SHRP-P-690

Asphalt Concrete Synthetic Reference Sample Program and the LTPP Asphalt Concrete Core Proficiency Sample Program

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Steele Engineering, Inc.
Tornado, West Virginia

Strategic Highway Research Program
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Contents

Abstract

All laboratories conducting tests for the LTPP program were required to be accredited by the AASHTO Accreditation Program (AAP). AAP includes site inspections of equipment and procedures, and participation in applicable proficiency sample testing. A few critical LTPP tests were not addressed fully by the AAP, and LTPP decided to conduct supplemental testing. The asphalt concrete synthetic reference sample program and the asphalt concrete core proficiency sample program were among the supplemental programs approved for implementation.

In the first of these two programs, a set of four specimens was circulated to all participating laboratories for testing in accordance with specified parameters. In the second program, two sets of cores (five per set) were shipped to the laboratories. Twenty-four laboratories participated in either one or both programs.

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

Part I, Summary of Research

Summary

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 on LTPP field samples were addressed by the AAP, which includes on site inspections of equipment and procedures, and participation in applicable proficiency sample series. However, a few critical tests in the SHRP LTPP studies, such as the diametral resilient modulus test, were not fully addressed. 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 Asphalt Concrete Synthetic Reference Sample Program and the Asphalt Concrete Core Proficiency Sample Program were among the supplemental programs approved for implementation.

The AC synthetic reference sample program was designed to verify calibration and stability of diametral resilient modulus test systems. The AC core proficiency sample program was designed to provide within laboratory and among laboratories precision data for tests performed in accordance with test protocol P07 for determining the diametral resilient modulus of asphalt concrete mixes. Further objectives included the drafting of single operator and multilaboratory precision statements in AASHTO/ASTM format, the determination of testing proficiency status for SHRP contract laboratories in accordance with the concepts used in proficiency sample programs at the National Institute for Standards and Technology (NIST), and preservation of information concerning the proficiency of SHRP contract laboratories in the LTPP data base for access by researchers using data generated from tests on LTPP field samples.

The Asphalt Concrete Synthetic Reference Sample research was designed, and synthetic specimens were obtained and prepared for shipment to participants by the Chevron Research Laboratory in Richmond, California. The raw data from this research was collected, collated, analyzed, and the results reported by Nittany Engineers and Management Consultants, Inc. (NEMC), of State College, Pennsylvania, in conjunction with the asphalt concrete core research. Management and oversight of the research was assigned to Steele Engineering, Inc.(SEI) of Tornado, West Virginia by SHRP.

The Asphalt Concrete Core Proficiency Sample research was performed under a SHRP contract by NEMC. Contract oversight was assigned to SEI by SHRP. Subsequent to completing the research plan design, NEMC obtained the cores required from the Pennsylvania State University Test Track, prepared the cores for shipment, and distributed them to participating laboratories. Raw test data was collected, collated, analyzed, and a report prepared by NEMC documenting results of the research.

In the AC Synthetic Reference Sample Program, a set of four SHRP reference specimens was rotated to all participating laboratories for testing in accordance with certain specified parameters. The initial reference specimen tests by each participant were blind, that is, the participant did not know the reference values. In subsequent testing by the same participant(which has universally occurred with only one exception) the acceptable range of reference values was revealed. The intent of this procedure was to provide participants with an opportunity to verify the calibration of their diametral resilient modulus testing system by testing the set of four synthetic reference specimens using standardized parameters. When response was not within the anticipated range, recalibration of the system was indicated. when response was within the anticipated range, authorization was given to proceed with testing the AC core proficiency samples.

In the Asphalt Concrete Core Proficiency Sample Program, two sets of core specimens (5 per set) were shipped to participating laboratories. Instructions accompanied each core shipment directing that cores were to be tested only after successful verification of system calibration using the synthetic reference set.

Twenty-four laboratories participated in either one or both programs. All participants made significant contributions to the success of the LTPP research effort. A list of participants is in Part II of this report.

A copy of the initiating letters and worksheets for these programs is also included in Part II.

The final combined unabridged comments and analyses for both the AC Synthetic Reference Sample Program and the AC Core Proficiency Sample Program are contained in Part III of this report.

A complete set of proficiency sample statements in AASHTO/ASTM format is contained in Appendix E of Part III.

Part II, List of Participants

Participating Laboratories

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

The Asphalt Institute
Research Park Drive
PO Box 14052
Lexington, KY 40512-4052

Chevron Research Company
Richmond, CA

Department of Civil Engineering
238 Harbert Engineering Center
Auburn University, AL 36849533

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

California Department of Transportation
5900 Folsom Boulevard, P O Box 19128
Sacramento, CA 95819

Federal Highway Adminstration
Central Direct Federal Division
PO Box 25246
Denver, CO 8022

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

Office of Materials
Iowa Department of Transportation
826 Lincoln Way
Ames, IA 50010

Materials and Research Center
Kansas Department of Transportation
2300 Van Buren Street
Topeka, KA 66611^R

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

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

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

Department of Civil and Mineral Engineering
University of Minnesota
500 Pillsbury Drive, S.E.
Minneapolis, MN 55455

MTS Systems Corporation
14000 Technology Drive
Eden Prairie, MN 55344-2290

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

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

North Carolina State University
Civil Engineering Department
Box 7908
Raliegh, NC 27695-7908

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

Transportation Research Institute
Oregon State University
201 Apperson Hall
Corvallis, OR 97331

Sahuaro Petroleum and Asphalt Company
1935 West McDowell Road
PO Box 6536
Phoenix, AZ 85005

Geotechnical and Materials Branch
Saskatchewan Highway and Transportation Department
1610 Park Street
Regina, Saskatchewan Canada S4P3V7

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

Steele Engineering, Inc.

December 20, 1989

^F1^
^F2^

Dear ^F3^:

Subject: SHRP asphalt concrete core proficiency sample program for resilient modulus (M_R) testing.

First, I want to thank each of you for agreeing to participate in this proficiency sample series. Further, in my opinion, this series of experiments is absolutely critical to the highest and best use of M_R data gathered as part of the SHRP Long Term Pavement Performance (LTPP) research. As a proficiency sample cooperator, your organization will be participating in the development of data required to determine the precision (and certain components of variance) of SHRP protocol P07, the M_R test for asphalt concrete.

It has been determined that the first step toward assuring the reliability of data obtained from test systems required by P07 is calibration. Briefly P07 requires a closed loop electrohydraulic testing machine with a function generator capable of applying varying haversine load pulses, durations, levels, and rest periods; from ASTM D4123-82 - a temperature control system as described in section 5.2, a recorder as described in section 5.3.1, load measurements as described in section 5.3.3, and loading strip as described in section 5.4; and deformations measured with flat head (3/8"x1/4") LVDTs wired to allow independent readings with results summed independently.

SHRP has been provided with a Triaxial Institute calibration proceedure that has been quite successful in reducing testing system variability. A copy is attached for your information and use. A set of synthetic reference specimens (as indicated in the calibration proceedure) will be rotated through your laboratory on a loan basis for use in verifying the calibration of your test system. These specimens are to be tested after calibration of the system as set forth in 5.6 of the attachment, and recorded on the form included under the block titled TEST DATA ON CALIBRATED EQUIPMENT.

Box 173 • Tornado, West Virginia 25202 • Tele. (304) 727-8719

To minimize delays, the laboratory should call me at 304-727-8719, or Robin High of TRDF in Austin, Texas at 1-800-234-8733 to determine whether the results are in the expected range. If so, the data forms are to be returned to my address. If not, the system should be recalibrated and the reference specimens tested again. It is anticipated that each laboratory will-

- °carefully unpack the reference specimens when received
- °retain the reference specimens no more than 2 work days
- °cross off your address before re-enclosing the shipping list
- °repack the reference specimens in the same or equivalent packaging
- °ship to the next laboratory on the list enclosed with the shipment

When the above indicated calibration and verification is completed, the laboratory may proceed with testing of the asphalt concrete core proficiency samples that will be distributed, along with forms and instructions, by David Anderson, Nittany Engineers and Management Consultants, Inc., 763 Cornwall Road, State College, PA 16803.

Please let me know if you have questions or comments.

Yours very truly

Garland W. Steele, P.E.
Steele Engineering, Inc.

att: 10 pages

cc: David Anderson
Robin High
Adrian Pelzner

Nittany Engineers and Management Consultants, Inc.

736 Cornwall Road • State College, Pennsylvania 16803 • (814) 237-6500

David A. Anderson Ph.D., P.E.; President-Treasurer
H. Randolph Thomas Ph.D., P.E.; Secretary

March 30, 1990

Mr. Garland Steele
Steele Engineering Inc.
Box 173
Tornado, WV 25202

Re: SHRP Asphalt Concrete Core Proficiency Sample Program for Modulus (M_R) Testing

Dear Mr. Steele:

I am enclosing an example of the letters that have been sent to the various laboratories that are participating in the SHRP Asphalt Concrete Core Proficiency Sample Program. The letters were sent to those listed on the enclosed list.

The cores have been sent to each laboratory. They should be in the hands of each laboratory during the week of April 2, 1990. As noted in the letter, the data from the reference cores are to be sent to Nittany Engineers. We will wait for your instructions before proceeding to analyze the data.

Sincerely,

David A. Anderson
President

DAA/rat

Attachments

Nittany Engineers and Management Consultants, Inc.

736 Cornwall Road • State College, Pennsylvania 16803 • (814) 237-6500

David A. Anderson Ph.D., P.E.; President-Treasurer
H. Randolph Thomas Ph.D., P.E.; Secretary

^D (March 23, 1990)

^F1^
^F3^

Re: SHRP Asphalt Concrete Core Proficiency Sample Program for Modulus (M_R) Testing

Dear ^F4^:

Nittany Engineers and Management Consultants, Inc. has been contracted by SHRP to provide cores and data analysis services for the SHRP Asphalt Concrete Core Proficiency Sample Program. Two sets of cores are being shipped to your laboratory for resilient modulus testing. However, the synthetic reference specimens and the calibration testing must be completed before these cores are tested. SHRP is further requiring that the reference core data from the laboratories be analyzed before the testing of the cores is to start. Therefore, please do not unpack the cores until you are instructed to do so by Mr. Garland Steele of Steele Engineering. The cores are well protected in their shipping package and should be stored unpacked at room temperature until you are instructed to proceed.

The protocol for calibrating your equipment is specified in an attachment that was included with a recent letter sent to you by Mr. Garland Steele. This protocol was developed by the Triaxial Institute and should be followed by your laboratory. Load cells, proving rings, or other transducers used in the calibration should be traceable to the Bureau of Standards (now the National Institute for Standards and Technology, NIST). The calibration should be performed just prior to the testing of either the reference specimens.

The forms included with this letter must be used to record the data from the reference specimens or the cores. Please xerox the forms as needed and fill them out as indicated, using a new cover sheet (Worksheet 1) each time that the reference specimens or cores are tested. The actual test data are to be recorded on Worksheet 2.

Two sets of specimens (5 specimens per set) are being sent to you from Nittany Engineers and Management Consultants, Inc. via UPS. The specimens are identified by the letter "O" or "N" followed by a two digit specimen number. Each set of cores is to be tested twice, on separate days, preferably a week apart. The order of testing should be assigned randomly and a different random order assigned on different days. These cores have not been trafficked and, consequently, there is no traffic direction marked on the cores. There are, however two diametral lines, labeled A or B, marked on each core. Each time a core is tested, randomly choose direction A or B for the first set of readings--do not systematically test one direction first.

The protocol for testing the reference specimens was sent to you previously. The protocol for testing the cores (P07) is included with this letter and must be followed when you test the cores. Once again, be certain to complete both worksheets each time the cores are tested. The worksheets are to be returned by regular US mail to Nittany Engineers at the following address:

Dr. David A. Anderson
736 Cornwall Road
State College, PA 16803
Telephone: (814) 237-6500

The tensile strength for the two sets of pavement cores that are being shipped to you have been determined (77°F) as follows:

Cores identified with "N", 223 lb/in^2
Cores identified with "O", 61 lb/in^2

Most likely you have already tested the reference specimens. If this is the case please complete the forms and return them to the address cited above. If you have not tested the reference specimens then please do so promptly when they are received and return the data forms so that the analysis of the data may be completed, thereby allowing the testing of the cores to proceed.

Sincerely yours,

David A. Anderson
President

DAA/rat

Attachments

cc: G. Steele
A. Pelzner

Nittany Engineers and Management Consultants, Inc.

736 Cornwall Road • State College, Pennsylvania 16803 • (814) 237-6500

David A. Anderson Ph.D., P.E.; President-Treasurer
H. Randolph Thomas Ph.D., P.E.; Secretary

May 26, 1990

Re: SHRP Asphalt Concrete Core Proficiency Sample Program for Modulus (M_R) Testing

Dear

The data forms that were sent to you previously did not have space to record both the instantaneous and recoverable vertical deformation. The enclosed forms have been revised to accommodate both instantaneous and vertical deformation and, in addition, include several minor editorial revisions.

Please complete the attached forms and forward to my address as soon as possible.

At this point only one of the participating laboratories has returned the forms. It is important that they be returned as soon as possible so that the data can be analyzed as per SHRP's request. Your early cooperation will be appreciated.

Sincerely yours,

David A. Anderson
President

DAA/rla

Attachments

cc: G. Steele
A. Pelzner

WORKSHEET NO. 1

SPECIMEN AND TEST DESCRIPTION
SHRP ASPHALT CONCRETE CORE PROFICIENCY SAMPLE PROGRAM

1. Specimen set identification code[1] 2357
2. Specimen number[2] _ 1
3. Direction of load[3] _
4. Test replication[4] _
5. Specimen thickness, in (to 0.01 in)
   1. _._ _ 2. _._ _ 3. _._ _ 4. _._ _ Avg. _._ _
6. Specimen diameter, in (to 0.01 in)
   1. _._ _ 2. _._ _ Avg. _._ _
7. Date of testing Day _ _ Month _ _ Year _ _
8. Comments[5] _ _ _ _ _ _ _ _ _ _ _ _
9. Written comments:

____

____

____

____

____

NOTES:

[1] Enter a letter according to the following:
- L for lucite reference specimen
- P for polypropylene reference specimen
- R for neophene rubber reference specimen
- F for teflon reference specimen
- N for the set of cores marked with the letter N
- O for the set of cores marked with the letter O

[2] Enter the one or two digit specimen number on the core
[3] Enter diametral direction, A or B as marked on cores, in which the load is applied
[4] Enter "1" or "2" according to whether the cores are being tested for the first or second time
[5] Use comment code as per SHRP Standard comment code(s) as shown on Page E3 of the SHRP Laboratory Testing Guide and on page P07-8 of SHRP Protocol P07.

WORKSHEET NO. 2

TEST DATA

SHRP ASPHALT CONCRETE CORE PROFICIENCY SAMPLE PROGRAM

1. Specimen set identification code __
2. Specimen number __ __
3. Direction of load __
4. Test replication __
5. Test temperature, °F (as measured) __ __ __.__
6. Preconditioning: Load _______ lb Number of Cycles __ __ __
7. Date of testing Day __ __ Month __ __ Year __ __

8. Recovery period, 0.9 seconds (report deformation in 0.001 in)

Load Cycle	Vertical Load, lb	Instantaneous Deformation			Total Deformation		
		Vertical	Horiz 1	Horiz 2	Vertical	Horiz 1	Horiz 2
1							
2							
3							
4							
5							

9. Recovery period, 1.9 seconds (report deformation in 0.001 in)

Load Cycle	Vertical Load, lb	Instantaneous Deformation			Total Deformation		
		Vertical	Horiz 1	Horiz 2	Vertical	Horiz 1	Horiz 2
1							
2							
3							
4							
5							

(continued on back)

WORKSHEET NO. 2

TEST DATA
SHRP ASPHALT CONCRETE CORE PROFICIENCY SAMPLE PROGRAM

1. Specimen set identification code _
2. Specimen number _ _
3. Direction of load _
4. Test replication _
5. Test temperature, °F (as measured) _ _ _._

10. Recovery period, 2.9 seconds (Report deformation in 0.001 in)

Load Cycle	Vertical Load, lb	Instantaneous Deformation			Total Deformation		
		Vertical	Horiz 1	Horiz 2	Vertical	Horiz 1	Horiz 2
1							
2							
3							
4							
5							

Submitted by

Date: ______________

____

Affiliation:

____

____

Checked and approved by

Date: ______________

____

Affiliation:

____

____

Nittany Engineers and Management Consultants, Inc.

736 Cornwall Road • State College, Pennsylvania 16803 • (814) 237-6500

David A. Anderson Ph.D., P.E.; President-Treasurer
H. Randolph Thomas Ph.D., P.E.; Secretary

^D (June 20, 1990)

^F1^
^F3^

Re: SHRP Asphalt Concrete Core Proficiency Sample Program for Modulus (M_R) Testing

Dear ^F4^:

Apparently there is some confusion regarding the sequence of events regarding the test program. Please note the following:

- Step 1. Reference specimens are sent to each laboratory for testing.

- Step 2. Data from reference specimens are sent by the individual participating laboratories to Nittany Engineers for statistical analysis. The purpose of the analysis is to be certain that the individual laboratories are producing reliable data.

- Step 3. After the data from the reference cores have been analyzed and the results reported to Garland Steele, official approval to proceed with the testing of the hot-mix cores will be sent by Garland Steele to the participating laboratories.

- Step 4. When the testing of the hot-mix cores is completed the participating laboratories are to send the test data to Nittany Engineers for statistical analysis.

In spite of the fact that a number of laboratories have completed the testing of the reference specimens, to date only one laboratory has submitted their data to Nittany Engineers. Until data on the reference specimens is available from a representative number of laboratories it will be impossible to ascertain the reliability of the test procedures in the individual laboratories.

It is imperative that you send the data from the reference specimens to Nittany Engineers as soon as possible so that the testing of the hot-mix cores may proceed in a timely manner.

Please note that the names of the participating laboratories will remain anonymous. However, if you would like to know how your results compared to those of others, you may request a copy of the data analysis report from Garland Steele.

Your early attention to the above will be appreciated. Please complete the attached form and return to Nittany Engineers in the envelope provided.

Sincerely yours,

David A. Anderson
President

DAA/rat

Attachments

cc: G. Steele
A. Pelzner

1. Received reference specimens Yes No

Testing completed (Date)____________________

Expect to complete testing on (Date)____________________

2. Previously submitted reference specimen data to Nittany Engineers Yes No

3. Capability for testing specimens not currently available but expected by (Date)____________________

4. Hot-mix cores received Yes No

Nittany Engineers and Management Consultants, Inc.

736 Cornwall Road • State College, Pennsylvania 16803 • (814) 237-6500

David A. Anderson Ph.D., P.E.; President-Treasurer
H. Randolph Thomas Ph.D., P.E.; Secretary

January 31, 1991

Dear

There have been several recent modifications to the P-007 resilient modulus testing protocol. These have been passed from SHRP to Mr. Garland Steele. He has asked me to transmit them to you. These changes are summarized on the attached sheet. Please make these changes on you existing P-007 protocol document. All testing conducted as part of the SHRP core proficiency program should adhere to these changes.

I have included a revised version of WORKSHEET 2. This revised worksheet consolidates all of the numbers on one page, simplifying the paper handling exercise. Please note that the worksheet requests that the deformation information be entered in units of 0.001-in. While this is not a critical requirement, it makes it much easier if you conform to this request so that we have uniformity as we enter the data into the database. In retrospect, perhaps we should have used microinches to avoid the use of decimals, but having started with units of 0.001-in, let us continue with those units.

I would like to once again bring your attention to two previous letters that were sent to you regarding the testing protocol and treatment and handling of the specimens. These letters are dated March 23, 1990 and June 20, 1990, and are enclosed for your review. If there are any further questions, I may be reached by fax at 814-237-6500 or leave a voice message at the same phone number. I may also be reached at 814-863-1912 during the day.

Thank you for your patience and cooperation in conforming to the many requests. It is imperative that these details be adhered to if we are to successfully analyze the data.

Sincerely,

David A. Anderson
President

cc: Steele; Pelzner

ATTACHMENT

There have been some changes in P-007 that are relevant to the testing of the SHRP Proficiency cores. The changes are as follows:

1. Section 7.3.1

   Change 35% to 30%
   Change 20% to 15%
   The value at the high test temperature remains unchanged.

2. Section 7.3.2

   The seating load should be 10% of the above values, i.e. at:

   40°F, 10% of 30% = 3% of tensile strength
   77°F, 10% of 15% = 1.5% of tensile strength
   104°F, 10% of 5% = 0.5% of tensile strength

3. Section 8.2

   Values of Poisson's ratio should be changed as follows:

   40°F, 0.20
   77°F, 0.35
   104°F, 0.50

4. Section 7.4

   The total accumulated vertical permanent deformation resulting from all previous conditioning and loading cycles shall not exceed the following values:

   40°F, 0.025 in
   77°F, 0.050 in
   104°F, 0.050 in

   If these values are to be exceeded with the loads suggested in Section 7.3.1, the loads should be reduced to the minimum possible values that allow the 0.0001-in resolution of the deformation readings as per Note 6.

5. Note 6

   The values in Note 6 should be changed to be consistent with the values cited above.

WORKSHEET NO. 2

January 31, 1991

TEST DATA

SHRP ASPHALT CONCRETE CORE PROFICIENCY SAMPLE PROGRAM

1. Specimen set identification code ___
2. Specimen number ___ ___
3. Direction of load ___
4. Test replication ___
5. Test temperature, F (as measured)___ ___ ___ . ___

6. Preconditioning: Load _________lb
   Number of Cycles ___ ___ ___ ___

7. Date of testing:
   Day ___ Month ___ Year ___

8. Recovery period, 0.9 seconds (Report deformation in 0.001 in)

Load Cycle	Vertical Load, lb	Instantaneous Deformation			Total Deformation		
		Vertical	Horiz 1	Horiz 2	Vertical	Horiz 1	Horiz 2
1							
2							
3							
4							
5							

9. Recovery period, 1.9 seconds (Report deformation in 0.001 in)

Load Cycle	Vertical Load, lb	Instantaneous Deformation			Total Deformation		
		Vertical	Horiz 1	Horiz 2	Vertical	Horiz 1	Horiz 2
1							
2							
3							
4							
5							

10. Recovery period, 2.9 seconds (Report deformation in 0.001 in)

Load Cycle	Vertical Load, lb	Instantaneous Deformation			Total Deformation		
		Vertical	Horiz 1	Horiz 2	Vertical	Horiz 1	Horiz 2
1							
2							
3							
4							
5							

Part III, Research Report

SHRP Resilient Modulus Round Robin Experiment

by

David A. Anderson
and
Charles E. Antle
Nittany Engineers and Management Consultants, Inc.
736 Cornwall Road
State College, Pennsylvania 16803

and

Garland W. Steele
Steele Engineering
Box 173
Tornado, West Virginia 25202

May 1993

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INTRODUCTION

The purpose of this study was to determine the among and within laboratory variability of the resilient modulus test for asphaltic concrete as specified by the Strategic Highway Research Program (SHRP) for use in the Long-Term Pavement Performance (LTPP) program. The SHRP test method, SHRP Protocol P07 dated September 1990, is based on the method proposed by the American Society for Testing and Materials (ASTM), Method of Test D 4123. A number of refinements that more clearly define the details of the test have been made in the SHRP version of the resilient modulus test. The reader is referred to the individual test methods to obtain more specific details of the test methods and to compare the two test methods. The SHRP P007 test method, dated September 1990 and as used for this study, is included for informational purposes in Appendix A.

