricated *and* tested in two thicknesses at a laboratory, and the errors in measuring the same specimen at a laboratory.

A total of ten laboratories participated in this experiment and provided their resulting data sets for analysis. This allowed for comparisons of the performance of the laboratories and this was done in several analyses as well as in the descriptive statistics presented in the figures and tables. Some attempt was made to indicate the source of the observed variation for the individual laboratories, that is to separate the variation due to the fabrication of the specimens and the variation due to the measuring of a given specimen. Thus, each of the participating laboratories has an excellent means for evaluating their performance in respect to that of the group, and this is the purpose stated in the first objective.

This experiment was designed so that the sources of variation in the measured M_R values could be evaluated for the group of participating laboratories. A statistical model for the experimental data is developed in order to separate the different sources of variation in the measured values for the M_R. The variability due to the laboratories, that is the

LABORATORY component of variance, is the first source identified. The within laboratory variation is separated into three components; the first is the BATCH, the second is the SPECIMEN and the third is the AXIS.

These are discussed in Part II of this report where the statistical model is presented and the importance of these factors is discussed. This statistical development and its analysis is the basis for the following sections. A description of the experiment is presented in the next section. A flow diagram describing the experiment as performed at each laboratory is given in Figure 1.

2. Design of the Experiment

This is a very large experiment and the resulting large data base provides the means for analyses in addition to those reported at this time. There are three target temperatures; 40, 77, and 104°F. There are two asphalt grades; AC 10 and AC 30. There was a single source for the aggregate, and batches of the aggregate selected at random were sent to the participating laboratories. Each laboratory received four bags of aggregate. Each laboratory was required to split each bag into two batches giving a total of eight batches. Each batch provided the aggregate for two 4-inch diameter by 1.5-inch thick and two 4-inch diameter by 3-inch thick test specimens. These specimens were "nested within the batches". This provided the means for evaluating the variability produced in the fabrication and testing of specimens of different thickness. Each core was then measured in two orthogonal directions and this was the basis for evaluating the measuring resilient modulus testing variability within a laboratory.

It was intended that each laboratory would provide both the instantaneous and the total M_R measurements, though of course these could not be done independently. However, two of the laboratories provided only total M_R measurements. It was also intended that these measurements would be made with recovery periods of 0.9, 1.9 and 2.9 seconds. All provided the 0.9 second measurements, but some did not provide data for the other recovery periods. No important differences were noted in the data for the different recovery periods,

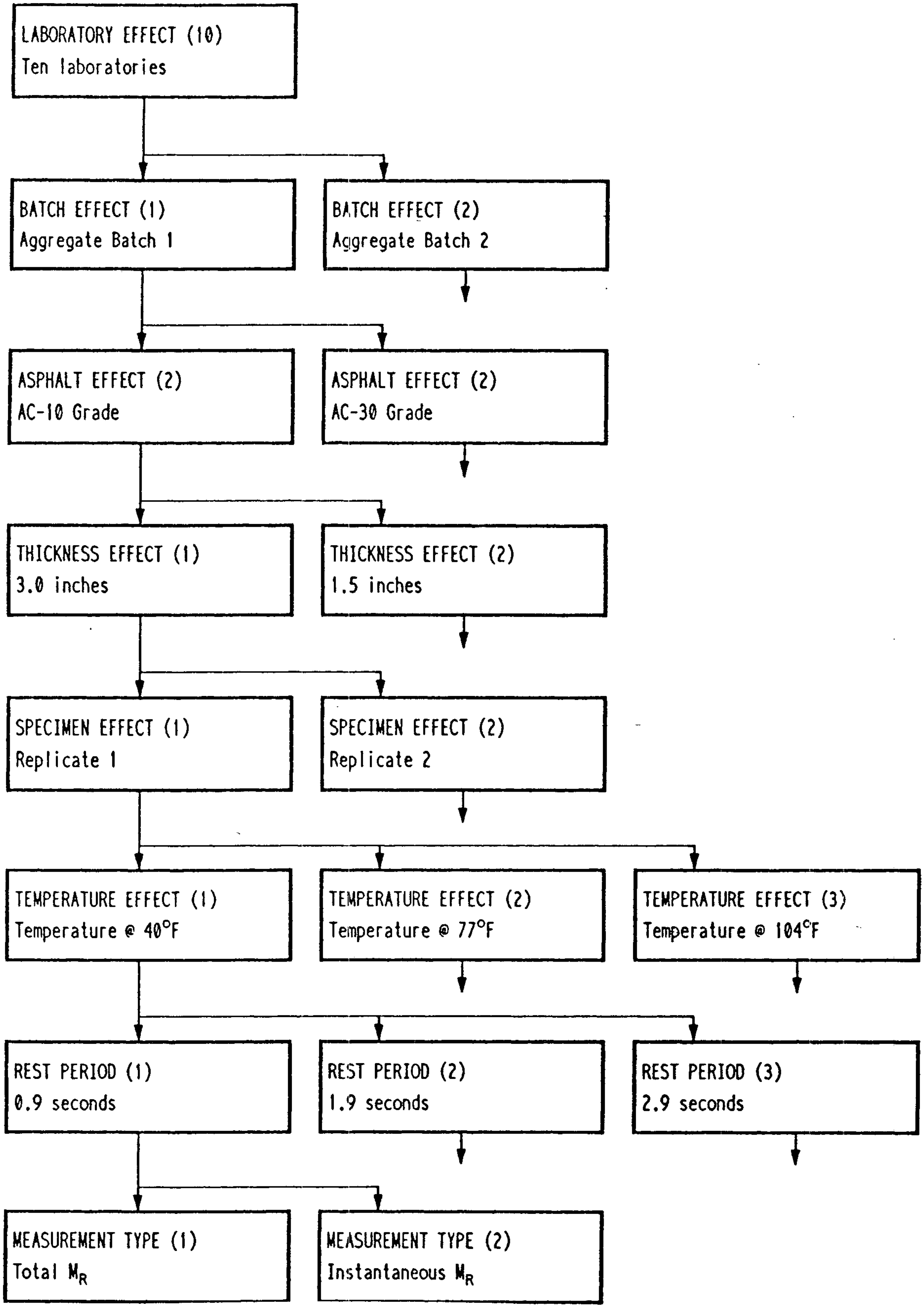

Figure 1. Flow chart for experiment.

and most of the ensuing analyses were done with only the 0.9 second data. Of course the data from the different recovery periods are not independent and there is little benefit to be gained by pooling them. The data base does, however, provide an excellent set of data from which to further evaluate the differences in the effects of the three recovery periods if this becomes an important question.

This large experiment may be divided into several smaller experiments for the purpose of answering particular questions. For example, consider the question of the effect of the thickness of the specimens. In this case, it is convenient to consider each set of two 1.5-inch specimens and their corresponding 3.0-inch specimens from the same batch, and use the difference in the averages of these as the unit for analysis. When this is done for each combination of temperature and asphalt the resulting set of data may be simply modeled as independent normal random variables. With this extensive data base a clear means is provided for evaluating the effect of specimen thickness, both for the laboratories as individuals and as a group.

The experiment may also be regarded as a large set of nested experiments. For example, the experimental data for temperature 77° F, recovery period of 0.9 second, AC 10 binder, and specimen length of 3 inches, provides a classic nested experiment with Laboratories, Batches, Specimens and Axis (or measurement error) as the nested factors. Much of the analysis of the experimental data was done with these separate nested experiments and then the results, especially in regard to coefficients of variation, combined over the set.

In summary, the following variables were included in this study:

- LAB--laboratory effect at ten levels.
- BATCH--eight batches for each laboratory, two batches randomly allocated to two replicates for two asphalts.
- ASPHALT--two asphalts, an AC-10 and an AC-30 grade.
- THICK--two sample thicknesses, 3.0-in. and 1.5-in. compacted from each batch.

- SPECIMEN--two replicate specimens compacted at each thickness for each batch made with the two asphalts.
- TEMPERATURE--three test temperatures, 40, 77 and 104°F.
- REST--three rest periods for each specimen at each temperature.
- TYPE--an instantaneous and a total resilient modulus calculated for each measurement.

3. Results for the Group of Laboratories

One of the primary concerns for which this experiment was designed was to evaluate the importance of the different sources of variation in the measured values of M_R in the laboratories which would be fabricating the test specimens and then measuring them for the purpose of developing or evaluating hot mix asphalt paving material. As described previously, there are four sources of variation or error that contribute to the overall variability in these measured values for the M_R. First is the laboratory differences or laboratory bias. The apparent laboratory differences may be observed in Figures 2-13 for the instantaneous M_R averages and in Figures 14-25 for the total M_R averages. It is clear from these figures that the results at different laboratories will contain a very large laboratory effect. The averages from which these figures were obtained are given in Appendix B.

The coefficient of variation for the laboratory effect, i.e., the standard deviation for the laboratory effect divided by the mean for the measurement, may be meaningful over a wide range of temperatures, asphalts, etc.. Thus it is the appropriate coefficient of variation that will be evaluated for each of the four sources of variation. It is seen in Table 2 that the laboratories which participated in this study made a very large contribution to the variation observed in the measured M_R values. Furthermore, data from one of the laboratories was far removed from the others and the data from that laboratory were omitted from the results in Table 2. The laboratory coefficient of variation averaged over the different asphalt grades, test temperatures, and sample thicknesses is approximately 40 percent for both the instantaneous and total resilient modulus measurements. This appears to be a large value and would indicate that improvements in the test method are needed. Some better means for

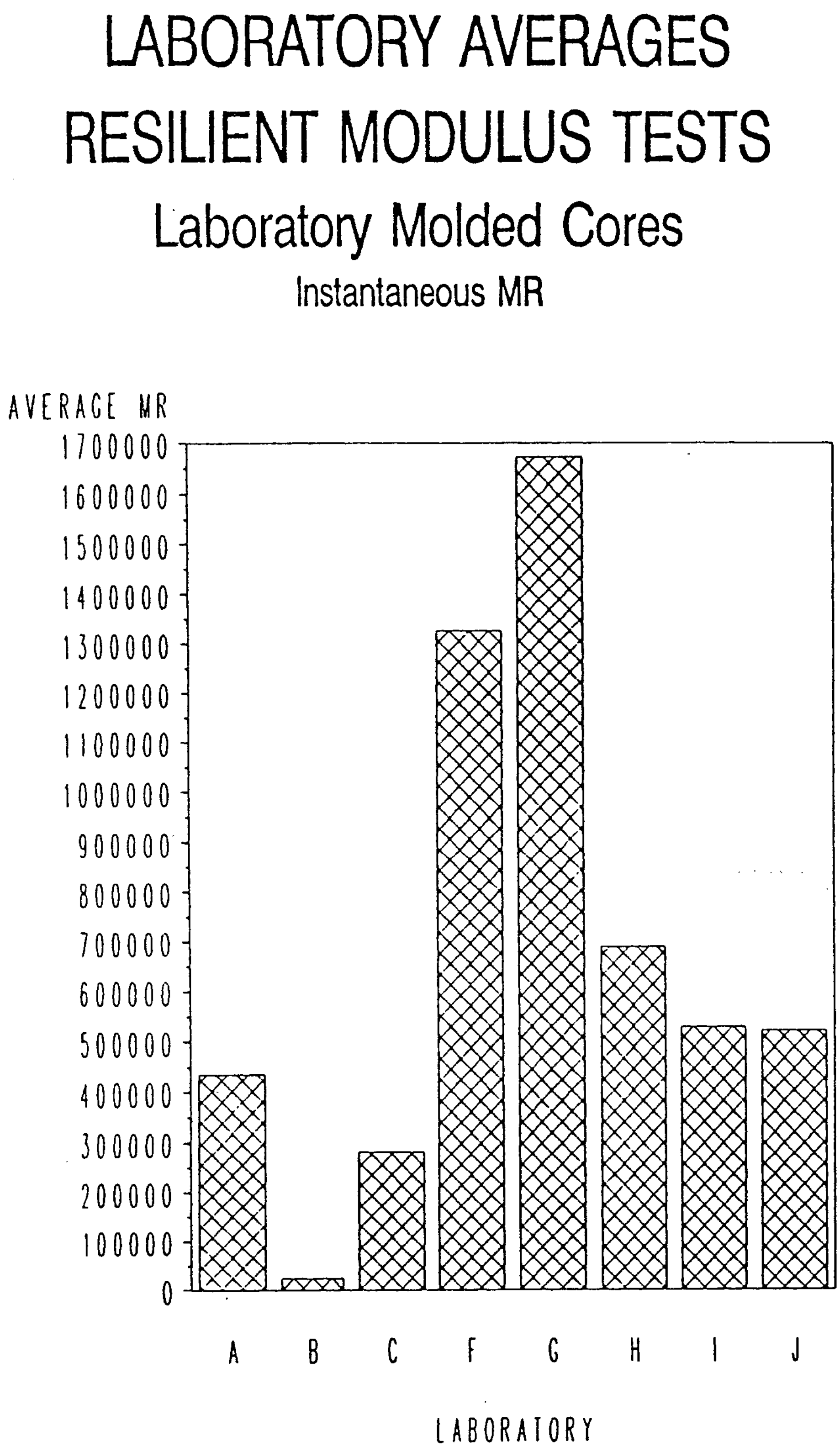

Figure 2. Instantaneous M_R for 1.5-in. specimens at 40°F, AC-10 asphalt.

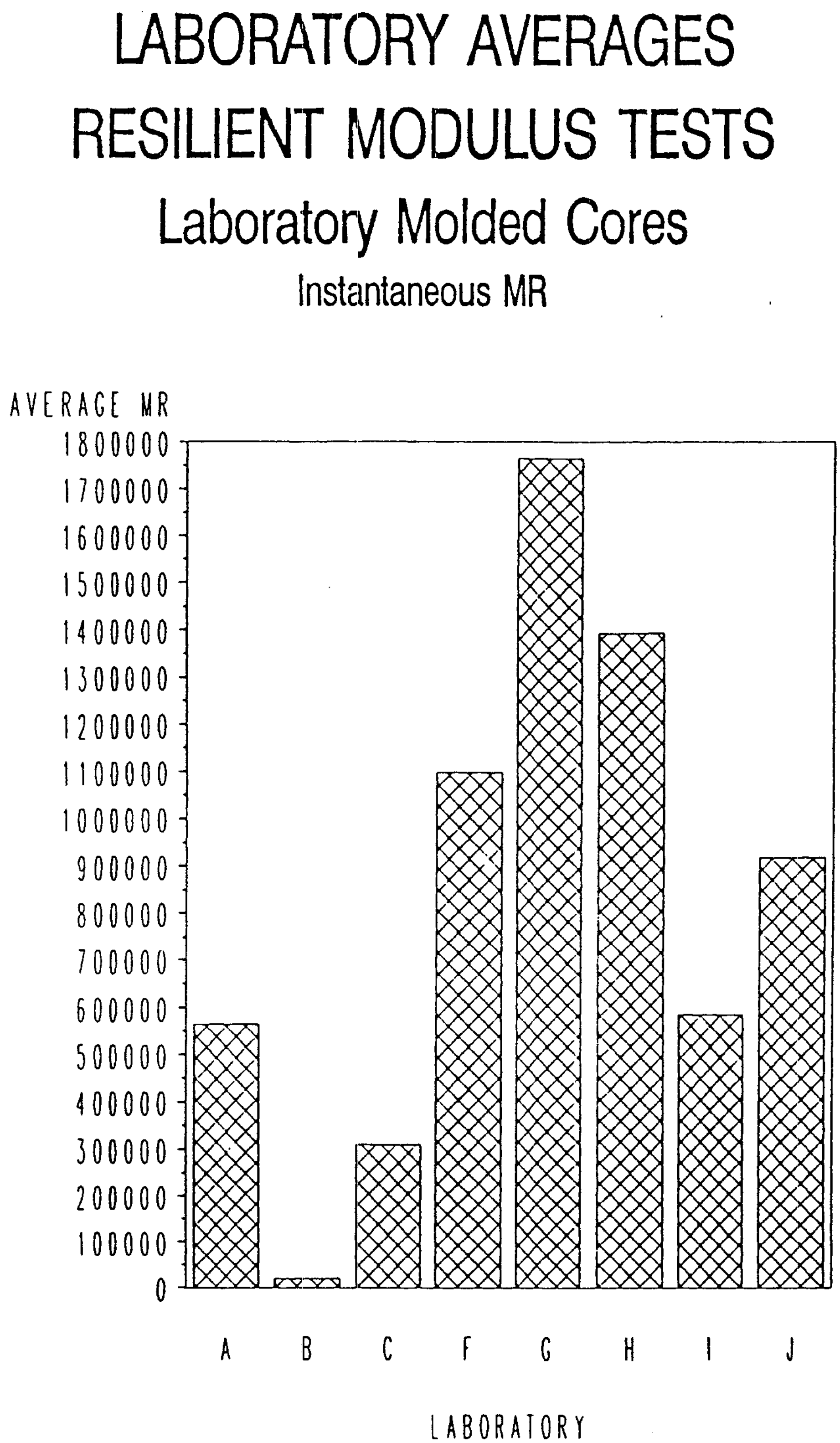

Figure 3. Instantaneous M_R for 3.0-in. specimens at 40°F, AC-10 asphalt.

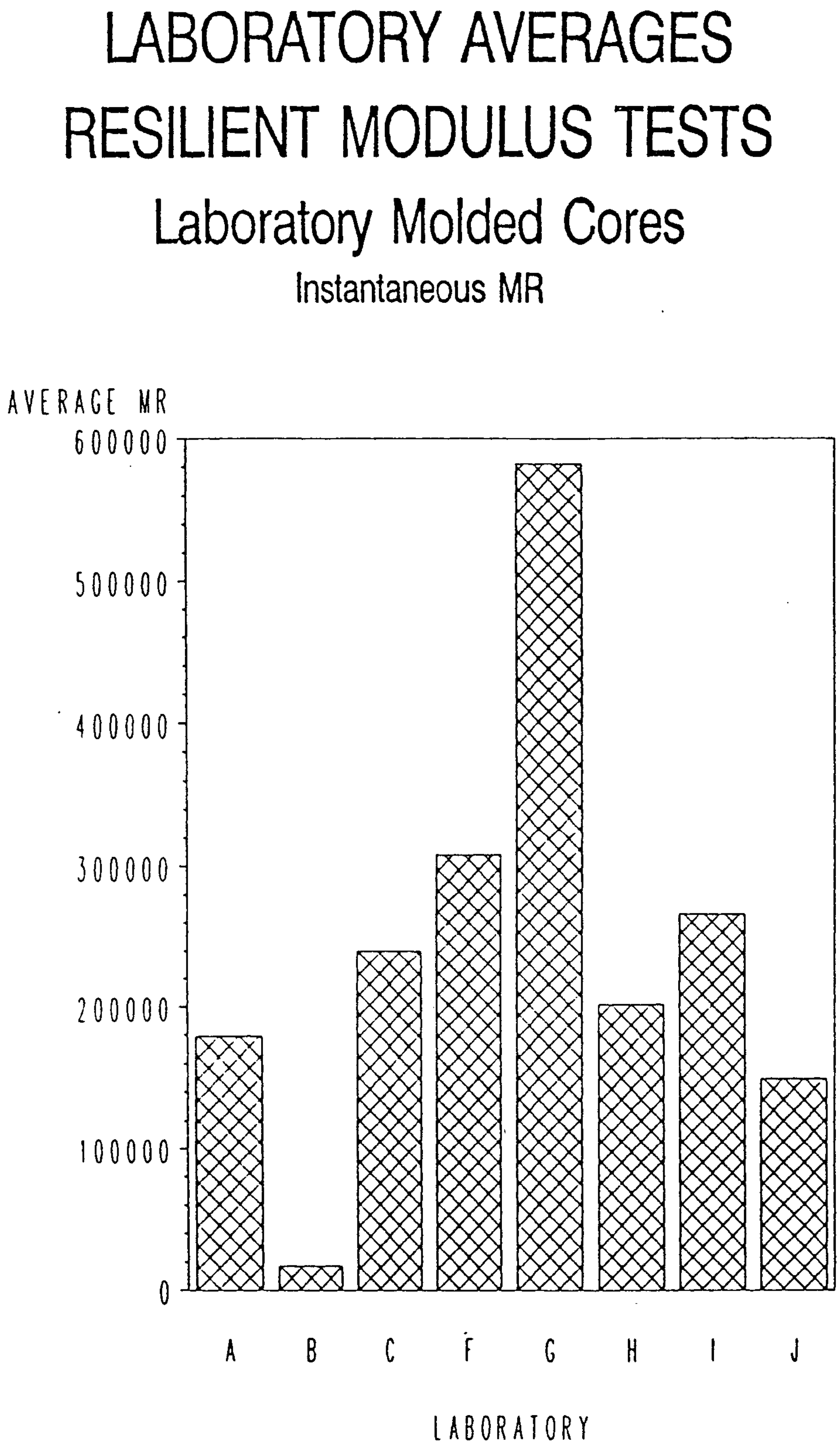

Figure 4. Instantaneous M_R for 1.5-in. specimens at 77°F, AC-10 asphalt.

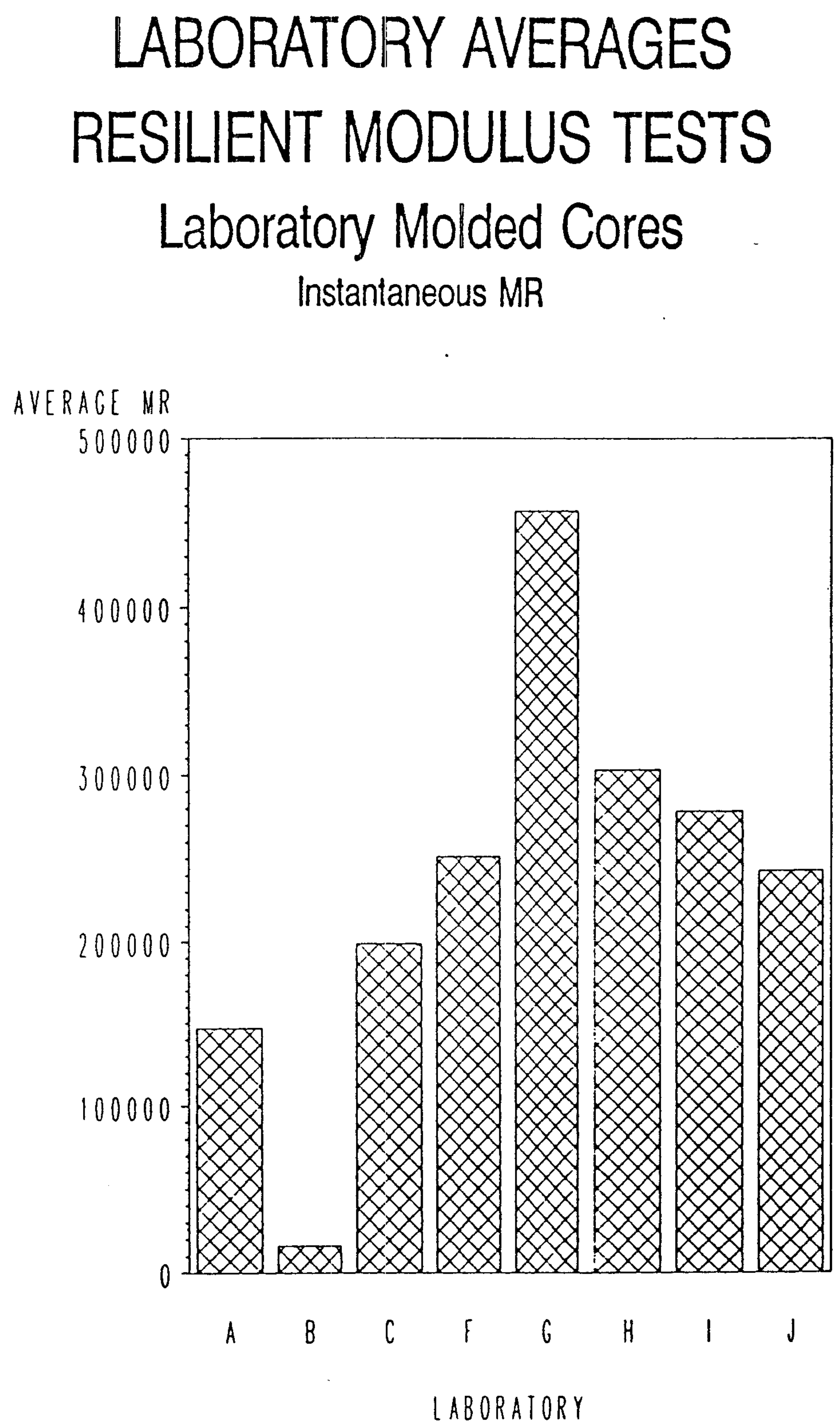

Figure 5. Instantaneous M_R for 3.0-in. specimens at 77°F, AC-10 asphalt.

