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SHRP-LTPP Materials Characterization: Five-Year Report

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Abstract

The Strategic Highway Research Program (SHRP) developed two materials characterization programs: one for field sampling, and another for laboratory testing. The SHRP field materials sampling and laboratory materials testing program encompassed all 50 states; 10 Canadian provinces; and Puerto Rico. This report documents the development and execution of these programs for both the General Pavement Studies (GPS) and the Specific Pavement Studies (SPS). These topics are described separately here, although they are linked inherently. Suggestions are given for future materials characterization within the Long-Term Pavement Performance program as it continues under the Federal Highway Administration.

Strategic Highway Research Program Long-Term Pavement Performance (SHRP-LTPP) Materials Characterization Program

Introduction

Background

The overall objective of LTPP and other SHRP-related research programs is to provide the tools for increasing pavement performance and service life in order to better serve the needs of the motoring public, and to provide for the delivery of goods and services without major increases in financial resources. A major component of LTPP that will enable researchers to meet this objective is the establishment of a National Pavement Performance Database (NPPDB) that contains inventory information and performance histories of pavement with various design features, materials, traffic loads, environmental conditions, and maintenance practices. The SHRP-LTPP program was structured to include GPS (**1**) of existing pavement sections and SPS (**2**) of new or rehabilitated pavement sections.

The experimental designs formulated for the General Pavement Studies (GPS) and Specific Pavement Studies (SPS) projects of the LTPP were developed and the sites selected using very vigorous selection criteria.

Some of the basic parameters and variables used in the selection process for the GPS and SPS studies included climate, traffic, pavement age and subgrade type. In the SHRP-LTPP program, a detailed materials characterization program was instituted to define fundamental materials properties such as resilient modulus and many other basic materials properties for all sites of the GPS and SPS programs. The Strategic Highway Research Program Overview should be consulted if the reader desires additional information concerning the LTPP Program (**3**).

The materials characterization program included those parameters required for current pavement design models and mechanistic analysis models, and the engineering properties generally needed to assess the characteristics and behavior of materials. Concomitant with the characterization of the material properties is the need for knowledge of the variations in these properties both between and within test sections so that the causes of performance differences between test sections can be evaluated. This information would provide a basis for improving the models for use in pavement design methods.

Attempts to control uniformity in construction are laudable and important; however, variation within and between sites still exist even under these controls. Because of this phenomenon it was essential in the LTPP program to develop and implement a sampling and testing plans that would provide the information necessary to evaluate in a consistent, effective manner these variations and their effect on performance.

During the SHRP-LTPP site selection projects, the experimental design parameter for subgrade type (fine or coarse) for the GPS and SPS sites was determined using state and provincial inventory and/or as-built records. Other information, which would be used to define a particular study in GPS or SPS (e.g., viscosity of AC layers and layer thicknesses) were also derived from the state and provincial data and/or records. This type of material data would be adequate for defining experiments; however, it is important to understand that this type of materials information is developed for and by normal construction quality control practices. Samples are taken from the asphalt concrete (AC) or Portland Cement Concrete (PCC) plant, delivery trucks and random locations along the roadway and tested to insure that materials are being produced, delivered and placed in accordance with state specifications. Although such sampling and testing practices are adequate and proper for normal construction quality control, they are inadequate for a scientifically designed pavement performance experiment such as SHRP-LTPP (4). Previous research studies of in-service pavements have shown that information and results acquired in a field site investigation visit (such as SHRP's drilling and sampling program), are often different characteristics than originally thought.

In the SHRP-LTPP program, it was necessary, indeed critical, to obtain insitu site specific materials information. GPS and SPS pavement performance will depend on many inter-related factors, not the least of which would be the thickness and quality of the materials comprising the pavements at the sites being monitored. It was one of SHRP's goals to acquire samples that could provide site specific, detailed and accurate information regarding thickness, quality, strength, modulus and other attributes of the pavement layers from the GPS and SPS sites. This information would be essential for subsequent verification of the experiment cell for the project and other detailed data analysis functions (4).

In light of these requirements, SHRP developed a two-tiered materials characterization program consisting of field material sampling and laboratory materials testing. This report documents the work performed in the SHRP-LTPP program since 1987 and details some of the findings from this massive effort.

Over the course of the first five years of LTPP, much has been learned in the SHRP-LTPP materials characterization program. This report provides documentation of the program through an overview of the entire program including GPS field materials sampling, GPS laboratory materials testing, SPS field material sampling and SPS laboratory materials testing. Each of these topics are treated separately; however, inherently they are linked together. This volume provides a detailed look at the materials characterization program instituted and conducted in SHRP-LTPP and offers suggestions for future direction of the program for the remainder of the SHRP-LTPP program.