This report describes the experiment program and the analysis of the data that was performed in order to establish the among and within laboratory variability in the SHRP resilient modulus test. Laboratories were first prequalified using synthetic test specimens. After being prequalified with the synthetic specimens those laboratories with acceptable levels of variability were allowed to proceed with the testing of two sets of field cores in order to establish values for among laboratory and among specimen variability.

TESTING PROGRAM

The testing program contained in this study was originally designed to prequalify the laboratories that would be conducting resilient modulus testing for the LTPP program. Initially, cores were to be obtained from two sites and five cores from each site (total of ten cores) were to be submitted to each of the participating laboratories for testing. In order to generate a statistically valid experiment, a number of laboratories, in addition to the LTPP laboratories, were added to the program. This brought the number of participating laboratories in the original experiment to thirteen.

Materials

Four synthetic "reference" specimens were used in an initial screening experiment to determine the performance of the laboratories. These specimens were coded as follows:

- Neoprene™ rubber: R
- Teflon™: T
- Polyethylene: P
- Polymethylmethacrylate (Lucite™): L

The synthetic reference specimens were machined to size, 2.50 in thick by 4.00 in. in diameter, from larger-sized stock. A single sample was used for each material such that each laboratory tested the same sample thereby eliminating any specimen to specimen variability that could result with multiple synthetic specimens.

The field cores were obtained by coring 4-in diameter cores from a local site that had not received any traffic. The first set of cores, identified by the code N, were from a one year old wearing course. The mix was well-compacted with approximately 6% air voids.

The second set of cores was from an area that had been paved with a base course mix. This mix was in-place for six years before it was cored. The in-place air voids for the mix was approximately 8%. These cores were identified by the code O. Both the N and the O cores were obtained as close together as possible in what appeared to be a homogeneous section of pavement. Each core was trimmed by sawing the bottom face of the core to give a thickness of 2.50 ± 0.1 in. Visual inspection showed that the cores from each section were similar in appearance, suggesting that the within-set material variability of the two sets of cores should be relatively small.

The two sets of cores were expected to give different results. The mix for the new set was of cores relatively fine (3/8-in. top size), the binder was relatively unaged, and there were few irregularities on the surface of the cores. This set of cores should have been the easiest to test and should have produced the smallest testing variability. The old set, on the other hand, was aged and consisted of a much coarser mix (1 1/4-in. top size), producing cores with greater surface irregularities. The old cores should have been more difficult to test, resulting in greater variability in the test results. A summary of the testing program indicating the number of participating laboratories is given in Figure 1.

Test Procedure

The resilient modulus test is performed by loading a cylindrical sample on its diametral plane as illustrated in Figure 2. The thickness of the test specimen is specified as approximately half of the diameter. As specified in the SHRP and ASTM resilient modulus test, the test sample is loaded with a pulse loading along a diametral plane with a pulse load of 0.1 s duration. The SHRP test protocol specifies a recovery period of 0.9, 1.9, or 2.9 s. The ASTM protocol specifies the loading sequence in a somewhat different manner.

A typical plot of the horizontal deflection versus time (ASTM D 4123) is shown in Figure 3. Historically, the resilient modulus test has been used to measure the "recoverable" deformation which has been interpreted as the elastic deformation. This recoverable, elastic,

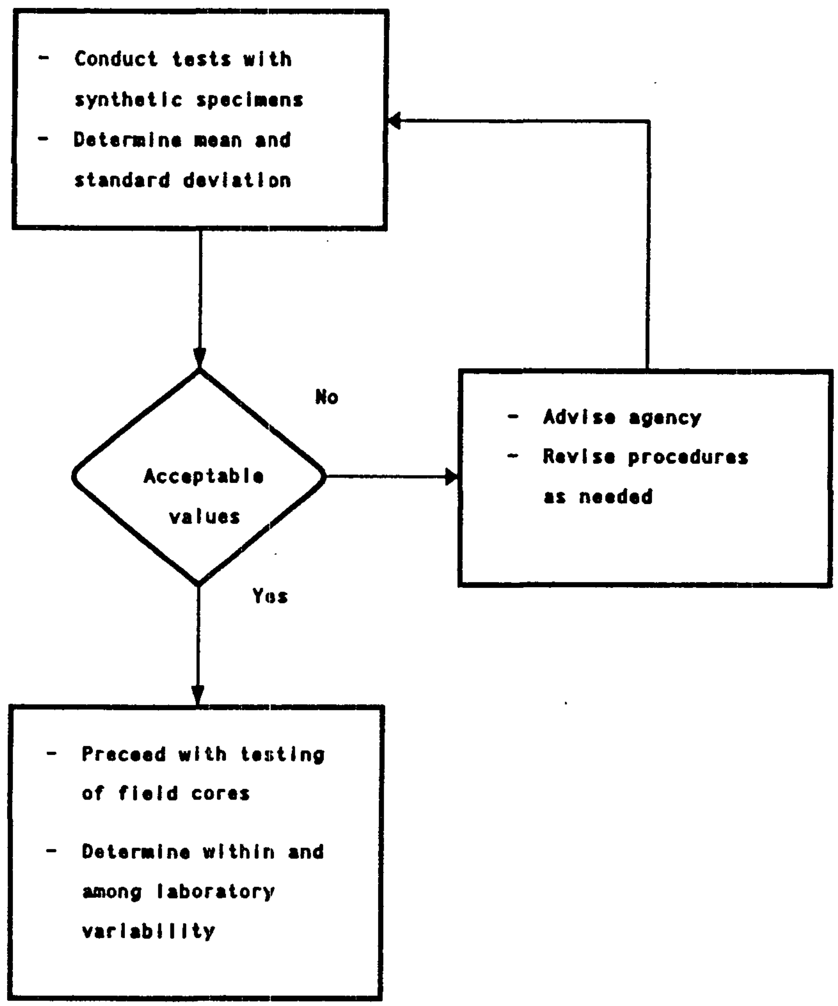
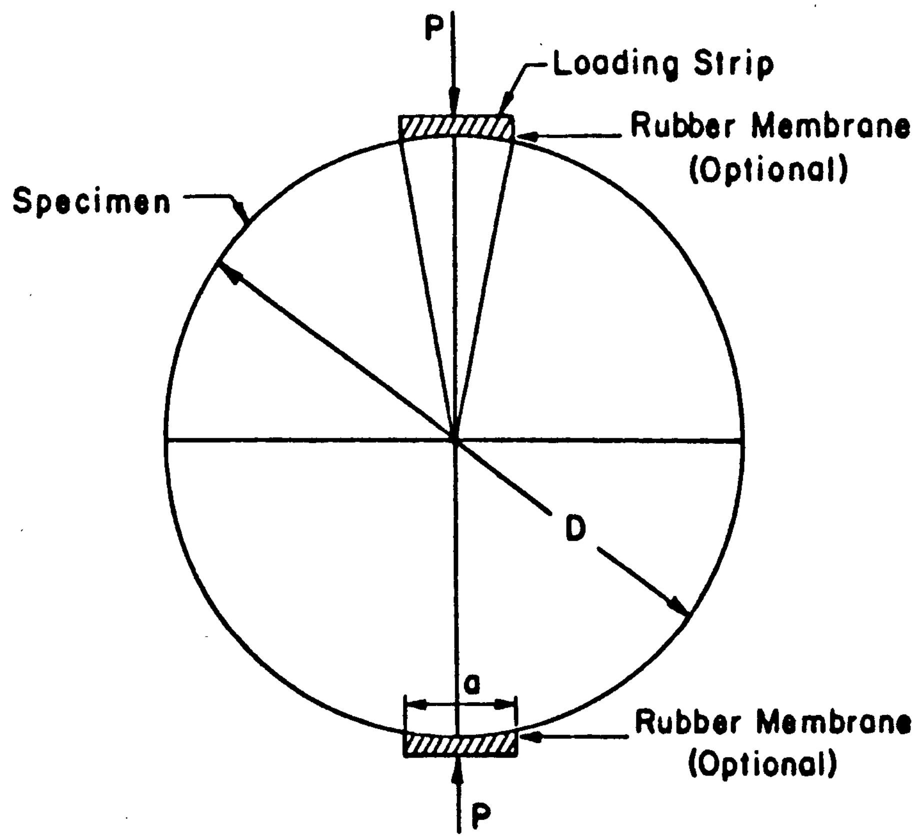
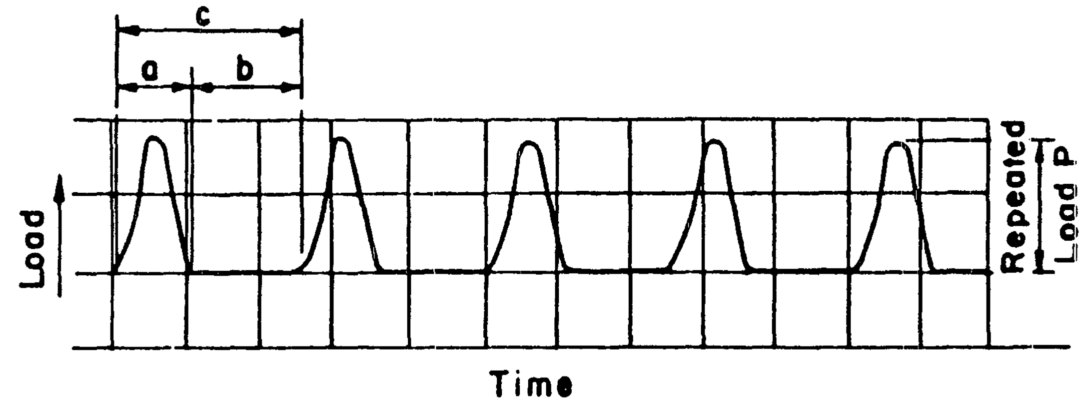


Figure 1. Testing program.



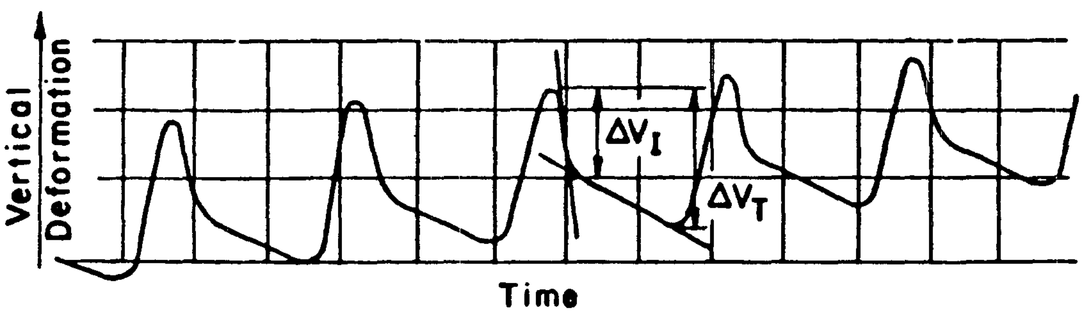
P = applied load
t = thickness of specimen
D = diameter of specimen
a = width of loading strip
= 0.5 in. (13 mm) for 4-in. (102-mm) diameter specimen
= 0.75 in. (19 mm) for 6-in. (152-mm) diameter specimen

Figure 2. Schematic of resilient modulud test.

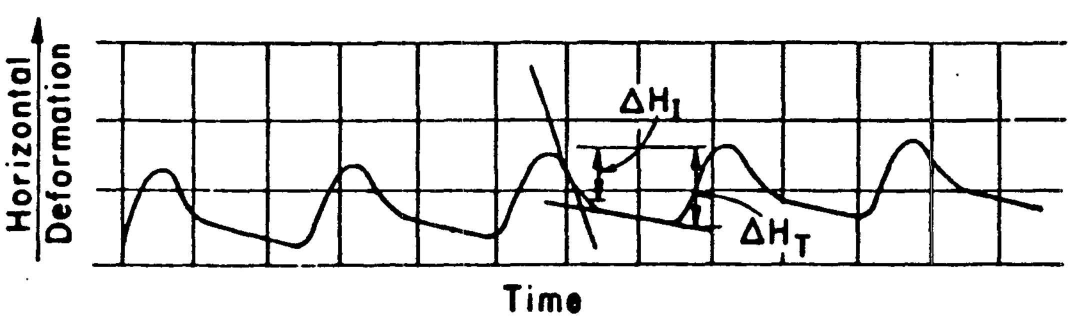


(a) Load-Time Pulse

a = duration of loading during one load cycle
b = recovery time
c = cycle time



(b) Vertical Deformation Versus Time



(c) Horizontal Deformation Versus Time

Figure 3. Typical plot of loading pulse and deformation versus loading time (After ASTM D 4123).

or instantaneous deformation is defined by the SHRP and ASTM protocols as shown in Figure 2. It is also possible to define the total deformation as illustrated in Figure 3. For the purposes of this study, only the recoverable deformation as defined in Figure 3 was used.

Measurements obtained during the test program also included the vertical deformation. Some researchers have used the vertical deformation to calculate Poission's ratio. However, Poission's ratio calculated using the vertical and horizontal deformation obtained from the resilient modulus test procedure as defined by SHRP and ASTM can lead to erroneous values. Therefore, the vertical deformation and calculated values of Poission's ratio were not included in this study.

The equation for calculating the resilient modulus is:

$$M_R = \frac{(P)(\mu + 0.27)}{t(\Delta h_1 + \Delta h_2)} \qquad 1$$

where:

M_R	=	resilient modulus, lb/in^2 (psi)
P	=	load, pounds
μ	=	Poission's ratio, dimensionless
t	=	thickness, inches
Δh_1, Δh_2	=	change in diameter for gauge one and gauge two, respectively

Because Poission's ratio cannot be reliably calculated in the resilient modulus test it is necessary to use an assumed value in the calculation of the resilient modulus. As specified in the SHRP Resilient Modulus Protocol P07, the following values were used for Poission's ratio:

at 40 °F, $\mu = 0.20$
at 77 °F, $\mu = 0.35$
at 104 °F, $\mu = 0.50$

Equation 1 contains provisions for Δh_1 and Δh_2 because the SHRP test method specifies two transducers, one on each face of the specimen. Other resilient modulus devices, such as the Retsina device automatically sum the deflection on the two faces of the specimen by virtue of the configuration of the measurement transducer.

The SHRP P-007 protocol specifies a closed-loop electro-hydraulic testing machine. The LTPP SHRP laboratories were required to use the closed-loop electro-hydraulic testing equipment. However, many of the other participants did not have this equipment available and pneumatic-loading devices were used. Typically, these devices use a Bellofram-type loading device. With these devices it is not possible to control the shape of the loading pulse and the resulting loading pulse has the appearance of a rounded square wave. In contrast, the SHRP P-007 protocol specifies a haversine-shaped loading pulse which is possible with a closed-loop electro-hydraulic testing machine.

Some of the key features of the SHRP P-007 protocol that differentiate it from the ASTM protocol include:

- A top-loading, closed-loop, electro-hydraulic testing machine with a function generator capable of applying a haversine-shaped load pulse is required.

- Two LVTD's are required for the measurement of the horizontal deformation and the two LVDT's must be wired so that each LVDT can be read and recorded independently.

- The indirect tensile strength of the test specimens must be first determined at 77 $\pm$ 2.0 °F and the required load for the resilient modulus is then based upon a percentage of the indirect tensile strength.

- Very specific details are given with respect to the alignment of the test specimen. This is in recognition of the difficulty in obtaining proper specimen alignment.

- Seating loads at 40, 77 and 104 °F respectively are specified as 3.0, 1.5, and 0.5 percent of the indirect tensile strength value measured at 77 ± 2.0°F.

- The specimens are preconditioned prior to testing using a specific procedure. A minimum of 30 load pulses are required before the data used to calculate the resilient modulus are recorded. A minimum of 10 successive horizontal deformation readings must agree within 10%.

- If adequate deformations (greater than 0.0001 in.) cannot be recorded using the loads calculated as a percentage of the tensile strength, then the loads can be increased. However, if the total cumulative vertical deformations are greater than 0.001 in. and the use of smaller load levels does not yield adequate deformations for measurement purposes, the preconditioning is discontinued and 10 load pulses are used for calculating the resilient modulus.

Testing Plan

As a precursor to the testing of the field cores, four synthetic "reference" specimens were sent to each laboratory to be certain that their equipment was working properly and that the data were properly reduced. The plan was to first ship the four synthetic specimens to each laboratory and to ship the field cores only after acceptable results were obtained with the synthetic specimens. This proved to be a very judicious exercise because a number of problems related to equipment calibration, test technique, and data reduction were uncovered. Several of the laboratories were required to re-test the synthetic specimens several times in order to obtain acceptable results, either in terms of obtaining acceptable accuracy or precision. In several cases extensive equipment modifications were required in order to obtain the required precision and accuracy. Only when each laboratory achieved acceptable results with the synthetic specimens were they allowed to proceed to the field cores. A number of laboratories also participated by testing only the synthetic specimens. These laboratories were included as a courtesy so that they could evaluate their test methods and procedures. The data from these laboratories are also presented in this report.

Both the synthetic specimens and the field cores were measured in replicate in two directions. The first of the replicate measurements was obtained by mounting the individual specimens in the testing machine and conducting the test procedure as specified in SHRP protocol P-007. Each specimen was then removed and the second of the replicate measurements was obtained by remounting the specimen in the testing device and repeating the P-007 test protocol. The laboratories were requested to make the replicate measurements on separate days. Each measurement consisted of the preconditioning step followed by measurements taken on five successive loading pulses. The load and the horizontal deformations were used to calculate five values of resilient modulus, one for each of the five loading pulses. The specimen was then rotated 90 degrees and the test repeated.

Each field core was tested on separate days providing a replicate measurement for each core. On each day, the individual cores were tested in two directions, at three test temperatures using three recovery periods. An analysis of the data showed that their were no statistical differences between the two directions and the measurements from the two directions were pooled. This provided a resilient modulus, $\bar{M}_R$ based on the average of five consecutive loading and two directions. Thus, the values of $\bar{M}_R$ reported in this study representative the average of the resilient moduli calculated from 10 measurements; 5 pulse loadings, and 2 directions.

EXPERIMENT DESIGN

This experiment was designed initially to evaluate the laboratories that were under contract to provide resilient modulus testing of asphalt cores for the LTPP program. Based on the results of this proficiency testing program, the laboratories were to be allowed to proceed with future SHRP LTPP resilient modulus testing activities. To make the experiment statistically valid, a number of non-SHRP laboratories were added to the experiment, bringing the number of initially planned laboratories to 13.

The SHRP laboratories participating in this experiment were not selected at random from any larger group of laboratories. Thus estimates of precision, coefficients of variation, etc., may not be regarded as applying to all laboratories at which resilient modulus testing is being done. However, the measures of variability that were calculated from the data are meaningful and do tell in a concise manner the accuracy and precision that may be expected to result from the work at these laboratories.

The first objective of the study was to screen the laboratories using the synthetic specimens in order to identify laboratories with acceptable performance. A total of 24 laboratories were involved in the screening process and 17 produced acceptable results. Field cores were subsequently sent to 15 of these laboratories for testing. After each laboratory conducted the testing with the synthetic specimens, their data were analyzed and they were appraised of their performance. Some of the laboratories found it necessary to modify their operations in order to improve their performance. The modifications included refinements in the data reduction, modifications to the testing frame and the LVDT's and their mounting systems, stiffening of the testing frame, and refinements in the data acquisition process. Six of the laboratories were unable to obtain acceptable performance with the synthetic specimens. To this extent, the data reported for the synthetic specimens and the field cores are not representative of the state of the art but are representative only of those laboratories that were able to obtain a specified level of performance with the synthetic specimens. Thus, the statements in this report regarding the among laboratory and amount testing variability are not representative of the current state of the art. If the laboratories were truly selected at random the among the general population of laboratories with resilient modulus equipment the among specimen variability would undoubtedly be considerably in excess of that reported in this study.

The second objective of this study was to establish the among and within laboratory variability of the selected laboratories. This was accomplished by testing the two sets of field cores. The analyses required to satisfy this objective are given in the next section of this report: detailed analyses are given in the Appendices. The models used for the analyses are described in subsequent sections of this report. The design of the experiment is given in the next section.

Experiment Design

This study was conducted in two stages. In the first stage four synthetic specimens of known materials neoprene rubber (R), teflon (T), polyethylene (P) and polymethylmethracrylate (L), were tested at each laboratory. A single synthetic reference sample machined from each material was circulated to each of the laboratories. Each of these specimens was tested in two directions and this was repeated at a later time in an independent manner by remounting the sample in the testing device. These tests were carried out with recovery periods of 0.9, 1.9 and 2.9 seconds. All testing of synthetic specimens was at a temperature of 77°F. For those laboratories that were to proceed to the testing of field cores, this first stage of the experiment served as a screen to prevent the testing of the asphalt cores in the next stage by a laboratory which would otherwise give unacceptable results. A number of additional laboratories asked to be included in the testing program and were also sent the synthetic reference specimens and their test results were included in the analyses. All laboratories were advised of their performance in the testing of the synthetic specimens. Those scheduled to continue with the testing of the field cores were allowed to test the asphalt cores only after acceptable performance was obtained with the synthetic specimens. Because several of the original 13 laboratories could not attain acceptable performance levels they were eliminated from the program and replaced by other laboratories.