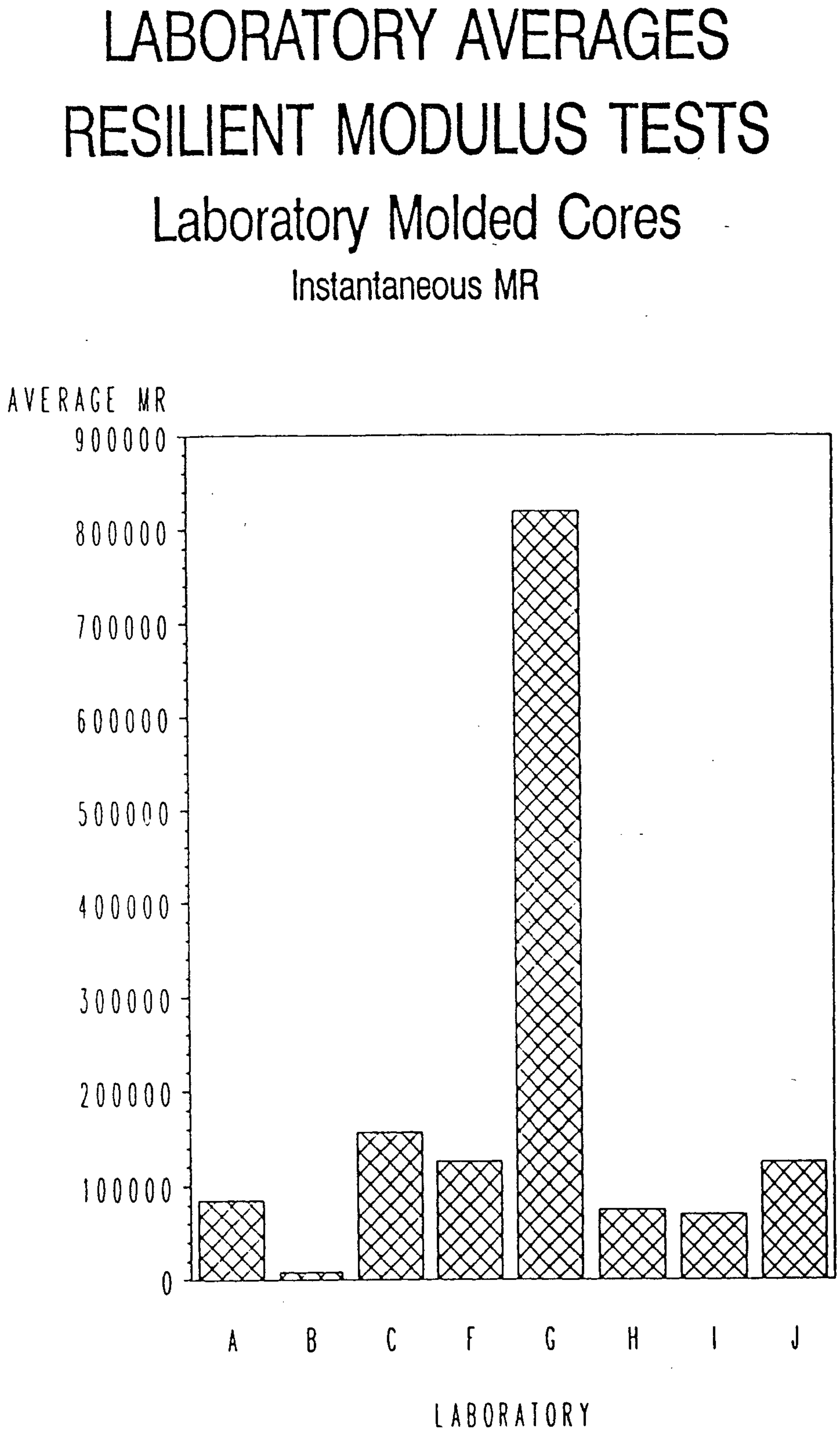

Figure 6. Instantaneous M_R for 1.5-in. specimens at 104°F, AC-10 asphalt.

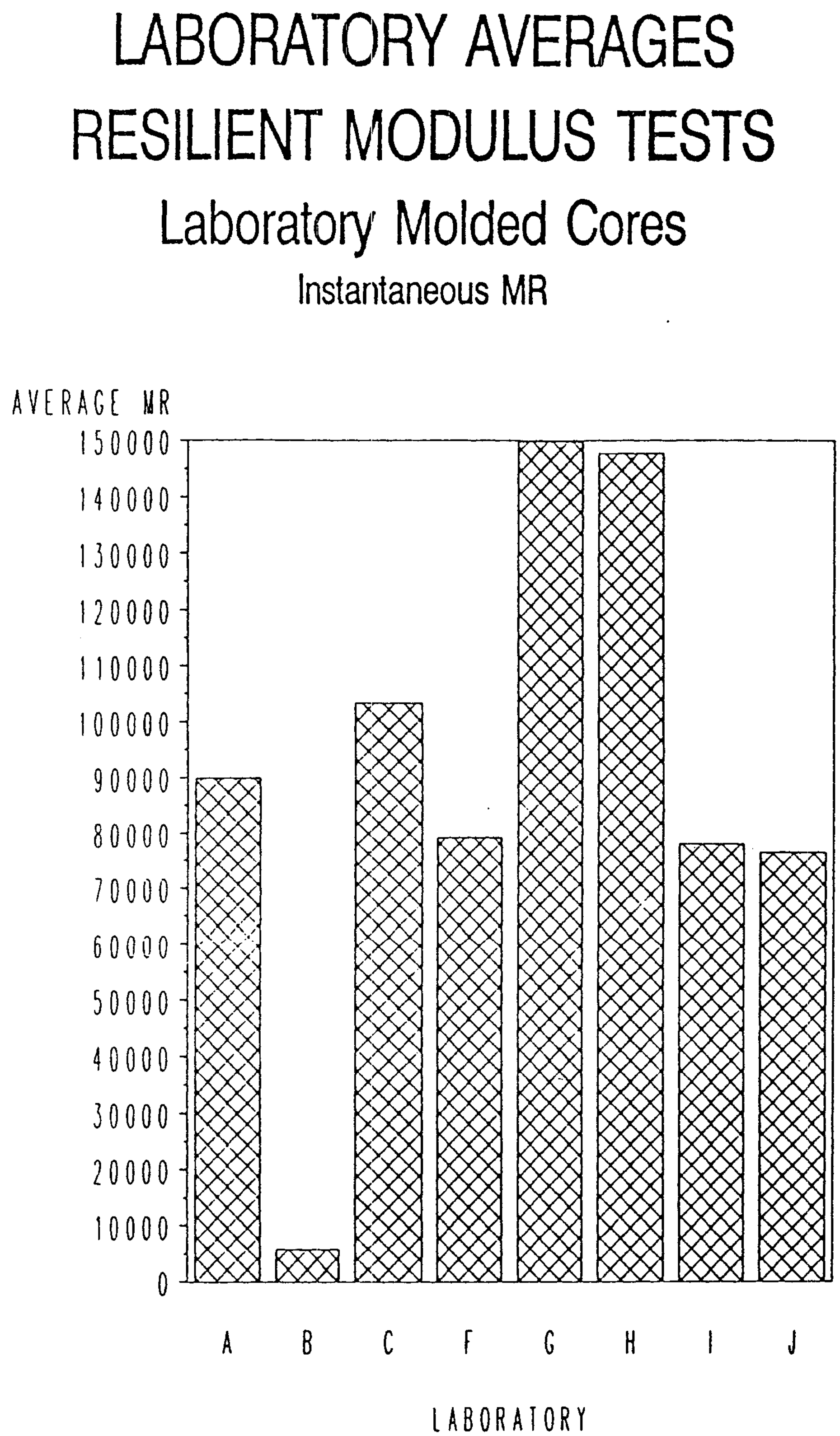

Figure 7. Instantaneous M_R for 3.0-in. specimens at 104°F, AC-10 asphalt.

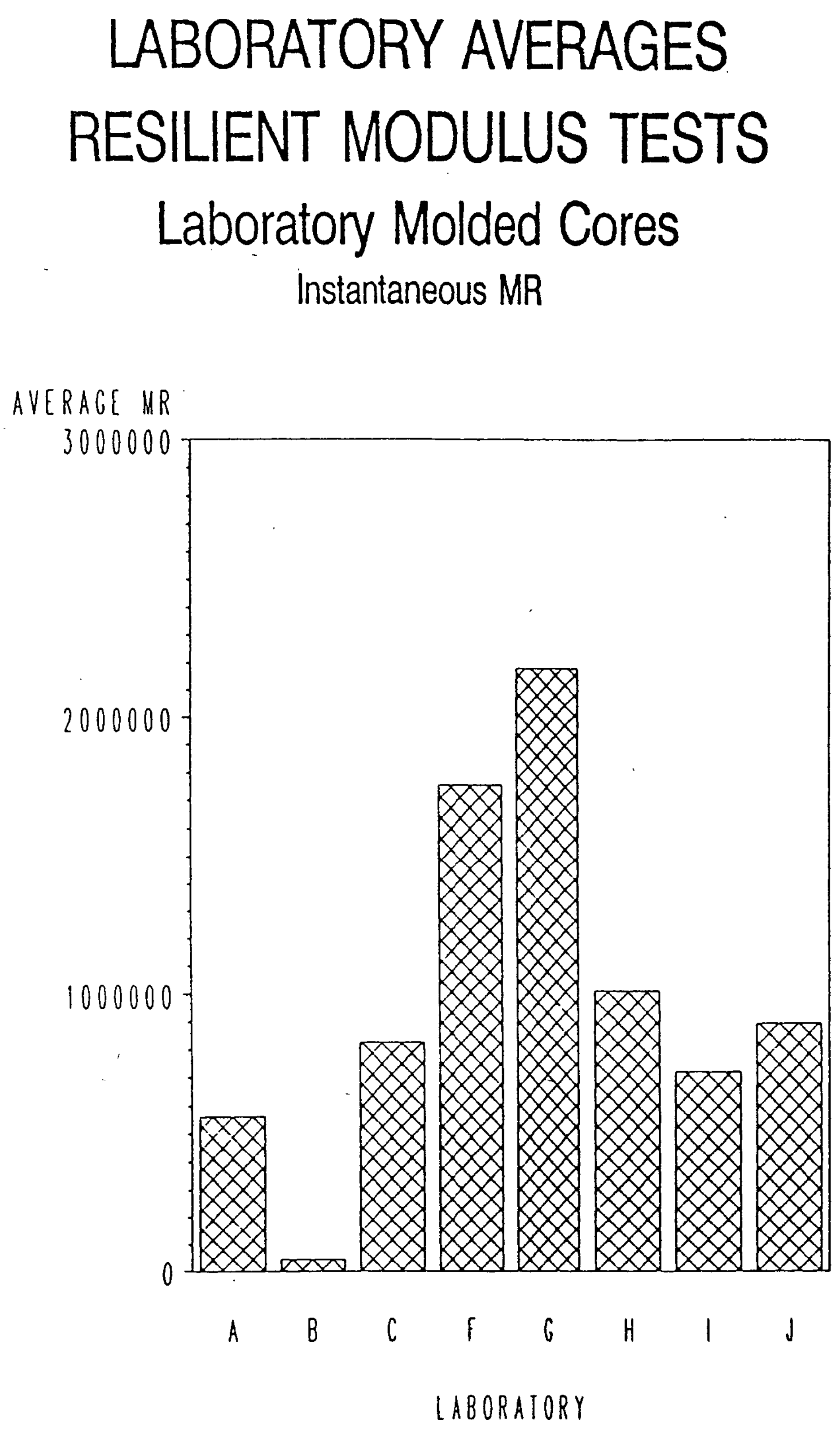

Figure 8. Instantaneous M_R for 1.5-in. specimens at 40°F, AC-30 asphalt.

LABORATORY AVERAGES
RESILIENT MODULUS TESTS
Laboratory Molded Cores
Instantaneous MR

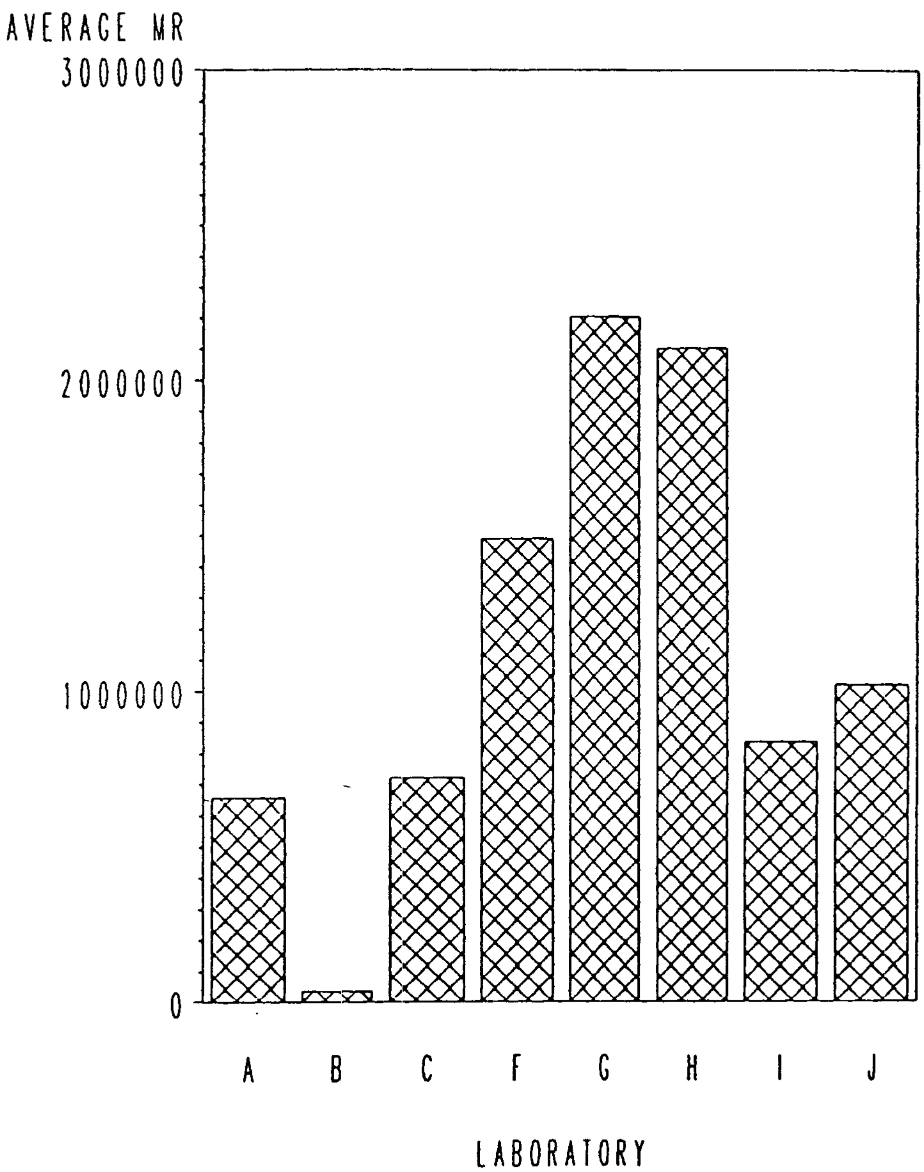

Figure 9. Instantaneous M_R for 3.0-in. specimens at 40°F, AC-30 asphalt.

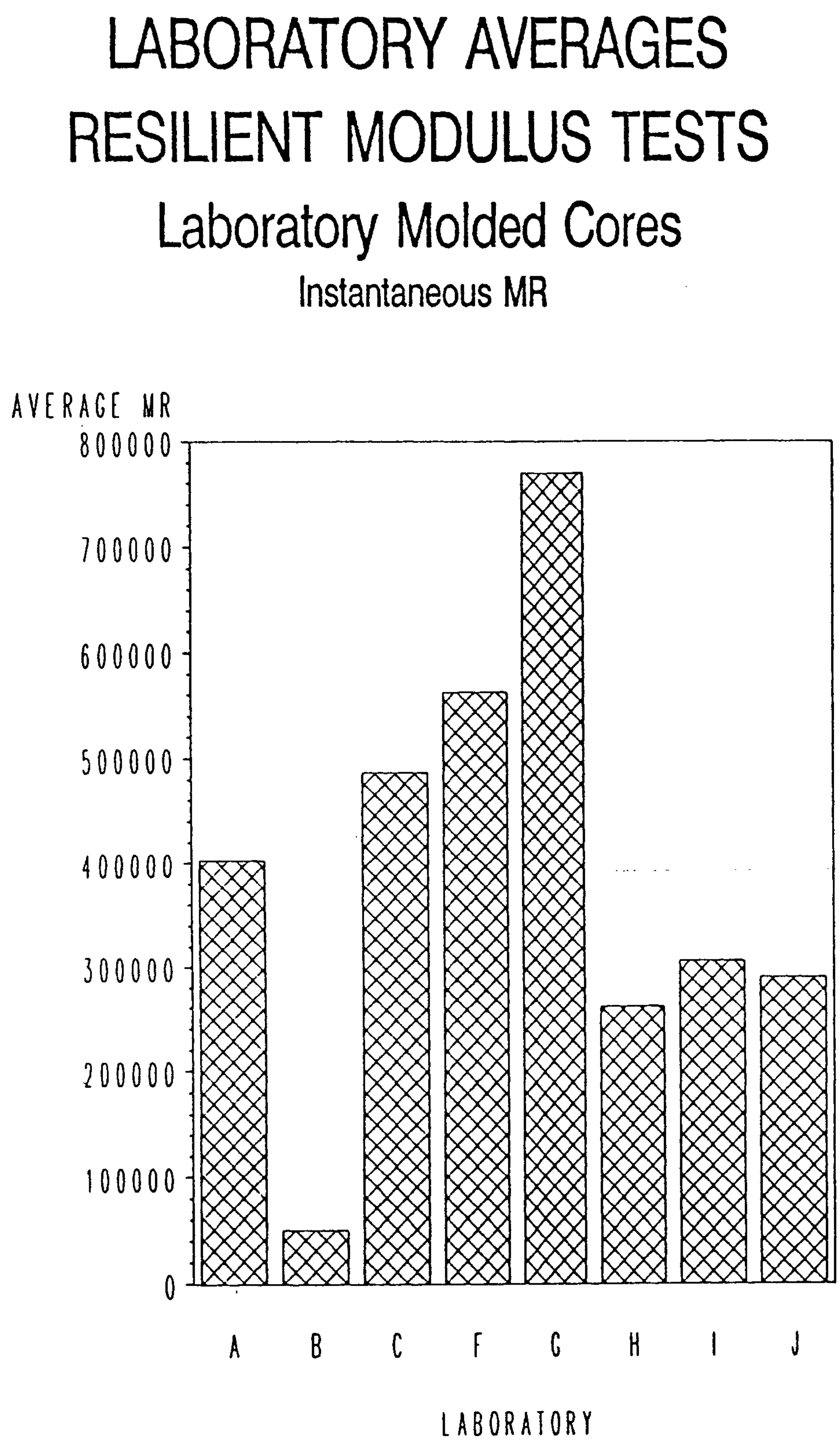

Figure 10. Instantaneous M_R for 1.5-in. specimens at 77°F, AC-30 asphalt.

LABORATORY AVERAGES
RESILIENT MODULUS TESTS
Laboratory Molded Cores
Instantaneous MR

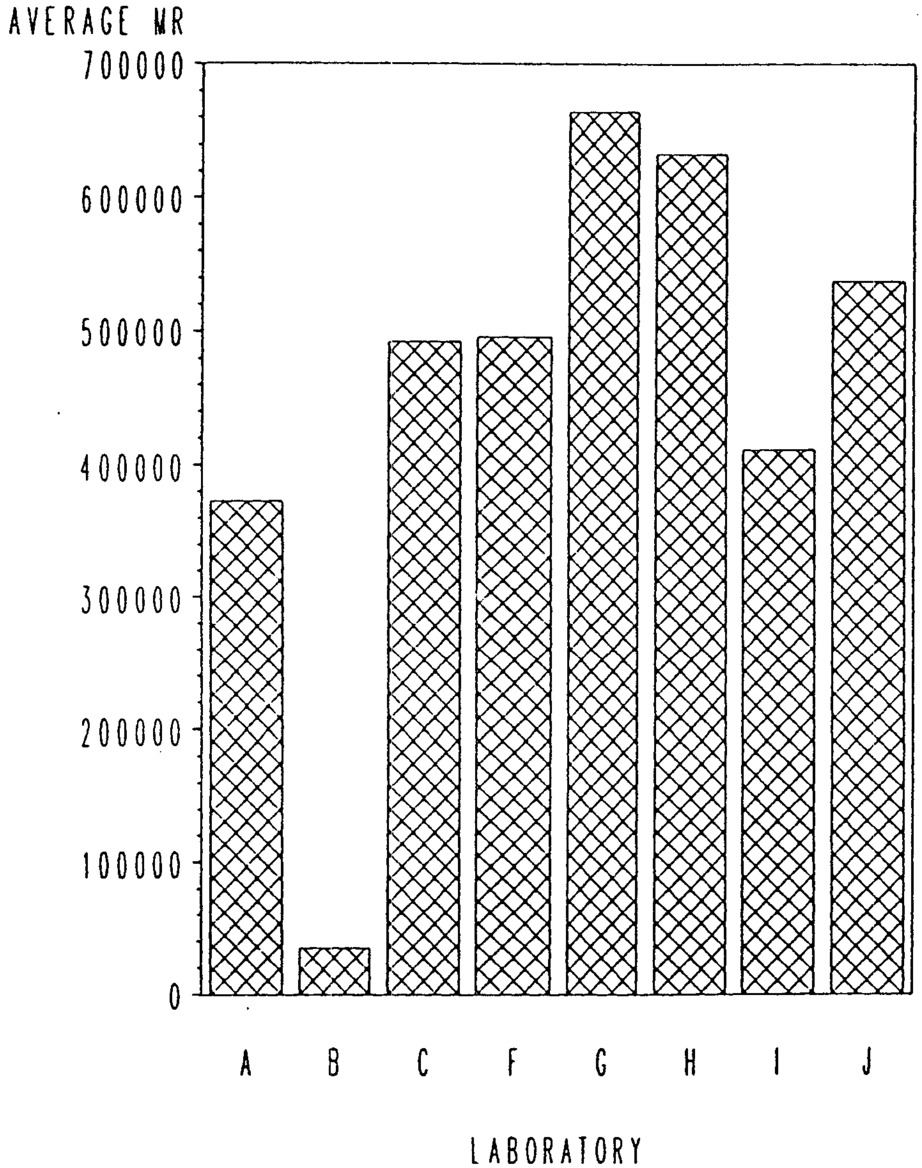

Figure 11. Instantaneous M_R for 3.0-in. specimens at 77°F, AC-30 asphalt.