Overview - Scope of Materials Characterization Program

The SHRP field materials sampling and laboratory testing program encompassed all 50 states in the U.S., 10 Canadian provinces, and Puerto Rico. The GPS field sampling program contained 775 test sections located throughout the North American continent. Each of these sections was drilled and sampled to obtain in situ information and testable core specimens. This program was conducted in strict conformance with a SHRP-LTPP drilling and sampling guide (**5**).

The drilling and sampling effort for each LTPP site involved the temporary closing of some interstate and primary pavement lanes normally subjected to high speed, high volume traffic. Coordination and cooperation of the state and provincial DOT's was required so that the drilling and sampling operations could be conducted in a safe and cost efficient manner.

The SHRP GPS drilling and sampling operations were conducted in the vicinity of the test section but not within the specific test section. This approach was adopted since samples retrieved from within the test sections could induce abnormal distress manifestations within the test section over time as a result of cracks or distortion emanating from the core locations. Patched coreholes and test pits and the associated abnormal distress development could result in spurious measurements from the monitoring devices (FWD, profilometer, etc.) (**4**).

Core samples, in addition to those needed for the basic GPS laboratory material testing program, were retrieved so that back-up samples were available for present or future testing. These samples could also be used in those instances where problems were encountered in testing any of the primary samples. Archival samples were also taken for any future appropriate use. These additional samples were obtained as precautions against the extra expense of return trips to the test section to retrieve additional samples (**4**).

The GPS drilling and sampling program was completed during 1989 and 1990. Samples retrieved during this program were shipped from the field to pre-determined laboratory testing contractors for further analysis and testing.

Development of the Field Sampling and Laboratory Testing Program

In July 1987, an Expert Task Group (ETG) was appointed to provide guidance, direction, and oversight to SHRP material sampling and testing efforts.

One of the ETG's first tasks was to nominate likely material tests that could serve the objectives of SHRP's LTPP program. These tests were selected based on the following rules:

Rule 1: Select tests familiar to highway engineers that provide basic materials characterization information so that users of the database have an overall common representation of the materials making up the pavement layers.

Rule 2: Select tests that provide or might provide an explanation or partial explanation of the performance of the pavement layers comprising the test section so as to

correlate pavement performance monitoring information that reflect the effects of design, construction quality, routine maintenance, time, traffic, climate and other factors with the in-place pavement materials at the site.

Rule 3: Use AASHTO standard tests whenever available. Use ASTM or other standard tests (including SHRP developed tests) if a particular test was desired but no AASHTO standard was available. Standard tests have withstood the "test of time" and are familiar to commercial testers and will be meaningful to the world-wide, general users of the LTPP database.

Rule 4: Do not use "research type" or "one-of-a-kind" tests. Such tests generally have been used only on a limited range of material types, may not be meaningful or applicable to the wide range of pavement materials or conditions making up the population of LTPP sites and would require special equipment and training for commercial testers.

Rule 5: Perform the same test on samples taken from two or more different locations at each LTPP site so as to gain understanding of testing variability and construction variability (4).

The ETG originally targeted 40 tests to be conducted in the GPS program. After a review of the budget for materials testing, the number of tests was reduced to 24 in accordance with the decision of the materials ETG (6,7,8). These 24 tests are identified later in this document.

The SPS field materials sampling and field testing program was even more complex than the GPS program. Due to the specific needs and anticipated results from each study; separate, distinct field sampling plans were needed for each of the nine experiments. This report describes material characterization activities for eight of the studies (SPS-1 through SPS-8). The SPS-9 experiment (Validation of SHRP Asphalt Specifications and Mix Design and Innovations in Asphalt Pavement) involving field verification studies were not finalized in the first five years of LTPP and are not discussed in detail in this document.

Each SPS project was unique in that additional test sections were required and constructed to state and provincial DOT standards. This situation complicated the effort and required customization of the field sampling design process.

The SPS field sampling plans were developed by the SHRP regional engineer and contractors in concert with the state and provincial DOT based on guidelines presented in SHRP Operational Memorandums. Each project was drilled and sampled by the state and provincial forces using these guidelines. Laboratory testing plans for each project were also developed by the SHRP regional personnel using these same guidelines.