Stage two of the experimentation was much more extensive. Each laboratory received five new and five old asphalt cores as described above. Each laboratory was instructed to test each of their two sets of five cores in two orthogonal directions at temperatures of 40, 77 and 104°F, with recovery periods of 0.9, 1.9, and 2.9 seconds. This entire arrangement was then to be repeated in an independent manner at a later time. It will be observed from the analysis of the resulting experimental data that the specimens were indeed quite homogeneous. The resilient modulus values for old and the new set of cores were quite different, as expected, and thus in the analysis the old and new cores were treated as a separate experiment. It was further found that the was no statistical difference between the two directions (neither the synthetic specimens or the cores had received any prior directional loading in the form of traffic) and the data from the two directions were pooled to calculate the average specimen resilient modulus, $\bar{M}_R$.

TEST RESULTS

Results for the Synthetic Specimens

The average resilient moduli values obtained by the 19 laboratories that participated in the testing of the synthetic cores are shown in Figures 4 through 7. A summary of the results of an Analysis of Variance for this experiment is given in Table 1. The statistical analyses from which these results were taken are given in Appendix B.

Results for the Old and New Asphalt Cores

Each field core was tested on separate days providing a replicate measurement for each core. On each day, the individual cores were tested in two directions, at three test temperatures using three recovery periods. An analysis of the data showed that their were no statistical differences between the two directions and the measurements from the two directions were pooled. This provided a resilient modulus, $\bar{M}_R$ based on the average of five consecutive loading and two directions. Thus, the values of $\bar{M}_R$ reported in this study representative the average of the resilient moduli calculated from 10 measurements; 5 pulse loadings, and 2 directions.

The average resilient moduli values obtained by the 15 laboratories that participated in the testing of the field cores are shown Figures 8 through 13. These are for the recovery period of 0.9 seconds; the plots for 1.9 and 2.9 seconds are similar. Fifteen laboratories qualified for the testing of the field cores. However, complete data are not reported for each laboratory. A number of the laboratories were unable to test the old cores at 104°F as a result of equipment limitations. In several instances a sufficiently small load could not be applied to the test specimen and in other cases the testing equipment did not have sufficient resolution for the deflection measurement. Problems were also encountered by a number of laboratories at the low test temperature. Typically, the laboratories that did not report test

Table 1. Estimated standard deviations and coefficients of variation for synthetic specimens.

Source	Specimen L		Specimen P		Specimen R		Specimen T	
	Sigma (psi)	CV, (%)	Sigma (psi)	CV (%)	Sigma (psi)	CV (%)	Sigma (psi)	CV (%)
Among Laboratories	51,843	9	28,642	12	1,360	21	17,579	12
Error	53,280	9	48,376	21	537	8	7,964	6
Mean (psi)	561,746		231,929		6,473		144,809	

Lucite Polyethylene Rubber Teflon.

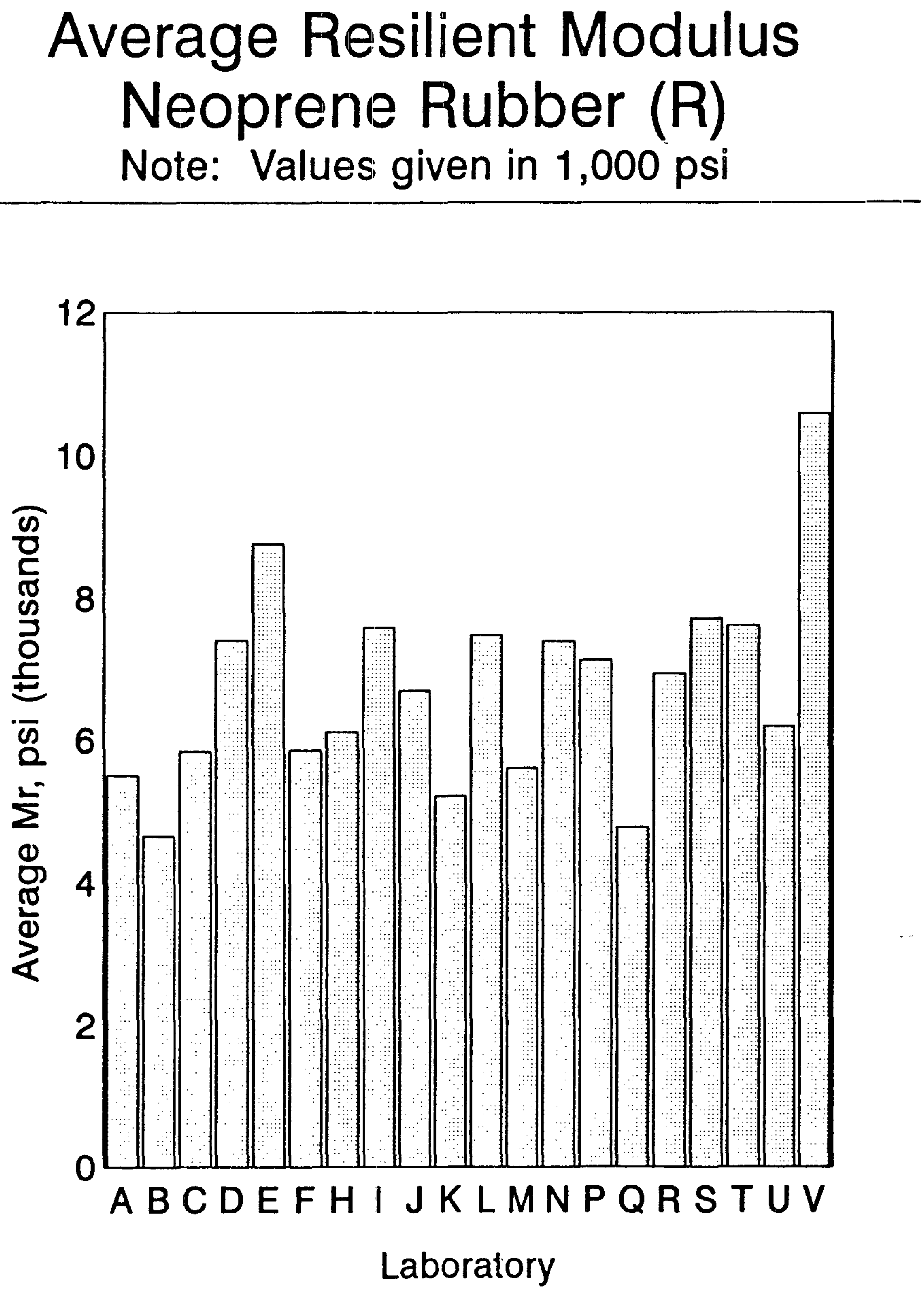


Figure 4. Average resilient modulus values for Neoprene™ synthetic specimens.

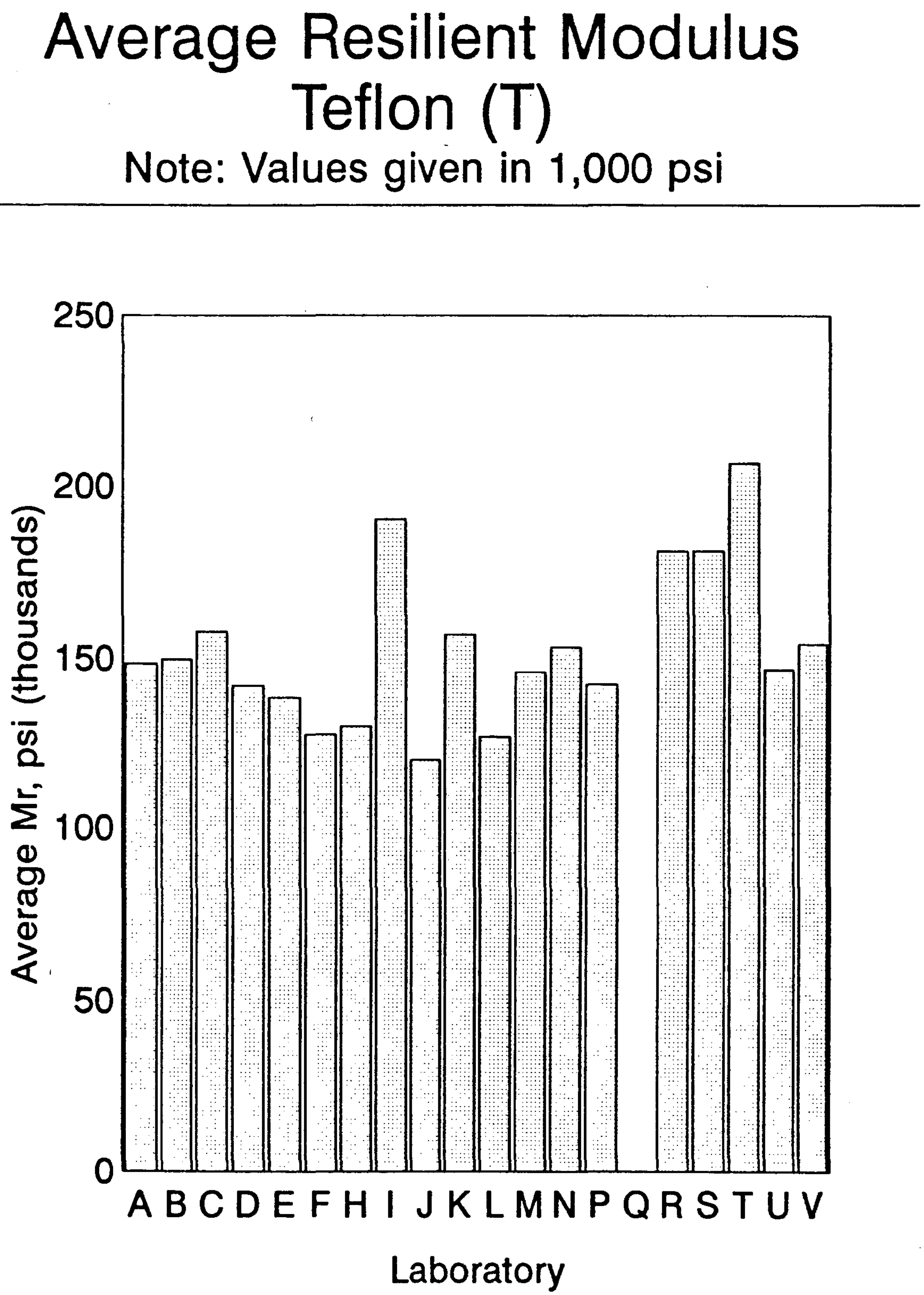


Figure 5. Average resilient modulus values for Teflon™ synthetic specimens.

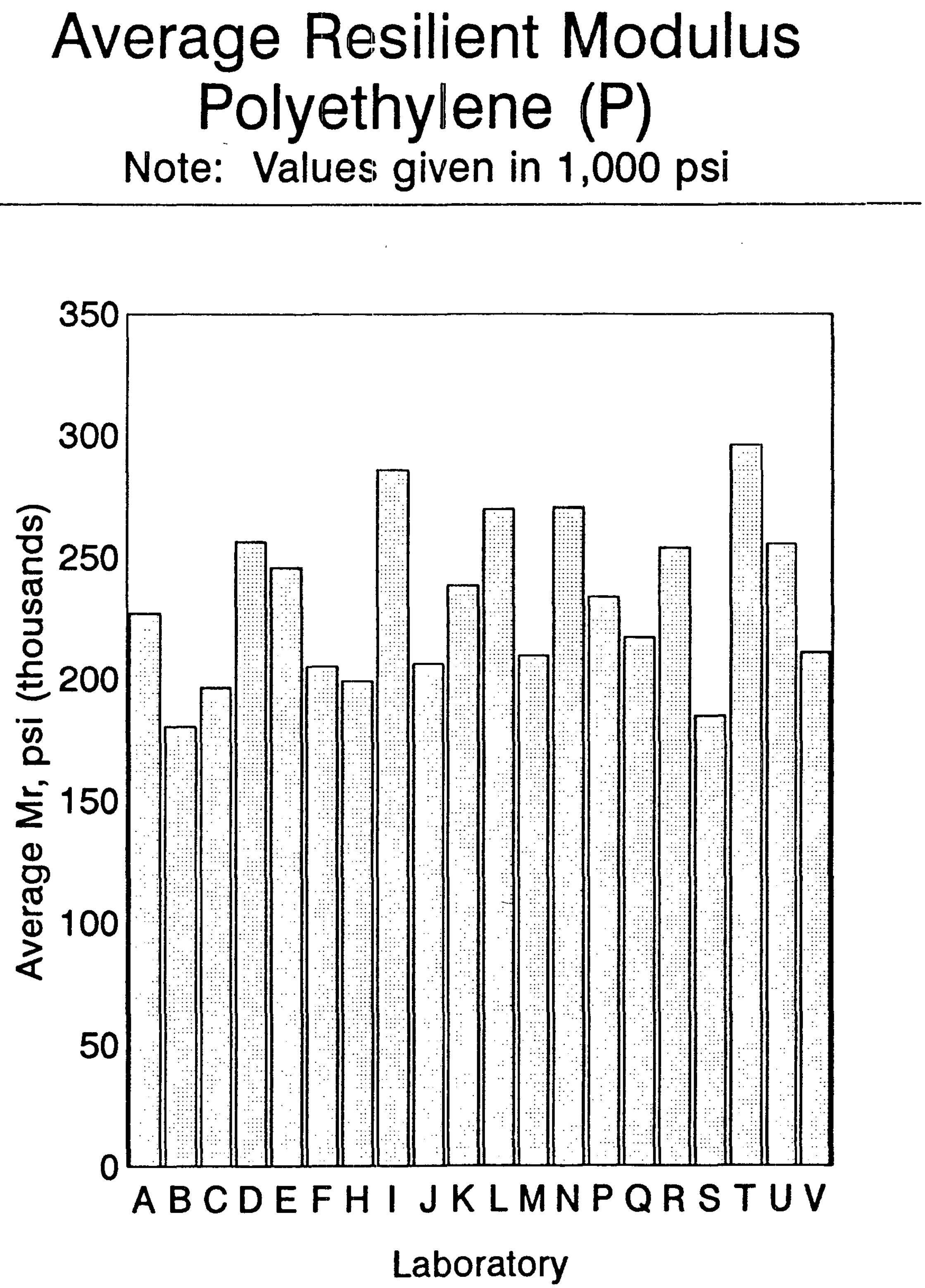


Figure 6. Average resilient modulus values for polyethylene synthetic specimens.

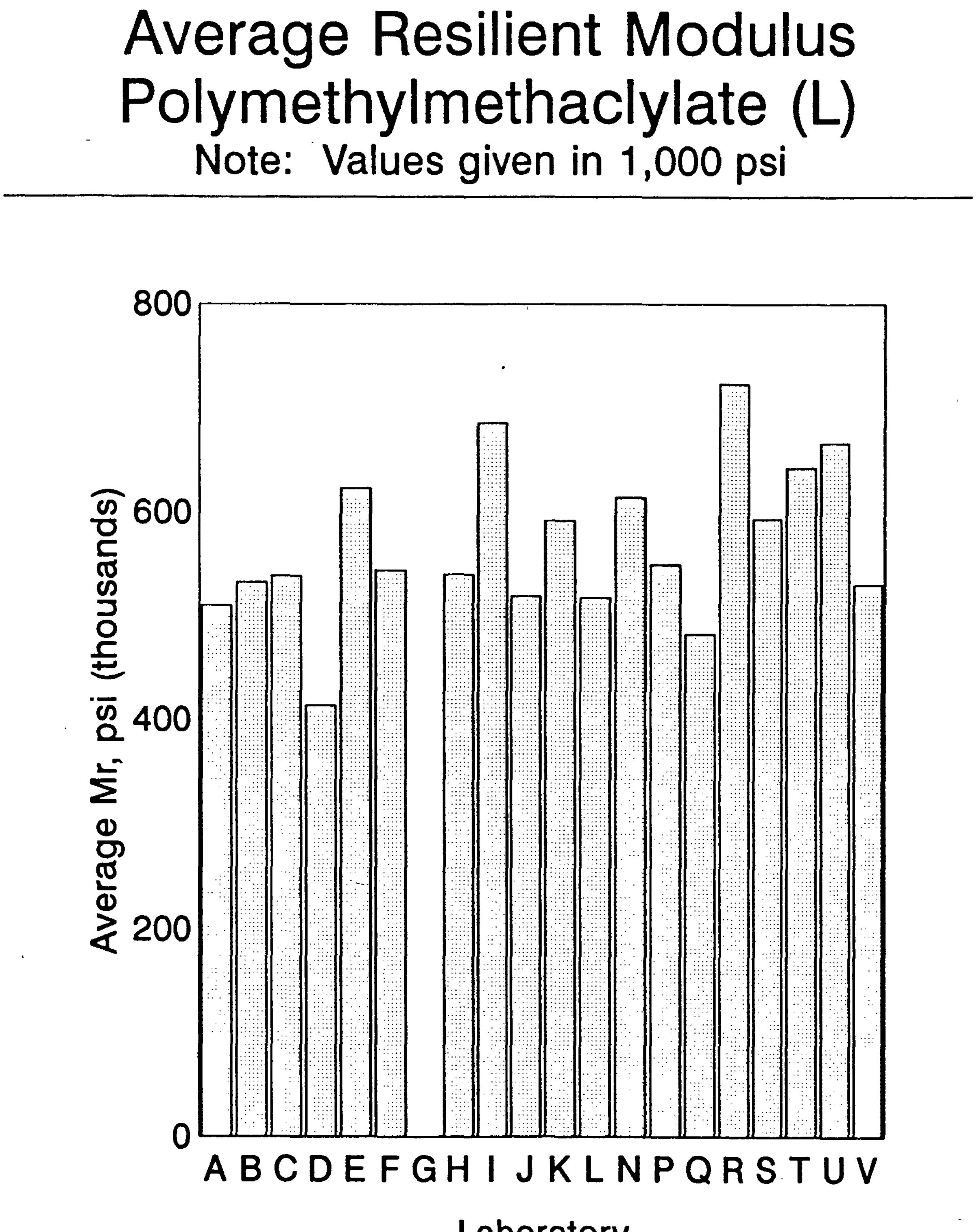


Figure 7. Average resilient modulus values for Lucite synthetic specimens.

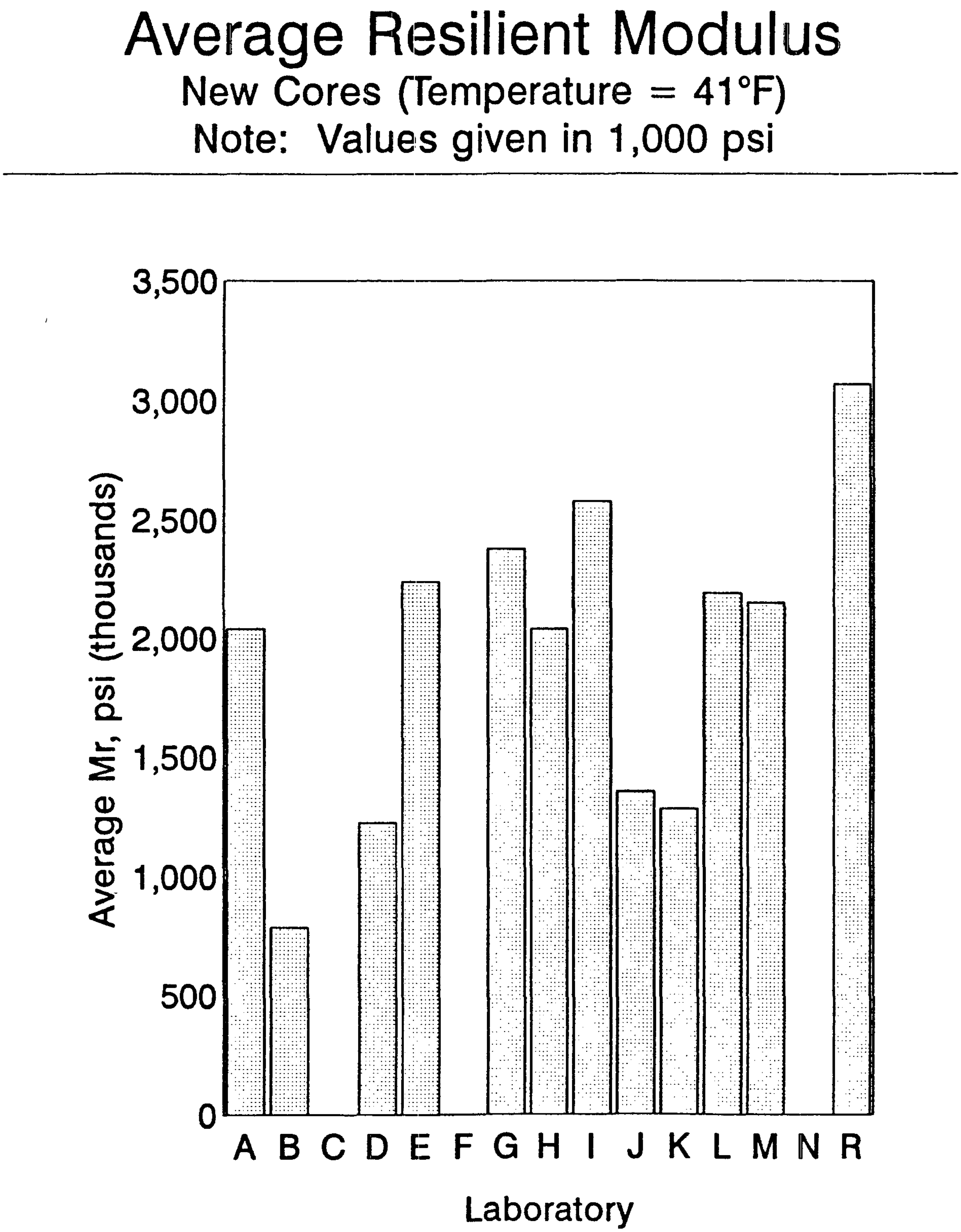


Figure 8. Average resilient moduli values: new cores at 41°F.