LABORATORY AVERAGES
RESILIENT MODULUS TESTS
Laboratory Molded Cores
Instantaneous MR

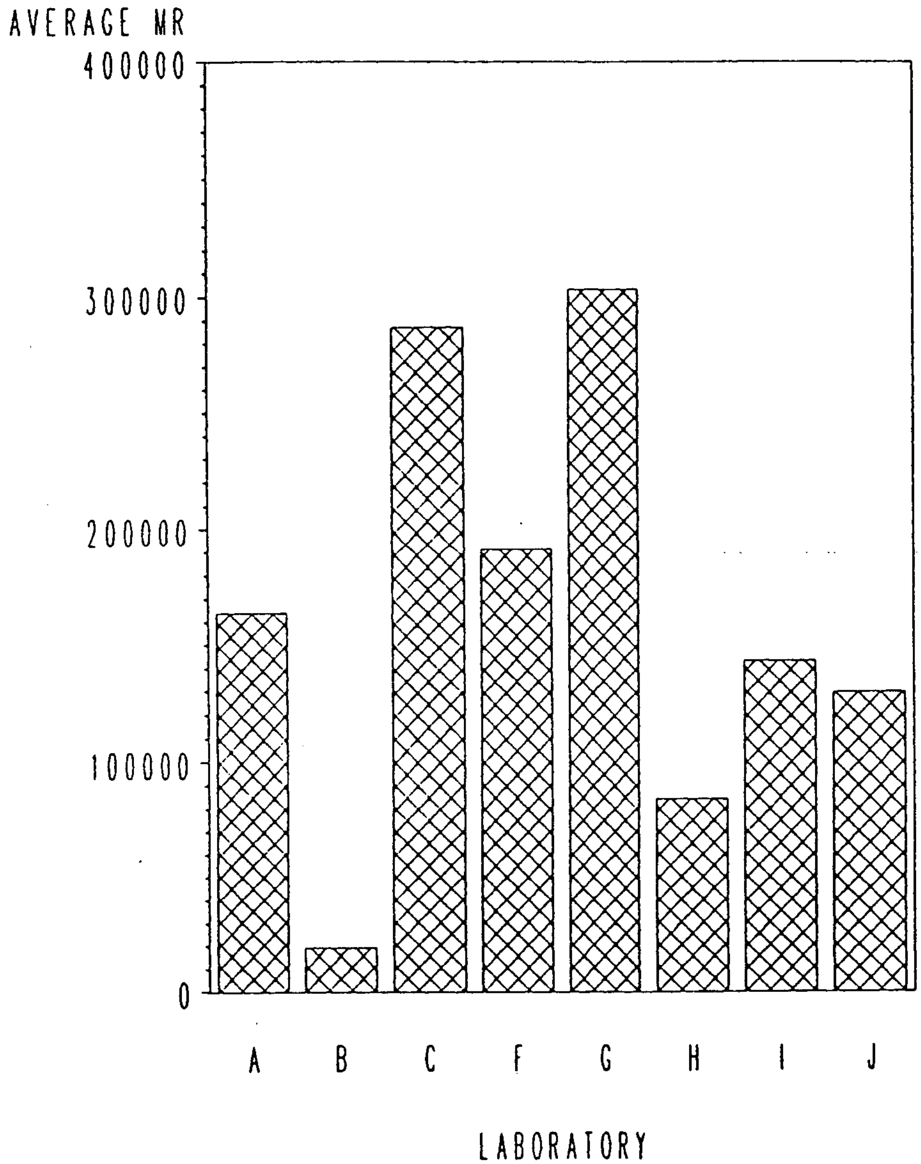

Figure 12. Instantaneous M_R for 1.5-in. specimens at 104°F, AC-30 asphalt.

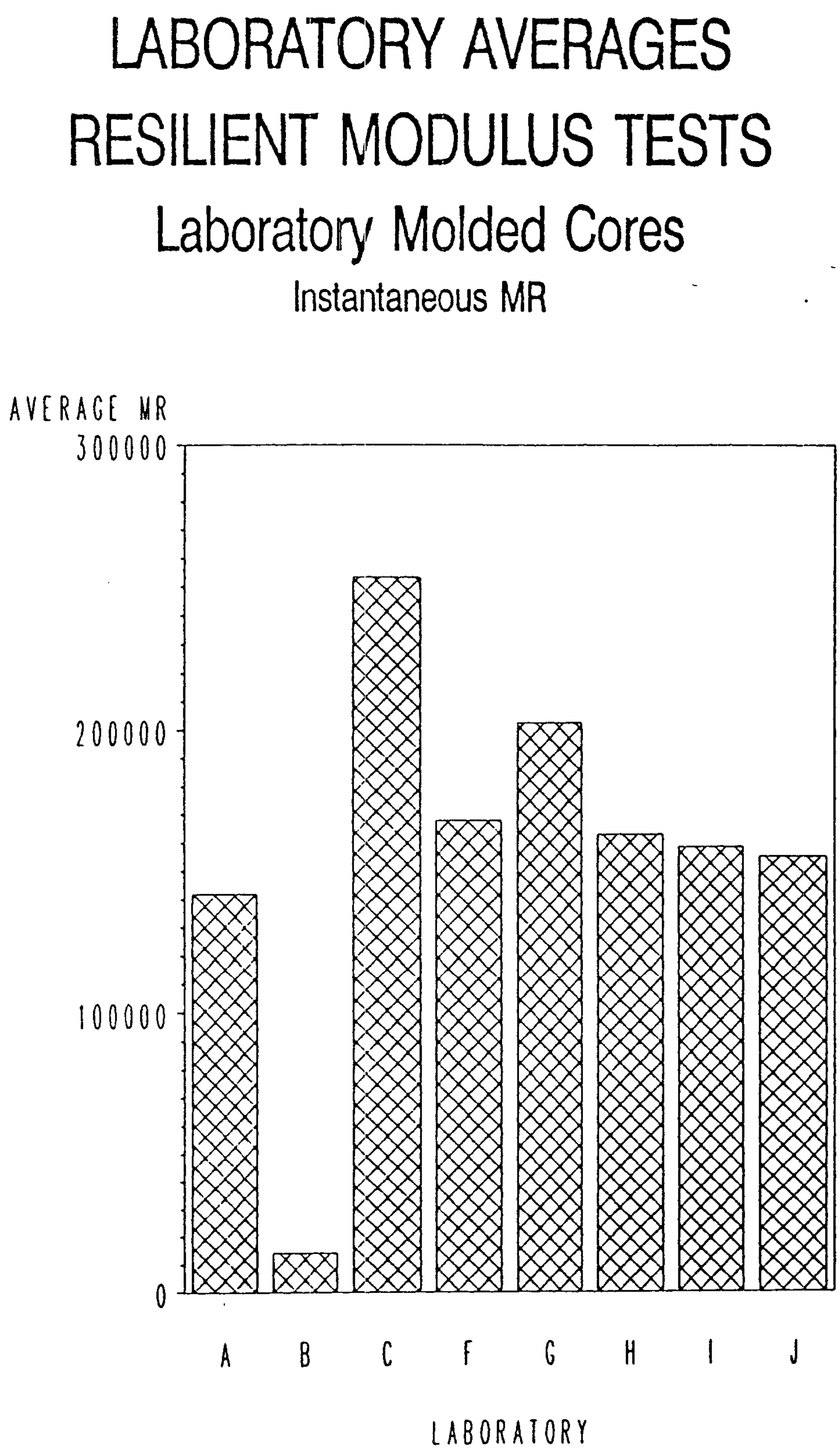

Figure 13. Instantaneous M_R for 3.0-in. specimens at 104°F, AC-30 asphalt.

LABORATORY AVERAGES
RESILIENT MODULUS TESTS
Laboratory Molded Cores
Total MR

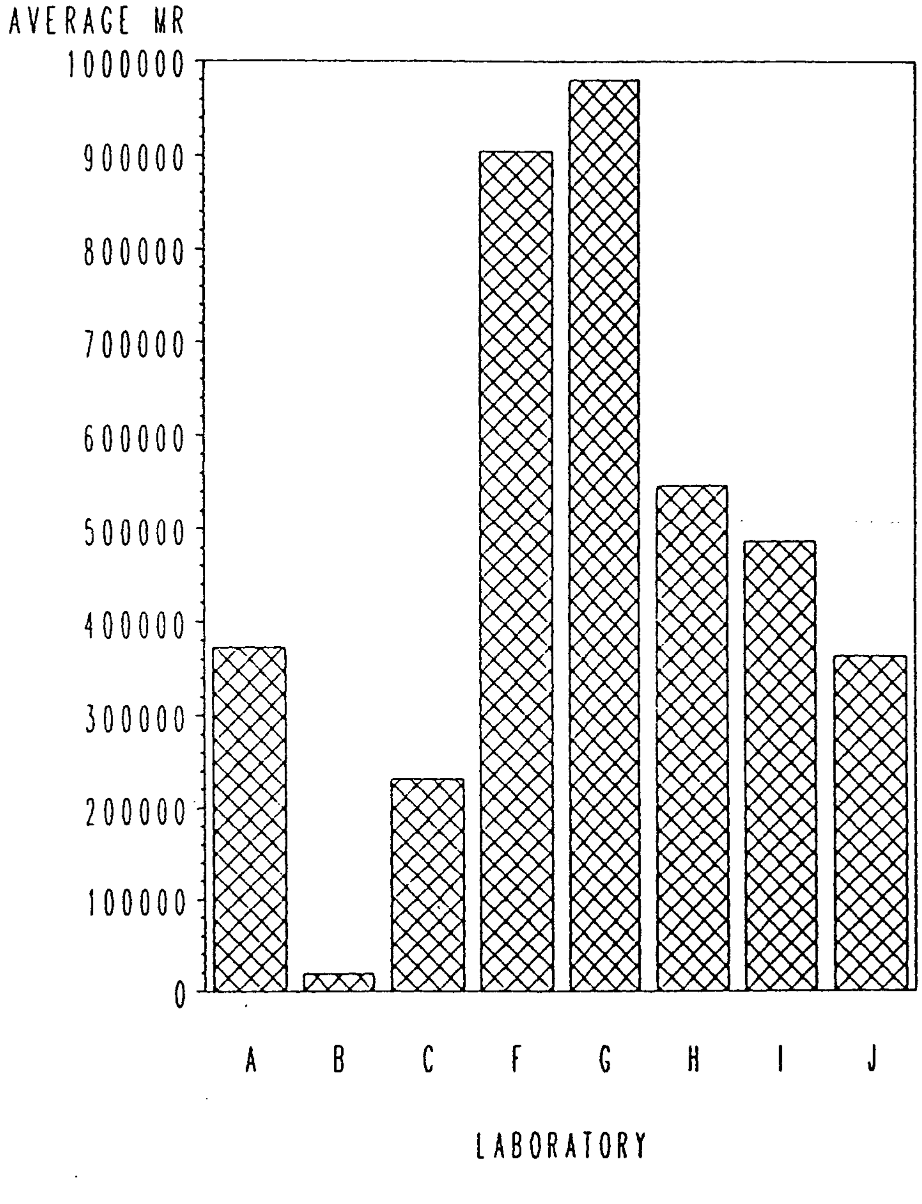

Figure 14. Total M_R for 1.5-in specimens at 40°F, AC-10 asphalt.

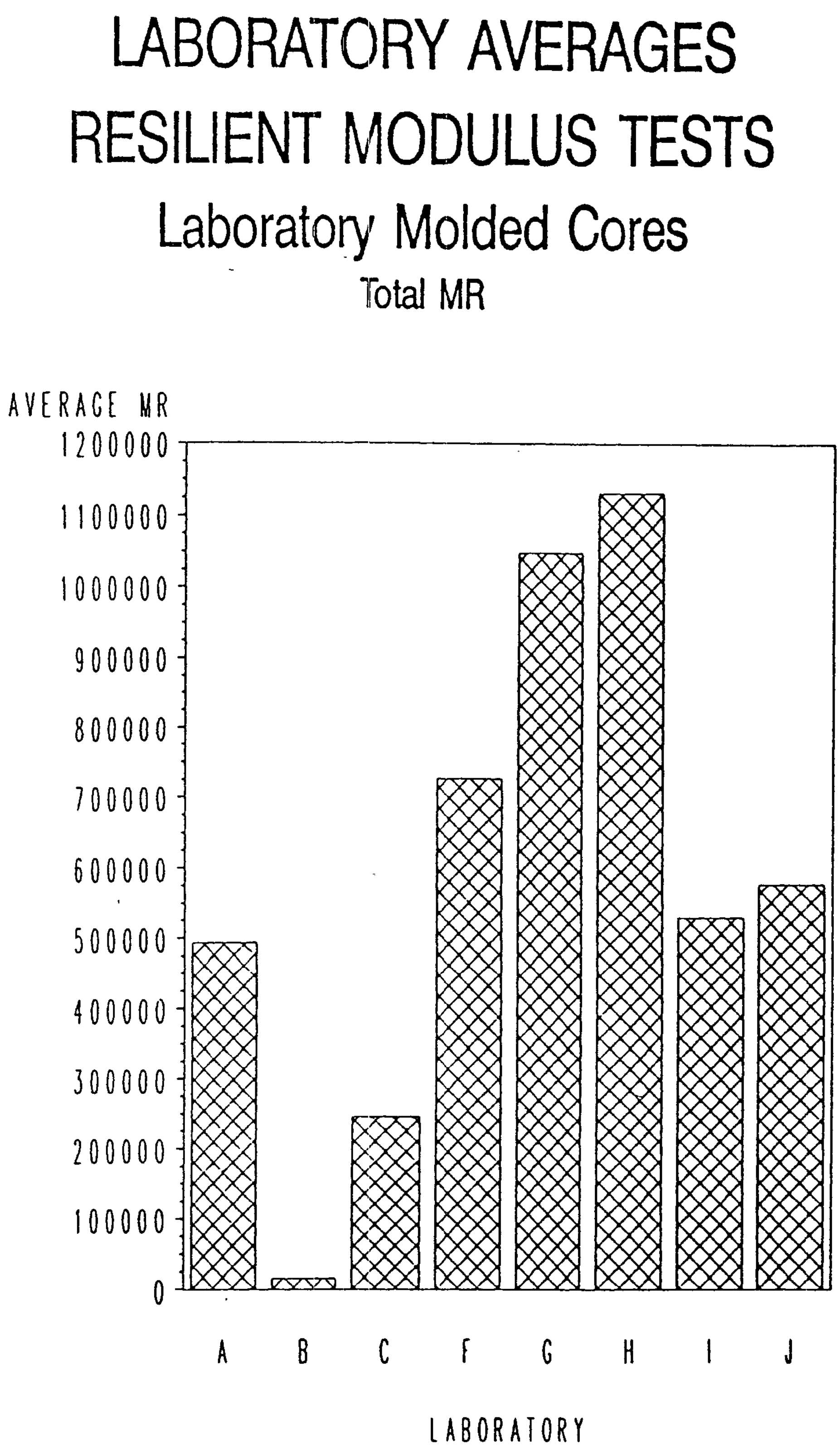

Figure 15. Total M_R for 3.0-in. specimens at 40°F, AC-10 asphalt.

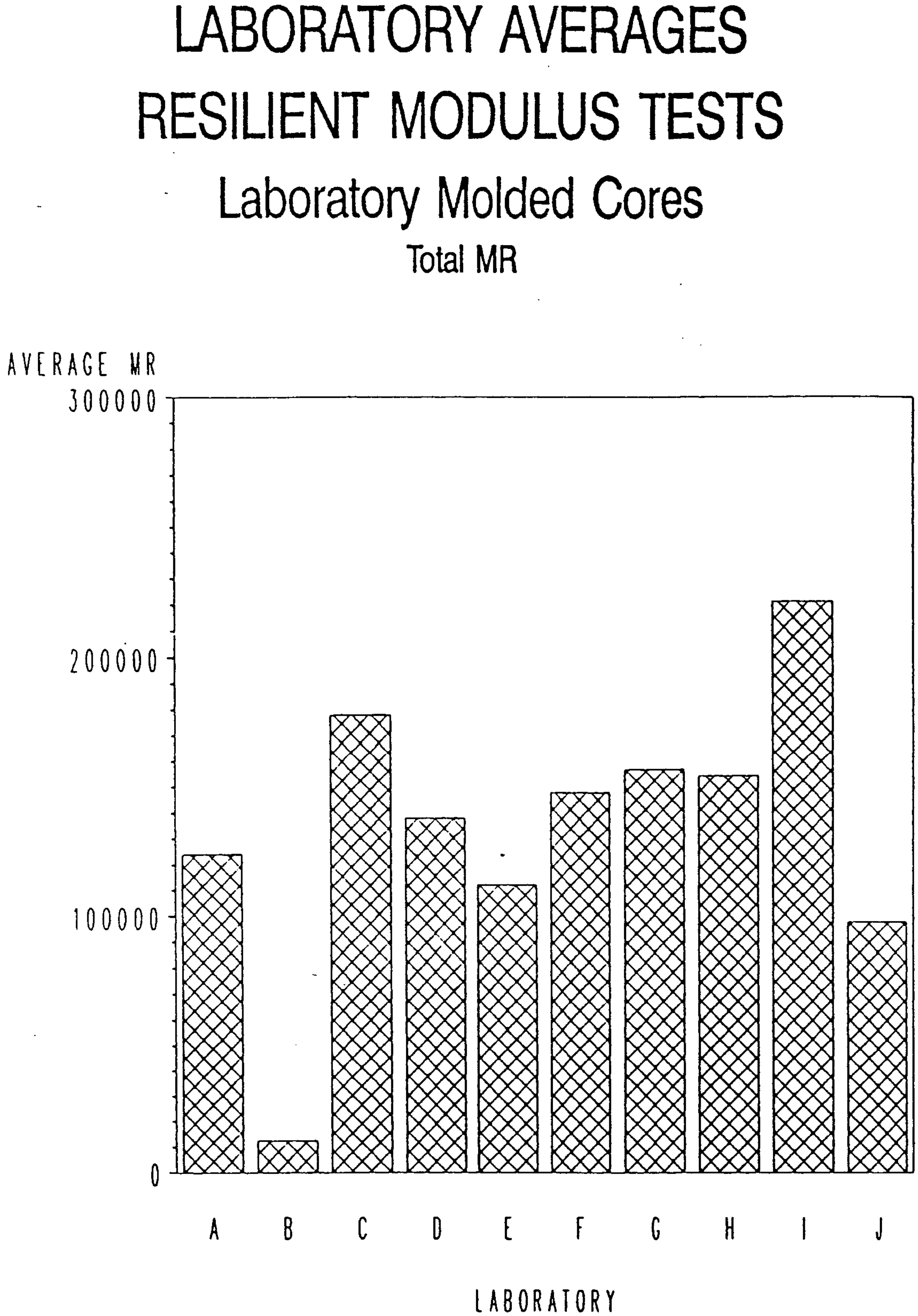

Figure 16. Total M_R for 1.5-in. specimens at 77°F, AC-10 asphalt.

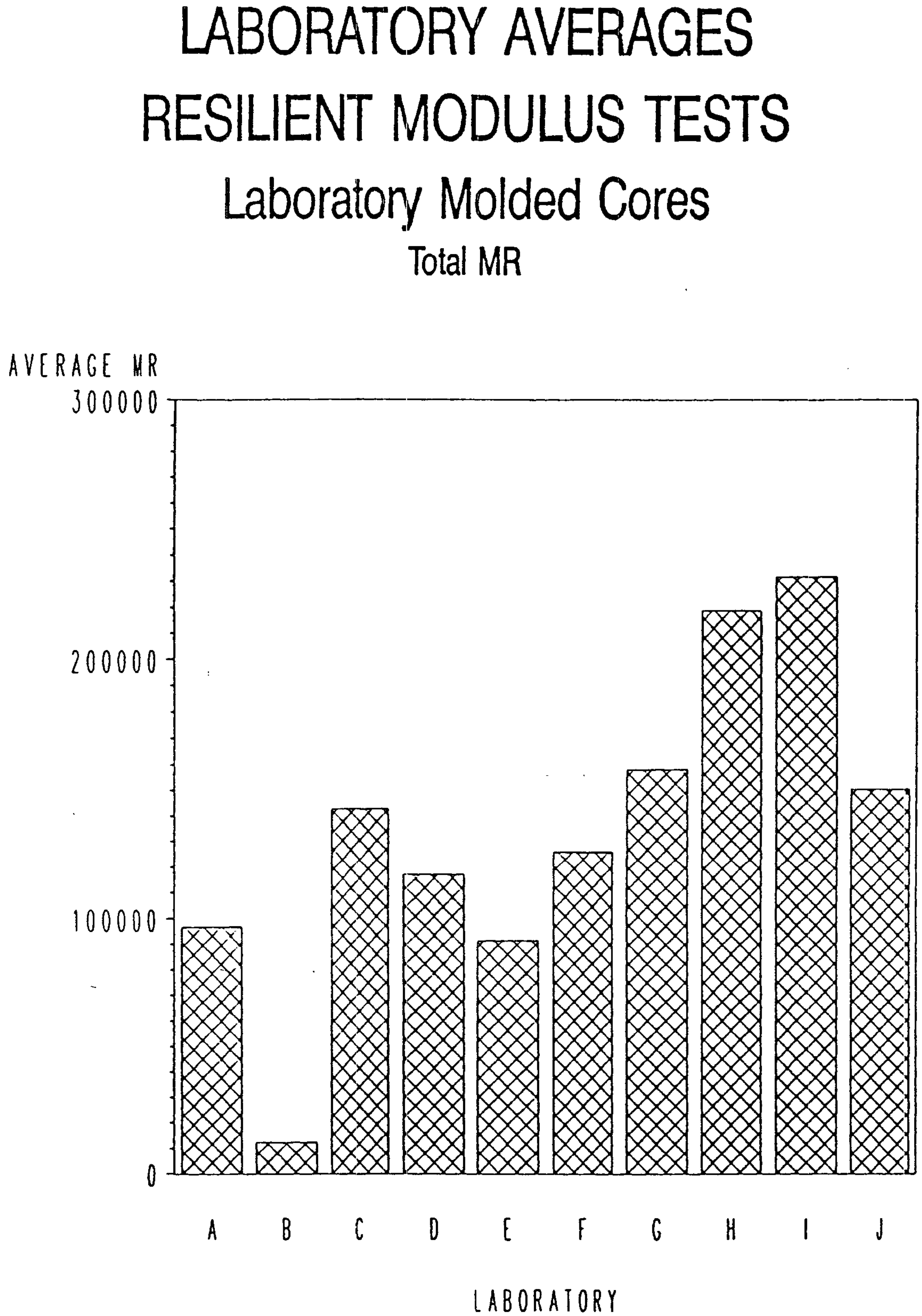

Figure 17. Total M_R for 3.0-in. specimens at 77°F, AC-10 asphalt.