The laboratory tests utilized by the SPS experiments were based on the basic tests scheduled for the GPS experiments. However, for every SPS experiment, a task group made up of SHRP staff, ETG members, SHRP regional personnel, and the SHRP technical assistance contractors identified and implemented additional tests which would insure adequate characterization of the materials for a SPS project.

The general principles involved in the GPS field materials sampling program were also used in conducting sampling operations on the SPS sites. However, very different sampling location layouts were required since the SPS sites have far greater linear dimensions (greater than 1 mile in length) when compared to the length of the GPS sites (500 ft.).

Since new construction was involved in SPS experiments, the sampling location points for some materials were not all from the roadway. For example, non-roadway locations would consist of aggregate stockpiles, hopper bins at the AC plant, delivery trucks, conveyor belts and lay-down machines. Such locations necessitated different procedures and differing quantities than for samples acquired from existing in-place GPS pavements. Finally, the sampling of SPS experiments would be accomplished under very different administrative arrangements than for GPS experiments.

There were more options for SPS sampling. The sampling could be done by state or provincial DOT in-house forces, by drilling contractors under existing retainer basis contracts with the state, by special contracts negotiated and awarded by the state/province and by new contracts awarded by the state to the same drilling contractors that had performed the GPS work for SHRP (4).

Summary

The remainder of this document outlines the specific history and operational aspects of 1) the GPS field sampling and testing program, 2) the SPS field sampling and testing program, 3) the GPS laboratory materials handling and testing program, and 4) the SPS laboratory material handling and testing program. Each section will outline the development of the plans, data collection requirements, the conduct of the program and the status of each portion of the SHRP materials characterization program, as well as, other pertinent details related to each portion. Additional background information related to this program may be found in the bibliography section of this report as well as in other SHRP-LTPP 5-year reports.

Field Material Sampling and Testing

Introduction

In fulfillment of the overall objectives of the SHRP-LTPP program, the LTPP field material sampling and field testing program provided important information to the National Pavement Performance Database (NPPDB). A primary source of the NPPDB information was the field data collected on the in-service pavements forming the GPS and test sections built and instrumented for more intensive evaluation of selected factors forming the SPS portion of the LTPP. The following sections of this document outline the efforts undertaken and implemented over the five years of SHRP-LTPP to provide a comprehensive evaluation of insitu field properties and to provide pavement materials to testing laboratories for further testing and classification.

GPS Field Materials Sampling and Field Testing

Organizational Structure

As indicated in Figure 1, a number of agencies were involved in the LTPP GPS operations. Efficient and timely conduct of the field material sampling and field testing activities would require a clear understanding of the administrative, supervisory and operational responsibilities of the various agency personnel.

The SHRP Regional Engineer (SRE) was responsible for administration and management of all SHRP contracts in the region including the contract for drilling and sampling. The SRE also provided for coordination between the various regional contractors and state highway departments and resolved questions and concerns that arose during the day-to-day operations of the field sampling and testing program.

The SRE also was responsible for supervision and approval of the SHRP Regional Coordination Office Contractor (RCOC) staff. The RCOC staff provided coordination between the activities of all contractors in their respective region.

The RCOC designated a drilling supervisor (SHRP Authorized Representative - SAR) to provide primary on-site supervision during the drilling and sampling operations. The SAR was responsible for the direction of field operations and worked with the drilling and sampling contractor to assure effective, efficient, and safe operations at the work site. Specific responsibilities of the SAR included: arranging for coordination or scheduling of the work with the state highway agencies including provisions for traffic control at the test section; exercising necessary judgment in authorizing minor on-site changes in work based on conditions encountered; implementing quality control and quality assurance procedures; obtaining photo documentation of exposed pavement layers in test pits; and providing initial approval of work completion forms.