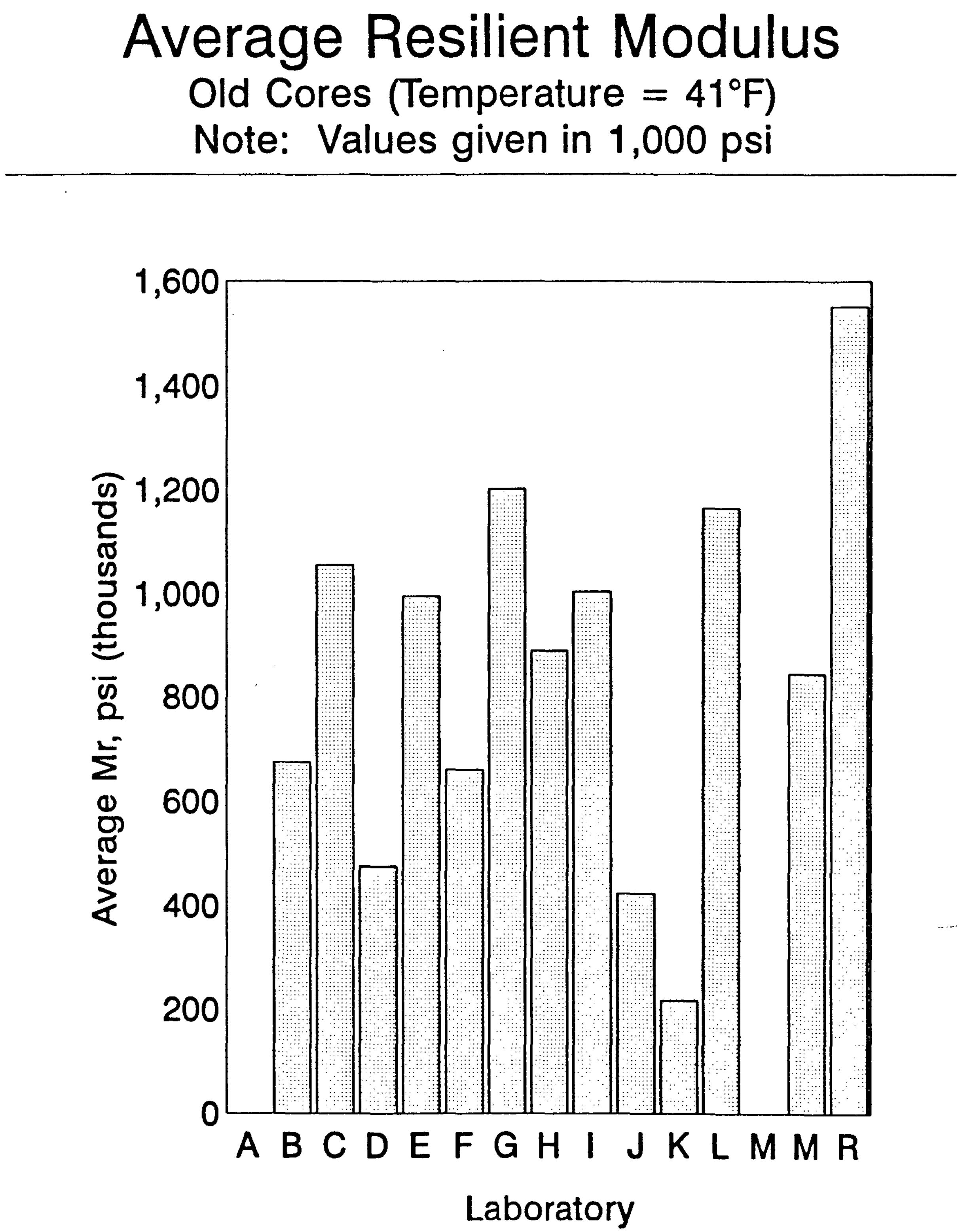


Figure 9. Average resilient moduli values: old cores at 41°F.

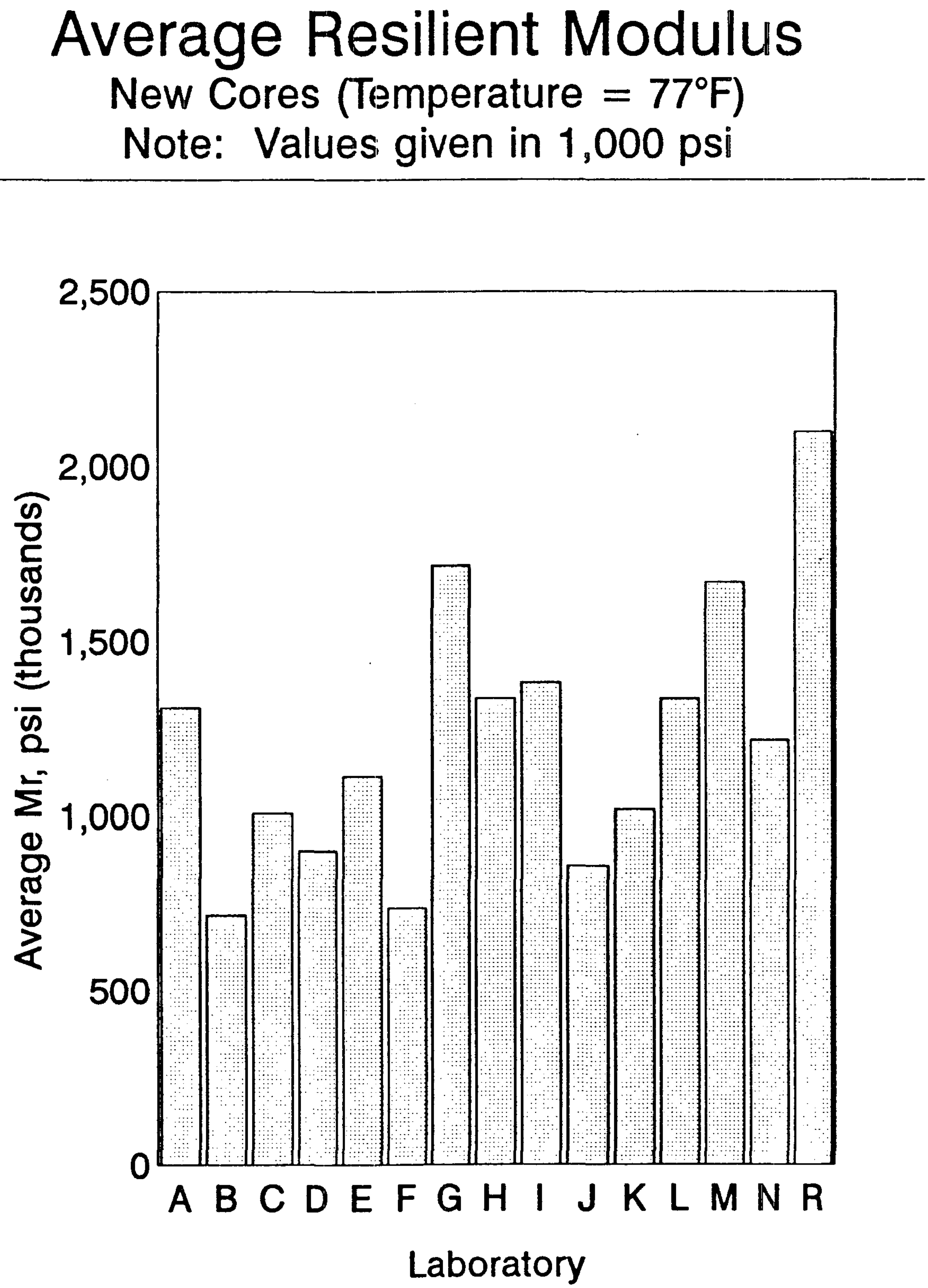


Figure 10. Average resilient moduli values: new cores at 77°F.

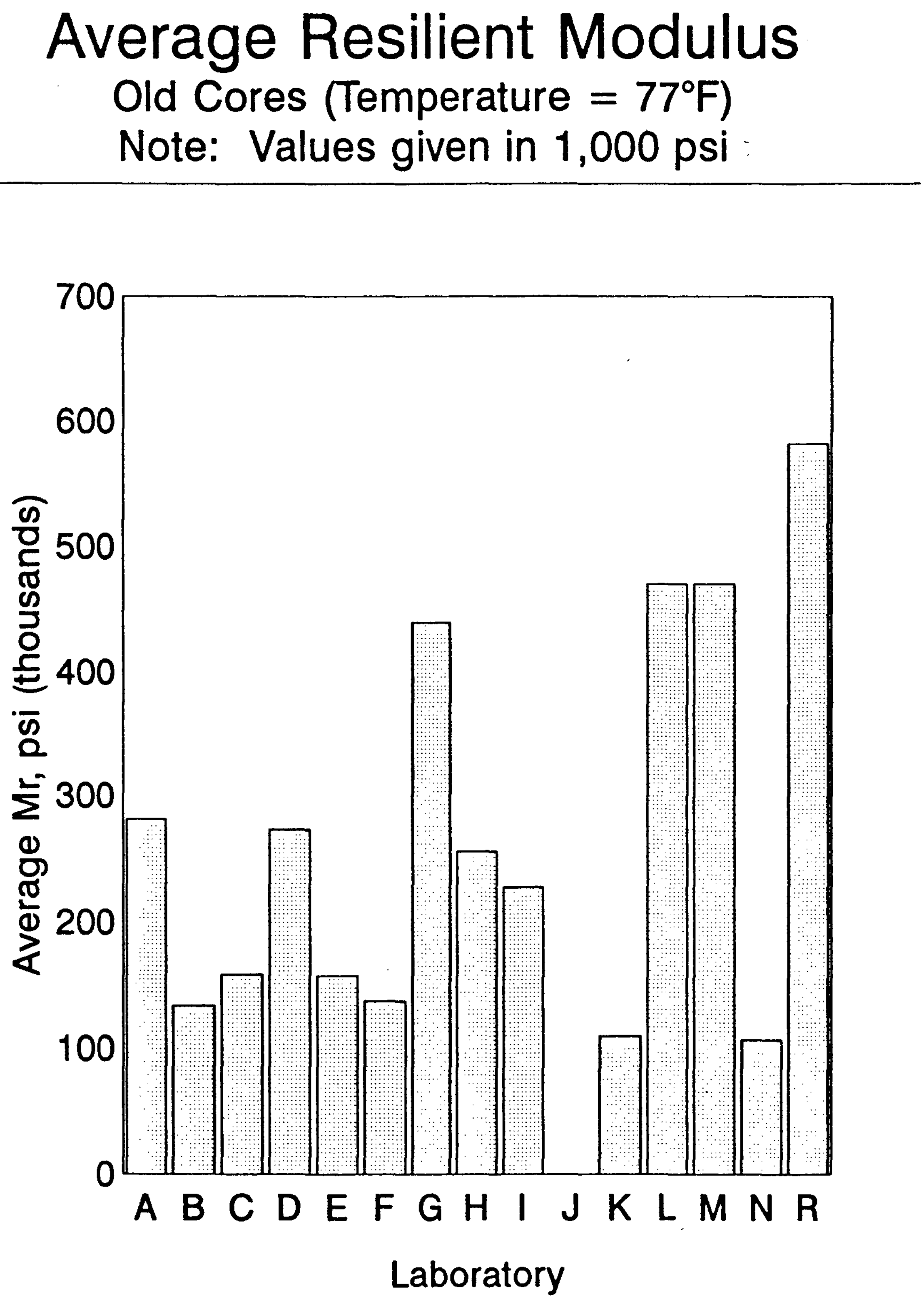


Figure 11. Average resilient moduli values: old cores at 77°F.

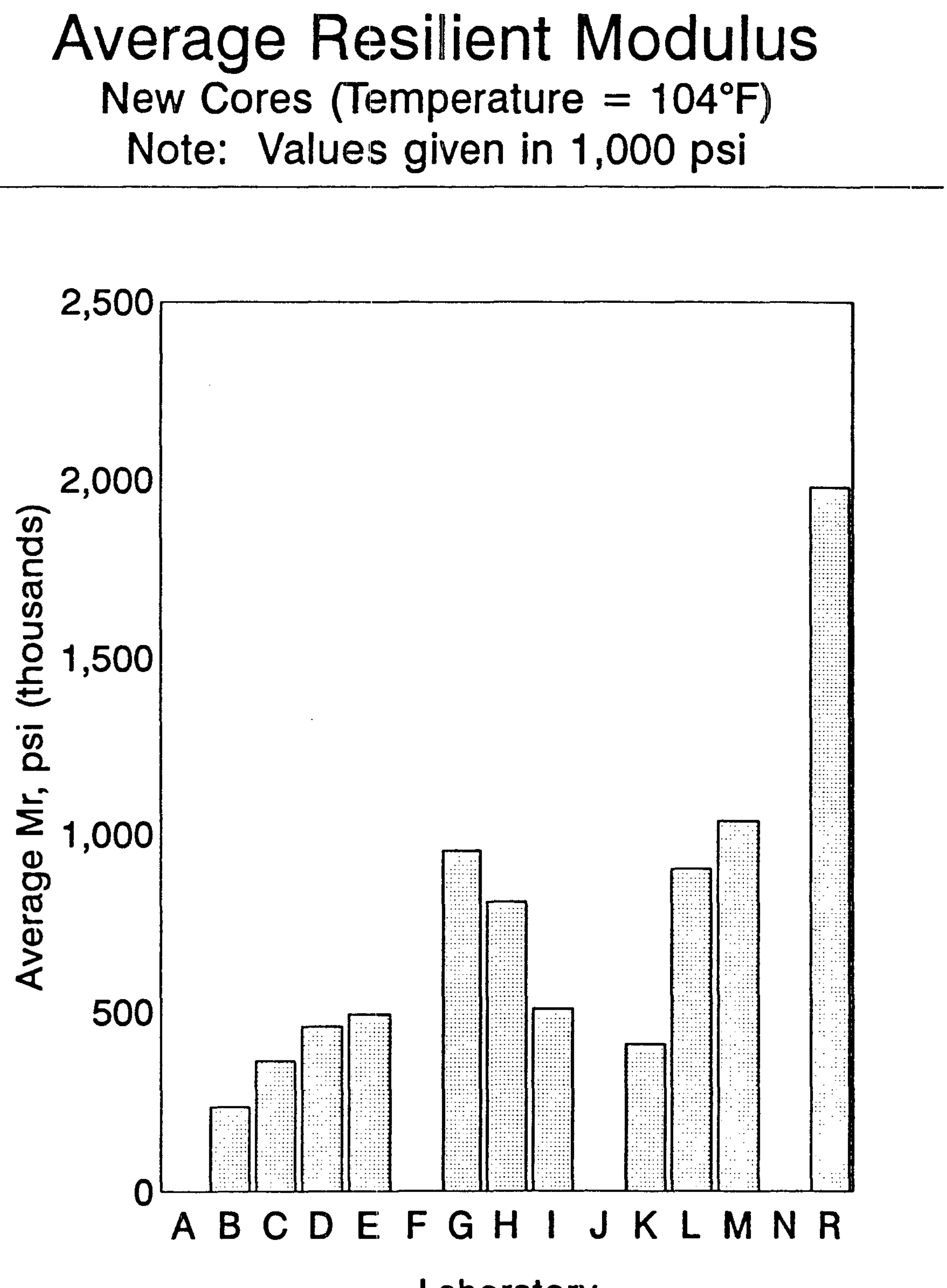


Figure 12. Average resilient moduli values: new cores at 104°F.

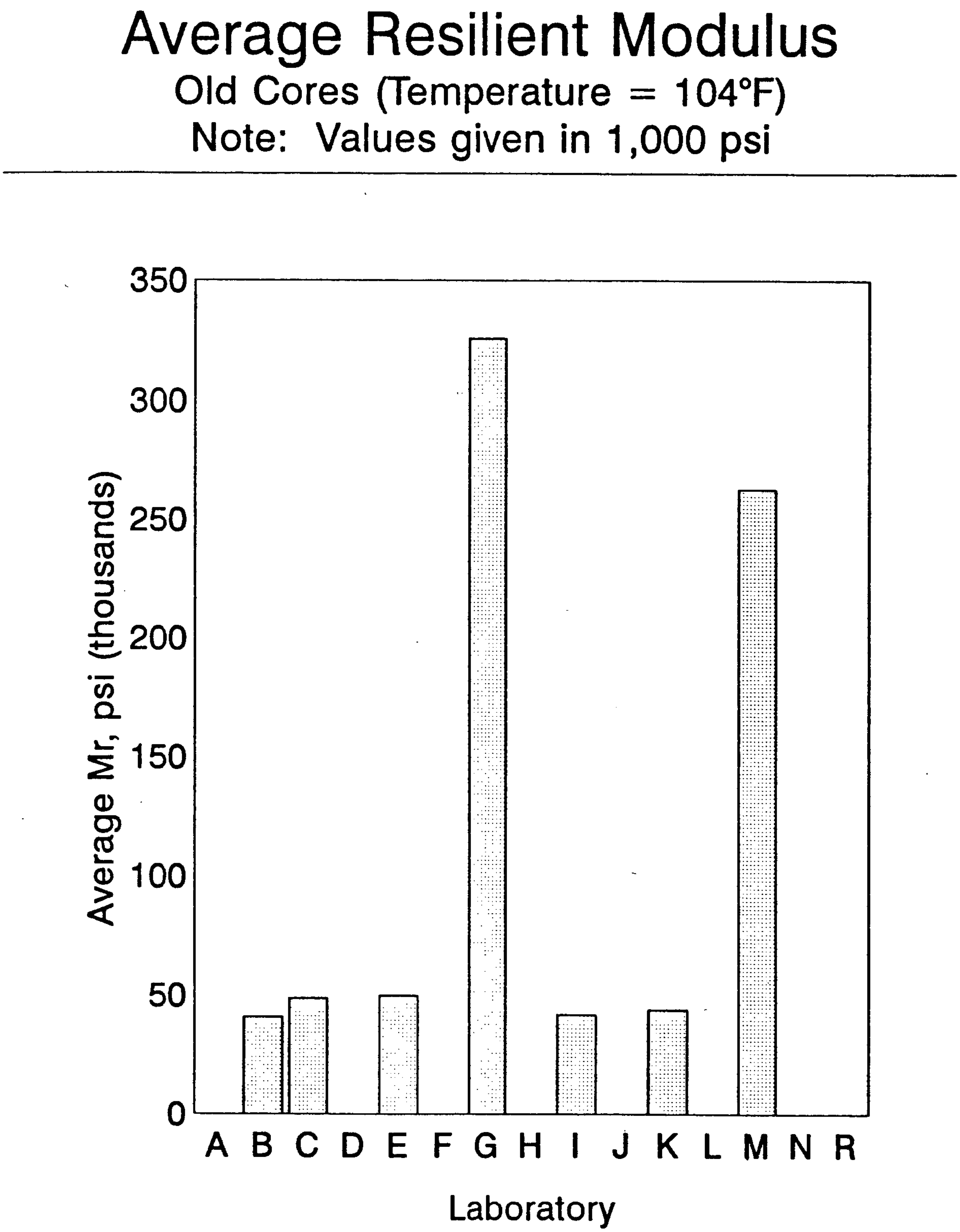


Figure 13. Average resilient moduli values: old cores at 104°F.

measurements at the low test temperature could not generate sufficient load to satisfy the resolution requirements of the deflection measurements. In other words, their equipment did not have sufficient capacity for the moduli of the cores. Thus, the data reported for the 15 laboratories is incomplete for a number of the laboratories.

The pooled standard deviation of these measured values for the new asphalt cores at a given laboratory should provide a reasonable indication of the repeatability of the resilient modulus as measured at a given laboratory for new cores. The same is true for the old cores. (No pooling of new and old would be advised given the difference in the M_R values.) The calculated standard deviations are the result of the combined variations in the cores and the measuring process. These components of variance are evaluated correctly for the group of laboratories by the Analysis of Variance as given in Appendix C. These standard deviations of the estimated resilient modulus at the laboratories are plotted in Figures 13 through 18. From these graphs it is clear that laboratory D, and sometimes laboratories E and G, have unacceptable performance in this regard.

The important features of the overall performance of the laboratories may be summarized as in Tables 2 and 3. These tables are developed from the information as given in the Nested Analysis of Variance in Appendix C. The information in these tables provides the basis for all statements regarding the precision and accuracy of these laboratories in the estimation of the resilient modulus of the asphalt cores.

<u>Observations from Test Results</u>

Some pertinent observations can be drawn from the test results obtained with the synthetic specimens and the field cores.

- The among laboratory variability associated with testing the synthetic specimens was much less than that associated with the field cores. This suggests that the synthetic specimens are easier to test and produce more repeatable results, strengthening the recommendation that the synthetic cores be used by a laboratory

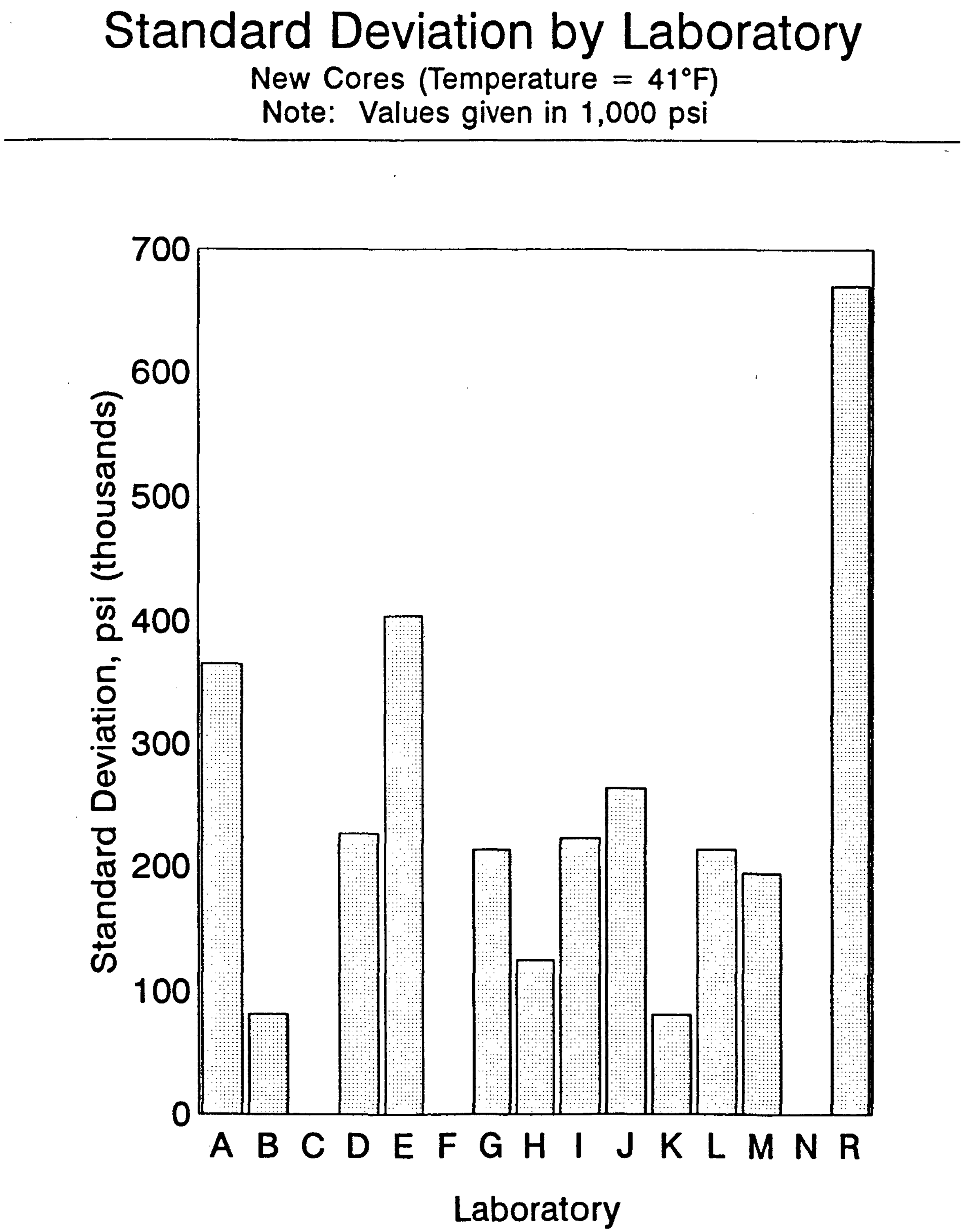


Figure 14. Within laboratory standard deviation: new cores at 41°F.