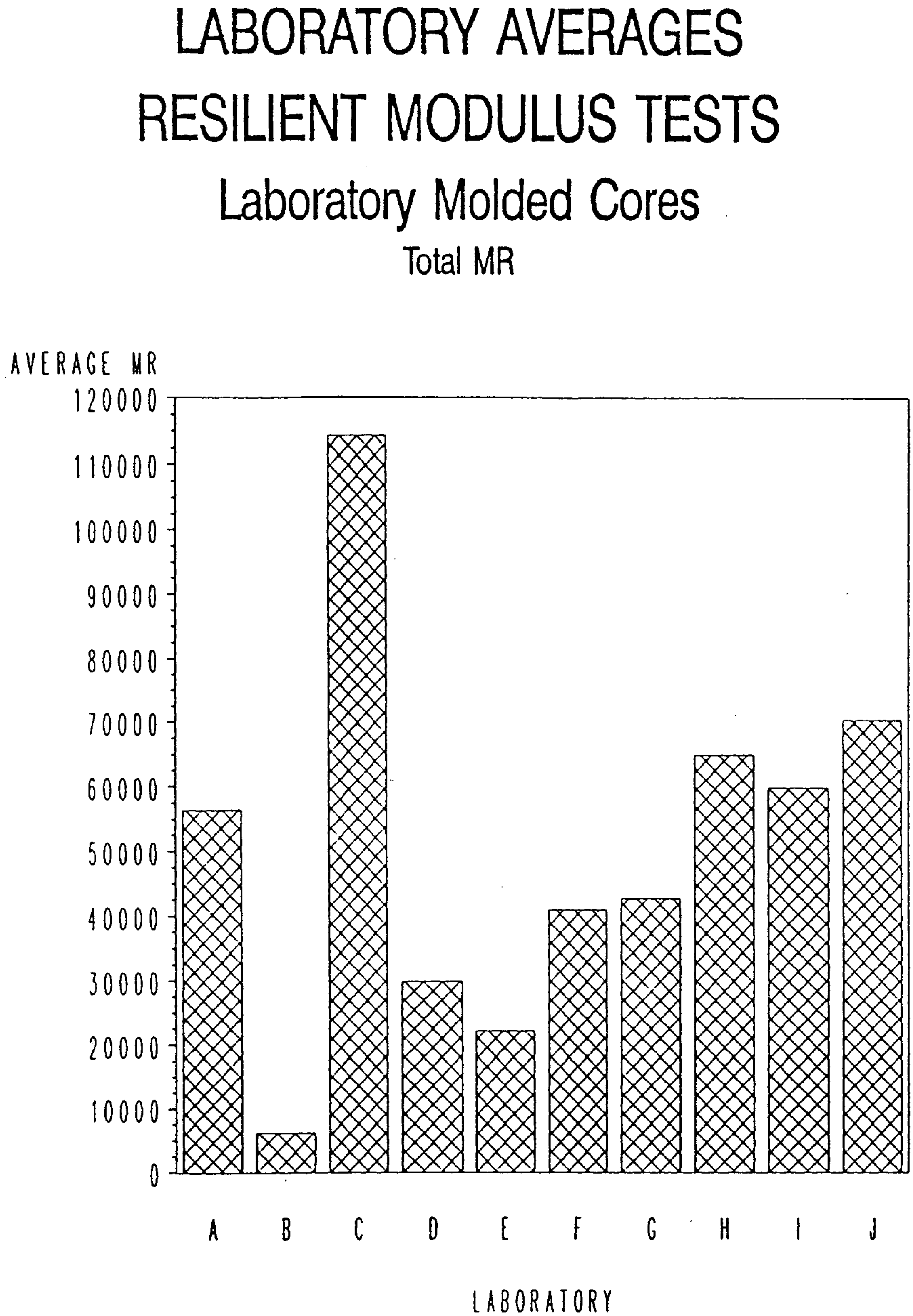

Figure 18. Total M_R for 1.5-in. specimens at 104°F, AC-10 asphalt.

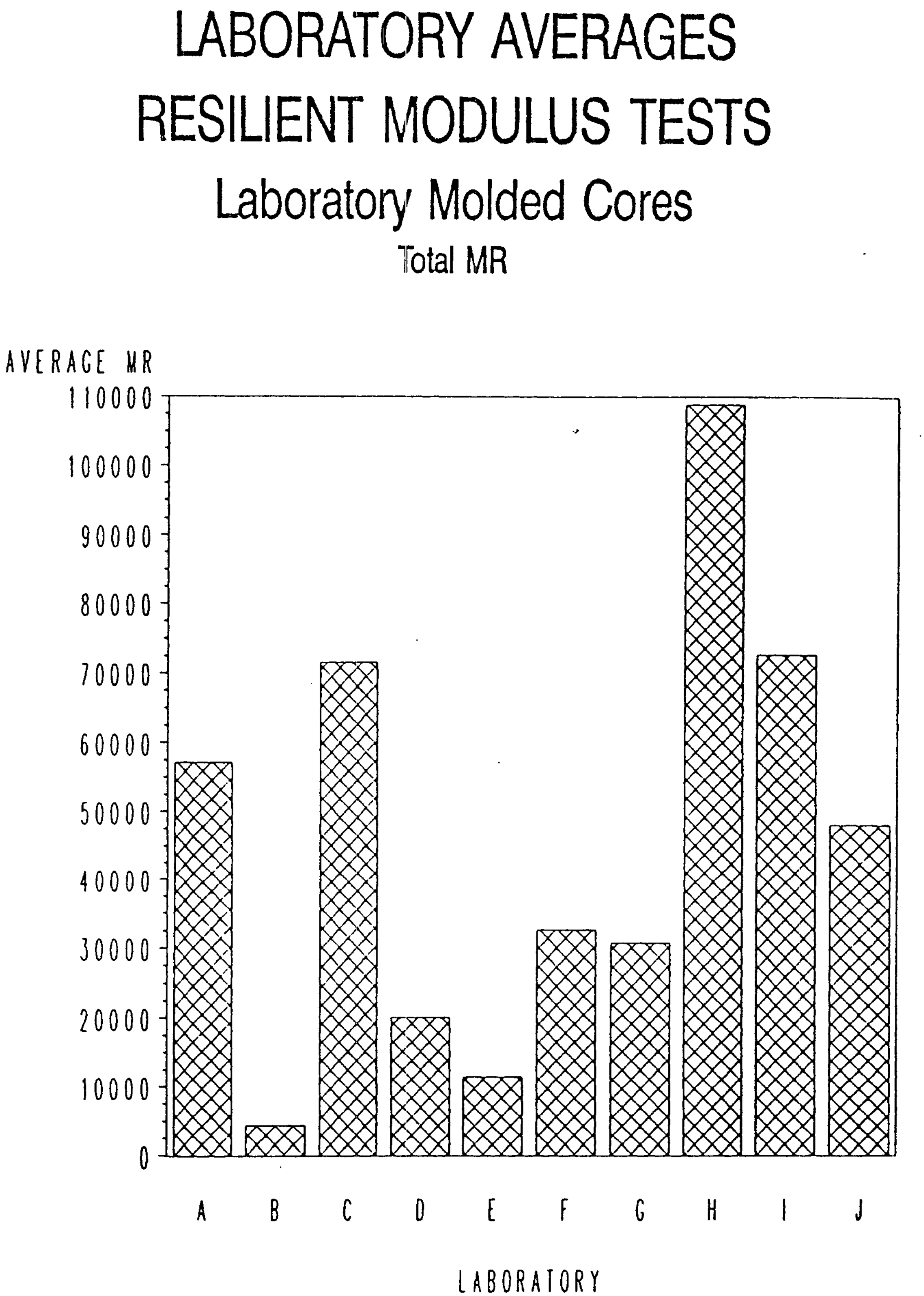

Figure 19. Total M_R for 3.0-in. specimens at 104°F, AC-10 asphalt.

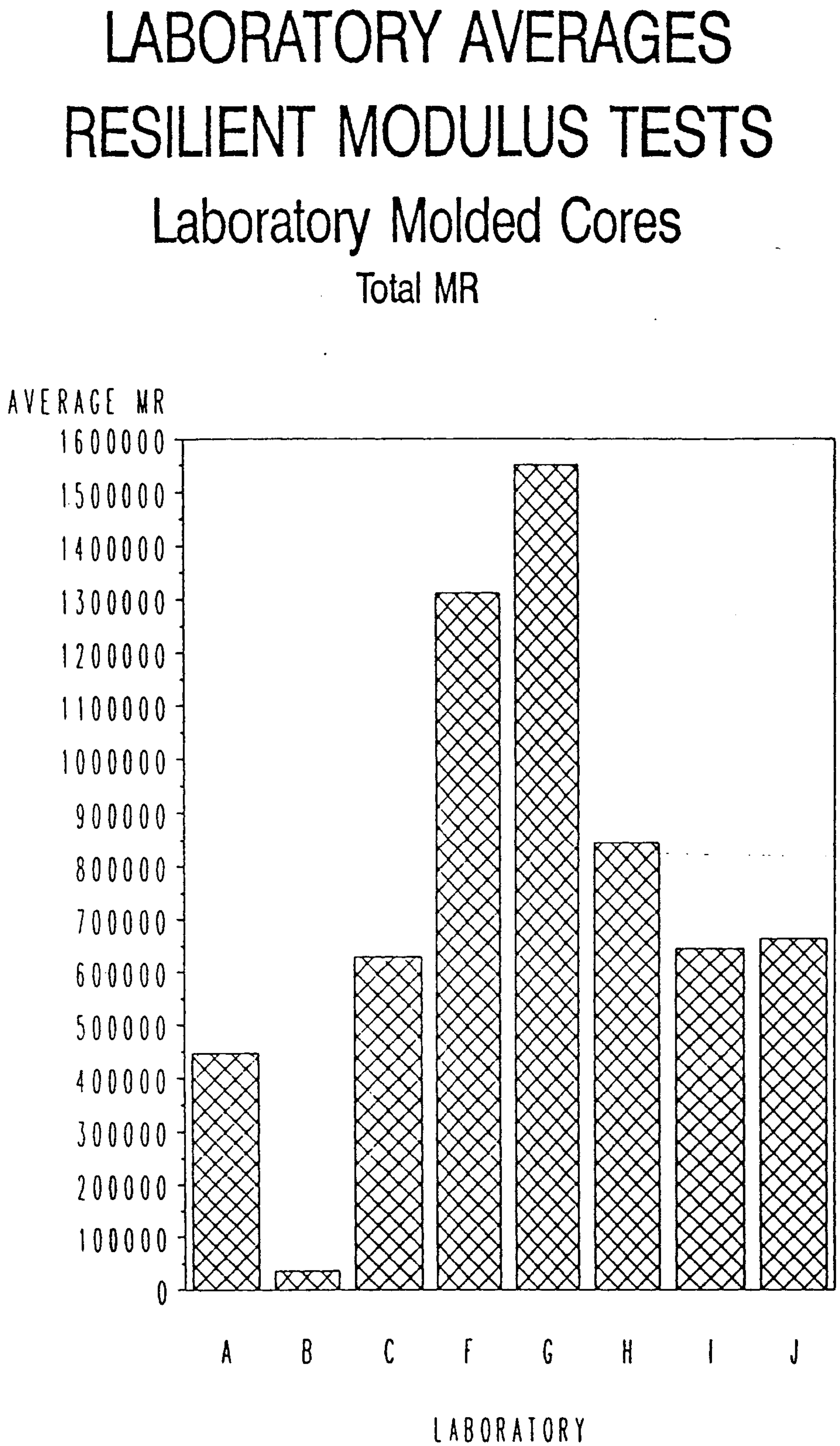

Figure 20. Total M_R for 1.5-in. specimens at 40°F, AC-30 asphalt.

LABORATORY AVERAGES
RESILIENT MODULUS TESTS
Laboratory Molded Cores
Total MR

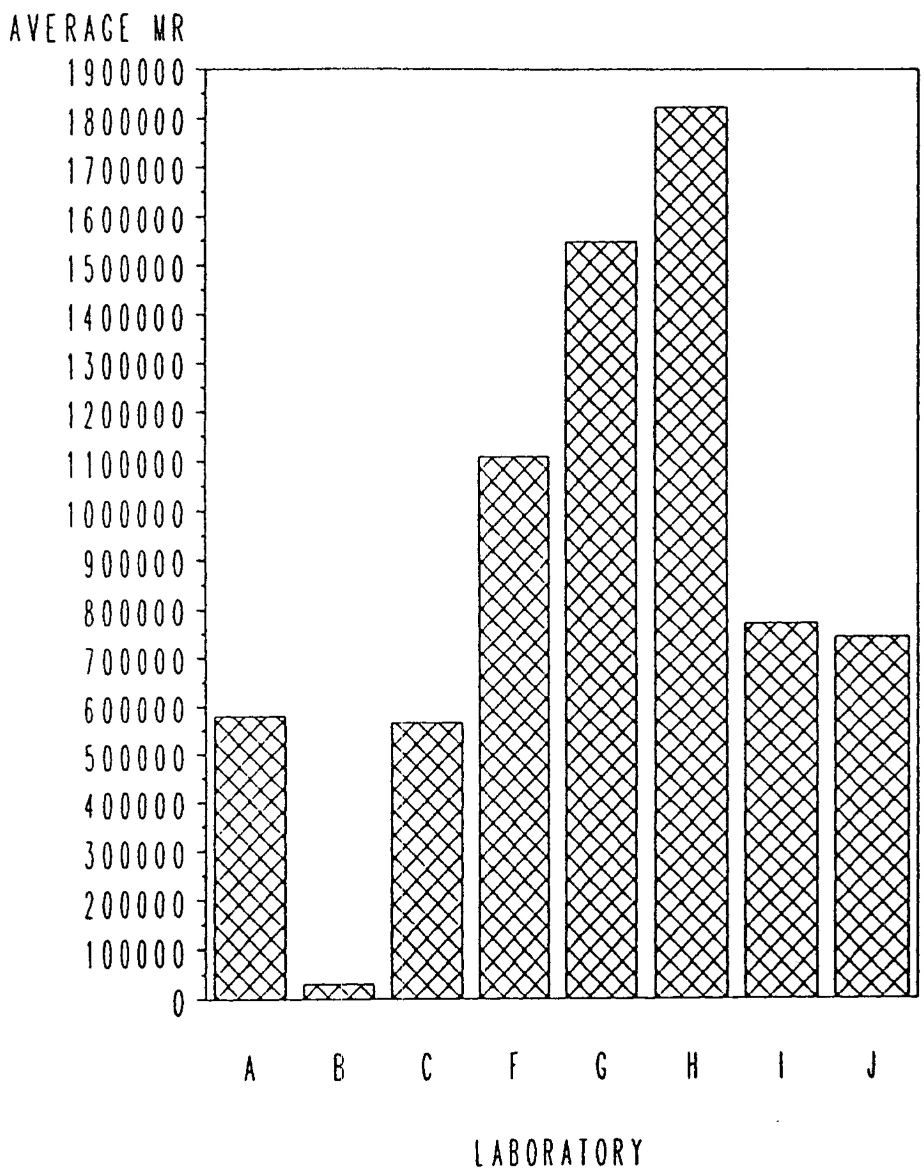

Figure 21. Total M_R for 3.0-in. specimens at 40°F, AC-30 asphalt.

LABORATORY AVERAGES
RESILIENT MODULUS TESTS
Laboratory Molded Cores
Total MR

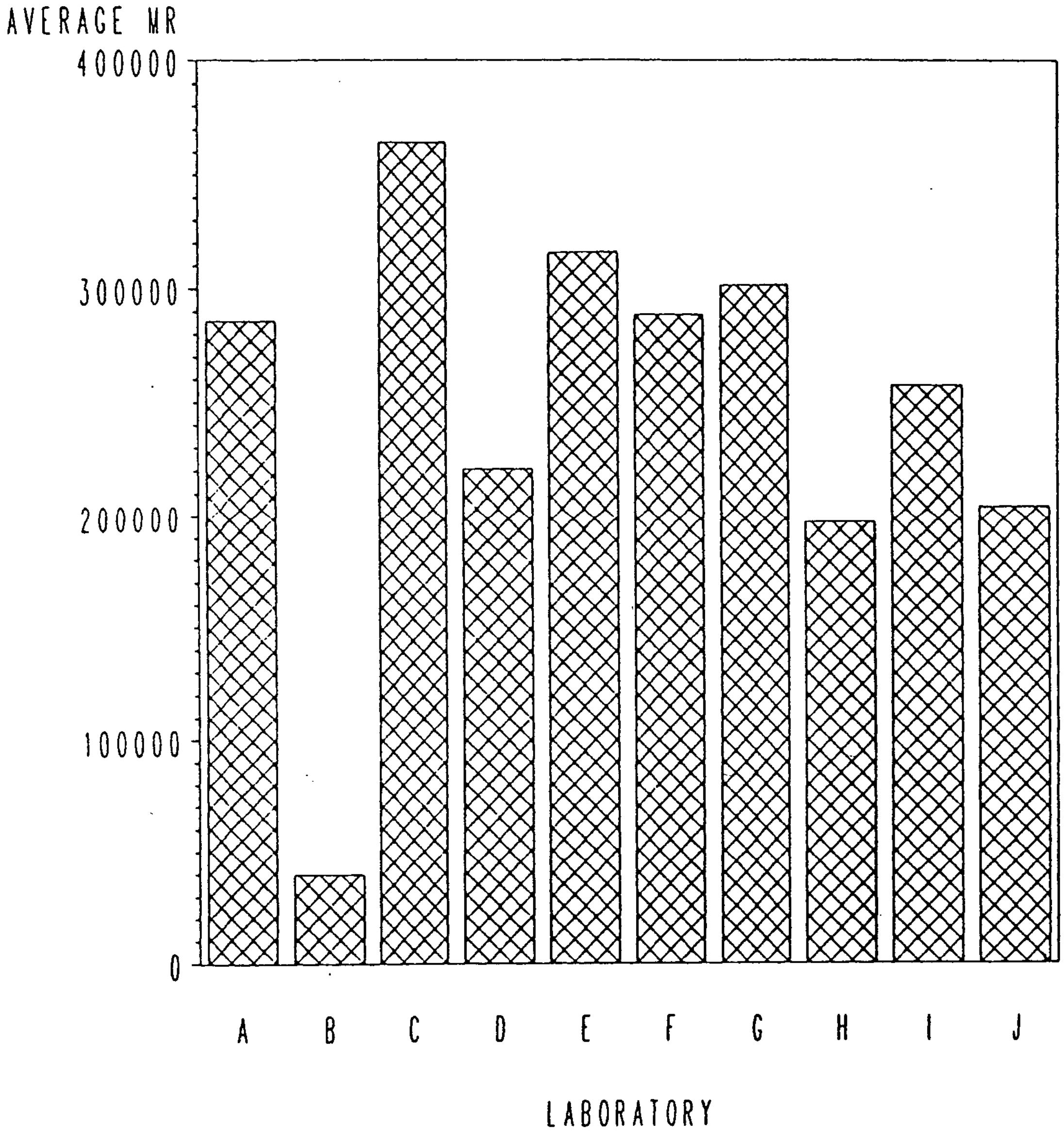

Figure 22. Total M_R for 1.5-in. specimens at 77°F, AC-30 asphalt.

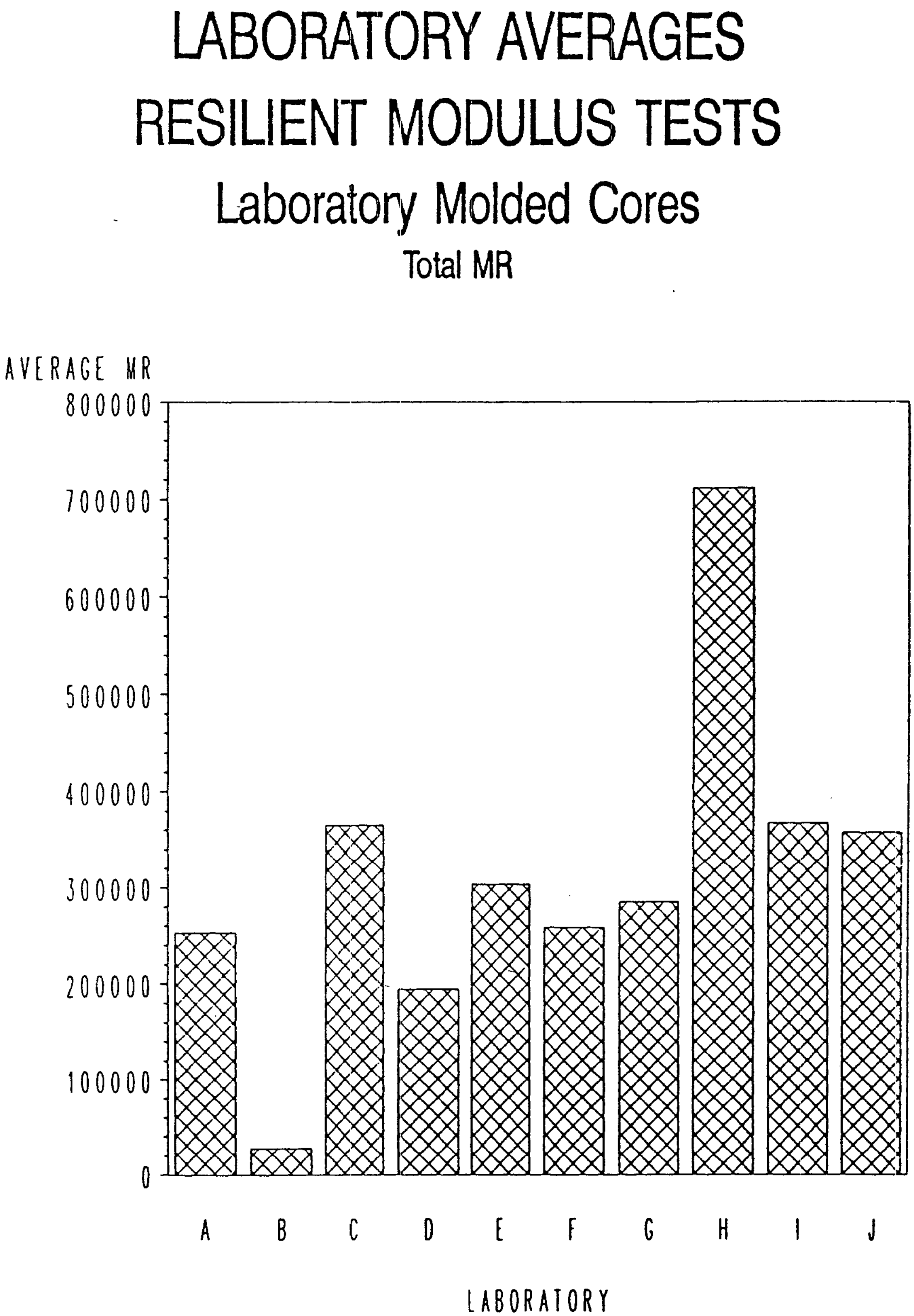

Figure 23. Total M_R for 3.0-in. specimens at 77°F, AC-30 asphalt.