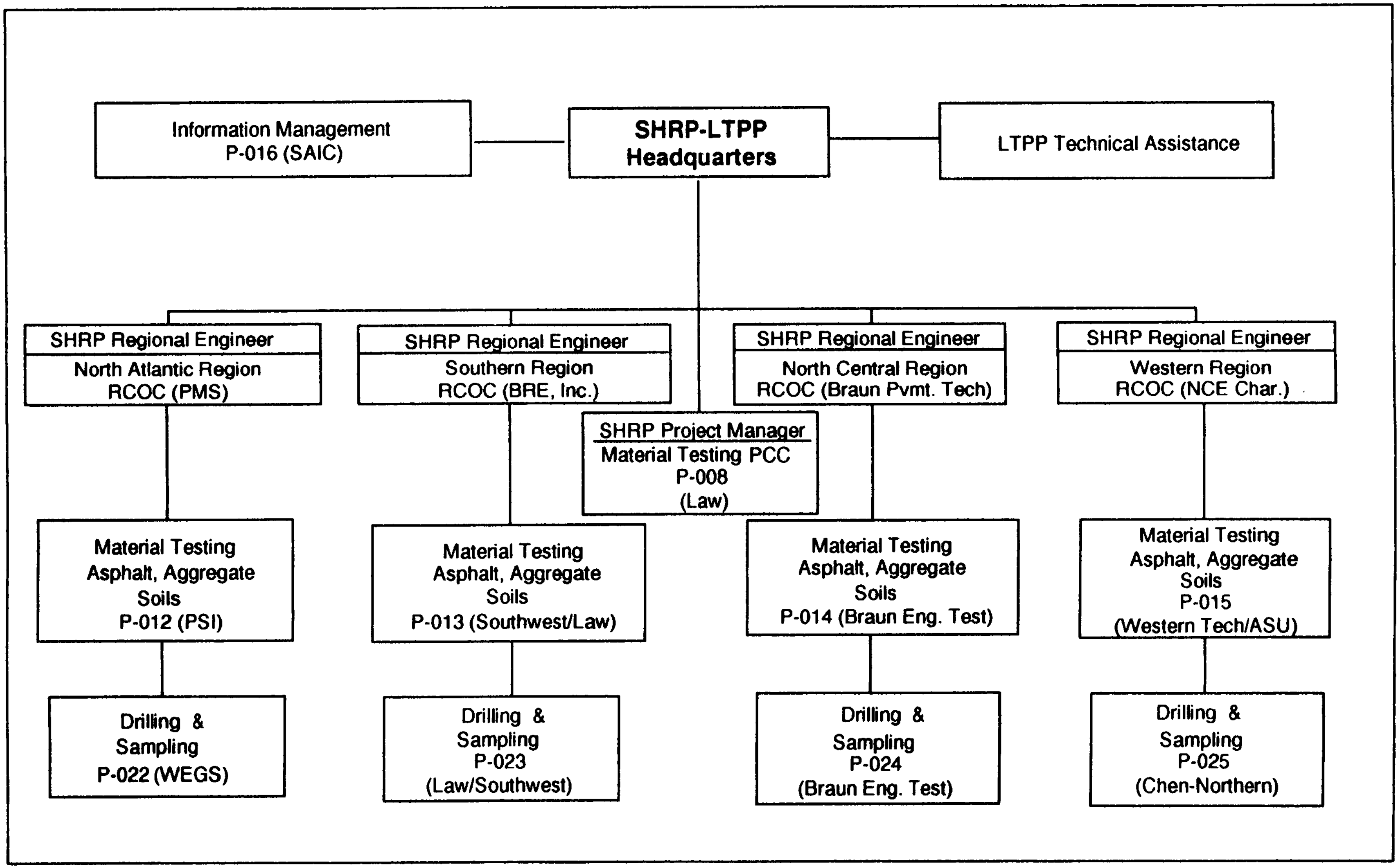


Figure 1. Agencies Involved in LTPP GPS Field Drilling and Sampling Operations

In addition to these responsibilities, the SAR performed all day-to-day coordination between SHRP central staff, the SHRP Regional Engineer, SHRP RCOC, the field material sampling contractor and the laboratory materials testing contractor. This necessitated a person with good communication and supervisory skills.

Development of Technical Provisions

Development of the SHRP field material sampling and testing technical provisions was undertaken over a period of time beginning in May 1986 with the issuance of the final SHRP Research Plans Report (**9**) and the June 1987 Data Collection Guide (**10**). Further development occurred in 1987 when the Draft Material Sampling and Testing Guide was initiated that proposed details for field material sampling and field testing for the SHRP GPS test sections (**11**). Based on a review of this documentation, complemented with information concerning the proposed number of pavement test sections and the typical pavement layer types and thicknesses, the technical provisions were developed (**12**).