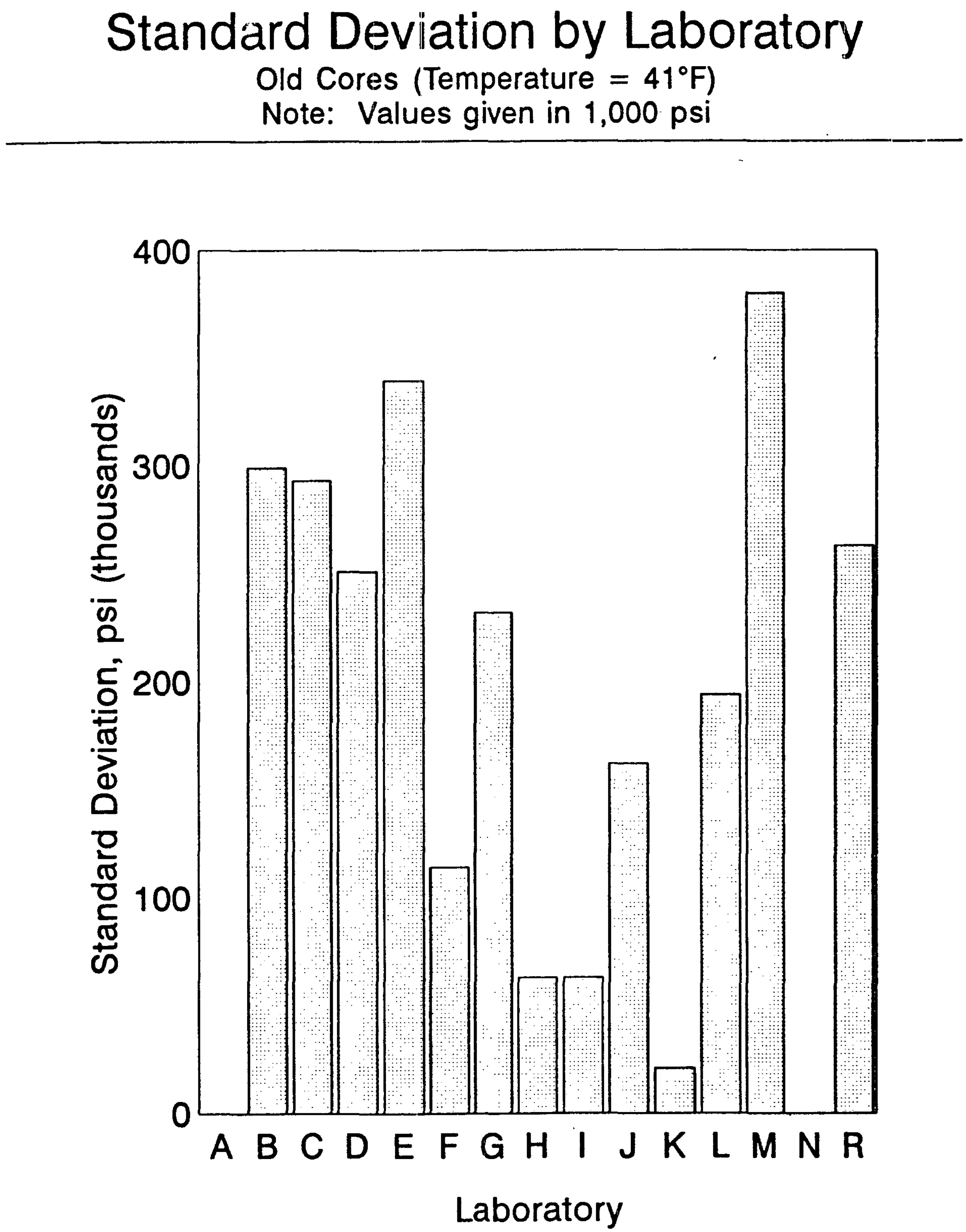


Figure 15. Within laboratory standard deviation: old cores at 41°F.

Standard Deviation by Laboratory

New Cores (Temperature = 77°F)
Note: Values given in 1,000 psi

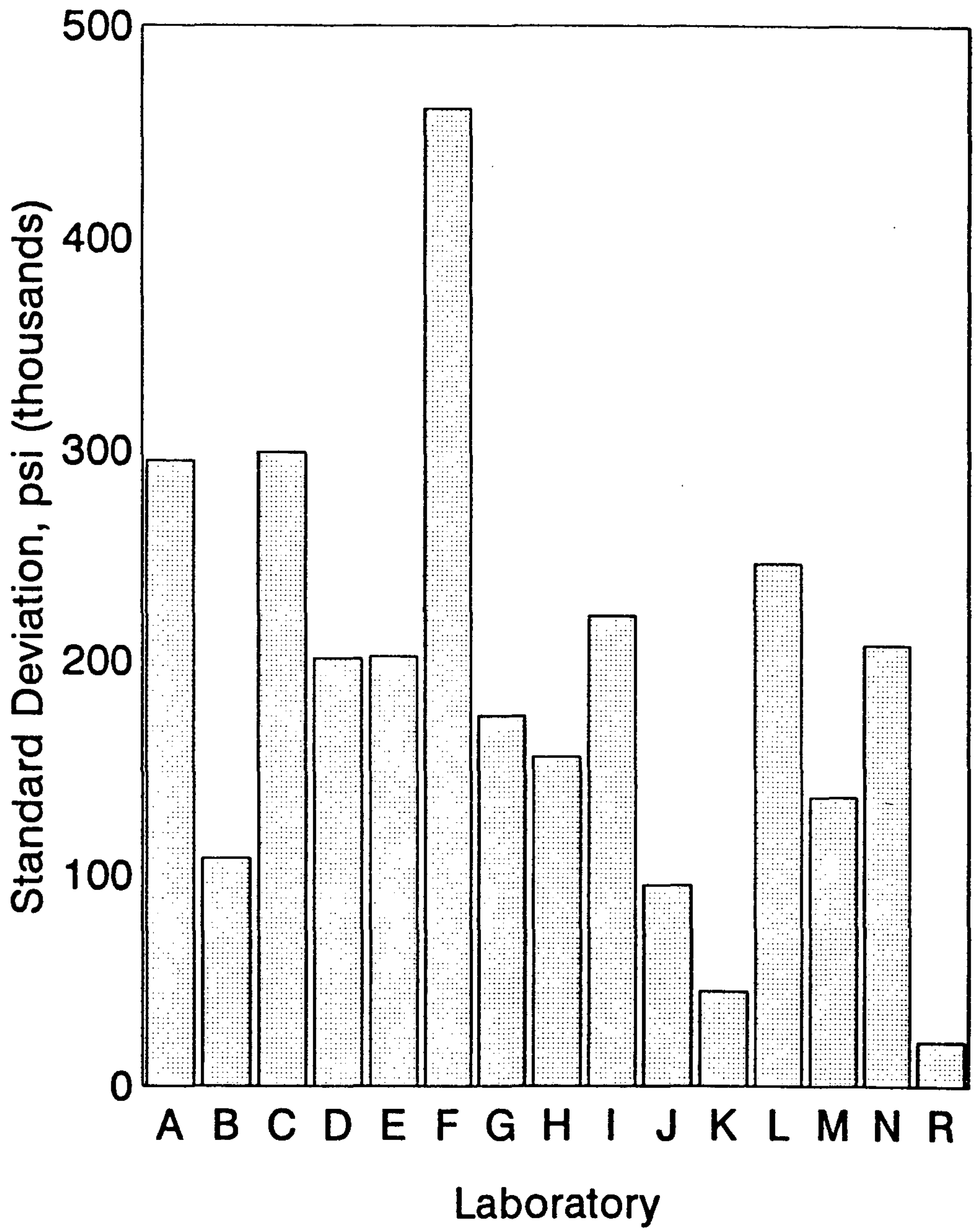


Figure 16. Within laboratory standard deviation: new cores at 77°F.

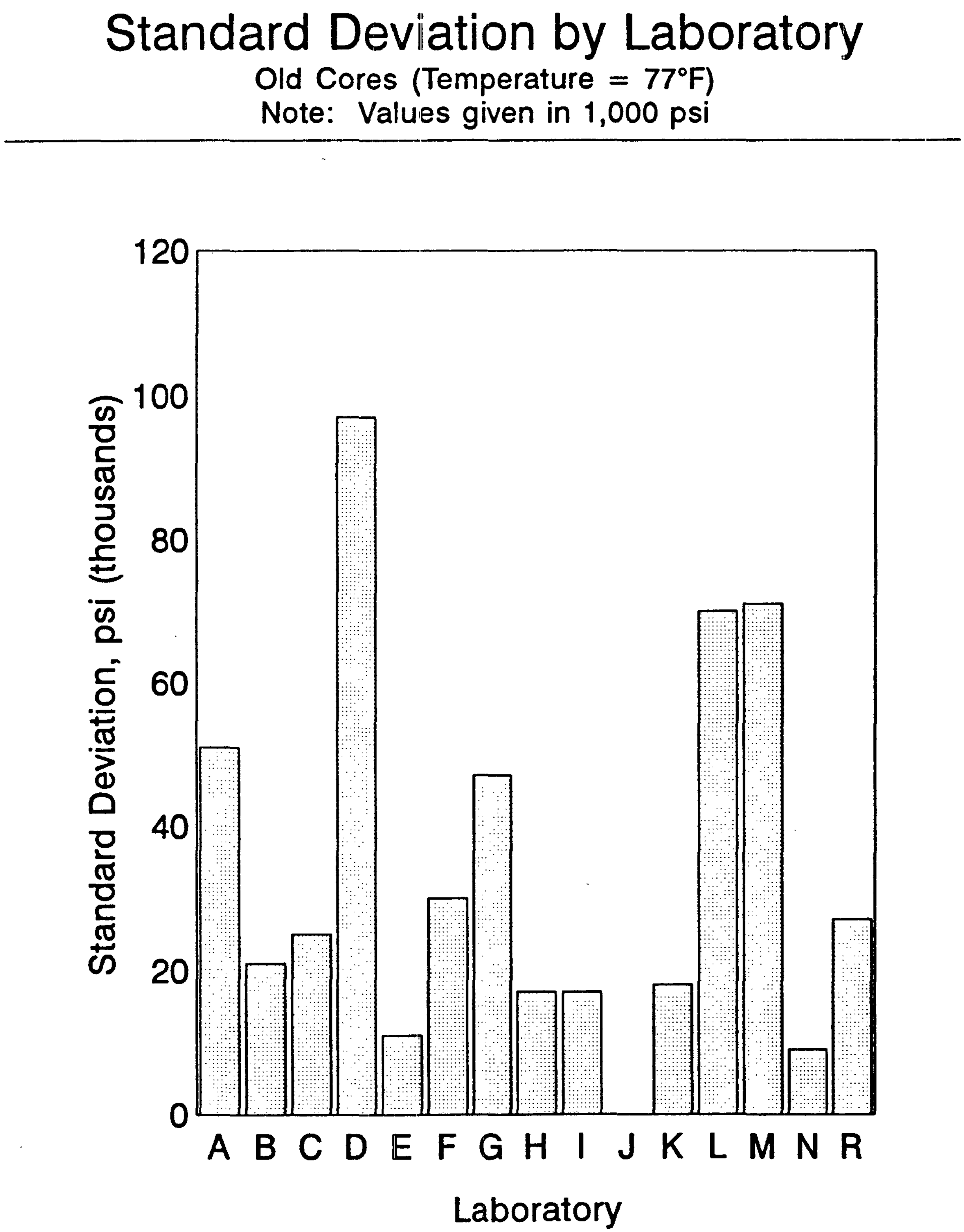


Figure 17. Within laboratory standard deviation: old cores at 77°F.

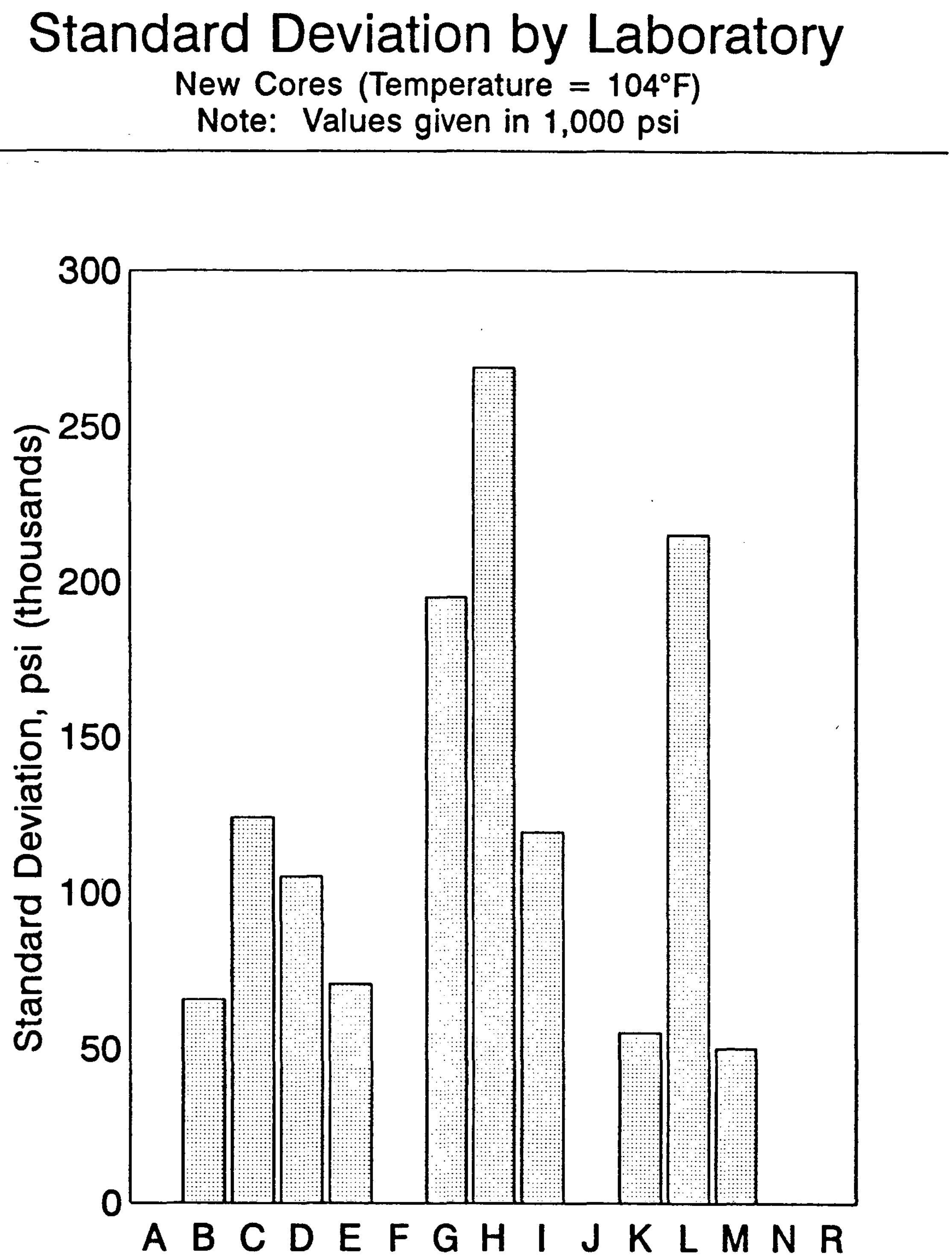


Figure 18. Within laboratory standard deviation: new cores at 104°F.

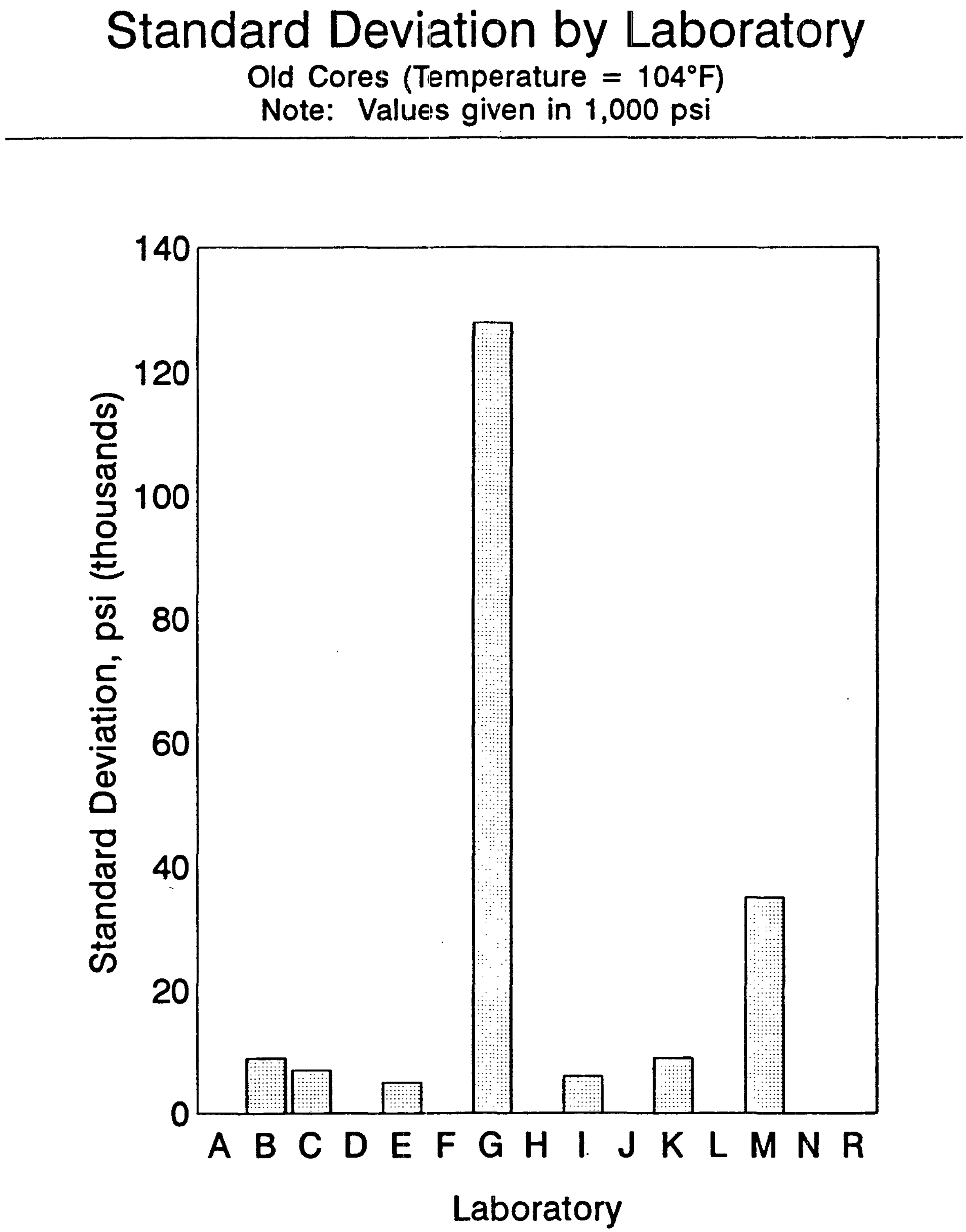


Figure 19. Within laboratory standard deviation: old cores at 104°F.

Table 2. Estimated standard deviations and coefficients of variation for new asphalt cores.

	Temperature, °F					
	41		77		104	
	Sigma (psi)	CV (%)	Sigma (psi)	CV (%)	Sigma (psi)	CV (%)
Recovery Period: 0.9 s						
Among Laboratories	612,000	35	293,000	27	294,000	53
Among Specimens	168,000	10	132,000	12	100,000	18
Error	149,000	9	234,000	22	112,000	20
Mean (psi)	1,727,000		1,085,000		552,000	
Recovery Period: 1.9 s						
Among Laboratories	626,000	36	298,000	28	270,000	52
Among Specimens	64,000	10	160,000	15	106,000	21
Error	119,000	7	199,000	19	98,000	19
Mean (psi)	1,721,000		1,060,000		515,000	
Recovery Period: 2.9 s						
Among Laboratories	593,000	34	336,000	32	287,000	52
Among Specimens	210,000	12	143,000	13	95,000	17
Error	317,000	18	192,000	18	87,000	16
Mean (psi)	1,755,000		1,062,000		551,000	

Table 3. Estimated standard deviations and coefficients of variation for old asphalt cores.

	Temperature, °F					
	41		77		104	
	Sigma (psi)	CV (%)	Sigma (psi)	CV (%)	Sigma (psi)	CV (%)
Recovery Period: 0.9 s						
Among Laboratories	336,000	43	140,000	58	72,000	111
Among Specimens	Negative*	Not Applicable	22,000	9	8,000	12
Error	197,000	25	33,000	14	11,000	17
Mean (psi)	773,000		240,000		64,000	
Recovery Period: 1.9 s						
Among Laboratories	338,000	44	127,000	56	91,000	121
Among Specimens	12,000	2	13,000	6	7,000	9
Error	201,000	26	35,000	15	15,000	20
Mean (psi)	763,000		228,000		75,000	
Recovery Period: 2.9 s						
Among Laboratories	349,000	50	135,000	58	138,000	137
Among Specimens	24,000	3	18,000	8	24,000	24
Error	155,000	22	15,000	7	26,000	26
Mean (psi)	697,000		235,000		101,000	

* Indicates specimens were very similar in resilient modulus.

strengthening the recommendation that the synthetic cores be used by a laboratory to verify their procedure, data analysis, and equipment or to compare results with other laboratories.