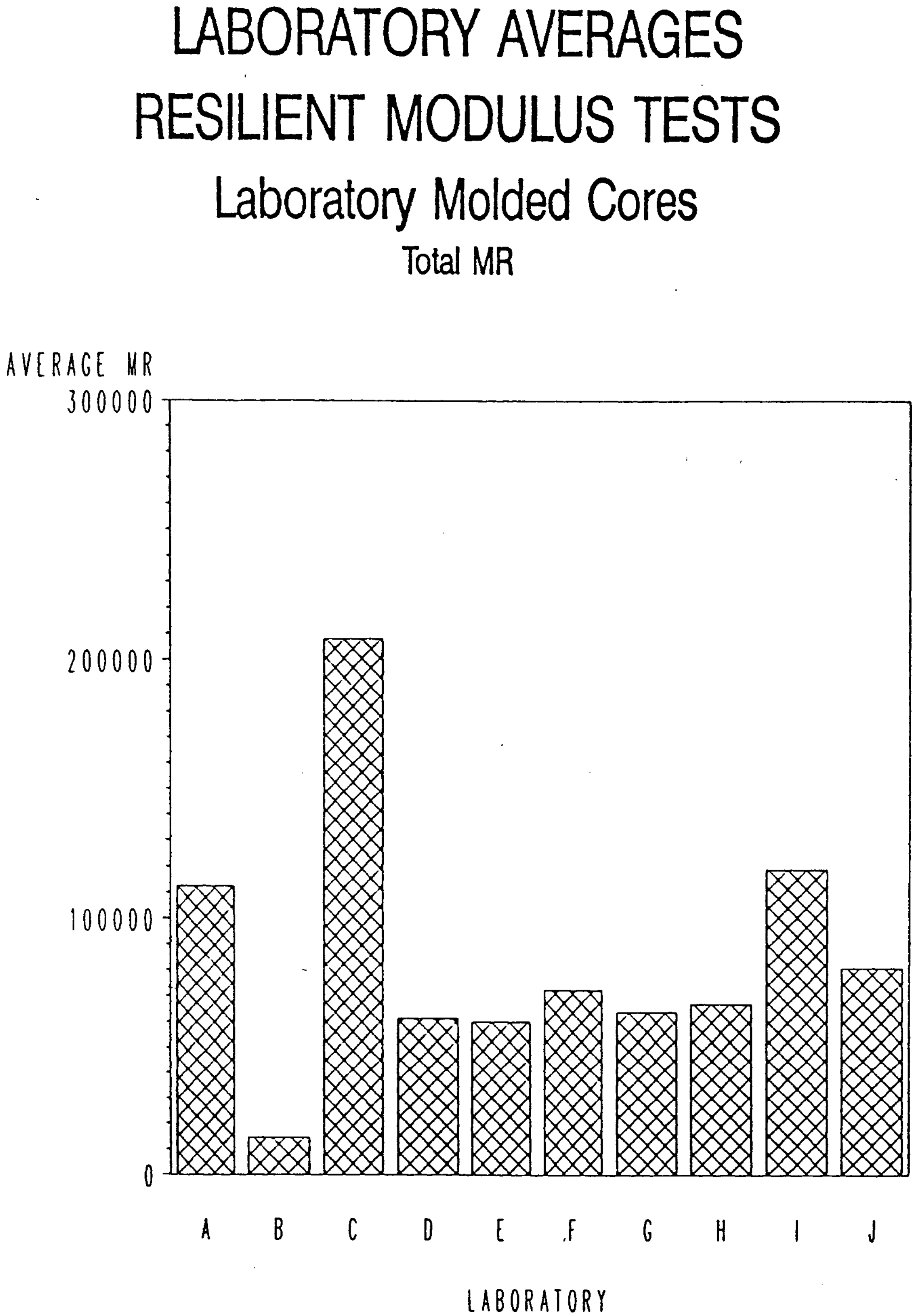

Figure 24. Total M_R for 1.5-in. specimens at 104°F, AC-30 asphalt.

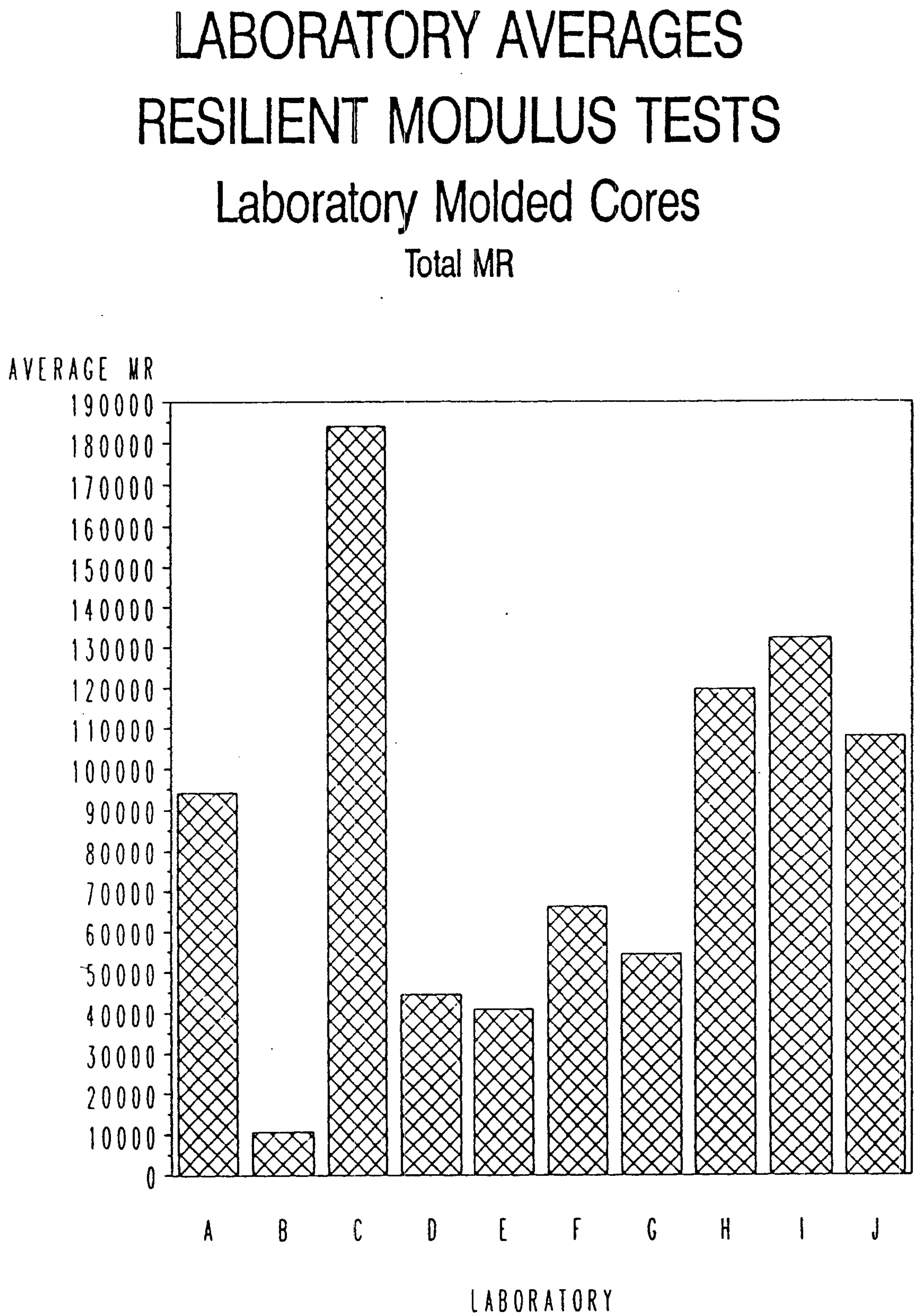

Figure 25. Total M_R for 3.0-in. specimens at 104°F, AC-30 asphalt.

Table 2. Coefficients of variation for each of the sources of variation, total mr measurements.

M_R Type	Asphalt Grade	Test Temp (°F)	Thick (in.)	Coefficient of Variation, percent			
				Lab	Batch	Specimen	Axis
I	AC-10	40	1.5	60.2	9.1	14.9	14.4
I	AC-10	40	3.0	46.5	NA	NA	38.3
I	AC-10	77	1.5	53.2	NA	24.3	16.5
I	AC-10	77	3.0	29.4	7.8	21.5	14.2
I*	AC-10	104	1.5	125.3	NA	51.8	80.1
I	AC-10	104	3.0	30.8	14.3	29.4	23.1
I	AC-30	40	1.5	49.6	NA	10.8	18.1
I	AC-30	40	3.0	46.0	NA	14.7	24.8
I	AC-30	77	1.5	45.0	0.8	11.6	13.4
I	AC-30	77	3.0	19.1	NA	15.9	12.4
I	AC-30	104	1.5	44.9	10.3	13.8	20.0
I	AC-30	104	3.0	15.7	NA	27.1	18.1
T	AC-10	40	1.5	45.9	10.6	15.2	16.5
T	AC-10	40	3.0	40.3	NA	NA	42.4
T	AC-10	77	1.5	24.3	NA	25.8	16.7
T	AC-10	77	3.0	31.1	7.3	22.0	16.2
T	AC-10	104	1.5	46.9	NA	28.2	35.9
T	AC-10	104	3.0	66.3	18.5	43.4	23.5
T	AC-30	40	1.5	43.0	6.6	6.7	18.8
T	AC-30	40	3.0	44.8	NA	NA	32.9
T	AC-30	77	1.5	19.4	3.3	12.3	14.5
**T	AC-30	77	3.0	20.0	NA	7.0	11.0
T	AC-30	104	1.5	45.3	19.5	19.3	23.4
T	AC-30	104	3.0	49.3	NA	37.7	18.5
Average M_R based on Type I tests only				40.0	3.8	16.7	19.4
Average M_R based on Type I tests only				41.5	6.0	19.2	23.6
Average M_R based on Type I and T tests				40.8	4.9	17.9	21.5

*Row omitted for average if Type I M_R
**Row omitted M_R
***Rows M_R
NA: Insufficient data available or negative standard deviation..

verifying the calibration of M_R test systems should be developed. It should be pointed out, however, that the laboratory effect indicates *both* the laboratory sample preparation (mixing and compaction) and the differences between laboratories in respective test procedures. Some better means of verifying the calibration and stability of M_R test systems in laboratories should be developed.

The second source of variation is the result of the differences which occur in the different batches of materials which were sent to the participating laboratories. Each batch was carefully taken from a large supply so that this source should not contribute very much to the variability in the measured values of the cores. This was indeed the case and the estimated values for the coefficient of variation for BATCHES was very small and sometimes negative estimates occurred in which case the estimate for the coefficient of variation is reported in the tables as "NA". Perhaps it should be noted that the Batch effect could have been divided into two components. The procedure by which a laboratory obtained the batches required the laboratory to split each "bag" of aggregate into two of these batches. If the Batch effect had been large, which was not the case, then it would have been important to determine if the variability resulted from the splitting process at the laboratory or from the division of aggregate into the "bags" before shipping.

The third source of variation is the result of the fabrication of two test specimens from the same batch at the same laboratory. This will be designated as the SPECIMEN factor and if it is large it will indicate that the fabrication process for the specimens is contributing in an important way to the variability in the measured M_R values. It was found that the average value for this coefficient of variation was somewhat larger than may be desired when all of the laboratories were considered as a group, 16.7 to 19.2 percent. It is possible with this data base to look at this effect for some of the individual laboratories. This is described in a later section.

The fourth source of variation is the result of the measuring process for a given specimen when repeated in an independent manner at a given laboratory. Since each specimen was to be measured in two directions, this provides an independent evaluation of the effect of measuring the specimens. This is noted as the AXIS effect and is an indication of the error in the measuring process at a given laboratory. Some of the laboratories did not measure in two directions so that they did not contribute to the evaluation of this variability. (Laboratories A, B, and C measured in only one direction and provided no replications of measured values on the same samples.) This effect would seem to be reasonable relative to the laboratory effect. It is possible to evaluate this effect for the individual laboratories which provided the measured values for two directions and this is described in the next section.

4. Results for Laboratories With Replications

Seven of the laboratories measured each core in two directions thereby providing the data needed for an evaluation of the measuring errors for a given laboratory. Separate Nested AOV's were carried out for each of these laboratories for both their instantaneous and total M_R measured values for a recovery period of 0.9 seconds and for each combination of temperature and asphalt (6 combinations). The results were then averaged and are reported respectively in Table 3 and 4 for the instantaneous and total M_R measurements. It is clear from these data that laboratories I and J must improve their procedures, as indicated by the large CV for both the (SPECIMEN) and (AXIS) effect.

There is no clear overall difference in the variation of the 1.5-inch specimens as compared to the 3.0-inch specimens. It does appear that some laboratories may have more difficulty in fabricating the 1.5-inch specimens while others may have more difficulty in the fabrication of the 3.0-inch specimens. For example, the comparison of the CV(SPECIMEN) at laboratory G for the two sizes (22.4 versus. 8.1) is a strong indication that there will be more variability in the production of the 1.5-inch cores at this laboratory. The reverse of this is observed for laboratory H.

There are two cases in Tables 3 and 4 where the CV(BATCH) is obviously too large. Although several data points that were clearly mistakes (for example, 5 times the

Table 3. Average of within laboratory coefficient of variation components for instantaneous M_R measurements.

Lab	Thick (in.)	Coefficients of Variation		
		Batch	Specimen	Axis
F	1.5	2.8	7.2	6.5
F	3.0	3.4	3.6	9.7
G	1.5	2.9	15.6	13.1
G	3.0	8.1	5.4	6.3
H	1.5	1.7	8.2	16.7
H	3.0	3.4	25.3	19.5
I	1.5	5.1	19.8	19.4
I	3.0	1.2	32.4	19.7
J	1.5	13.8	17.2	50.2
J	3.0	3.6	9.2	35.8

Note: The above based on 0.9 second recovery period. Each is the average of 6 values averaged over three temperatures and two asphalts.

Table 4. Average of within laboratory coefficient of variation components for instantaneous total M_R measurements.

Lab	Thick (in.)	Coefficient of Variation		
		Batch	Specimen	Axis
D	1.5	4.0	8.3	10.3
D	3.0	3.5	6.2	12.7
E	1.5	4.3	2.2	11.3
E	3.0	3.7	5.2	14.2
F	1.5	1.5	8.5	6.3
F	3.0	2.0	7.2	7.5
G	1.5	4.1	22.4	8.7
G	3.0	15.7	8.1	5.8
H	1.5	1.1	5.4	20.7
H	3.0	5.9	16.4	22.9
I	1.5	5.3	18.4	19.2
I	3.0	1.6	34.6	17.7
J	1.5	13.3	12.5	44.6
J	3.0	.06	10.6	28.5

Note: The above based on 0.9 second recovery period. Each is the average of 6 values averaged over three temperatures and two asphalts, excluding laboratories D and E at 40'F.

corresponding replicated value or more) were corrected or omitted, there may yet be mistakes in the data that produce such values as these two observed for the average of the CV(BATCH). In any event the variations produced by the differences in the BATCHES sent to the laboratories is quite reasonable for all of the laboratories as well as for the group of laboratories as already noted.

5. Results of the Analyses of the Size Effect

For a first look at this question the data for each separate laboratory were arranged so that the differences between the average of the two 1.5-inch specimens and the two 3.0-inch specimens within the same BATCH could be observed for all of the measured M_R values. This dependent set of differences provided for a given laboratory about 72 values for the observed differences, and for at least one laboratory these were all positive while for another they were all negative. It was then very clear that there was a very large laboratory by specimen thickness interaction.

The question as to whether the observed differences due to thickness at the individual laboratories were in fact important differences required an answer. Independent samples may be formed for these differences at a given laboratory in a very simple manner. By considering only the samples for a given temperature and given asphalt and then with each of the 4 batches forming the differences in the average of the measured M_R for the 1.5-inch and the 3.0-inch specimens within that batch, the resulting measurements are independent. The results of this process are given in Table 5 for the instantaneous M_R measurements. It may be observed that for laboratories B and F these differences are always negative and for H and I they are always positive. The PRT is the P-value for the resulting T test of no real difference for each of the lines in the table. The test based on only the 4 samples in that sense is not powerful, but it does clearly indicate that many of these observed differences are not chance events. More powerful tests based upon pooling some lines would produce even more impressive P-values, but would seem to be unnecessary. No doubt the thickness effect is real and more to the point the LABORATORY by THICK effect is also real. The corresponding reduced data for the total M_R measurements is presented in Table 6 and it will

Table 5. Differences instantaneous M_R measurements for 3.0 and 1.5-in. specimens.

Lab	Temp	AC	Coefficient of variation			
			Difference	% Difference	PRT	NSAMP
A	40.0	30.0	94,783	17.4	0.41	3
A	77.0	10.0	-31,938	-19.6	NA	1
A	77.0	30.0	-29,471	-8.8	0.55	3
A	104.0	10.0	4,638	5.3	NA	1
A	104.0	30.0	-22,241	-14.8	0.40	3
B	40.0	10.0	-2,375	-11.2	0.68	2
B	40.0	30.0	-6,618	-15.0	0.32	4
B	77.0	10.0	-1,185	-6.1	0.50	4
B	77.0	30.0	-16,808	-39.2	0.00	4
B	104.0	10.0	-2,594	-34.4	NA	1
B	104.0	30.0	-5,620	-33.3	0.03	4
C	40.0	10.0	29,440	8.6	0.44	4
C	40.0	30.0	-105,294	-13.6	0.13	4
C	77.0	10.0	-41,124	-18.9	0.07	4
C	77.0	30.0	5,459	3.2	0.94	4
C	104.0	10.0	-53,006	-39.8	0.16	4
C	104.0	30.0	-33,475	-11.6	0.66	4
F	40.0	10.0	-227,318	-18.7	0.01	4
F	40.0	30.0	-264,046	-16.1	0.06	4
F	77.0	10.0	-57,036	-20.3	0.03	4
F	77.0	30.0	-59,452	-11.2	0.08	4
F	104.0	10.0	-46,211	-45.2	0.01	4
F	104.0	30.0	-23,859	-13.5	0.04	4
G	40.0	10.0	90,771	5.4	0.56	4
G	40.0	30.0	27,508	1.3	0.87	4
G	77.0	10.0	-126,167	-25.0	0.10	4
G	77.0	30.0	-105,223	-14.7	0.00	4
G	104.0	10.0	-669,003	-133.0	0.02	4
G	104.0	30.0	-100,975	-39.8	0.00	4
H	40.0	10.0	707,401	67.5	0.00	4
H	40.0	30.0	1,088,757	70.1	0.00	4
H	77.0	10.0	98,135	36.2	0.12	4
H	77.0	30.0	371,535	82.8	0.00	4
H	104.0	10.0	73,236	61.6	0.06	4
H	104.0	30.0	79,420	63.6	0.02	4

Note: Average based on 0.9 second recovery period. The P-value for testing for no real differences is given by PRT.

Table 5 (cont'd). Differences instantaneous M_R measurements for 3.0 and 1.5-in. specimens.

Lab	Temp	AC	Coefficient of variation			
			Difference	% Difference	PRT	NSAMP
I	104.0	30.0	15,225	8.4	0.40	4
J	40.0	10.0	399,358	59.0	0.03	4
J	40.0	30.0	122,255	12.9	0.50	4
J	77.0	10.0	101,618	55.2	0.02	4
J	77.0	30.0	248,495	60.1	0.01	4
J	104.0	10.0	-46,214	-43.3	0.08	4
J	104.0	30.0	25,694	17.5	0.41	4

Note: Average based on 0.9 second recovery period. The P-value for testing for no real differences is given by PRT.

Table 6. Differences total M_R measurements for 3.0 and 1.5-in. specimens.

Lab	Temp	AC	Coefficient of variation			
			Difference	% Differernce	PRT	NSAMP
A	40.0	10.0	121,247	28.0	NA	1
A	40.0	30.0	132,439	35.2	0.31	3
A	77.0	10.0	-27,500	-25.0	NA	1
A	77.0	30.0	-32,487	-12.5	0.24	3
A	104.0	10.0	775	1.4	NA	1
A	104.0	30.0	-18,190	-17.7	0.22	3
B	40.0	10.0	-2,129	-12.6	0.56	2
B	40.0	30.0	-5,751	-17.1	0.17	4
B	77.0	10.0	-238	-1.8	0.65	4
B	77.0	30.0	-13,454	-39.7	0.01	4
B	104.0	10.0	-1,705	-29.5	NA	1
B	104.0	30.0	-4,074	-32.5	0.01	4
C	40.0	10.0	13,900	5.0	0.61	4
C	40.0	30.0	-64,055	-10.2	0.29	4
C	77.0	10.0	-35,122	-21.5	0.07	4
C	77.0	30.0	442	1.7	0.99	4
C	104.0	10.0	-42,647	-44.6	0.19	4
C	104.0	30.0	-24,077	-9.8	0.70	4
D	77.0	10.0	-21,091	-16.6	0.02	4
D	77.0	30.0	-26,205	-12.0	0.35	4
D	140.0	10.0	-9,795	-39.7	0.00	4
D	140.0	30.0	-16,851	-31.7	0.01	4
E	77.0	10.0	-20,698	-19.5	0.14	4
E	77.0	30.0	-13,252	-4.3	0.38	4
E	104.0	10.0	-10,682	-63.6	0.00	4
E	104.0	30.0	-19,108	-38.1	0.01	4
F	40.0	10.0	-178,774	-22.0	0.00	4
F	40.0	30.0	-208,096	-16.9	0.05	4
F	77.0	10.0	-22,185	-16.1	0.06	4
F	77.0	30.0	-28,310	-10.3	0.03	4
F	104.0	10.0	-8,268	-22.6	0.01	4
F	104.0	30.0	-5,082	-7.5	0.33	4

Note: Averages based on 0.9 second recovery period. The P-value for testing for no real differences is given by PRT.

Table 6. Differences total M_R measurements
for 3.0 and 1.5-in. specimens.

Lab	Temp	AC	Coefficient of variation			
			Difference	% Differemce	PRT	NSAMP
G	40.0	10.0	66,966	6.5	0.60	4
G	40.0	30.0	-2,689	-0.2	0.99	4
G	77.0	10.0	1,169	1.8	0.97	4
G	77.0	30.0	-16,207	-5.7	0.13	4
G	104.0	10.0	-11,915	-34.7	0.21	4
G	104.0	30.0	-9,543	-15.1	0.14	4
H	40.0	10.0	583,988	67.9	0.02	4
H	40.0	30.0	979,771	73.8	0.00	4
H	77.0	10.0	63,435	32.5	0.08	4
H	77.0	30.0	245,746	77.2	0.00	4
H	104.0	10.0	44,106	46.9	0.08	4
H	104.0	30.0	53,135	56.6	0.01	4
I	40.0	10.0	42,843	11.7	0.73	4
I	40.0	30.0	116,898	16.3	0.15	4
I	77.0	10.0	15,042	8.1	0.76	4
I	77.0	30.0	109,992	35.1	0.01	4
I	104.0	10.0	11,717	12.2	0.50	4
I	104.0	30.0	13,081	8.8	0.39	4
J	40.0	10.0	218,025	50.5	0.02	4
J	40.0	30.0	73,855	10.4	0.31	4
J	77.0	10.0	56,923	48.5	0.01	4
J	77.0	30.0	155,079	54.9	0.01	4
J	104.0	10.0	-21,331	-35.4	0.03	4
J	104.0	30.0	26,924	29.4	0.26	4

Note: Averages based on 0.9 second recovery period. The P-value for testing for no real differences is given by PRT.

be observed that the total M_R measurements are in agreement with the observations regarding the instantaneous M_R measurements in regard to the effect of the thickness of the specimen.

The variability of the measured M_R values for the two thicknesses was considered above where it was seen that in regard to the resulting variability, there is no overall benefit for either thickness although some laboratories have less variability with one thickness or the other. It should be pointed out that the effect of the thickness variable includes the effect of fabricating specimens of different thickness as well as the variability of testing specimens of varying thickness.

6. Statistical Model for the Measured M_R Values

The measured values for the M_R for a test specimen at given levels for temperature, asphalt grade, recovery period and size may be modeled as

$$M_R(i,j,k,l) = \text{MU} + \text{LABORATORY}(i) + \text{BATCH}(i,j) + \text{SPECIMEN}(i,j,k) + \text{AXIS}(i,j,k,l)$$

where it is assumed that

MU is the true but unknown mean for the specimen

LABORATORY(i) is a normal random variable with mean of zero and standard deviation of SIGMA(LAB)

BATCH(i,j) is a normal random variable with mean of zero and standard deviation of SIGMA(BATCH)

SPECIMEN(i,j,k) is a normal random variable with mean of zero and standard deviation of SIGMA(SPEC)

AXIS(i,j,k,l) is a normal random variable with mean of zero and standard deviation of SIGMA(AXIS).

It is assumed that these factors, LABORATORY, BATCH, SPECIMEN, and AXIS account for the observed variation in measured values for the M_R of a specimen. The purpose of the statistical analysis with this model was to estimate these standard deviations as defined in the model statement. The observed differences in the laboratory averages contain some contributions from all of these sources and an appropriate Nested AOV will separate out the contributions from all four of these sources. The results from these analyses are presented in Table 7 for both the instantaneous and the total M_R measurements. It should be noted that the data from Laboratory B was excluded from the analyses which produced the tables in the remainder of this report. The above analyses also provided the information needed for the construction of Table 1 in Part III and the further analyses in regard to the precision and accuracy, also given in Part III.

7. Summary

The objectives for this experiment were obtained. A great deal of data were gathered and provided answers to additional questions such as :

- The differences in the M_R values do not appear to be large for the different recovery periods. Given that 0.9 seconds is customarily used by researchers and is the value given in the current ASTM specification, there appears to be no reason for changing the recovery period. The recommendation, therefore, is to continue using 0.9 seconds as the recovery period.

- Some laboratories determine only the total M_R. When a laboratory measured both the total and the instantaneous M_R were usually quite similar. The simple correlation between the measured and total instantaneous value at laboratory A was found to be 0.98 and for laboratory I the simple correlation was 0.99. The instantaneous and total resilient modulus values are used differently in pavement analyses and should be chosen based on the applicability of the particular modulus.

- The test results show no clear advantage with respect to 1.5-in. specimens versus 3.0-in. specimens.

- A better means should be devised for a daily physical verification of test system standardization in order to reduce the large laboratory variability. It is theoretically possible to do a statistical calibration across a given set of laboratories in order to further reduce the laboratory variation. The possibilities for using the present data base in order to provide a statistical calibration was

Table 7. Standard Deviations for Each of the Factors in the Statistical Model.

M_R Type	Asphalt Grade	Test Temp (°F)	Thick (in.)	Standard deviation, psi			
				Lab	Batch	Specimen	Axis
I	10	40.0	3.0	495,072	NA	NA	407,780
I	10	77.0	1.5	158,761	NA	72,610	49,145
I	10	77.0	3.0	86,237	22,994	63,055	41,530
I	10	104.0	1.5	295,971	NA	122,378	189,169
I	10	104.0	3.0	32,505	15,070	31,082	24,410
I	30	40.0	1.5	606,884	NA	132,505	221,739
I	30	40.0	3.0	647,178	NA	206,837	348,213
I	30	77.0	1.5	198,514	3,416	51,063	59,178
I	30	77.0	3.0	101,714	NA	84,816	66,002
I	30	104.0	1.5	81,199	18,663	24,974	36,047
I	30	104.0	3.0	27,399	NA	47,281	31,554
T	10	40.0	1.5	284,756	65,846	94,464	102,446
T	10	40.0	3.0	300,992	NA	NA	316,805
T	10	77.0	1.5	35,953	NA	38,138	24,772
T	10	77.0	3.0	47,955	11,305	33,955	24,891
T	10	104.0	1.5	24,084	NA	14,507	18,448
T	10	104.0	3.0	31,690	8,841	20,714	11,244
T	30	40.0	1.5	404,372	61,756	62,703	177,013
T	30	40.0	3.0	497,585	NA	NA	365,780
T	30	77.0	1.5	51,020	8,623	32,463	38,282
T	30	77.0	3.0	123,597	NA	80,595	361,302
T	30	104.0	1.5	38,542	16,572	16,458	19,967
T	30	104.0	3.0	43.453	NA	33,254	16,268

NA indicates negative standard deviation explored, and the results were somewhat mixed.

- The resources needed to completely analyze this very large data base are not available to the authors of this report. However, the data base is intended to be maintained and available for further analyses as needed. It would be expected that participating, and other laboratories would use the information from this experiment to make improvements in their methods of fabricating and measuring cores so that the present study will be out of date at some time in the future. It will serve, however, to provide a baseline from which to evaluate these improved methods.

8. Conclusions

The following conclusions are based on the data collected and analyzed in this program.

- A 0.9 second recovery period appears to provide essentially the same information as the 1.9 or 2.9 seconds recovery period.

- The among laboratory variability indicates a need for a better method of standardizing the test systems used to determine the diametral resilient modulus, this is particularly the case when the results are to be used to predict the performance of hot mix asphalt pavements.

- Increasing the number of test specimens will not reduce the among laboratory variability of this test method.

- The repeatability for total resilient modulus values is generally somewhat better than the repeatability for instantaneous resilient modulus values. As noted earlier this may be simply because two of the better performing laboratories measured only the total M_R values.

- Based on the limited analysis of the correlation of the measured instantaneous and total M_R, it appears that, for a given mixture at a given temperature, a linear function could be used to determine either from the other. It may be desirable to consider only the total M_R and derive the instantaneous from the total as long as the mixture-asphalt-temperature specific correlation factor is known.

- There is no well identified advantage for the 3.0-in. or 1.5-in. thick specimens. Specimens in practice will most likely range from 1.5-in. to 3.0-in. in thickness. Therefore, it seems that all specimens with thicknesses in this range should be equally acceptable.

- The coefficient of variation (CV) for the within laboratory measurement errors is about the same for specimens fabricated with AC 10 and specimens fabricated with AC 30. It was generally about 25%.

- As expected the mean values reported for the total and the instantaneous resilient modulus of specimens fabricated with AC 30 are higher than the mean values reported for specimens fabricated with AC 10.

- Some laboratories were clearly better than others and perhaps a group of the best 5 laboratories could be used to better define the potential variability for this test method. This analysis was not within the scope of the present study, but would be a useful analysis. One laboratory (B) was eliminated from the statistical analyses because it was clearly too far outside the range of the others.

PART IV AASHTO/ASTM FORMAT PRECISION STATEMENTS

1. Development of the 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 as noted earlier this may be separated into three components accounting for the variability from the sampling of a batch of material (BATCH), the fabrication of the specimen (SPECIMEN), and the measuring of a specimen (AXIS). The AXIS component is the usual within laboratory measurement error and would describe the variation that occurs when the same specimen is measured independently a second time in the same laboratory. The use of two directions for the measurements more accurately reflects the variation in the measuring process and also assures that the specimen will be mounted in an independent manner for the two tests. This AXIS component could have been simply called the ERROR. The SD(AXIS) will be an important component in every statement of precision.

The SPECIMEN component relates to the variation that occurs in the fabrication of the specimen and would be included in any overall measure of variation that corresponds to the fabrication and measurement of the M_R for a specimen. Thus if from a given (small homogeneous) batch of material two or more test specimens are fabricated, then the SPECIMEN component would be needed to account for the differences that will occur in the true M_R values for the cores.

The BATCH component was quite small and is omitted from further consideration. However, it may be important in cases where there may be a large amount of material which is sampled in several locations for the purpose of evaluating the properties of the resulting mixtures. No general statements can be made regarding batches in a typical laboratory setting. It should be noted that the values for the BATCH component in that case would be larger than those obtained in this experiment because the material from which these batches were obtained was by design an homogeneous source with batches made up to be as nearly alike as possible. Indeed the resulting small contributions (often 0) accounted for by the BATCH component indicate that the method of preparing the batches was quite good. The primary interest in this experiment is in evaluating the components of variation due to laboratories, the fabrication of test specimens and the measuring of the M_R for the test specimens.

The within laboratory measure of precision regarding the measurement of a single specimen under a given set of conditions is provided by the SIGMA(AXIS) and these values are given in Table 7 (SD(AXIS)) and in Table 8 (1S). This is the within laboratory single operator standard deviation of the measurement error.

The within laboratory measure of precision regarding the fabrication and subsequent measuring of the M_R value will have a standard deviation of SIGMA(F + M) and is given by

$$[\text{VARIANCE (SPECIMEN)} + \text{VARIANCE (AXIS)}]^{0.5}$$

which is the square root of the sum of the variances of the components for fabrication and measurement of a test specimen. These may be obtained from the entries in Table 7, taking note of the fact that the variances needed are the squares of the respective standard deviations.

One of the other entries in Table 8 is the EST_MR which is the average of the laboratory averages for the M_R and is somewhat different from the simple average of all measurements made by the laboratories. The data from Laboratory B is excluded from all the tables in this section and the data from Laboratory H is excluded from one entry in the table. The 1S% values are the percentages of the EST_MR which the 1S represents. The D2S values are 2.8 times the 1S values and $\pm$ these D2S values provide 0.95 probability limits for the difference of two measurements at a given laboratory by the same operator on the same specimen.

The reproducibility measures for precision include a laboratory component as well as a fabrication and measurement component. It will be assumed that the batch component may

Table 8. Single Laboratory Precision Statements.

M_R Type	Asphalt Grade	Temp (°F)	Thick (in.)	Estimated M_R (psi)	1S (psi)	1S (%)	D2S (psi)
I	AC-10	40	1.5	778,054	128,656	17	360,237
I	AC-10	40	3.0	946,758	407,780	43	1,141,783
I	AC-10	77	1.5	275,024	49,154	18	137,607
I	AC-10	77	3.0	267,896	41,530	16	116,284
I	AC-10	104	1.5	207,814	189,169	91	529,673
I	AC-10	104	3.0	103,443	24,410	24	68,347
I	AC-30	40	1.5	1,134,075	221,739	20	620,868
I	AC-30	40	3.0	1,288,217	348,213	27	974,996
I	AC-30	77	1.5	439,824	59,178	13	165,698
I	AC-30	77	3.0	514,919	66,002	13	184,807
I	AC-30	104	1.5	185,952	36,047	19	100,931
I	AC-30	104	3.0	177,283	31,554	18	88,352
T	AC-10	40	1.5	554,643	102,4446	18	286,848
T	AC-10	40	3.0	678,021	316,805	47	887,054
T	AC-10	77	1.5	147,677	24,772	17	69,361
T	AC-10	77	3.0	147,801	24,891	17	69,695
T	AC-10	104	1.5	55,657	18,448	33	51,655
T	AC-10	104	3.0	50,346	11,244	22	31,483
T	AC-30	40	1.5	869,682	177,013	20	495,637
T	AC-30	40	3.0	1,018,814	365,780	36	1,024,184
T	AC-30	77	1.5	270,326	38,282	14	107,189
*T	AC-30	77	3.0	297,719	33,666	11	94,264
T	AC-30	104	1.5	93,747	19,967	21	55,908
T	AC-30	104	3.0	93,613	16,268	17	45,551

*Laboratory H was omitted for this entry

Data in this table computed in accordance with ASTM C 670 be neglected. Thus if a batch of material is sent to a laboratory at random from a group such as those in this experiment, the resulting measured value for the M_R of a test specimen will be a random variable with standard deviation which will be noted as SD(L+F+M) where it is indicated that there is a laboratory, a fabrication and a measurement error to be considered. In fact, the variance of the sum of these independent errors will be the sum of their variances so that the SD(L+F+M) will be the square root of the sum of these variances. Values for SD(L+F+M) are given in Table 9. The large laboratory effect discussed earlier is responsible for most of this large standard deviation. This standard deviation will be referred to as the multilaboratory standard deviation and it is given in Table 9 as 1S. The 1S% in Table 9 is the percent of the EST_MR value that the 1S represents.

The DS2 entries in Table 9 with a ± attached would provide 0.95 probability limits for the difference in the measurements of two samples where the specimens have been fabricated and measured at two laboratories chosen at random from a group of laboratories such as these in the study.

2. Examples of Precision Statements

The examples chosen for illustration will be for a total M_R with recovery period of 0.9 seconds. Suppose a given 3.0-in. thick specimen fabricated with AC 10 is to be measured two times in a given laboratory by the same operator and that the measurements take place in an independent manner at 77°F. Then with probability of 0.95 the measured values will differ by less than the D2S value given in Table 8, i.e. by less than 69,695.

Suppose two specimens of 3-inch thickness are to be fabricated with AC 10 asphalt at two different laboratories from the group included in this experiment and these specimens are to have their total M_R measured at their respective laboratories at 77°F. The resulting measurements should differ by less than the D2S as given in Table 9 for the Multiple Laboratory probability limits, i.e. by less than 178,678. When this value is compared with the corresponding single laboratory D2S of 69,695 as given in the first example it is again clear that the laboratory component of variance is unacceptably large for the purpose of

Table 9. Multiple Laboratory Precision Statements.

M_R	Asphalt Grade	Test Temp(F)	Thick (in.)	Estimated M_R (psi)	1S (psi)	1S (%)	D2S (psi)
I	10	40.0	1.5	778,054	567,482	73	1,588,951
I	10	40.0	3.0	946,758	641,390	68	1,795,891
I	10	77.0	1.5	275,024	181,363	66	507,816
I	10	77.0	3.0	267,896	114,619	43	320,934
I	10	104.0	1.5	207,814	371,968	179	1,041,510
I	10	104.0	3.0	103,443	51,172	49	143,281
I	30	40.0	1.5	1,134,075	659,571	58	1,846,799
I	30	40.0	3.0	1,288,217	763,461	59	2,137,691
I	30	77.0	1.5	439,824	213,348	49	597,373
I	30	77.0	3.0	514,919	147,973	29	414,323
I	30	104.0	1.5	185,952	92,284	50	258,394
I	30	104.0	3.0	177,283	63,102	36	176,687
T	10	40.0	1.5	554,643	317,025	57	887,669
T	10	40.0	3.0	678,021	436,992	64	1,223,576
T	10	77.0	1.5	147,677	57,972	39	162,322
T	10	77.0	3.0	147,801	63,814	43	178,678
T	10	104.0	1.5	55,657	33,628	60	94,158
T	10	104.0	3.0	50,346	39,494	78	110,584
T	30	40.0	1.5	869,682	445,850	51	1,248,379
T	30	40.0	3.0	1,018,814	617,565	61	1,729,181
T	30	77.0	1.5	270,326	71,571	26	200,398
*T	30	77.0	3.0	297,719	72,636	24	203,381
T	30	104.0	1.5	93,747	46,423	50	129,983
T	30	104.0	3.0	93,613	57,085	61	159,837

*Laboratory H was omitted for this entry
Data in this table computed in accordance with ASTM C 670

discriminating between the difference in performance of different mixtures.

APPENDIX A

INITIATING LETTER AND OTHER DOCUMENTS SENT TO ALL PARTICIPANTS

June 6, 1991

Oregon

DEPARTMENT OF TRANSPORTATION

Highway Division

Materials & Research Section

FILE CODE:

W.J. Quinn
Engineer of Materials and Research
Oregon State Highway Division
Highway Engineering Laboratory
800 Airport Road S.E.
Salem, OR 97310

To: Participants in the SHRP Asphalt Concrete Laboratory Molded Proficiency Sample Program

GENERAL

Round One samples have been sent to your laboratory for testing in the SHRP Asphalt Concrete Laboratory Molded Proficiency Sample Program. The Round One shipment included the following materials:

2 qts. AC-10 asphalt cement
2 qts. AC-30 asphalt cement
4 bags aggregate

Each bag of aggregate in the shipment has two sample numbers attached. For example, the 4 bags of aggregate in a shipment could have the following sample numbers attached:

1st bag	1st sample number	AC-10,190
	2nd sample number	AC-30,690
2nd bag	1st sample number	AC-10,191
	2nd sample number	AC-30,691
3rd bag	1st sample number	AC-10,192
	2nd sample number	AC-30,692
4th bag	1st sample number	AC-10,193
	2nd sample number	AC-30,693

<u>When your laboratory has been authorized to test the Round One AC lab molded proficiency samples</u>, proceed as follows:

Each bag of aggregate will be split into two (2) samples (AASHTO T248-method A). The two samples will be carefully rebagged in separate bags and each of the new bags of aggregate will be numbered with <u>one (1)</u> of the sample numbers attached to the original bag of aggregate from which it was split. PLEASE follow the above procedure carefully since the information derived from SHRP proficiency programs depends upon each participating laboratory maintaining the sample identity in accordance with program design.

800 Airport Road SE
Salem, OR 97310
(503) 378-2621
FAX (503) 373-1312

734-2267 (Rev. 2-91)

When all four of the original bags of aggregate have been split, rebagged, and identified by sample number as indicated above, your laboratory will have eight bags of aggregate. Four bags of aggregate will have sample numbers beginning with AC-10, and four bags will have sample numbers beginning with AC-30.

The four bags of aggregate with sample numbers beginning with AC-10 will be used with AC-10 asphalt. The other four bags of aggregate with sample numbers beginning with AC-30 will be used with the AC-30 asphalt.

Each of the eight bags of aggregate will be individually split into four increments (AASHTO T248-method A) in order to prepare four-4 inch diameter specimens from each bag, including two specimens 3 inches in height and two specimens 1-1/2 inches in height. The total number of molded 4 inch diameter specimens from all bags will be 32 as follows:

ASPHALT	SPECIMENS & HEIGHT	SPECIMEN ID
AC-10	8 (2 per bag) - 1 1/2 inch	A
	8 (2 per bag) - 3 inch	B
AC-30	8 (2 per bag) - 1 1/2 inch	A
	8 (2 per bag) - 3 inch	B

SPECIMEN IDENTIFICATION

Each molded specimen shall be identified by the aggregate sample number (which begins with the asphalt grade), the specimen identification shown above, and the specimen number (either a "1" or a "2" indicating the 1st specimen molded or the 2nd specimen molded). Following is a list of example specimen identification numbers for the sample numbers previously noted.

AC-10	AC-30
AC-10,190A1	AC-30,690A1
AC-10,190A2	AC-30,690A2
AC-10,190B1	AC-30,690B1
AC-10,190B2	AC-30,690B2
AC-10,191A1	AC-30,691A1
AC-10,191A2	AC-30,691A2
AC-10,191B1	AC-30,691B1
AC-10,191B2	AC-30,691B2
AC-10,192A1	AC-30,692A1
AC-10,192A2	AC-30,692A2
AC-10,192B1	AC-30,692B1
AC-10,192B2	AC-30,692B2
AC-10,193A1	AC-30,693A1
AC-10,193A2	AC-30,693A2
AC-10,193B1	AC-30,693B1
AC-10,193B2	AC-30,693B2

PREPARATION OF SPECIMENS

Each bag of aggregate shall be thoroughly mixed and then split into the portions needed in accordance with AASHTO T248 – Method A, using care not to segregate the samples.

The specimens shall be molded per Section 6.1 of ASTM D4123-82, however, for the Asphalt Concrete Laboratory Molded Sample Proficiency Sample Program, the Marshall method of compaction shall not be used to compact the specimens. The specimens shall be molded using 5.0% asphalt by dry weight of the total weight of each specimen. The type and number of molded specimens are as shown in the general remarks above.

After the preparation of the specimen, two diametral axes should be marked on the specimen. One axis should be chosen to perform the initial testing (0° orientation) and a line should be drawn on the test specimens to indicate this axis. The other axis should be marked at a 90 degree angle (90° orientation) to the initial axis.

TEST PROCEDURE

The molded specimens shall be tested as per SHRP Protocol P07, "Resilient Modulus for Asphaltic Concrete". The Indirect Tensile Strength has been previously measured using SHRP Protocol P07 as 30 psi for the AC-10 asphalt and 117 psi for the AC-30 asphalt and the load levels for each temperature should be adjusted according to Section 7.3.1 of Protocol P07. Section 7.5.2 of Protocol P07 shall be strictly followed (thus the specimen is tested once on a 0° axis and then rotated and tested once on a perpendicular, 90°, axis). The order of testing specimens shall be randomized. For instance, using the example specimen identification numbers listed previously, the following would be an acceptable order of testing:

1. AC-30,691A2
2. AC-30,692B1
3. AC-10,190B1
4. AC-30,691B1
5. AC-30,693B2
6. AC-10,193A2
7. AC-30,693A2
8. AC-30,690B1
9. AC-30,692A2
10. AC-30,690A2
11. AC-10,193B1
12. AC-30,691A1
13. AC-10,192B2
14. AC-10,190B2
15. AC-30,190B2
16. AC-10,191B1
17. AC-10,192A1
18. AC-10,191B2
19. AC-30,690A1
20. AC-30,693A1
21. AC-30,691B2
22. AC-30,692A1
23. AC-30,693A2
24. AC-10,192B1
25. AC-10,193A1
26. AC-10,191A2
27. AC-10,191A1
28. AC-30,692B2
29. AC-10,193B2
30. AC-10,190A1
31. AC-10,190A2
32. AC-10,192A2

Perform a void content test on each specimen as per AASHTO T269-80 (1986).