- There is no consistent pattern in regard to the effect of recovery period on the resilient modulus and the results do not favor any one of the recovery periods with respect to producing less variability.

- The old and new field cores were rather homogeneous with a small component of variance for (SPECIMENS). This is an important observation: while each laboratory had a different set of cores, the observed differences in laboratory means can not be explained by differences in the cores. Of course each laboratory received a random selection of cores and this outcome should be expected.

- The LABORATORY component of variance for the field cores is quite large. Improvements in the test method and better techniques for calibrating the test equipment for this test may be required if measurements made at different laboratories are to be useful.

  The magnitude of the LABORATORY component of variance is of particular concern when the laboratories upon which the component of variance was based were all prequalified with the synthetic specimens.

- Continued use of synthetic reference specimens is probably warranted and should be included as part of the test procedure.

STATISTICAL ANALYSES

Statistical analyses were conducted using the synthetic specimens and the field cores. The old and the new field cores were considered as two separate experiments given the differences in their resilient moduli values. The purpose of the statistical analyses was to establish the data required to generate the ASTM measures of precision.

Statistical Model for the Synthetic Specimen Experiment

The estimated resilient modulus, $\bar{M}_R$, for a synthetic specimen may be modeled as

$$\bar{M}_R(i,j) = \mu + \text{LABORATORY}(i) + \text{ERROR}(j)$$

where it is assumed that

μ	=	the true but unknown mean for the specimens of this type
LABORATORY(i)	=	a normal random variable with mean of zero and standard deviation of SIGMA(LAB)
ERROR(i,j)	=	a normal random variable with mean of zero and standard deviation of SIGMA(ERROR).

The SIGMA(LAB) and SIGMA(ERROR) terms are of the greatest interest in this analysis. Since the same specimens were sent to each laboratory there is no SPECIMEN contribution to the variance in this setting. Thus the appropriate statistical analysis is simply a one-way (LABORATORY) components of variance analysis. This analysis was done for the each of the 4 specimens in separate analyses using the GLM procedure and the results are given in Appendix B. These analyses also provided the information given in Table 2.

The Statistical Model for the Asphalt Core Experiment

In this experiment the model for the estimated resilient modulus, $\bar{M}_R$ for an asphalt core (old or new) may be modeled as

$$\bar{M}_R(i,j,k) = \mu + \text{LABORATORY}(i) + \text{SPECIMEN}(i,j) + \text{ERROR}(i,j,k)$$

where it is assumed that

μ	=	true but unknown mean for the core
LABORATORY(i)	=	normal random variable with mean of zero standard deviation of SIGMA(LAB)
SPECIMEN(i,j)	=	normal random variable with mean of zero standard deviation of SIGMA(SPECIMEN)
ERROR(i,j,k)	=	normal random variable with mean of zero and standard deviation of SIGMA(ERROR).

It is assumed that the terms LABORATORY, SPECIMEN and ERROR, are the sources in the variation observed in the estimates of the resilient modulus and the purpose of the analysis is to separate isolate the contribution from each of these sources.

This experiment is a nested design and the appropriate analysis may be done with NESTED statistical analysis procedure. The results from a nested analysis of variance for the old and new cores are contained in Appendix C. These analyses also provided the information given in Tables 2 and 3.

ASTM Measures of Precision

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 is simply the pooled within laboratory error standard deviation, SIGMA(ERROR) as given in Table 2 and Table 3. The ASTM notation for the within laboratory standard deviation is D1S and

$$\text{D1S} = \text{SIGMA(ERROR)}$$

D1S or SIGMA(ERROR) is a measure of within laboratory repeatability will be referred to as the within laboratory single operator standard deviation. Two identical specimens measured in the same laboratory should have a difference that is within ±2.8 D1S about 95% of the time. From Tables 2 or 3 the appropriate error margin would simply be 2.8 times the SIGMA(ERROR).

The reproducibility measure includes within laboratory variability as well as among laboratory variability; it indicates the degree to which a test result at one laboratory may vary if done at another laboratory. Accordingly, the reproducibility standard deviation is given by

$$\{[\text{SIGMA(LAB)}]^2 + [\text{SIGMA(ERROR)}]^2)\}^{0.5}$$

which is the square root of the sum of squares of the laboratory and error standard deviations. This will be referred to as the multi-laboratory standard deviation and is referred to as D2S.

Two identical specimens measured in two different laboratories should have a difference that is within ±2.8 D2S about 95% of the time. The value of the multi-laboratory standard deviation can be calculated from the entries in Table 2 or 3. The results for both within laboratory and between laboratory precision statements are presented for several cases of interest in the following section.

Examples of Precision Statements from the SHRP Asphalt Concrete Core Proficiency Sample Program

Consider the above definitions for the setting in which we are measuring new cores at 41°F with a recovery period of 0.9 seconds. From Table 2 the SIGMA(ERROR) is 149,000 psi; this is D1S or the within laboratory single operator standard deviation. Therefore, the results of two properly conducted resilient modulus tests conducted in the same laboratory by the same operator on a core sample of this type should not differ by more than 421,000 psi from each other. This may be compared with the mean value or 1,727,00 psi for the new cores at 41°F. The numbers 149,00 and 421,00 represent the D1S and D2S limits as indicated in AASHTO R4, section 2.1.1 (ASTM C 670). In a similar manner the within laboratory precision statements for the other temperatures, new or old cores, may be obtained with the aid of Tables 2 and 3.

Again consider the setting in which we have new cores to be tested at 41°F and between laboratory precision statements are to be calculated. The appropriate standard deviation in this case will be

$$[149{,}000^2 + 612{,}000^2]^{0.5}$$

where the 149,000 is the within laboratory standard deviation or the ERROR(SIGMA) and the 612,000 is the LABORATORY(SIGMA) as given in Table 2. Thus the multi-laboratory standard deviation for this setting is 629,000 psi. When this is multiplied by 2.8 it follows that the results of properly conducted resilient modulus tests from two different laboratories on asphalt concrete core samples of this type should not differ by more than 1,779,000 psi. These numbers, 629,000 and 1,779,000 psi, represent the 1S and D2S limits as indicated in AASHTO R4, section 2.1.1 (ASTM C 670).

Since the measurement for a single core should not be expected to provide a precise value for a pavement section, it is more informative to ask how many cores will need to be extracted, measured and averaged in order to obtain a required precision. The information in

Tables 2 and 3 will provide the means for calculating an answer. For example, if 5 cores are extracted and each is measured independently at 40°F and recovery period of 0.9 sec using four independent samples, the within laboratory standard deviation of the average will be

$$\left[\frac{(164{,}000)^2}{5}+\frac{(119{,}000)^2}{20}\right]^{0.5}$$

The above examples serve to illustrate the manner in which the results of this study may be applied. Further presentation of the data in terms of precision and accuracy statements are is given in Appendix E. To further illustrate the among and within laboratory variability it may be helpful to consider the 0.95 probability limits which can be calculated from the data in Table 2 and the data presented in Appendix E. Two limits which are usually calculated from the data are:

- <u>Single operator limits</u> which represent the difference between two independent measurements on the same core by a single operator at a given laboratory with a probability of 0.95.

- <u>Multiple laboratory limits</u> which represent the difference between two measurements at two different laboratories on the same core with a probability of 0.95.

These two limits are given in Table 4 for the three test temperatures for the old and new set of cores (recovery period 0.9 seconds). Two additional sets of 0.95 probability limits are:

- <u>Single operator limits for a single measurement</u> on a given core tested by a given operator at a given laboratory.

Table 4. Single operator and within laboratory limits: 0.95 level.

Core Set	Temp (°F)	Average Resilient Modulus (psi)	Single Operator 0.95 Probability Limits (psi)		Multiple Laboratory 0.95 Probability Limits (psi)	
			Difference in Two Means	Range in Two Measurements on Given Core	Difference in Two Measurements on Same Core at Different Laboratories	Range in Measurements on Same Core at Different Laboratories
New	41	1,727,000	±421,000	1,435,000 to 2,019,000	±1,782,000	492,000 to 2,962,000
	77	1,085,000	±662,000	626,000 to 1,544,000	±1,061,000	352,000 to 1,818,000
	104	552,000	±317,000	332,000 to 772,000	±890,000	0 to 1,169,000
Old	41	773,000	±557,000	387,000 to 1,159,000	±1,102,000	11,000 to 1,535,000
	77	240,000	±93,000	175,000 to 305,000	±407,000	0 to 522,000
	104	64,000	±31,000	42,000 to 86,000	±206,000	0 to 207,000

- Multiple laboratory limits for a single measurement on a given core tested at a laboratory chosen at random.

The first of these probability limits simply accounts for the within laboratory variation and is calculated as the mean $\pm$ 1.96 ERROR(SIGMA). A single measurement at this laboratory will be within these limits 95 percent of the time. The second of these probability limits accounts for the among laboratory variation in addition to the within laboratory variation. If a given core is sent to a laboratory selected at random from the laboratories in this study the 0.95 probability limits for this single measurement will include the resulting test value 95 percent of the time. These limits illustrate the uncertainty in the resilient modulus as in accordance with the testing capabilities of the laboratories included in this study.

The within laboratory limits are perhaps manageable and are as can be expected for this type of test. However, the limits for the between laboratory case are clearly unacceptable and modifications to the test procedure will be necessary for this test method to be a useful engineering measurement. With this variability the test results cannot differentiate between pavements or mixtures with different performance characteristics. Taking more cores does not reduce the among laboratory component of variance and therefore does not provide benefit in reducing the among laboratory variability.

SUMMARY

The objectives for this study were been attained. A total of 25 laboratories participated to some extent in the testing of the synthetic specimens and each laboratory was appraised of their performance. Suggestions regarding improvements in technique were provided where appropriate. All participating laboratories benefitted from this evaluation.

The statistical analyses of the variation observed in the estimates of the resilient modulus has brought out several important facts. There was a large laboratory component in the observed data for the asphalt cores. Improvements are needed in the test procedure if meaningful test results are to be obtained for field cores. Some means for the standardization and calibration of equipment and procedures must be devised if measurements at different laboratories are to be useful. As a minimum the use of synthetic reference specimens must be continued.

In this experiment the SPECIMEN component for both new and old cores appear to be quite reasonable. In practice, especially for old cores there may be considerably more variation from core to core. Thus the SPECIMEN component of variance as estimated in this experiment is likely low compared to what might be expected when characterizing many field projects.

The data for this experiment were obtained over a period of about 2 years. As noted in the report there is little basis for regarding these participating laboratories as a random sample from some larger group. Furthermore, several of the participating laboratories may have modified their testing procedures during the time of this experiment. On the other hand the field cores were tested only at laboratories that were prequalified on the basis of their results with the synthetic specimens. For these reasons, the results from this experiment should be regarded as providing a good picture of the accuracy and precision of the resilient modulus testing as done by these selected laboratories during the time of the experiment.

With this understanding it is surely true that this experiment and its analysis do provide an excellent picture of the amount and sources of variability that would be expected to have occurred in the resilient modulus testing that was being carried out in this time. It would also be fair to consider these results as some sort of baseline from which to make comparisons as better methods are developed and evaluated.

The following conclusions are valid based on the set of data collected as part of this study:

- The resilient modulus test is difficult to perform and requires considerable attention to detail in order to obtain sufficiently repeatable results.

- Rest periods of 0.9, 1.9, and 2.9 seconds produce essentially the same variability.

- The use of synthetic samples to verify the procedure among laboratories is warranted and should be included in the test method.

- Based on the data obtained from the pre-qualified laboratories that tested the two sets of field cores, the among laboratory variability raises serious doubts as to the value of this test method for judging or predicting the performance of asphaltic pavements or mixtures.

- Improvements in the test method must be made in order for this test method to be an acceptable method for characterizing asphalt concrete mixtures.

- Increasing the number of cores tested will not significantly reduce the variability in the test method.

APPENDIX A.

SHRP PROTOCOL P-007

RESILIENT MODULUS FOR ASPHALTIC 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) - "Indirect Tension Test for Resilient Modulus of Bituminous Mixtures", 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) approval by the SHRP Regional Engineer to begin AC resilient modulus testing (laboratory must pass (a) the synthetic specimen AC resilient modulus sample proficiency testing program and (b) the AC core specimen resilient modulus sample proficiency testing program), (2) approval of Form L04 by the SHRP RCOC, (3) visual examination and thickness of asphaltic concrete (AC) cores and thickness determination of layers within the AC cores using Protocol P01, and (4) 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. A test specimen shall consist of only one material or layer with a thickness greater than 1.5 inches. The desired thickness for testing is approximately 2 inches. If the thickness of a particular AC layer to be tested is greater than the desired testing thickness of 2 inches, then the 2 inch specimen to be used for testing shall be obtained from the middle of the AC layer by sawing the specimen. If a core from an AC layer is between 1.5 and 2 inches and has relatively smooth and uniform front and back faces then no sawing is required and the specimen for this layer may be tested as is.

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. Normally, cores obtained from sample locations C7 and C19 are used for the indirect tensile strength test. The indirect tensile strength test is performed to assist in selecting a stress (or applied load) level for subsequent resilient modulus testing. The test shall be performed in accordance with Attachment A of this protocol.

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, respectively, which has a layer thickness greater than 1.5 inches). Normally, only the cores designated by the SHRP RCOC for P07 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); and C8 (for resilient modulus test using Protocol P07). The test results determined for each test specimen from the specified core locations shall be assigned SHRP Laboratory Test Number "1". Cores obtained from sample locations C9 and C10 shall be used as backup test specimens for the resilient modulus 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); and C20 (for resilient modulus test using Protocol P07). The test results determined for each test specimen from the specified core locations shall be assigned SHRP Laboratory Test Number "2". Cores obtained from sample locations C21 and C22 shall be used as backup test specimens for the resilient modulus testing.

If any of the test specimens obtained from the specified core locations are damaged or untestable, other cores (C9 or C10 in place of C8 for the beginning of the test section and C21 or C22 in place of C20 for the end of the test section) should be used. However, it is inappropriate to substitute test specimens from one end of the GPS Section for test specimens at the other end. Use comment code 30 on data sheets T07A and T07B if the designated specimens do not meet minimum specimen standards such that a replacement specimen from another location (such as C9 or C10 for the beginning of the test section and C21 or C22 for the end of the test section) was used.

The following definitions are used throughout this protocol:

(a) Layer: That part of the pavement produced with similar material and placed with similar equipment and techniques. The material within a particular layer is assumed to be homogeneous. The layer thickness 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 (1987).

NOTE 1 - Delete Note 1 from Scope

2. APPLICABLE DOCUMENTS

2.1 ASTM Documents: As listed in ASTM D4123-82 (1987).

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 (1987).

3.2 As described in Section 3.2 of ASTM D4123-82 (1987).

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

(a) Indirect tensile strength is determined on a test specimen at 77 ± 2°F (normally specimens obtained from C7 and C19) using the procedure described in Attachment A to Protocol P07. The value of indirect tensile strength determined by this procedure is used to estimate the indirect tensile stress and compressive load to be applied to the test specimens during the resilient modulus determinations.

(b) The test specimen(s) (normally specimens obtained from C8 and C20) are to be tested each along a single diametral axis and at three separate testing temperatures, 41, 77 and 104°F plus or minus two degrees fahrenheit (15, 25, and 40°C plus or minus one degree C). For each test temperature, repetitive haversine load pulses of 0.1-second duration with a rest period of 0.9 second are applied to the individual test specimens to produce an indirect tensile stress on the specimen (a predefined percentage of the indirect tensile strength as determined in 3.3 (a) above).

(c) After completion of resilient modulus testing at 104°F, the test specimen shall be returned to 77°F and an indirect tensile strength test shall be performed in accordance with Attachment A of this protocol. This test is performed to determine the indirect tensile strength of the specific specimen used for the resilient modulus testing.

4. SIGNIFICANCE AND USE

4.1 As stated in Section 4.1 of ASTM D4123-82 (1987).

5. APPARATUS

5.1 Testing Machine - The testing machine shall be a top loading, 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 period.

NOTE 2 - Delete Note 2 from Section 5.1 of ASTM D4123-82 (1987).

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 (1987).

5.3.2 Deformation Measurement - The values of vertical and horizontal deformation shall be measured with linear variable differential transducers (LVDT's). LVDT's used to measure horizontal deformations should be located 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 assured by using spring loaded LVDT's and attaching a flat head (3/8" x 1/4") as a contact point. 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 transducer can be read independently and the results summed during the test program.

NOTE 3 - Delete the last two sentences of Note 3 of ASTM D4123-82 (1987).

5.3.3 Load Measurement - As required in Section 5.3.3 of ASTM D4123-82 (1987).

5.4 Loading Strip - As required in Section 5.4 of ASTM D4123-82 (1987).

6. TEST SPECIMENS

6.1 Laboratory-Molded Specimens - Delete Section 6.1 of ASTM D4123-82 (1987).

6.2 Core Specimens - As described in Section 6.2 of ASTM D4123-82 (1987).

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. Any testable layers identified in the P01 test (From T01B) shall be separated. 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 separated from each other by sawing.

6.4 Diametral Axis - Mark one diametral axis on both the front and back faces of each specimen to be tested. An appropriate, centering type marking device shall be used to ensure that the diametral markings on the front and back faces of the test specimen lie in the same vertical plane. The axis shall be parallel to the traffic direction symbol (arrow) or "T" marked during the field coring operations.

6.5 The thickness (t) of each test specimen shall be measured to the nearest 0.1 inch (2.5 mm) prior to testing. The thickness shall be determined by averaging four measurements equally spaced around the test specimen. A test specimen shall consist of a single pavement material or layer greater than 1.5 inches in thickness. The desired thickness for testing is approximately 2 inches. If the thickness of a particular AC layer to be tested is one-half inch or more greater than the desired testing thickness of 2 inches, then the 2 inch specimen to be used for testing shall be obtained from the middle of the AC layer by sawing the specimen. If a core from an AC layer is between 1.5 and 2 inches and has relatively smooth front and back faces then no sawing is required and the specimen for this layer may be tested as is.

6.6 The diameter (D) of each test specimen shall be determined prior to testing using a caliper to the nearest 0.01 inch (0.25 mm) by averaging two diameters at the mid-height of the test specimen. Measure (1) the diameter of the axis parallel to the direction of traffic and (2) the diameter of the axis perpendicular (90 degrees) to the axis measured in (1) above. These two measurements shall be averaged to determine the diameter of the test specimen.

6.7 If the average diameter of the core is outside the range of 3.85 to 4.15 inches, the core shall not be tested. A replacement core shall be selected for the resilient modulus test.

7. PROCEDURE

7.1 <u>General</u>

(a) Determine the indirect tensile strength of the designated test specimens at 77°± 2°F (normally specimens obtained from sample locations C7 and C19) using the procedure described in Attachment A to Protocol P07.

(b) The test specimen(s) designated for resilient modulus testing (normally specimens obtained from C8 and C20) shall be brought to the first test temperature (41±2°F) as specified in Section 7.1 of ASTM D4123-82 (1987).

(c) The procedure described in Section 7.1 of ASTM D4123-82 (1987) shall be completed to bring the test specimens to the remaining desired test temperatures (77±2°F, 104±2°F).

7.2 <u>Alignment and Specimen Seating</u>

At each temperature, the test specimen shall be placed in the loading apparatus and positioned so that the diametral markings are centered top to bottom within the loading strips on both the front and back face of the specimen along the axis parallel to the direction of traffic. This is a critical alignment and should be conducted with great care. An alignment method which has been successfully used with cores is to place the test specimen within the curved portion of the bottom loading strip with the specimen cradled between the fingers of the left and right hands. The marked diametral axis (axis parallel to the direction of traffic) should then be located so that the diametral line intersects the center of the curved portion of the bottom loading strip. To correctly seat the specimen in the bottom loading strip, the specimen can be moved within the curved portion of the loading strip by applying slight pressure from the fingertips on both sides of the bottom curved portion of the core. The diametral marking can then be used to insure that the specimen is aligned from top to bottom, front to back. The alignment of the front face of the specimen can be checked by insuring that the diametral marking is centered on the top and bottom loading strips. With the use of a mirror, the back face can be similarly aligned. The 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). The electronic measuring system shall be adjusted and balanced as necessary. Prior to testing and after the horizontal deformation device is mounted on the test specimen, adjustments are required in the relative position of the transducers in order to approach a "null" or a near zero voltage position (a similar "null" position shall be produced for the LVDT's used to measure the vertical deformations during testing). When starting from the "null" position, the "travel" of the transducer shaft should be sufficient to require no further adjustment in the transducer position for the duration of a test.

The line of contact between the specimen and each loading strip is critical for proper test results. The specimen shall be free of any projections or depressions higher or deeper than 0.1 inch (2.50 mm). Specimens having projections or depressions greater than 0.1 inch should not normally be tested. However, if no suitable replacement specimen is available that meets the 0.1 inch criteria, that test shall be conducted on the designated specimen. Code 39 has been provided to document this situation.

7.3 Preconditioning

Preconditioning and testing shall be conducted while the specimen is located in a temperature-control cabinet meeting the requirements of Section 5.2 of ASTM D4123-82 (1987).

7.3.1 Selection of the applied loads for preconditioning and testing at the three test temperatures is 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 use in conducting the resilient modulus determinations at the test temperatures of 41 ± 2, 77 ± 2 and 104 ± 2°F (15, 25 and 40°C ± 1C), respectively. Minimum specimen seating loads of 3, 1.5 and .5 percent of the 77°F tensile strength value shall be maintained during resilient testing for test temperatures, respectively, of 41±2, 77±2 and 104±2°F (15, 25 and 40±1°C).

7.3.2 The sequence of resilient modulus testing shall consist of initial testing at 41°F, followed by intermediate testing at 77°F and final testing at 104°F. The test specimens shall be brought to the specified temperature prior to each test (i.e. initial, intermediate and final), in accordance with Section 7.1 of ASTM D4123-82 (1987). The test specimen shall be preconditioned along the axis prior to testing by applying a repeated haversine-shaped load pulse of 0.1-second duration with a rest period of 0.9 second, until a minimum of ten (10) successive horizontal deformation readings agree within 10 percent. 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 41±2°F, 50-100 for 77±2°F and 20-50 for 104±2°F. The minimum number of load applications for a given situation must be such that the resilient deformations are stable (see note 5 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 .0001 inches) cannot be recorded using 5 to 30% 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 (1987).