After all testing of the specimens is accomplished, the samples shall be retained until the SHRP statistical analysis has been completed.

REPORT

The following information should be recorded on the attached Worksheets:

Worksheet 1 - General Specimen Information

1. method used to mold the specimens
2. weight of aggregate used for each specimen
3. weight of asphalt used for each specimen
4. diameter of each specimen
5. height of each specimen
6. weight of each test specimen
7. bulk specific gravity of each specimen
8. void content of each specimen
9. general remarks regarding test specimens.

One Worksheet "1" is needed to report all of the relevant information for Round One of the SHRP Asphalt Concrete Laboratory Molded Proficiency Sample Program.

Worksheet 2 - Test Data Reporting: Specimen at 0° Orientation

1. specimen number
2. test temperature (as measured during the test procedure)
3. preconditioning - load used
4. preconditioning - number of cycles
5. date of test
6. vertical load and vertical and horizontal deformation readings obtained during the test for each rest period
7. comment codes - as per SHRP Standard Comment code(s) shown on Page E3 (attached) of the SHRP Laboratory Testing Guide and on pages P07-7 and P07-8 of SHRP Protocol P07.
8. general comments

One Worksheet "2" is used to report the information for one specimen at one test temperature and one axis. A total of 96 Worksheet "2"'s will be needed per laboratory to report the information obtained from Round One of the SHRP Asphalt Concrete Laboratory Molded Proficiency Sample Program.

Worksheet 3 - Test Data Reporting: Specimen Rotated 90°

1. specimen number
2. test temperature (as measured during the test procedure)
3. preconditioning - load used
4. preconditioning - number of cycles
5. date of test
6. vertical load and vertical and horizontal deformation readings obtained during the test for each rest period
7. comment codes - as per SHRP Standard Comment code(s) shown on Page E3 (attached) of the SHRP Laboratory Testing Guide and on pages P07-7 and P07-8 of SHRP Protocol P07.
8. general comments

One Worksheet "3" is used to report the information for one specimen at one test temperature and one axis. A total of 96 Worksheet "3"'s will be needed per laboratory to report the information obtained from Round One of the SHRP Asphalt Concrete Laboratory Molded Proficiency Sample Program.

Please direct any questions regarding the procedures for molding and/or testing to Garland Steele, (304) 727-8719. At the completion of all testing and test data reporting for Round One, please return the test data worksheet forms to the following address:

Ron Noble, Materials Unit Engineer
800 Airport Road SE
Salem, OR 97310

Thank you for participating in the SHRP Asphalt Concrete Laboratory Molded Proficiency Sample Program.

Ron Noble

Ron Noble

Attachments: (1) Protocol P07
(2) Data worksheets
(3) Page E-3 of the SHRP-LTPP Guide for Laboratory Materials Handling and Testing, November 1989.

ATTACHMENT 1

This attachment contains SHRP Protocol P07, "Resilient Modulus of Asphalt Concrete."

SHRP PROTOCOL: P07

For SHRP Test Designation: AC07

RESILIENT MODULUS FOR ASPHALTIC CONCRETE

This SHRP Protocol describes procedures for determination of the resilient modulus of asphaltic concrete (bituminous concrete) using repeated load indirect tensile testing techniques. This test shall be performed in accordance with ASTM D4123-82 (1987), as modified herein. Those sections of the ASTM Standard included in this protocol by reference and without modifications shall be followed as written in the Standard. All other sections of this protocol shall be followed as herein written.

Resilient modulus testing shall be conducted after; (1) initial layer assignment using Form L04, (2) visual examination and thickness of asphaltic concrete (AC) cores and thickness of layers within the AC cores using Protocol P01, and (3) final layer assignment based on the P01 test results (corrected Form L04, if needed). Resilient modulus testing shall be conducted on asphalt concrete specimens that are greater than 1.5 inches in thickness that have been selected for testing.

Prior to performing the resilient modulus test, the indirect tensile strength shall be measured on one test specimen from the same layer and near the same location as the core specimen(s) to be tested for resilient modulus. The indirect tensile strength test shall be performed in accordance with Attachment A of this protocol to assist in selecting a stress (or applied load) for resilient modulus testing.

Test Core Locations and Assignment of SHRP Laboratory Test Numbers

Eight AC core locations have been designated for the P07 test on every pavement section included in GPS-1, GPS-2, GPS-6, and GPS-7 (asphaltic concrete over granular base, asphaltic concrete over bound base, AC overlay over asphaltic concrete, and AC overlay over JPC, greater than 1.5 inches, respectively). The cores designated by SHRP for testing shall be used.

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

The designated locations for 4-inch diameter cores are: C7 (for indirect tensile strength test using Attachment A of Protocol P07); C8, C9, C10 (for resilient modulus test using Protocol P07). The test results determined for each test specimen from these specified core locations shall be assigned SHRP Laboratory Test Number "1". SHRP will specify which cores, of those designated, to be used for testing.

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

The designated locations for 4-inch diameter cores are: C19 (for indirect tensile strength test using Attachment A of Protocol P07); C20, C21, C22 (for resilient modulus test using Protocol P07). The test results determined for each test specimen from these specified core locations shall be assigned SHRP Laboratory Test Number "2". SHRP will specify which cores, of those designated, to be used for testing.

If any of the test specimens obtained from the specified core locations are damaged or untestable, other cores that have not been identified for other testing can be used. However, it is inappropriate to substitute test specimens from one end of the GPS Section for test specimens at the other end. An appropriate comment code shall be used in reporting the test results.

The following definitions 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 homogenous. The layer thickness can be equal to or less than the core thickness or length.

(b) Core: An intact cylindrical specimen of the pavement materials that is removed from the pavement by drilling at the designated location. A core can consist of, or include, one, two or more different layers.

(c) Test Specimen: That part of the layer which is used for, or in, the specified test. The thickness of the test specimen can be equal to or less than the layer thickness.

1. SCOPE

1.1 As described in Section 1.1 of ASTM D4123-82.

NOTE 1 - Delete Note 1 from Scope

2. APPLICABLE DOCUMENTS

2.1 ASTM Documents: As listed in ASTM D4123. D4123-82 Indirect Tension Test for Resilient Modulus of Bituminous Mixtures.

2.2 SHRP Protocols

P01 Visual Examination and Thickness of Asphaltic Concrete Cores.

3. SUMMARY OF METHOD

3.1 As described in Section 3.1 of ASTM D4123-82.

3.2 As described in Section 3.2 of ASTM D4123-82.

3.3 For each resilient modulus test, the following general procedures will be followed.

(a) Indirect tensile strength is determined on one test specimen at $77 \pm 2°F$ using the procedure described in Attachment A to Protocol P07.

(b) The test specimen(s) are to be tested each along two diametral axes and at three separate testing temperatures, 41, 77 and 104°F plus or minus two degrees F (15, 25, and 40°C plus or minus one degree C). For each test temperature, repetitive haversine load pulses of 0.1-second duration are applied to the individual test specimens to obtain an indirect tensile stress on the specimen (a predefined percentage of the indirect tensile strength as determined in 3.3 (a) above), with rest periods of varying

duration between load pulses as described in the Procedure section.

4. SIGNIFICANCE AND USE

4.1 As stated in Section 4.1 of ASTM D4123-82.

5. APPARATUS

5.1 Testing Machine - The testing machine shall be a closed loop electrohydraulic testing machine with a function generator capable of applying a haversine shaped load pulse over a range of load durations, load levels, and rest periods.

NOTE 2 - Delete Note 2 from Section 5.1 of ASTM D4123-82.

5.2 Temperature Control System - As described in Section 5.2 of ASTM D4123-82.

5.3 Measurement and Recording System - The measuring and recording system shall include sensors for measuring and recording horizontal and vertical deformations. The system shall be capable of recording horizontal deformations in the range of 0.00001 inch (0.00025 mm) of deformation. Loads shall be accurately calibrated prior to testing.

5.3.1 Recorder - As described in Sections 5.3.1 of ASTM D4123-82.

5.3.2 Deformation Measurement - The values of vertical and horizontal deformation shall be measured with linear variable differential transducers (LVDT's). LVDT's should be at mid-height opposite each other on the specimens horizontal diameter. The sensitivity of these measurement devices shall be selected to provide the deformation readout required in 5.3. A positive contact between the LVDT's and specimen shall always be maintained during the test procedure. This can be maintained by using spring loaded LVDT's and attaching a flat head to the LVDT (3/8" x 1/4"). This flat LVDT head is required to prevent movement variations during the test (round or bevelled LVDT heads can be affected by the roughness of the core surface during testing). In addition, the two LVDT's shall be wired so that each gauge can be read independently and the results summed independently during the test program.

NOTE 3 - Delete the last two sentences of Note 3 of ASTM D4123-82.

5.3.3 Load Measurement - As required in Section 5.3.3 of ASTM D4123-82.

5.4 Loading Strip - As required in Section 5.4 of ASTM D4123-82.

6. TEST SPECIMENS

6.1 Laboratory-Molded Specimens - Delete Section 6.1 of ASTM D4123-82.

6.2 Core Specimens - As described in Section 6.2 of ASTM D4123-82.

6.3 The test specimens designated for M_r testing shall be selected and prepared for resilient modulus testing. The test specimen(s) shall represent one AC layer at each end of the GPS section. If the field core includes two or more different AC layers, layers shall be separated at the layer interface by sawing the field core with a diamond saw in the laboratory. The traffic direction symbol shall be marked on each layer below the surface layer. Separate any testable layers as identified in the P01 test (From T01B). Thin layers shall be removed from other testable layers. Any combination of thin layers which do not meet the testable layer criterion shall <u>not</u> be sawed from each other.

6.4 Diametrical Axes - Mark two diametrical axis on each test specimen to be tested. One axis shall be parallel to the traffic direction symbol (arrow) or "T" marked during the field coring operations. The other axis shall be marked at a 90 degree angle from the arrow (or "T") placed on the specimen during field coring operations, as required by SHRP Protocol P01 (Section 4.4).

6.5 The thickness (t) of each test specimen shall be measured prior to testing to the nearest 0.1 inch (2.5 mm). The thickness shall be determined by averaging four measurements equally spaced around the test specimen.

6.6 The diameter (D) of each test specimen shall be determined prior to testing to the nearest 0.01 inch (0.25 mm) by averaging two diameters measured by a caliper at right angles to each other at about the mid-height of the test specimen.

7. PROCEDURE

7.1 (a) Determine the indirect tensile strength of the designated test specimen at 77°± 2°F using the procedure described in Attachment A to Protocol P07.

(b) The test specimen(s) designated for resilient modulus testing shall be brought to the lowest temperature of the test temperature range specified in Section 3.3 (b) of this protocol.

(c) Follow the procedure described in Section 7.1 of ASTM D4123-82 to bring the test specimens to the desired test temperature.

7.2 Place the test specimen in the loading apparatus and position the sample so that the diametral markings are centered top to bottom within the loading strips on both the front and back faces. The first axis to be tested (section 6.4) is to be the axis parallel to the direction of traffic (i.e. the load is being applied along the axis parallel to traffic). Adjust and balance the electronic measuring system as necessary.

7.3 Preconditioning and testing shall be conducted with the specimen located in a temperature-control cabinet meeting the requirements in Section 5.2 of this protocol.

7.3.1 Selection of the applied loads for preconditioning and testing at the three test temperatures are based on the indirect tensile strength, determined as specified in Section 7.1 (a) of this protocol and Attachment A to Protocol P07. Select tensile stress levels of 30, 15, and 5 percent of the tensile strength, measured at 77°F (25°C), for the test temperatures of 41 $\pm$ 2, 77 $\pm$ 2 and 104 $\pm$ 2°F (15, 25 and 40°C $\pm$ 1C), respectively. Minimum specimen seating loads of 3, 1.5 and .5% of the 77°F tensile strength value shall be maintained during resilient modulus testing for all test temperatures.

7.3.2 Testing is to be conducted in the following order of temperatures: First at 41 $\pm$ 2°F, then at 77°F and the final at 104 $\pm$ 2°F. Bring the test specimens to the specified temperature before each test, in accordance with Section 7.1 of this protocol. Precondition the test specimen along each axis prior to testing by applying a repeated haversine-shaped load pulse of 0.1-second duration with a rest period of 0.9 seconds, until successive horizontal deformation readings agree within 10%. The number of load applications to be applied will depend upon the test temperature. The expected ranges in number of load applications for preconditioning are 50-150 for 40°F, 50-100 for 77°F and 20-50 for 104°F. The minimum number of load applications for a given situation must be such that the resilient deformations are stable (see note 5 and note 6 of ASTM D4123-82 (1987).

NOTE 6 - Loads as low as 10 lbf and load repetitions as few as 5 (for loads between 5 and 25 lbf) have been used. If adequate deformations (greater than 0.0001 inches) cannot be recorded using 5 to 35% of the tensile strength measured at 77°F (25°C), then the loads can be increased in load increments of 5 (i.e. 10, 15, 20, 25%). If load levels different from 5, 15 and 30% of the tensile strength measured at 77°F (25°C) are used, these should be noted on the data sheet.

Delete Note 7 of ASTM D4123-82.

7.4 Monitor both the horizontal and vertical deformations during preconditioning of the test specimens. If total cumulative vertical deformations greater than 0.001 inch (0.025 mm) occur, reduce the applied load to the minimum value possible and still retain an adequate deformation for measurement purposes (See Note 6). If use of smaller load levels will not yield adequate deformations for measurement purposes, discontinue preconditioning and use 10 load pulses for resilient modulus determination, and so indicate on the test report.

7.5 After preconditioning a specimen for a specific test temperature, the resilient modulus test shall be conducted as specified below.

7.5.1 Apply a minimum of 30 load pulses (each 0.1-second load pulse has a rest period of 0.9 seconds) and record measured deformations as specified in Section 7.6 of this protocol. The rest period is then increased to 1.9 seconds and a minimum of 30 load repetitions are applied. The rest period is then increased to 2.9 seconds and a minimum of 30 load repetitions are applied (see Section 7.6 of this protocol).

7.5.2 After testing is completed for the first axis tested (load applied along the axis parallel to the direction of traffic) rotate the specimen to the axis 90 degrees from the axis parallel to traffic and repeat Steps 7.3.2 through 7.5.1 of this protocol.

7.5.3 After the specimen(s) have been tested along both axes at a specific test temperature, bring the specimen to the next higher temperature in accordance with 5.2 and repeat 7.3.2 through 7.5.2 of this protocol.

7.6 Measure and record the recoverable horizontal and vertical deformations over at least 5 loading cycles (see Figure 2 of ASTM D4123-82) after the repeated resilient deformations have become stable. One loading cycle consists of one load pulse and a subsequent rest period. The vertical deformation measurements shall also be measured and reported. The resilient modulus will be calculated along each axis for each rest period and temperature by averaging the deformations measured for 5 representative loading cycles.

8. CALCULATIONS

8.1 As described in Section 8.1 of ASTM D4123-82.

8.2 In calculating the resilient moduli using the equations identified in 8.1, Poisson's Ratio shall be assumed. A value of 0.35 has been found to be reasonable for bituminous mixtures at 77°F (25°C). Values of 0.20 and 0.5 are to be used for 41° and 104°F (5, 40°C), respectively.

9. REPORT

The following information is to be recorded on Form T07A and Work Sheets "1" and "2" as appropriate.

9.1 Sample Identification shall include: Laboratory Identification Code, State Code, SHRP Section ID, Layer Number, Field Set Number, Sample Location Number, and SHRP Sample Number.

9.2 Test identification, shall include: SHRP Test Designation, SHRP Protocol Number, SHRP Laboratory Test Numbers and Test Date.

9.3 Report the following test results for each test specimen on Form T07A.

(a) Thickness of the test specimen, (t), to the nearest 0.1 inch.

(b) Diameter of the test specimen (D), to nearest 0.01 inch.

(c) Test temperature, to the nearest °F.

(d) Indirect tensile strength, to the nearest psi, (From Form T07B at the required temperature).

(e) Resilient load used at each temperature, to the nearest lbf.

(f) Seating load used at each temperature, to the nearest lbf.

9.4 Report the following test data for each test specimen on Work sheets "1" and "2" as appropriate.

(a) The average load level and average recoverable horizontal and vertical deformations measured (over 5 loading cycles) for each test temperature, rest period, and diametrical axis tested. The horizontal movement for each LVDT shall be reported separately.

(b) The average resilient modulus (Mr) and standard deviation calculated along each axis tested at each test temperature and load rest period.

(c) The number of preconditioning cycles used for each test temperature and axis, and the amount of cumulative permanent horizontal and vertical deformations that occurred during each of the tests.

9.5 Use Form T07A to report the following test data to SHRP.

(a) Poisson's ratio assumed at each test temperature.

(b) Average instantaneous and total resilient moduli at each rest period at each test temperature for (i) axis parallel to traffic and (ii) for axis oriented 90 degrees to traffic.

9.6 Comments shall include SHRP Standard comment code(s) as shown on Page E3 of the SHRP Laboratory Testing Guide and any other note, as needed. Additional codes for special comments associated with Protocol P07 are given below.

Code	Comment
25	The specimen was skewed (either end of the specimen departed from perpendicularity to the axis by more than 0.5 degrees or 1/8 inch in 12 inches, as tested by placing the specimen on a level surface).
26	Resilient modulus determinations were generally done within four minutes, as required in Section 7.4 of ASTM D4123-82.
27	The resilient modulus determinations were generally not done within four minutes. Average duration is shown in the accompanied note.
28	The tests were performed in a temperature control cabinet.
29	Dummy specimen was used to monitor temperature of the test

specimen during Mr testing.

30 The designated specimen was damaged and not tested. A replacement specimen from another location was used for the Mr testing.

31 Tests for all three temperatures could not be performed because the specimen was damaged during testing.

35 The line of contact between the specimen and each loading strip was straight and free from any projections or depressions higher or deeper than 0.01 inches (0.25 mm).

39 The projections/depressions on the test surface (as described in Code 35) were higher or deeper than 0.1 inch. The specimen was tested because there was no other replacement specimen.

40 The test specimen did not have any traffic direction symbol (arrow or "T"). A line was drawn to show the axis of the specimen during the first set of Mr determinations. The second set of Mr determinations were done with the axis oriented 90 degrees to the line.

9.7 The summary test data for one test specimen at one temperature, three rest periods and two axis are recorded on one sheet of Form T07A. For each test specimen and temperature, Form T07A shall be accompanied by one sheet of Worksheet "1" and one sheet of Worksheet "2". For a complete set of tests on a specimen, a total of (1) three Form T07A's, (2) three Worksheet "1"'s, (3) three Worksheet "2"'s and (4) one Form T07B.

ATTACHMENT A - TO SHRP PROTOCOL P07
DETERMINATION OF INDIRECT TENSILE STRENGTH OF ASPHALTIC CONCRETE

Attachment A of Protocol P07 describes procedures for determination of the indirect tensile strength of asphaltic concrete (bituminous concrete) using a constant load rate.

The indirect tensile strength testing shall be conducted after; (1) initial layer assignment using Form L04, (2) visual examination and thickness of asphaltic concrete (AC) cores and thickness of layers within the AC cores using Protocol P01, and (3) final layer assignment based on the P01 test results (corrected Form L04, if needed). Indirect tensile strength testing shall be conducted on asphalt concrete specimens that are greater than 1.5 inches in thickness that have been selected for testing. One test specimen shall be used for each indirect tensile strength test.

1. SCOPE

1.1 This method covers the determination of the indirect tensile strength at 77°F (25°C) of compacted dense graded, hot-mixed, hot-laid asphaltic concrete mixtures as defined by ASTM D3515 (Bituminous Paving Mixtures, Hot-Mix, Hot-Laid). For GPS pavements, this procedure is applicable to the specimens for asphaltic concrete layers of GPS-1, GPS-2, GPS-6 and GPS-7 pavements.

1.2 The value of indirect tensile strength determined by this method is used to estimate the indirect tensile stress applied to the specimens for resilient modulus determination. The values stated in inch-pound units are to be regarded as a standard. All values given in parenthesis are for information only.

2. APPLICABLE DOCUMENTS

2.1 SHRP Protocols

P01 - Visual Examination and Thickness of Asphaltic Concrete Cores
P07 - Resilient Modulus for Asphaltic Concrete

2.2 ASTM Documents

C 39 - Compressive Strength of Cylindrical Concrete Specimens

D4123 - Indirect Tension Test for Resilient Modulus of Bituminous Mixtures

D3515 - Specifications for Hot-Mixed, Hot-Laid Bituminous Paving Mixtures

3. SUMMARY OF METHOD

3.1 An asphalt concrete sample is loaded in compression along the diametrical axis at a fixed deformation rate, until failure occurs. Failure is defined as the point or deformation when the load no longer increases. This maximum load sustained by the specimen is used to calculate the indirect tensile strength.

4. SIGNIFICANCE AND USE

4.1 The value of the indirect tensile strength at 77°F (25°C) is used to estimate the indirect tensile stress (or applied load) used to determine the resilient modulus of test specimens.

5. APPARATUS

5.1 The Axial Loading Machine shall conform to the requirements of Test Method C39 and may be of any type of sufficient capacity that will provide a rate of loading (within 5 percent) of 2 inches (50.8 mm) per minute. The testing machine described in accordance with SHRP Protocol P07, Section 5.1 (Testing Machine) with additional capability for providing a compressive load at a controlled vertical deformation rate (within 5 percent) of 2 inches per minute (50.8 mm per minute) may also be used.

5.2 Loading Strip - As described in Section 5.4 of ASTM D4123.

5.3 Load Measurement - As described in Section 5.3.3 of ASTM D4123.

6. PREPARATION OF TEST SPECIMENS

6.1 Core Specimen - The cores shall have smooth and parallel surfaces and conform to the height requirement specified for specimens under Section 6.2 of this Attachment.

6.2 Specimen Size

6.2.1 The indirect tension specimen to be tested shall have a thickness of at least 1.5 inches. The thickness shall be measured prior to testing in accordance with SHRP Protocol P01, Section 5 (Procedure for Thickness Measurement).

6.2.2 The average diameter of the test specimen shall be determined prior to testing to the nearest 0.01 inches (2.5 mm) by averaging two diameters measured by a caliper at right angles to each other (the diametrical axes tested) at about mid-height of the test specimen. The average value shall be determined and reported on the data sheets (Form T07B).

6.2.3 If the average diameter of the core is outside the range of 3.85 to 4.15 inches, the core shall not be tested without coordination with and approval by the respective Regional Coordination Office.

6.3 The procedure described in Attachment B of Protocol P01 shall be followed for identifying individual layers with an asphalt concrete core. Prior to performing the test, all different materials or layers shall be separated by the use of a diamond saw. A test specimen shall consist of only one material or layer, as defined in Protocol P07.

7. PROCEDURE

7.1 Place the test specimen in a controlled temperature cabinet and follow the procedure described in Section 7.1 of ASTM D4123-82 to bring the test specimen to the test temperature of 77°F (25°C).