7.4 Both the horizontal and vertical deformations shall be monitored during preconditioning of the test specimen. 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 does not yield adequate deformations for measurement purposes, discontinue preconditioning and generate 10 load pulses for resilient modulus determination, and so indicate on the test report.

7.5 Testing

After preconditioning a specimen at 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 application of load pulses shall continue beyond 30 until the range in deformation values of five (5) successive horizontal deformation values (i.e. from lowest to highest values) is less than 10% of the average of the five (5) deformation values.

7.5.2 After the specimen has been tested at a specific temperature, bring the specimen to the next higher temperature in accordance with Section 7.1 of ASTM D4123-82 (1987) and repeat steps 7.3.1 through 7.5.1 of this protocol.

7.5.3 After testing is completed at 104°F, the specimen shall be brought to a temperature of 77±2°F and an indirect tensile strength test conducted on the test specimen as specified in Attachment A.

7.6 Measure and record the recoverable horizontal and vertical deformations over the last 5 loading cycles (see Figure 2 of ASTM D4123-82) after the repeated resilient deformations have become stable (step 7.5). One loading cycle consists of one load pulse and a subsequent 0.9 second rest period. The resilient modulus will be calculated individually for each of the last five load cycles and an average resilient modulus obtained.

8. CALCULATIONS

8.1 As described in Section 8.1 of ASTM D4123-82 (1987).

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 is to be used for bituminous mixtures at 77°F (25°C). Values of 0.20 and 0.50 are to be used for 41° and 104°F (5, 40°C), respectively.

9. REPORT

9.1 The following general information is to be recorded on Form T07A:

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

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

9.1.3 Report the following specific information for each test specimen on Form T07A.

(a) Record a "yes" to indicate whether the layer to be tested was sawed (so as to obtain the desired thickness for testing, i.e. approximately 2 inches) or a "no" if sawing was not required.

(b) Average thickness of the test specimen, (t), to the nearest 0.1 inch (per Section 6.5 of this protocol).

(c) Average diameter of the test specimen (D), to nearest 0.01 inch (per Section 6.6 of this protocol).

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

(e) Indirect tensile strength, to the nearest psi, (Previously reported on Form T07B). This is the indirect tensile test result that was used to assist in selecting a stress (or applied load) level for resilient modulus testing.

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

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

(h) Poisson's ratio assumed for each test temperature (0.20 at 40±2°F, 0.35 at 77±2°F and 0.50 at 104±2°F)

(i) The rest period, secs.

(j) Average instantaneous and total resilient moduli at each test temperature (as calculated in accordance with Section 8.1 of ASTM D4123-82 (1987)).

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 observed by placing the specimen on a level surface and measuring the departure from perpendicularity.
27	The tests were not performed in a temperature-controlled cabinet and the resilient modulus determinations were not completed within four minutes as required in Section 7.5 of ASTM D4123-82 (1987) (use the accompanying note ("7(b) NOTE") portion of Form T07A to document the actual length of time used for the resilient modulus determinations).
28	The test was not performed in a temperature control cabinet. But the resilient modulus determinations were completed within 4 minutes as required.
29	A "dummy" specimen was used to monitor the temperature of the test specimen during M_r testing.
30	The designated specimen did not meet minimum specimen standards and was not tested. A replacement specimen from another location was used for the M_r testing.
31	Tests for all three temperatures could not be performed because the specimen was damaged and/or excessively deformed during testing.
39	The projections/depressions on the test surface were higher or deeper than 0.1 inch. The specimen was tested because there was no other replacement specimen (use the accompanying note ("7(b) NOTE") portion of Form T07A to record the average projection/depression(s) of the tested specimen).
40	The test specimen did not have any traffic direction symbol (arrow or "T"). An arbitrary line was drawn to show the axis of the specimen during resilient modulus testing.

9.2 The following general information is to be recorded on "Worksheet 1 for Test Data Sheet T07A":

9.2.1 Sample Identification shall include: SHRP Section ID, Layer Number, Field Set Number, Sample Location Number, and SHRP Sample Number.

9.2.2 Test identification, shall include: SHRP Laboratory Test Number and Test Date.

9.2.3 Report the following specific information for each test specimen at each test temperature on Worksheet 1:

(a) The resilient and total vertical load levels and recoverable horizontal and vertical deformations measured over the last 5 loading cycles for each test temperature. The horizontal movement for each LVDT shall be reported separately.

(b) The seating load used over the last 5 loading cycles for each test temperature.

(c) The instantaneous and total resilient modulus for each load cycle.

(d) The average resilient modulus (M_r) for the last 5 load cycles and standard deviation calculated at each test temperature.

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

(f) The total number of applied load cycles obtained in determining the resilient modulus values.

9.3 The summary test data for one test specimen at one temperature 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". For a complete set of tests on <u>one</u> specimen, a total of (1) one Form T07A, (2) three Worksheet "1"'s, and (4) two Form T07B's are required.

SHEET NO ___ OF ___

SHRP-LTPP LABORATORY MATERIAL HANDLING AND TESTING
LABORATORY MATERIAL TEST DATA
TEST DATA SHEET T07A

ASPHALT CONCRETE LAYER
RESILIENT MODULUS TEST

SHRP TEST DESIGNATION: AC07/SHRP PROTOCOL P07

LABORATORY PERFORMING TEST: ______________________________
LABORATORY IDENTIFICATION CODE: _ _ _ _

SHRP REGION __________ STATE __________ *STATE CODE* _ _
LTPP EXPT. __________ *SHRP SECTION ID* _ _ _ _ _ _
SAMPLED BY: ______________________ *FIELD SET NUMBER* _
DRILLING AND SAMPLING AGENCY/CONTRACTOR
DATE SAMPLED: _ _-_ _-_ _ _ _

1. *LAYER NUMBER* (FROM CORRECTED LAB SHEET L04) _____
2. *SHRP LABORATORY TEST NUMBER* _____
3. *LOCATION NUMBER* _ _ _
4. *SHRP SAMPLE NUMBER* _ _ _ _
5. *TEST SPECIMEN DATA* (Section 9.1 of Protocol P07)
   (a) *WAS TESTED LAYER SAWED? (YES/NO)* _ _ _
   (b) *SPECIMEN THICKNESS, INCH* _._ _
   (c) *SPECIMEN DIAMETER, INCH* _ _._ _
   (d) *TEST TEMPERATURE, °F* _ _ _. _ _ _. _ _ _.
   (e) *INDIRECT TENSILE STRENGTH, PSI* (From Form T07B) _ _ _ _.
   (f) *SEATING LOAD USED AT EACH TEMPERATURE, LBF* _ _ _. _ _ _. _ _ _.
   (g) *RESILIENT LOAD USED AT EACH TEMPERATURE, LBF* _ _ _ _ _. _ _ _ _ _. _ _ _ _ _.
6. *TEST RESULTS* (Section 9.1 of Protocol P07)
   (a) *POISSON'S RATIO AT EACH TEMPERATURE* _._ _ _._ _ _._ _
   (b) *REST PERIOD, SECS* _._ _
   (c) *AVERAGE Mr VALUES* (From Work Sheet "1")
   AXIS PARALLEL TO TRAFFIC; _ _ _ _ _ _ _ _. _ _ _ _ _ _ _ _. _ _ _ _ _ _ _ _.
   INSTANTANEOUS Mr _ _ _ _ _ _ _ _. _ _ _ _ _ _ _ _. _ _ _ _ _ _ _ _.
   TOTAL Mr _ _ _ _ _ _ _ _. _ _ _ _ _ _ _ _. _ _ _ _ _ _ _ _.
7. *COMMENTS* (Section 9.1 of Protocol P07)
   (a) *CODE* _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
   _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _
   (b) *NOTE* ______ ______ ______
   ______ ______ ______
8. *TEST DATE* _ _-_ _-_ _ _ _-_ _-_ _ _ _-_ _-_ _

SPECIMEN FROM: (a) BEGINNING OF GPS SECTION, (b) END OF GPS SECTION
GENERAL REMARKS: ______________________________

Submitted By, Date __________________ Check and Approved, Date __________________

Laboratory Chief SHRP Representative
Affiliation__________________ Affiliation__________________

SHEET NO ___ OF ___

WORKSHEET 1 FOR TEST DATA SHEET T07A
AXIS PARALLEL TO TRAFFIC

SHRP SECTION ID __ __ __ __ __ __

LAYER NUMBER (FROM CORRECTED LAB SHEET L04) ____

LOCATION NUMBER _ _ _

TEST TEMPERATURE _ _ _°F

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

FIELD SET NUMBER _

SHRP LABORATORY TEST NUMBER _

SHRP SAMPLE NUMBER _ _ _ _

POISSON'S RATIO _._ _

REST PERIOD	LOAD CYCLE	RESILIENT VERTICAL LOAD, LBF	SEATING LOAD	VERTICAL DEFORMATION	HORIZONTAL DEFORMATION LVDT 1	HORIZONTAL DEFORMATION LVDT 2	INSTANTANEOUS RESILIENT MOD.
0.9	1	_ _ _.	_ _.	._ _ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	_ _ _ _ _ _ _ _
	2	_ _ _.	_ _.	._ _ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	_ _ _ _ _ _ _ _
	3	_ _ _.	_ _.	._ _ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	_ _ _ _ _ _ _ _
	4	_ _ _.	_ _.	._ _ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	_ _ _ _ _ _ _ _
	5	_ _ _.	_ _.	._ _ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	_ _ _ _ _ _ _ _
				AVERAGE RESILIENT MODULUS			_ _ _ _ _ _ _ _
				STANDARD DEVIATION			_ _ _ _ _ _ _

REST PERIOD	LOAD CYCLE	TOTAL VERTICAL LOAD, LBF	SEATING LOAD	VERTICAL DEFORMATION	HORIZONTAL DEFORMATION LVDT 1	HORIZONTAL DEFORMATION LVDT 2	TOTAL RESILIENT MOD.
0.9	1	_ _ _.	_ _.	._ _ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	_ _ _ _ _ _ _ _
	2	_ _ _.	_ _.	._ _ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	_ _ _ _ _ _ _ _
	3	_ _ _.	_ _.	._ _ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	_ _ _ _ _ _ _ _
	4	_ _ _.	_ _.	._ _ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	_ _ _ _ _ _ _ _
	5	_ _ _.	_ _.	._ _ _ _ _ _ _	._ _ _ _ _ _	._ _ _ _ _ _	_ _ _ _ _ _ _ _
				AVERAGE RESILIENT MODULUS			_ _ _ _ _ _ _ _
				STANDARD DEVIATION			_ _ _ _ _ _ _

Calculation of permanent deformation per load cycle.	
c1 = number of preconditioning cycles	____.
c2 = cumulative permanent vertical deformation	._ _ _ _ _ _
c3 = cumulative permanent horizontal deformation	._ _ _ _ _ _
c4 = total number of load cycles during test	_ _ _ _.
c5 = cumulative permanent vertical deformation after preconditioning	._ _ _ _ _ _
c6 = cumulative permanent horizontal deformation after preconditioning	._ _ _ _ _ _
c7 = cumulative permanent vertical deformation per load cycle ((c2-c5)/(c4-c1))	._ _ _ _ _ _
c8 = cumulative permanent horizontal deformation per load cycle ((c3-c6)/(c4-c1))	._ _ _ _ _ _

GENERAL REMARKS: ______________________________

Submitted By, Date ______________________ Checked and Approved, Date ______________________

Laboratory Chief SHRP Representative

SHEET NO ___ OF ___

SHRP-LTPP LABORATORY MATERIAL HANDLING AND TESTING
LABORATORY MATERIAL TEST DATA
TEST DATA SHEET T07B

ASPHALT CONCRETE LAYER
RESILIENT MODULUS TEST

SHRP TEST DESIGNATION: AC07/SHRP PROTOCOL P07

LABORATORY PERFORMING TEST: ____________________
LABORATORY IDENTIFICATION CODE: _ _ _ _

SHRP REGION ________ STATE ________ *STATE CODE* _ _
LTPP EXPT. ________ *SHRP SECTION ID* _ _ _ _ _ _
SAMPLED BY: ____________________ *FIELD SET NUMBER* _
DRILLING AND SAMPLING AGENCY/CONTRACTOR
DATE SAMPLED: _ _-_ _-_ _ _ _

1. *LAYER NUMBER* (FROM CORRECTED LAB SHEET L04) ____
2. *SHRP LABORATORY TEST NUMBER* ____
3. *LOCATION NUMBER* _ _ _
4. *SHRP SAMPLE NUMBER* _ _ _ _
5. *AVERAGE TEST SPECIMEN HEIGHT, IN.* _ _._
6. *AVERAGE TEST SPECIMEN DIAMETER, IN.* _ _._ _

AXIS TESTED: PARALLEL TO TRAFFIC

7. *TOTAL MAXIMUM LOAD SUSTAINED BY SAMPLE, LBF.*
   (2 inches/min. 77°F) _ _ _ _ _.
8. *INDIRECT TENSILE STRENGTH, PSI* _ _ _ _._
9. *COMMENTS*
   (Section 9.1 of Protocol P07)
   (a) *CODE* _ _ _ _ _ _
   (b) *NOTE* _ _ _ _ _ _ ____________________
10. *TEST DATE* _ _-_ _-_ _

SPECIMEN FROM: (a) BEGINNING OF GPS SECTION, (b) END OF GPS SECTION
GENERAL REMARKS: ____________________

Submitted By, Date ____________________ Checked and Approved, Date ____________________

Laboratory Chief
Affiliation ____________________

SHRP Representative
Affiliation ____________________

APPENDIX B.

ANALYSIS OF VARIANCE

SYNTHETIC SPECIMENS

SAS

------------------------------------SPECIMEN R ------------------------------------

General Linear Models Procedure

Dependent Variable: RM

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	47516315.17	5279590.57	18.33	0.0001
Error	18	5184584.43	288032.47		
Corrected Total	27	52700899.60			

R-Square	C.V.	Root MSE	RM Mean
0.901622	8.291511	536.6866	6472.72321

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LABORATORY	9	47516315.17	5279590.57	18.33	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LABORATORY	9	47516315.17	5279590.57	18.33	0.0001

------------------------------------SPECIMEN R ------------------------------------

General Linear Models Procedure

Source	Type III Expected Mean Square
LABORATORY	Var(Error) + 2.6984 Var(LABORATORY)

SAS

-----------------------------------SPECIMEN T -----------------------------------

General Linear Models Procedure

Dependent Variable: RM

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	8075744480	897304942	14.15	0.0001
Error	18	1141722636	63429035		
Corrected Total	27	9217467116			

R-Square	C.V.	Root MSE	RM Mean
0.876135	5.499839	7964.235	144808.517

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LABORATORY	9	8075744480	897304942	14.15	0.0001

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LABORATORY	9	8075744480	897304942	14.15	0.0001

-----------------------------------SPECIMEN T -----------------------------------

General Linear Models Procedure

Source	Type III Expected Mean Square
LABORATORY	Var(Error) + 2.6984 Var(AGENCY)

SAS

----------------------------------SPECIMEN P ----------------------------------

General Linear Models Procedure

Dependent Variable: RM

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	40984809499	4553867722	1.95	0.1096
Error	18	42124021121	2340223396		
Corrected Total	27	83108830621			

R-Square	C.V.	Root MSE	RM Mean
0.493146	20.85803	48375.86	231929.220

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LABORATORY	9	40984809499	4553867722	1.95	0.1096

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LABORATORY	9	40984809499	4553867722	1.95	0.1096

----------------------------------SPECIMEN P ----------------------------------

General Linear Models Procedure

Source	Type III Expected Mean Square
LABORATORY	Var(Error) + 2.6984 Var(LABORATORY)

SAS analysis of variance (Procedure GLM) for the Synthetic Specimens

----------------------------------SPECIMEN L ----------------------------------

General Linear Models Procedure

Dependent Variable: RM

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	79303121574	8811457953	3.10	0.0316
Error	13	36904347620	2838795971		
Corrected Total	22	116207469194			

R-Square	C.V.	Root MSE	RM Mean
0.682427	9.484764	53280.35	561746.730

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LABORATORY	9	79303121574	8811457953	3.10	0.0316

Source	DF	Type III SS	Mean Square	F Value	Pr > F
LABORATORY	9	79303121574	8811457953	3.10	0.0316

----------------------------------SPECIMEN L ----------------------------------

General Linear Models Procedure

Source	Type III Expected Mean Square
LABORATORY	Var(Error) + 2.2222 Var(LABORATORY)

APPENDIX C.

NESTED ANALYSES OF VARIANCE

FIELD CORES

NESTED ANALYSIS OF VARIANCE FOR THE RESILIENT MODULUS EXPERIMENT

---------------------NEW CORES TEMPERATURE=40F RECPD=0.9 ---------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	119	44641794
AGENCY	7	39431204
SPECNO	32	3425084
ERROR	80	1785506

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	375141	424990	100.0000
AGENCY	5633029	374433	88.1039
SPECNO	107034	28238	6.6445
ERROR	22319	22319	5.2516

Mean	1726.71257733
Standard error of mean	230.16283672

---------------------NEW CORES TEMPERATURE=40F RECPD=1.9 ---------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	118	44869951
AGENCY	7	40737050
SPECNO	32	3013523
ERROR	79	1119378

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	380254	432718	100.0000
AGENCY	5819579	391632	90.5051
SPECNO	94173	26917	6.2204
ERROR	14169	14169	3.2745

Mean	1721.27325882
Standard error of mean	235.92269050

NESTED ANALYSIS OF VARIANCE FOR THE RESILIENT MODULUS EXPERIMENT

---------------------NEW CORES TEMPERATURE=40F RECPD=2.9 ---------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	118	53101055
AGENCY	7	37710807
SPECNO	32	7432324
ERROR	79	7957924

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	450009	497059	100.0000
AGENCY	5387258	352096	70.8358
SPECNO	232260	44230	8.8984
ERROR	100733	100733	20.2658

Mean	1755.22870328
Standard error of mean	225.45912388

--------------------NEW CORES TEMPERATURE=77F RECPD=0.9 --------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	161	23918938
AGENCY	9	13368886
SPECNO	40	4438031
ERROR	112	6112021

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	148565	158005	100.0000
AGENCY	1485432	86004	54.4311
SPECNO	110951	17429	11.0309
ERROR	54572	54572	34.5380

Mean	1085.12452426
Standard error of mean	101.76806825

NESTED ANALYSIS OF VARIANCE FOR THE RESILIENT MODULUS EXPERIMENT

---------------------NEW CORES TEMPERATURE=77F RECPD=1.9 ----------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	161	23161250
AGENCY	9	13840996
SPECNO	40	4906055
ERROR	112	4414198

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	143859	153715	100.0000
AGENCY	1537888	88575	57.6229
SPECNO	122651	25727	16.7371
ERROR	39412	39412	25.6400

Mean	1060.38725784
Standard error of mean	103.65498936

---------------------NEW CORES TEMPERATURE=77F RECPD=2.9 ---------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	142	22189424
AGENCY	8	14942262
SPECNO	36	3648123
ERROR	98	3599039

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	156264	170067	100.0000
AGENCY	1867783	112987	66.4372
SPECNO	101337	20354	11.9683
ERROR	36725	36725	21.5944

Mean	1061.90750678
Standard error of mean	122.04796370

NESTED ANALYSIS OF VARIANCE FOR THE RESILIENT MODULUS EXPERIMENT

--------------------NEW CORES TEMPERATURE=102F RECPD=0.9 ----------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	107	10235873
AGENCY	6	8121042
SPECNO	27	1191262
ERROR	74	923569

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	95662	109059	100.0000
AGENCY	1353507	86645	79.4476
SPECNO	44121	9934	9.1084
ERROR	12481	12481	11.4440

Mean	552.13204352
Standard error of mean	119.50853360

--------------------NEW CORES TEMPERATURE=102F RECPD=1.9 --------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	107	8827646
AGENCY	6	6883270
SPECNO	27	1229685
ERROR	74	714691

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	82501	93843	100.0000
AGENCY	1147212	72919	77.7027
SPECNO	45544	11267	12.0057
ERROR	9658	9658	10.2916

Mean	514.81172093
Standard error of mean	110.02534680

NESTED ANALYSIS OF VARIANCE FOR THE RESILIENT MODULUS EXPERIMENT

--------------------NEW CORES TEMPERATURE=102F RECPD=2.9 ---------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	87	7300941
AGENCY	5	6045197
SPECNO	23	811110
ERROR	59	444634

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	83919	98960	100.0000
AGENCY	1209039	82313	83.1778
SPECNO	35266	9111.108483	9.2068
ERROR	7536.174840	7536.174840	7.6153

Mean	550.93464250
Standard error of mean	126.47194379

------------------------- SPEC=O TEMP=40F RECPD=0.9 -------------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	135	18339499
AGENCY	8	13657930
SPECNO	34	1088539
ERROR	93	3593030

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	135848	151407	100.0000
AGENCY	1707241	112772	74.4828
SPECNO	32016	-2083.722798	0.0000
ERROR	38635	38635	25.5172

Mean	772.93554566
Standard error of mean	120.30682492

NESTED ANALYSIS OF VARIANCE FOR THE RESILIENT MODULUS EXPERIMENT

------------------------- SPEC=O TEMP=40F RECPD=1.9 -------------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	134	18946861
AGENCY	8	13817326
SPECNO	34	1395962
ERROR	92	3733573

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	141394	155061	100.0000
AGENCY	1727166	114328	73.7309
SPECNO	41058	150.836739	0.0973
ERROR	40582	40582	26.1718

Mean	763.43676037
Standard error of mean	121.30061783

------------------------- SPEC=O TEMP=40F RECPD=2.9 -------------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	115	14948790
AGENCY	7	12309803
SPECNO	30	772490
ERROR	78	1866497

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	129989	146666	100.0000
AGENCY	1758543	122143	83.2797
SPECNO	25750	593.545219	0.4047
ERROR	23929	23929	16.3156

Mean	696.62670612
Standard error of mean	133.40561791

NESTED ANALYSIS OF VARIANCE FOR THE RESILIENT MODULUS EXPERIMENT

-------------------------- SPEC=O TEMP=77F RECPD=0.9 --------------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	133	2503904
AGENCY	8	2311958
SPECNO	34	90850
ERROR	91	101096

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	18826	21169	100.0000
AGENCY	288995	19558	92.3914
SPECNO	2672.053024	499.684094	2.3605
ERROR	1110.948470	1110.948470	5.2481

Mean	239.50948343
Standard error of mean	49.82685959

-------------------------- SPEC=O TEMP=77F RECPD=1.9 --------------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	135	2109944
AGENCY	8	1933745
SPECNO	35	62343
ERROR	92	113855

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	15629	17520	100.0000
AGENCY	241718	16107	91.9328
SPECNO	1781.238961	175.830773	1.0036
ERROR	1237.559047	1237.559047	7.0636

Mean	227.64658301
Standard error of mean	44.78805312

NESTED ANALYSIS OF VARIANCE FOR THE RESILIENT MODULUS EXPERIMENT

-------------------------- SPEC=O TEMP=77F RECPD=2.9 --------------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	116	2002270
AGENCY	7	1859523
SPECNO	31	61685
ERROR	78	81061

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	17261	19713	100.0000
AGENCY	265646	18357	93.1234
SPECNO	1989.849499	316.331176	1.6047
ERROR	1039.244777	1039.244777	5.2719

Mean	234.93698692
Standard error of mean	50.98359899

-------------------------- SPEC=O TEMP=102F RECPD=0.9 --------------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	65	272534
AGENCY	4	261905
SPECNO	19	5664.393108
ERROR	42	4965.119275

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	4192.834663	5367.059660	100.0000
AGENCY	65476	5183.525317	96.5804
SPECNO	298.125953	65.317218	1.2170
ERROR	118.217126	118.217126	2.2026

Mean	64.57605864
Standard error of mean	35.18171108

NESTED ANALYSIS OF VARIANCE FOR THE RESILIENT MODULUS EXPERIMENT

------------------------- SPEC=O TEMP=102F RECPD=1.9 -------------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	67	447872
AGENCY	4	430797
SPECNO	19	6844.377622
ERROR	44	10231

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	6684.654695	8479.098595	100.0000
AGENCY	107699	8201.642645	96.7278
SPECNO	360.230401	44.934702	0.5299
ERROR	232.521249	232.521249	2.7423

Mean	74.70064985
Standard error of mean	43.50571969

------------------------- SPEC=O TEMP=102F RECPD=2.9 -------------------------

Nested Random Effects Analysis of Variance for Variable ERI

Variance Source	Degrees of Freedom	Sum of Squares
TOTAL	47	710868
AGENCY	3	659410
SPECNO	15	32032
ERROR	29	19426

Variance Source	Mean Square	Variance Component	Percent of Total
TOTAL	15125	20368	100.0000
AGENCY	219803	19120	93.8708
SPECNO	2135.487117	578.534034	2.8404
ERROR	669.867565	669.867565	3.2888

Mean	101.32036583
Standard error of mean	74.55385872

APPENDIX D.

LABORATORY AVERAGES AND STANDARD DEVIATIONS

FOR SYNTHETIC AND CORE SPECIMENS

LABORATORY AVERAGES FOR RESILIENT MODULUS TESTS FOR SYNTHETIC SPECIMENS

OBS	SPECIMEN	LAB	N	RM
1	L	A	3	510366.67
2	L	B	6	532549.12
3	L	C	2	538573.00
4	L	D	1	413333.33
5	L	E	2	623040.95
6	L	F	2	544195.00
7	L	H	2	539990.56
8	L	I	2	685936.51
9	L	J	2	519500.00
10	L	K	2	591818.18
11	L	L	2	517943.55
12	L	N	2	614275.60
13	L	P	2	550008.00
14	L	Q	4	482975.00
15	L	R	4	723657.14
16	L	S	6	593792.90
17	L	T	6	642989.00
18	L	U	4	666644.43
19	L	V	2	530703.10
20	P	A	6	226900.00
21	P	B	6	180470.86
22	P	C	2	196199.00
23	P	D	2	256436.01
24	P	E	2	245880.30
25	P	F	2	204995.00
26	P	H	2	198899.29
27	P	I	2	285773.33
28	P	J	2	206140.00
29	P	K	2	238461.54
30	P	L	6	269568.63
31	P	M	6	209500.00
32	P	N	2	270246.17
33	P	P	6	233636.00
34	P	Q	4	217100.00
35	P	R	4	253811.30
36	P	S	6	184503.47
37	P	T	6	295864.00
38	P	U	4	255400.70
39	P	V	2	210725.50
40	R	A	6	5500.00
41	R	B	6	4651.29
42	R	C	2	5841.50
43	R	D	2	7413.00
44	R	E	2	8767.52
45	R	F	2	5860.00
46	R	H	2	6118.22
47	R	I	2	7594.52
48	R	J	2	6696.00
49	R	K	2	5218.85

LABORATORY AVERAGES FOR RESILIENT MODULUS TESTS FOR SYNTHETIC SPECIMENS

OBS	SPECIMEN	LAB	N	RM
50	R	L	6	7483.11
51	R	M	6	5616.67
52	R	N	2	7401.28
53	R	P	4	7131.08
54	R	Q	4	4775.00
55	R	R	4	6941.12
56	R	S	6	7713.22
57	R	T	3	7619.00
58	R	U	4	6196.42
59	R	V	2	10598.80
60	T	A	6	148416.67
61	T	B	6	149702.92
62	T	C	2	157783.50
63	T	D	2	142024.54
64	T	E	2	138452.09
65	T	F	2	127795.00
66	T	H	2	130128.10
67	T	I	2	190404.46
68	T	J	2	120270.00
69	T	K	2	156987.18
70	T	L	6	127076.34
71	T	M	6	146166.67
72	T	N	2	153406.59
73	T	P	4	142488.00
74	T	R	4	181291.50
75	T	S	3	181289.56
76	T	T	6	206705.00
77	T	U	4	146883.84
78	T	V	1	154310.80

AVERAGES AND STANDARD DEVIATIONS FOR THE CORE SPECIMENS
BY LABORATORIES

---------------------- RECPD=0.9 TEMP=40 SPEC=N ----------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
1	0.9	40	N	A	2041.42	365.490	20
2	0.9	40	N	B	785.06	82.778	20
3	0.9	40	N	D	1224.56	226.353	8
4	0.9	40	N	E	2239.87	404.835	8
5	0.9	40	N	G	2378.18	213.531	18
6	0.9	40	N	H	2040.20	125.318	10
7	0.9	40	N	I	2579.42	222.204	10
8	0.9	40	N	J	1353.46	263.357	10
9	0.9	40	N	K	1281.33	81.242	20
10	0.9	40	N	L	2191.18	213.685	20
11	0.9	40	N	M	2149.50	194.200	10
12	0.9	40	N	R	3068.72	670.478	12

---------------------- RECPD=0.9 TEMP=40 SPEC=O ----------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
13	0.9	40	O	B	676.22	299.580	20
14	0.9	40	O	C	1056.48	293.314	20
15	0.9	40	O	D	476.60	251.134	10
16	0.9	40	O	E	997.67	339.485	8
17	0.9	40	O	F	661.72	114.883	20
18	0.9	40	O	G	1203.76	232.807	20
19	0.9	40	O	H	893.07	63.036	10
20	0.9	40	O	I	1006.36	63.004	10
21	0.9	40	O	J	424.59	162.414	10
22	0.9	40	O	K	218.17	21.033	20
23	0.9	40	O	L	1166.66	194.894	20
24	0.9	40	O	M	848.75	380.725	8
25	0.9	40	O	R	1552.57	263.065	2

AVERAGES AND STANDARD DEVIATIONS FOR THE CORE SPECIMENS
BY LABORATORIES

------------------------ RECPD=0.9 TEMP=77 SPEC=N ------------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
26	0.9	77	N	A	1310.82	295.688	20
27	0.9	77	N	B	719.17	108.177	20
28	0.9	77	N	C	1007.37	299.179	20
29	0.9	77	N	D	902.18	201.147	8
30	0.9	77	N	E	1112.63	202.857	8
31	0.9	77	N	F	738.06	461.370	24
32	0.9	77	N	G	1717.39	174.368	16
33	0.9	77	N	H	1336.81	155.862	9
34	0.9	77	N	I	1381.39	221.005	10
35	0.9	77	N	J	858.78	95.142	9
36	0.9	77	N	K	1017.92	45.134	20
37	0.9	77	N	L	1335.39	246.680	20
38	0.9	77	N	M	1668.90	136.955	10
39	0.9	77	N	N	1215.10	207.904	10
40	0.9	77	N	R	2100.39	21.669	4

------------------------ RECPD=0.9 TEMP=77 SPEC=O ------------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
41	0.9	77	O	A	281.584	51.4278	20
42	0.9	77	O	B	134.303	21.4214	20
43	0.9	77	O	C	159.838	25.7095	18
44	0.9	77	O	D	273.681	97.3998	10
45	0.9	77	O	E	158.321	11.0045	9
46	0.9	77	O	F	138.134	30.4973	10
47	0.9	77	O	G	440.163	47.2305	20
48	0.9	77	O	H	256.410	17.0619	10
49	0.9	77	O	I	228.054	17.0967	10
50	0.9	77	O	K	110.504	18.4085	20
51	0.9	77	O	L	471.469	70.2170	20
52	0.9	77	O	M	471.875	71.2048	8
53	0.9	77	O	N	107.949	9.8036	8
54	0.9	77	O	R	582.075	27.8031	4

AVERAGES AND STANDARD DEVIATIONS FOR THE CORE SPECIMENS
BY LABORATORIES

---------------------- RECPD=0.9 TEMP=102 SPEC=N ----------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
55	0.9	102	N	B	235.16	66.631	20
56	0.9	102	N	C	363.48	124.610	20
57	0.9	102	N	D	460.29	105.105	8
58	0.9	102	N	E	493.64	71.941	10
59	0.9	102	N	G	952.71	195.881	16
60	0.9	102	N	H	808.07	269.297	10
61	0.9	102	N	I	508.26	119.243	10
62	0.9	102	N	K	408.71	55.409	20
63	0.9	102	N	L	901.90	215.008	20
64	0.9	102	N	M	1035.25	50.883	8
65	0.9	102	N	R	1978.26	.	1

---------------------- RECPD=0.9 TEMP=102 SPEC=O ----------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
66	0.9	102	O	B	41.114	9.811	20
67	0.9	102	O	C	49.426	7.807	20
68	0.9	102	O	E	50.015	5.135	10
69	0.9	102	O	G	326.063	128.252	20
70	0.9	102	O	I	42.973	6.711	10
71	0.9	102	O	K	44.048	9.577	10
72	0.9	102	O	M	263.500	35.809	6

---------------------- RECPD=1.9 TEMP=40 SPEC=N ----------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
73	1.9	40	N	A	2016.36	321.937	20
74	1.9	40	N	B	775.52	96.217	20
75	1.9	40	N	D	1193.75	311.606	8
76	1.9	40	N	E	2183.92	273.259	8
77	1.9	40	N	G	2471.90	292.727	18
78	1.9	40	N	H	2120.10	150.171	10
79	1.9	40	N	I	2660.10	184.980	10
80	1.9	40	N	J	1282.39	187.739	9
81	1.9	40	N	K	1281.93	76.741	20
82	1.9	40	N	L	2125.34	218.166	20
83	1.9	40	N	M	2150.50	140.896	10
84	1.9	40	N	R	3259.50	595.255	11

AVERAGES AND STANDARD DEVIATIONS FOR THE CORE SPECIMENS
BY LABORATORIES

---------------------- RECPD=1.9 TEMP=40 SPEC=O ----------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
85	1.9	40	O	B	702.82	337.101	20
86	1.9	40	O	C	1016.07	301.440	20
87	1.9	40	O	D	439.14	204.677	10
88	1.9	40	O	E	936.50	181.216	8
89	1.9	40	O	F	666.18	173.467	20
90	1.9	40	O	G	1180.62	182.344	20
91	1.9	40	O	H	912.04	80.829	10
92	1.9	40	O	I	1015.44	72.138	10
93	1.9	40	O	J	285.12	52.545	10
94	1.9	40	O	K	212.35	25.758	19
95	1.9	40	O	L	1122.29	157.580	20
96	1.9	40	O	M	917.00	397.583	8
97	1.9	40	O	R	1490.47	641.579	2

---------------------- RECPD=1.9 TEMP=77 SPEC=N ----------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
98	1.9	77	N	A	1201.51	284.293	20
99	1.9	77	N	B	713.69	105.153	20
100	1.9	77	N	C	967.37	304.259	20
101	1.9	77	N	D	873.86	237.528	8
102	1.9	77	N	E	1129.85	220.313	8
103	1.9	77	N	F	695.69	378.349	24
104	1.9	77	N	G	1747.82	181.249	16
105	1.9	77	N	H	1365.83	132.349	10
106	1.9	77	N	I	1399.87	241.911	10
107	1.9	77	N	J	868.87	201.392	8
108	1.9	77	N	K	1001.86	50.286	20
109	1.9	77	N	L	1284.39	267.773	20
110	1.9	77	N	M	1710.20	126.755	10
111	1.9	77	N	N	1134.91	198.949	10
112	1.9	77	N	R	2234.38	50.615	4

AVERAGES AND STANDARD DEVIATIONS FOR THE CORE SPECIMENS
BY LABORATORIES

---------------------- RECPD=1.9 TEMP=77 SPEC=O ----------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
113	1.9	77	O	A	251.742	46.026	20
114	1.9	77	O	B	132.657	20.989	20
115	1.9	77	O	C	145.079	19.898	18
116	1.9	77	O	D	344.111	157.671	10
117	1.9	77	O	E	158.589	15.770	10
118	1.9	77	O	F	129.650	46.130	10
119	1.9	77	O	G	452.269	48.565	20
120	1.9	77	O	H	259.266	26.005	10
121	1.9	77	O	I	240.625	21.946	10
122	1.9	77	O	K	113.105	18.994	20
123	1.9	77	O	L	399.151	62.383	20
124	1.9	77	O	M	490.000	62.831	10
125	1.9	77	O	N	96.358	8.385	8
126	1.9	77	O	R	625.170	37.766	3

--------------------- RECPD=1.9 TEMP=102 SPEC=N ---------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
127	1.9	102	N	B	230.24	64.794	20
128	1.9	102	N	C	342.56	116.206	20
129	1.9	102	N	D	444.36	113.772	8
130	1.9	102	N	E	493.64	71.941	10
131	1.9	102	N	G	992.42	188.150	16
132	1.9	102	N	H	624.75	189.603	10
133	1.9	102	N	I	505.40	121.203	10
134	1.9	102	N	K	402.78	48.809	20
135	1.9	102	N	L	804.58	238.497	20
136	1.9	102	N	M	1086.88	61.276	8
137	1.9	102	N	R	1780.24	.	1

--------------------- RECPD=1.9 TEMP=102 SPEC=O ---------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
138	1.9	102	O	B	47.184	8.004	20
139	1.9	102	O	C	46.523	8.054	20
140	1.9	102	O	E	50.015	5.135	10
141	1.9	102	O	G	354.559	128.697	20
142	1.9	102	O	I	41.971	2.599	10
143	1.9	102	O	K	44.481	11.269	10
144	1.9	102	O	M	292.625	43.788	8

AVERAGES AND STANDARD DEVIATIONS FOR THE CORE SPECIMENS
BY LABORATORIES

----------------------- RECPD=2.9 TEMP=40 SPEC=N -----------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
145	2.9	40	N	A	2016.75	373.52	20
146	2.9	40	N	B	802.24	99.66	19
147	2.9	40	N	D	1188.04	337.25	9
148	2.9	40	N	E	2183.92	273.26	8
149	2.9	40	N	G	2363.22	243.91	18
150	2.9	40	N	H	2103.48	118.69	10
151	2.9	40	N	I	2626.51	168.51	10
152	2.9	40	N	J	1566.33	1078.91	10
153	2.9	40	N	K	1265.76	60.70	20
154	2.9	40	N	L	2193.97	245.63	20
155	2.9	40	N	M	2113.70	232.28	10
156	2.9	40	N	R	3444.82	617.37	11

----------------------- RECPD=2.9 TEMP=40 SPEC=O -----------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
157	2.9	40	O	B	631.71	247.527	20
158	2.9	40	O	D	457.02	236.924	10
159	2.9	40	O	E	899.60	200.023	8
160	2.9	40	O	F	671.71	206.395	20
161	2.9	40	O	G	1163.87	199.643	20
162	2.9	40	O	H	922.53	86.615	10
163	2.9	40	O	I	1022.37	58.967	10
164	2.9	40	O	J	269.38	66.089	10
165	2.9	40	O	K	210.31	23.465	20
166	2.9	40	O	L	1075.92	128.624	20
167	2.9	40	O	M	948.75	402.068	8
168	2.9	40	O	R	1414.11	702.829	2

AVERAGES AND STANDARD DEVIATIONS FOR THE CORE SPECIMENS
BY LABORATORIES

---------------------- RECPD=2.9 TEMP=77 SPEC=N ----------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
169	2.9	77	N	A	1193.63	291.732	20
170	2.9	77	N	B	709.42	101.631	20
171	2.9	77	N	D	892.38	253.861	8
172	2.9	77	N	E	1129.85	220.313	8
173	2.9	77	N	F	657.36	372.248	24
174	2.9	77	N	G	1773.93	212.282	16
175	2.9	77	N	H	1369.66	137.800	10
176	2.9	77	N	I	1402.92	205.119	10
177	2.9	77	N	J	839.32	105.792	9
178	2.9	77	N	K	992.81	47.753	20
179	2.9	77	N	L	1272.16	265.629	20
180	2.9	77	N	M	1743.60	157.678	10
181	2.9	77	N	N	1113.39	186.797	11
182	2.9	77	N	R	2352.45	33.000	3

---------------------- RECPD=2.9 TEMP=77 SPEC=O ----------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
183	2.9	77	O	A	249.112	42.728	19
184	2.9	77	O	B	129.684	16.684	20
185	2.9	77	O	D	376.115	168.878	8
186	2.9	77	O	E	158.589	15.770	10
187	2.9	77	O	F	111.118	15.794	10
188	2.9	77	O	G	468.140	54.265	20
189	2.9	77	O	H	255.654	29.446	10
190	2.9	77	O	I	244.726	26.300	10
191	2.9	77	O	K	108.476	19.074	20
192	2.9	77	O	L	377.366	61.790	20
193	2.9	77	O	M	514.700	63.986	10
194	2.9	77	O	N	94.213	7.895	8
195	2.9	77	O	R	634.680	2.263	2

AVERAGES AND STANDARD DEVIATIONS FOR THE CORE SPECIMENS BY LABORATORIES

---------------------- RECPD=2.9 TEMP=102 SPEC=N ----------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
196	2.9	102	N	B	232.85	67.413	20
197	2.9	102	N	D	447.72	129.890	8
198	2.9	102	N	E	493.64	71.941	10
199	2.9	102	N	G	995.31	200.918	16
200	2.9	102	N	H	668.72	79.508	10
201	2.9	102	N	I	505.82	132.681	10
202	2.9	102	N	K	408.51	45.997	20
203	2.9	102	N	L	741.38	212.374	20
204	2.9	102	N	M	1135.25	90.172	8
205	2.9	102	N	R	1931.89	.	1

---------------------- RECPD=2.9 TEMP=102 SPEC=O ----------------------

OBS	RECPD	TEMP	SPEC	LAB	AVERAGE	STD	NSAMP
206	2.9	102	O	B	54.877	27.742	20
207	2.9	102	O	E	50.015	5.135	10
208	2.9	102	O	G	400.763	212.793	20
209	2.9	102	O	I	43.719	3.979	10
210	2.9	102	O	K	42.364	10.104	10
211	2.9	102	O	M	363.125	71.489	8

APPENDIX E.

PRECISION STATEMENTS

Table 1
PRECISION STATEMENTS
for
SYNTHETIC REFERENCE SPECIMENS

Specimen & Type of Index	Mean total M_R(psi) at 50# load	1s[1]	1s%[1]	d2s[1]
Single Operator Precision				
neoprene	6,473	537	8	1,519
teflon	144,809	7,964	6	22,562
poly	231,929	48,376	21	136,828
lucite	561,746	53,280	9	150,699
Multi-laboratory Precision				
neoprene	6,473	1,462	21	4,135
teflon	144,809	19,299	12	54,586
poly	231,929	56,219	12	159,011
lucite	561,746	74,340	9	210,265

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

Table 2
PRECISION STATEMENTS for the
RESILIENT MODULUS of
NEW ASPHALT CORES

Type of index, temperature, and rest period	mean total M_R (psi)	1s[2]	1s%[2]	d2s[2]
Single Operator Precision.				
41° F				
0.9 seconds	1,727,000	149,000	9	421,000
1.9 s	1,721,000	119,000	7	337,000
2.9 s	1,755,000	317,000	18	897,000
77° F				
0.9 s	1,085,000	234,000	22	662,000
1.9 s	1,060,000	199,000	19	563,000
2.9 s	1,062,000	192,000	18	543,000
104° F				
0.9 s	552,000	112,000	20	317,000
1.9 s	505,000	98,000	19	277,000
2.9 s	551,000	87,000	16	246,000
Multilaboratory Precision.				
41° F				
0.9 seconds	1,727,000	630,000	36	1,782,000
1.9 s	1,721,000	637,000	37	1,802,000
2.9 s	1,755,000	672,000	38	1,902,000
77° F				
0.9 s	1,085,000	374,000	34	1,061,000
1.9 s	1,060,000	358,000	34	1,014,000
2.9 s	1,062,000	387,000	36	1,095,000
104° F				
0.9 s	552,000	315,000	57	890,000
1.9 s	505,000	287,000	56	812,000
2.9 s	551,000	300,000	54	848,000

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

Table 3
PRECISION STATEMENTS for the RESILIENT MODULUS of OLD ASPHALT CORES

Type of index, temperature, and rest period	mean total M_R(psi)	1s[3]	1s%[3]	d2s[3]
Single Operator Precision.				
41° F				
0.9 seconds	773,000	197,000	25	557,000
1.9 s	763,000	201,000	26	569,000
2.9 s	697,000	155,000	22	438,000
77° F				
0.9 s	240,000	33,000	14	93,000
1.9 s	228,000	132,000	58	373,000
2.9 s	235,000	136,000	58	384,000
104° F				
0.9 s	64,000	11,000	17	31,000
1.9 s	75,000	15,000	20	42,000
2.9 s	101,000	26,000	26	74,000
Multilaboratory Precision.				
41° F				
0.9 seconds	773,000	389.000	50	1,102,000
1.9 s	763,000	393.000	52	1,112,000
2.9 s	697,000	382.000	55	1,080,000
77° F				
0.9 s	240,000	144.000	60	407,000
1.9 s	228,000	132.000	58	373,000
2.9 s	235,000	136.000	58	384,000
104° F				
0.9 s	64,000	73.000	114	206,000
1.9 s	75,000	92.000	123	261,000
2.9 s	101,000	140.000	139	397,000

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