7.2 Mark a diametral axis, along the traffic loading direction, on the front and back faces of the specimen to be tested. An appropriate, centering type, marking device shall be used to ensure that the diametral marks on the front and back faces of the test specimen lie in the same vertical plane.

7.3 Place the test specimen in the loading apparatus and position as stated in SHRP Protocol P07. The indirect tensile strength shall be measured along the axis marked parallel to traffic (i.e. the load is being applied along the axis parallel to traffic). Adjust and balance the electronic measuring system as necessary.

7.4 Apply a compressive load at a controlled deformation rate along the axis marked parallel to traffic. A deformation rate of 2 inches (50.8 mm) per minute shall be used.

7.5 Monitor the load during the entire loading time, or until the load sustained by the specimen begins to decrease.

8. CALCULATIONS

8.1 For the specimen tested, calculate the indirect tensile strength based on the following equation:

$$S_t = ((((1.273*P_o)/t))*((\sin(57.2958/D))-((1/(2*D))))$$

or

$$S_t = 0.156\ P_o/t, \text{ for a 4 inch diameter core.}$$

where:

P_o = Maximum load sustained by the specimen, lbs.
t = Specimen thickness, inches
D = Specimen diameter, inches.

9. REPORT

The following information is to be recorded on Form T07B.

9.1 Sample Identification shall include: Laboratory Identification Code, State Code, SHRP Section ID, Field Set Number, Layer Number, Sample Location Number, SHRP Sample Number.

9.2 Test Identification shall include: SHRP Test Designation, SHRP Protocol Number, SHRP Laboratory Test Number, Test Date.

9.3 Test Results

Report the following on Form T07B.

9.3.1 Average test specimen height to the nearest 0.1 inch (2.5 mm).

9.3.2 Average test specimen diameter to the nearest 0.01 inch (0.25 mm).

9.3.3 Total maximum load sustained by the sample in pounds - force to the nearest whole number.

9.3.4 Indirect tensile strength to the nearest psi.

9.3.5 Comments shall include SHRP Standard comment code(s) as shown on Page E3 of the SHRP Laboratory Testing Guide and any other note as needed.

9.3.6 Test date.

ATTACHMENT 2

This attachment contains the necessary worksheets needed to record the data generated in the AC molded sample proficiency testing program. Only one Worksheet "1" is required, however, multiple copies (≈ 100) should be made of Worksheet "2" and Worksheet "3", respectively.

WORKSHEET 1 - PAGE 1
SHRP AC MOLDED PROFICIENCY SAMPLE PROGRAM
GENERAL SPECIMEN INFORMATION

SHEET NO. ____ OF ____

SPECIMEN ID NUMBER	WEIGHT OF AGGREGATE USED (GRAMS)	WEIGHT OF ASPHALT CEMENT USED (GRAMS)	DIAMETER (IN.)	HEIGHT (IN.)	WEIGHT (GRAMS)	BSG	VOID CONTENT (%)
AC-10, ___A1	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-10, ___A2	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-10, ___B1	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-10, ___B2	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-10, ___A1	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-10, ___A2	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-10, ___B1	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-10, ___B2	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-10, ___A1	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-10, ___A2	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-10, ___B1	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-10, ___B2	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-10, ___A1	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-10, ___A2	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-10, ___B1	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-10, ___B2	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __

WORKSHEET 1 - PAGE 2
SHRP AC MOLDED PROFICIENCY SAMPLE PROGRAM
GENERAL SPECIMEN INFORMATION

SHEET NO. ____ OF ____

SPECIMEN ID NUMBER	WEIGHT OF AGGREGATE USED (GRAMS)	WEIGHT OF ASPHALT CEMENT USED (GRAMS)	DIAMETER (IN.)	HEIGHT (IN.)	WEIGHT (GRAMS)	BSG	VOID CONTENT (%)
AC-30, ____A1	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-30, ____A2	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-30, ____B1	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-30, ____B2	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-30, ____A1	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-30, ____A2	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-30, ____B1	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-30, ____B2	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-30, ____A1	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-30, ____A2	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-30, ____B1	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-30, ____B2	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-30, ____A1	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-30, ____A2	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-30, ____B1	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __
AC-30, ____B2	__ __ __ __.__	__ __ __ __.__	__.__	__.__	__ __ __ __.__	_._ _ _	__ . __

WORKSHEET 1 - PAGE 3
SHRP AC MOLDED PROFICIENCY SAMPLE PROGRAM
GENERAL SPECIMEN INFORMATION

SHEET NO. ____ OF ____

GENERAL COMMENTS: (use as many sheets as necessary to list any general or special comments).

WORKSHEET 2
SHRP AC MOLDED PROFICIENCY SAMPLE PROGRAM
ORIGINAL AXIS (AXIS ROTATED 0°)

SHEET NO ____ OF ____

SHRP SAMPLE NUMBER ________________ *TEST TEMPERATURE* __ __ __.__ °F
PRECONDITIONING: (a) LOAD __ __ __. (b) NO. OF CYCLES __ __ __ __
TEST DATE __ __-__ __-__ __ __ __

			INSTANTANEOUS			TOTAL		
REST PERIOD	LOAD CYCLE	VERTICAL LOAD, LB.	VERTICAL DEFORMATION	HORIZONTAL DEFORMATION LVDT 1	HORIZONTAL DEFORMATION LVDT 2	VERTICAL DEFORMATION	HORIZONTAL DEFORMATION LVDT 1	HORIZONTAL DEFORMATION LVDT 2
0.9	1	__ __ __.	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __
	2	__ __ __.	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __
	3	__ __ __.	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __
	4	__ __ __.	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __
	5	__ __ __.	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __
1.9	1	__ __ __.	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __
	2	__ __ __.	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __
	3	__ __ __.	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __
	4	__ __ __.	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __
	5	__ __ __.	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __
2.9	1	__ __ __.	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __
	2	__ __ __.	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __
	3	__ __ __.	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __
	4	__ __ __.	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __
	5	__ __ __.	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __	.__ __ __ __ __ __

COMMENT CODES: __ __ __ __ __ __ __ __ __ __ __ __
GENERAL REMARKS: ____

Submitted By, Date ________________ Checked and Approved, Date ________________

Affiliation ________________ Affiliation ________________

WORKSHEET 3

SHRP AC MOLDED PROFICIENCY SAMPLE PROGRAM

PERPENDICULAR AXIS (AXIS ROTATED 90°)

SHEET NO ____ OF ____

SHRP IDENTIFICATION NUMBER ____________ TEST TEMPERATURE _ _ _._ °F

PRECONDITIONING: (a) LOAD _ _ _. (b) NO. OF CYCLES _ _ _ _

TEST DATE _ _-_ _-_ _ _ _

			INSTANTANEOUS			TOTAL		
REST PERIOD	LOAD CYCLE	VERTICAL LOAD, LBF	VERTICAL DEFORMATION	HORIZONTAL DEFORMATION LVDT 1	HORIZONTAL DEFORMATION LVDT 2	VERTICAL DEFORMATION	HORIZONTAL DEFORMATION LVDT 1	HORIZONTAL DEFORMATION LVDT 2
0.9	1	_ _ _.	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _
	2	_ _ _.	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _
	3	_ _ _.	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _
	4	_ _ _.	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _
	5	_ _ _.	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _
1.9	1	_ _ _.	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _
	2	_ _ _.	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _
	3	_ _ _.	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _
	4	_ _ _.	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _
	5	_ _ _.	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _
2.9	1	_ _ _.	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _
	2	_ _ _.	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _
	3	_ _ _.	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _
	4	_ _ _.	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _
	5	_ _ _.	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _

COMMENT CODES: _ _ _ _ _ _ _ _ _ _ _ _

GENERAL REMARKS: ____________________

Submitted By, Date ____________ Checked and Approved, Date ____________

Affiliation ____________ Affiliation ____________

ATTACHMENT 3

COMMENT CODE	SHRP STANDARD COMMENT
02	The test specimen is flawed, not ideal, still tested.
03	Procedural mistake is made by the laboratory or the laboratory suspects that some test parts were not in strict conformance to the protocol.
04	Test results (partially) do not seem reasonable; no explanation is provided.
05	Test results (partially) do not seem reasonable; explanation is provided in the following note.
06	Test is suspect, sample was misnumbered.
07	Test is suspect, sample was not correctly identified.
08	Equipment was not in calibration (found after inspection).
09	L/D (specimen length to diameter) ratio is not according to the requirement of the test for layer thickness.
10	L/D ratio is not according to the requirement for maximum size aggregate.
11	The technician's results are not consistent with the previous technician's results.
12	This test is a replacement for the previous test.
13	SHRP has directed a deviation in the test procedure.
99	Other comment (see the following note).

On the test data form, the SHRP standard comment code may be followed by an explanatory note.

Round 1 Hot Mix Asphalt
Laboratory Molded Proficiency Sample Programs.

Four additional items were conveyed to participants subsequent to distribution of the initiating letter. The items are listed below.

°The % passing the #4 screen in all samples is:

60%

°Specific gravity and absorption of the aggregate in Round 1 is:

<u>AASHTO T-85</u>
bulk specific gravity=2.66
bulk specific gravity SSD=2.69
apparent specific gravity=2.75
absorption or moisture SSD=1.27%
<u>AASHTO T-84</u>
bulk specific gravity=2.63
bulk specific gravity SSD=2.66
apparent specific gravity=2.73
absorption or moisture SSD=1.42%

°Specific gravity of the asphalt cement in Round 1 is:

AC-10=1.030
AC-30=1.035

°Use about ½ the energy for compacting the 1½" length specimens that is used for compacting the 3" length specimens. Compact test specimens only by means of the gyratory or the kneading compactor.

APPENDIX B

Averages and Standard Deviations
for
Laboratory Molded
Hot Mix Asphalt Specimens

Note: In the following table, the laboratory averages for the resilient modulus, ALL_MEAN, is an overall estimate of the resilient modulus for a 0.9 second recovery period.

TYPE	AC	TEMP	SIZE	LAB	AVERMR	ALL_MEAN	STD	CV	NS
I	10	40	1.5	A	434352	778054	56419	13	2
I	10	40	1.5	B	22981	778054	2104	9	4
I	10	40	1.5	C	280288	778054	56035	20	8
I	10	40	1.5	F	1325133	778054	63741	5	16
I	10	40	1.5	G	1673180	778054	262903	16	16
I	10	40	1.5	H	687157	778054	119305	17	13
I	10	40	1.5	I	526307	778054	194655	37	16
I	10	40	1.5	J	519962	778054	294422	57	14
I	10	40	3.0	A	563596	946758	111448	20	2
I	10	40	3.0	B	20379	946758	2795	14	7
I	10	40	3.0	C	309728	946758	99508	32	8
I	10	40	3.0	F	1097814	946758	74044	7	16
I	10	40	3.0	G	1763951	946758	326558	19	16
I	10	40	3.0	H	1391962	946758	560823	40	16
I	10	40	3.0	I	583387	946758	122428	21	16
I	10	40	3.0	J	916870	946758	602168	66	15
I	10	77	1.5	A	178680	275024	20857	12	2
I	10	77	1.5	B	16950	275024	4289	25	7
I	10	77	1.5	C	239694	275024	48567	20	8
I	10	77	1.5	F	308119	275024	31503	10	16
I	10	77	1.5	G	582464	275024	113438	19	16
I	10	77	1.5	H	201010	275024	27655	14	13
I	10	77	1.5	I	265970	275024	102725	39	15
I	10	77	1.5	J	149231	275024	80308	54	15
I	10	77	3.0	A	146741	267896	20088	14	2
I	10	77	3.0	B	15706	267896	1764	11	9
I	10	77	3.0	C	198570	267896	57651	29	8
I	10	77	3.0	F	251082	267896	25455	10	16
I	10	77	3.0	G	456297	267896	73468	16	16
I	10	77	3.0	H	302511	267896	105521	35	16
I	10	77	3.0	I	277949	267896	91150	33	16
I	10	77	3.0	J	242118	267896	73834	30	15
I	10	104	1.5	A	85215	207814	17264	20	2
I	10	104	1.5	B	8264	207814	1972	24	4
I	10	104	1.5	C	156266	207814	71010	45	8
I	10	104	1.5	F	125328	207814	14000	11	16
I	10	104	1.5	G	818773	207814	504898	62	16
I	10	104	1.5	H	74464	207814	6324	8	14
I	10	104	1.5	I	70156	207814	23758	34	16
I	10	104	1.5	J	124495	207814	87488	70	15
I	10	104	3.0	A	89853	103443	45289	50	2
I	10	104	3.0	B	5758	103443	742	13	6
I	10	104	3.0	C	103261	103443	36446	35	8
I	10	104	3.0	F	79117	103443	11071	14	16
I	10	104	3.0	G	149769	103443	30316	20	16
I	10	104	3.0	H	147716	103443	71646	49	16
I	10	104	3.0	I	78018	103443	41434	53	16
I	10	104	3.0	J	76365	103443	25919	34	16

TYPE	AC	TEMP	SIZE	LAB	AVERMR	ALL_MEAN	STD	CV	NS
I	30	40	1.5	A	561476	1134075	213794	38	6
I	30	40	1.5	B	42389	1134075	8463	20	7
I	30	40	1.5	C	824325	1134075	151670	18	8
I	30	40	1.5	F	1753156	1134075	233672	13	16
I	30	40	1.5	G	2176904	1134075	192568	9	16
I	30	40	1.5	H	1010262	1134075	283918	28	16
I	30	40	1.5	I	718953	1134075	165428	23	16
I	30	40	1.5	J	893448	1134075	398936	45	15
I	30	40	3.0	A	656259	1288217	288361	44	6
I	30	40	3.0	B	34435	1288217	3745	11	6
I	30	40	3.0	C	719031	1288217	195039	27	8
I	30	40	3.0	F	1488571	1288217	136165	9	14
I	30	40	3.0	G	2204412	1288217	189717	9	16
I	30	40	3.0	H	2099020	1288217	691967	33	16
I	30	40	3.0	I	833851	1288217	225498	27	16
I	30	40	3.0	J	1016378	1288217	357499	35	15
I	30	77	1.5	A	402437	439824	86397	21	6
I	30	77	1.5	B	50454	439824	5858	12	7
I	30	77	1.5	C	486355	439824	135497	28	8
I	30	77	1.5	F	563105	439824	53420	9	16
I	30	77	1.5	G	769527	439824	40108	5	16
I	30	77	1.5	H	261286	439824	55908	21	16
I	30	77	1.5	I	305826	439824	77820	25	16
I	30	77	1.5	J	290233	439824	101017	35	15
I	30	77	3.0	A	372965	514919	96170	26	6
I	30	77	3.0	B	34891	514919	3160	9	6
I	30	77	3.0	C	491814	514919	77710	16	8
I	30	77	3.0	F	495184	514919	46522	9	14
I	30	77	3.0	G	664304	514919	34785	5	16
I	30	77	3.0	H	632822	514919	118809	19	16
I	30	77	3.0	I	410813	514919	116366	28	16
I	30	77	3.0	J	536532	514919	130845	24	16
I	30	104	1.5	A	164046	185952	33001	20	6
I	30	104	1.5	B	19202	185952	4452	23	8
I	30	104	1.5	C	286832	185952	91258	32	8
I	30	104	1.5	F	191245	185952	22241	12	16
I	30	104	1.5	G	303218	185952	41368	14	16
I	30	104	1.5	H	84203	185952	20154	24	15
I	30	104	1.5	I	142842	185952	36744	26	16
I	30	104	1.5	J	129280	185952	65136	50	16
I	30	104	3.0	A	141806	177283	38450	27	6
I	30	104	3.0	B	13925	177283	2229	16	7
I	30	104	3.0	C	253357	177283	90898	36	8
I	30	104	3.0	F	167725	177283	25869	15	14
I	30	104	3.0	G	202243	177283	16698	8	16
I	30	104	3.0	H	162807	177283	33588	21	16

TYPE	AC	TEMP	SIZE	LAB	AVERMR	ALL_MEAN	STD	CV	NS
I	30	104	3.0	I	158067	177283	76459	48	16
I	30	104	3.0	J	154974	177283	64760	42	16
T	10	40	1.5	A	372333	554643	20804	6	2
T	10	40	1.5	B	18321	554643	1472	8	4
T	10	40	1.5	C	230906	554643	49278	21	8
T	10	40	1.5	F	904400	554643	42395	5	16
T	10	40	1.5	G	979961	554643	202837	21	16
T	10	40	1.5	H	545749	554643	110708	20	13
T	10	40	1.5	I	486123	554643	184351	38	16
T	10	40	1.5	J	363031	554643	179824	50	14
T	10	40	3.0	A	493581	678021	56822	12	2
T	10	40	3.0	B	15830	678021	2010	13	7
T	10	40	3.0	C	244807	678021	70915	29	8
T	10	40	3.0	F	725625	678021	41624	6	16
T	10	40	3.0	G	1046927	678021	177614	17	16
T	10	40	3.0	H	1130144	678021	625963	55	16
T	10	40	3.0	I	528966	678021	110966	21	16
T	10	40	3.0	J	576095	678021	252664	44	15
T	10	77	1.5	A	123962	147677	2395	2	2
T	10	77	1.5	B	12410	147677	2123	17	7
T	10	77	1.5	C	177859	147677	44074	25	8
T	10	77	1.5	D	137836	147677	14841	11	16
T	10	77	1.5	E	111901	147677	20656	18	16
T	10	77	1.5	F	147826	147677	15479	10	16
T	10	77	1.5	G	156671	147677	46673	30	16
T	10	77	1.5	H	154144	147677	19593	13	13
T	10	77	1.5	I	221296	147677	84415	38	15
T	10	77	1.5	J	97602	147677	46114	47	15
T	10	77	3.0	A	96462	147801	13062	14	2
T	10	77	3.0	B	12321	147801	1251	10	9
T	10	77	3.0	C	142737	147801	43476	30	8
T	10	77	3.0	D	116746	147801	15502	13	16
T	10	77	3.0	E	91203	147801	15045	16	16
T	10	77	3.0	F	125641	147801	11329	9	16
T	10	77	3.0	G	157839	147801	44474	28	16
T	10	77	3.0	H	218296	147801	53027	24	16
T	10	77	3.0	I	231366	147801	75463	33	16
T	10	77	3.0	J	149915	147801	39938	27	15
T	10	104	1.5	A	56317	55657	12775	23	2
T	10	104	1.5	B	6234	55657	1392	22	4
T	10	104	1.5	C	114216	55657	53163	47	8
T	10	104	1.5	D	29902	55657	4394	15	16
T	10	104	1.5	E	22169	55657	3625	16	16
T	10	104	1.5	F	40845	55657	4799	12	16
T	10	104	1.5	G	42716	55657	19453	46	16
T	10	104	1.5	H	64801	55657	6218	10	14
T	10	104	1.5	I	59703	55657	19851	33	16

TYPE	AC	TEMP	SIZE	LAB	AVERMR	ALL_MEAN	STD	CV	NS
T	10	104	1.5	J	70241	55657	39313	56	15
T	10	104	3.0	A	57092	50346	27492	48	2
T	10	104	3.0	B	4353	50346	757	17	6
T	10	104	3.0	C	71569	50346	30084	42	8
T	10	104	3.0	D	20107	50346	2887	14	16
T	10	104	3.0	E	11487	50346	1895	16	16
T	10	104	3.0	F	32576	50346	4722	14	16
T	10	104	3.0	G	30802	50346	11176	36	16
T	10	104	3.0	H	108832	50346	46628	43	16
T	10	104	3.0	I	72628	50346	39960	55	14
T	10	104	3.0	J	48018	50346	13615	28	16
T	30	40	1.5	A	446912	869682	235834	53	6
T	30	40	1.5	B	35570	869682	6627	19	7
T	30	40	1.5	C	628170	869682	124452	20	8
T	30	40	1.5	F	1312013	869682	188403	14	16
T	30	40	1.5	G	1549600	869682	163361	11	16
T	30	40	1.5	H	843247	869682	268610	32	16
T	30	40	1.5	I	644167	869682	139699	22	15
T	30	40	1.5	J	663663	869682	200810	30	15
T	30	40	3.0	A	579351	1018814	235668	41	6
T	30	40	3.0	B	29370	1018814	3454	12	6
T	30	40	3.0	C	564115	1018814	157031	28	8
T	30	40	3.0	F	1108287	1018814	96059	9	14
T	30	40	3.0	G	1546911	1018814	201667	13	16
T	30	40	3.0	H	1823018	1018814	644055	35	16
T	30	40	3.0	I	768787	1018814	211656	28	15
T	30	40	3.0	J	741230	1018814	217747	29	15
T	30	77	1.5	A	285672	270326	61869	22	6
T	30	77	1.5	B	39692	270326	6432	16	7
T	30	77	1.5	C	364275	270326	98249	27	8
T	30	77	1.5	D	220410	270326	42071	19	16
T	30	77	1.5	E	315795	270326	29580	9	16
T	30	77	1.5	F	288184	270326	19569	7	16
T	30	77	1.5	G	300956	270326	23785	8	16
T	30	77	1.5	H	196741	270326	44973	23	16
T	30	77	1.5	I	257083	270326	63908	25	16
T	30	77	1.5	J	203822	270326	65275	32	15
T	30	77	3.0	A	253185	297719	52349	21	6
T	30	77	3.0	B	27455	297719	2992	11	6
T	30	77	3.0	C	364717	297719	78933	22	8
T	30	77	3.0	D	194205	297719	32211	17	16
T	30	77	3.0	E	302543	297719	40796	13	16
T	30	77	3.0	F	257850	297719	19000	7	14
T	30	77	3.0	G	284749	297719	29508	10	16
T	30	77	3.0	H	442468	297719	28213	6	14
T	30	77	3.0	I	367075	297719	113429	31	16

TYPE	AC	TEMP	SIZE	LAB	AVERMR	ALL_MEAN	STD	CV	NS
T	30	77	3.0	J	357428	297719	76319	21	16
T	30	104	1.5	A	112259	93747	21689	19	6
T	30	104	1.5	B	14378	93747	3215	22	8
T	30	104	1.5	C	208037	93747	83298	40	8
T	30	104	1.5	D	61201	93747	6074	10	16
T	30	104	1.5	E	59886	93747	5413	9	16
T	30	104	1.5	F	72132	93747	9379	13	16
T	30	104	1.5	G	63735	93747	13062	20	16
T	30	104	1.5	H	66859	93747	20789	31	15
T	30	104	1.5	I	118944	93747	30673	26	16
T	30	104	1.5	J	80668	93747	41174	51	16
T	30	104	3.0	A	94069	93613	21369	23	6
T	30	104	3.0	B	10585	93613	1658	16	7
T	30	104	3.0	C	183960	93613	66859	36	8
T	30	104	3.0	D	44349	93613	6902	16	16
T	30	104	3.0	E	40778	93613	7621	19	16
T	30	104	3.0	F	66124	93613	10422	16	14
T	30	104	3.0	G	54192	93613	3311	6	16
T	30	104	3.0	H	119429	93613	24789	21	16
T	30	104	3.0	I	132025	93613	64055	49	16
T	30	104	3.0	J	107592	93613	38880	36	16