The technical provisions were based on a review of overall LTPP objectives, published test methods (AASHTO, ASTM, etc.), research on unit prices, consideration of the technical needs of LTPP, and a review of information concerning the required number of samples and field tests for various levels of reliability related to the probable variability of pavement materials. Some of the tasks performed were:

- development of assumptions, considerations and rationale for the sampling and testing requirements
- development of matrices for each GPS experiment showing the proposed types, numbers, and methods for field material sampling
- preparation of assumed typical sections and field sampling layout plans
- acquiring and analyzing unit price data from sampling and testing organizations around the country
- development of cost summaries by experiment, and SHRP region
- analyzing cost implications for different levels of sampling
- development of concepts for the Program Announcements/RFQ's and Field Sampling contracts (**4**)

Many assumptions guided the process as follows:

- test sections are 500 ft. in length and are located on in-service pavements
- field sampling and testing cannot be conducted within the 500 ft. monitoring area

- the amount of field material sampling is dependent on the number and types of laboratory material characterization tests

- high quality work is required by SHRP

- there is a finite cost limit for field material sampling

- safety for drilling operations traffic control and patching of pavement openings conducted by the state

During the development of the technical provisions, the final candidate GPS sections had not yet been selected; therefore, the number, locations, and pavement layering were unknown. However, sufficient information was known about the number, type, and geographic locations of the GPS sections to make reasonable estimates of the scope of the field sampling program.

The document, entitled *Technical Provisions and Fee Schedules for Field Sampling and Field Testing* (May 6, 1988) (12), along with the *Program Announcement* (June 1988) (13) were used by prospective drilling and sampling contractors in submitting their proposals and bid prices for the required work. After receipt and processing of the proposals, the Expert Task Group (ETG) members for material sampling and testing independently rated and ranked the proposals. Contract awards were then made on the basis of the summarized ETG recommendations, SHRP Executive Committee endorsement, negotiations with the proposers and other standard requirements of SHRP. The contracts were awarded for each region in the latter part of 1988 as follows:

SHRP REGION	Drilling and Sampling Contractor
North Atlantic	Westinghouse Environmental and Geotechnical Services
Southern	Joint Venture: Law Engineering Southwestern Laboratories
North Central	Braun Engineering Testing
Western	Chen-Northern

Revised plans-reduction in lab testing requirements

Following the award of the GPS field sampling and field testing contracts, an analysis of the total anticipated expenditures revealed large potential overruns of the budgeted amounts for the laboratory materials testing work. Since other funds were available and was reallocation of funds was not considered feasible. A decision was, therefore, reached to reduce the overall scope of the LTPP materials testing program. As a result of this decision, and the subsequent reduction in laboratory materials testing, the field material sampling and testing plans were

revised. In addition, the requirement for a smaller number of asphalt and concrete cores in the laboratory resulted in a smaller number of cores extracted from the GPS test sections. Additionally, a smaller amount of bulk samples of unbound material was needed. This reduction in field material sampling improved the efficiency of the operation and saved valuable time in the field. The sampling plans for the GPS sections may be found in Appendix B of SHRP-LTPP-0G-006, SHRP-LTPP Guide for Field Material Sampling, Handling and Testing, May 1990 (5).

Pilot Study Testing in North Carolina

During the week of December 5, 1988 a pilot test of the drilling and sampling operations was conducted on several LTPP sites in the vicinity of Greensboro, North Carolina. The pilot study was performed on four different pavement types (Asphalt Concrete on Granular Base, Asphalt concrete over bound base, Jointed Plain Concrete and Continuously Reinforced Concrete) primarily to determine if the proposed drilling and sampling operations were realistic and efficient. The drilling and sampling contractors crew chiefs and other key contractor personnel observed the field operations and gained valuable experience.

Preparation for the pilot study included a planning meeting with participation by SHRP, all participating SHRP contractors and the North Carolina Department of Transportation. Arrangements were also made by SHRP for representatives from the RCOC and drilling and sampling contractors for each of the SHRP regions to attend one day of the study on a staggered basis. During the conduct of this study, all SHRP regional personnel were introduced to the field drilling and sampling operations. For the pilot study, the first version (November 23, 1988) of the SHRP-LTPP Guide for Field Material Sampling, Handling and Testing was utilized.

The following series of activities were undertaken for each test section in the pilot study. Lane closure was established early in the day (e.g. 9:00 am.). The four test sections in North Carolina were located on 4-lane divided highways resulting in the ability to maintain traffic with a full lane closure. Since traffic was not extremely heavy on the pavement sections, no traffic backups occurred. After lane closure was in place, the first activity was deflection (FWD) measurements at the bulk sampling areas about 50 ft. beyond the test section. During the same time period, the locations of various sampling points were marked on the pavement. The contractor had three separate two-person crews on the job performing three activities simultaneously. One crew operated a drill rig that cut the 12 in. cores and obtained the bulk samples with a 12 in. auger. They obtained the split spoon and Shelby tube (where appropriate) samples of the subgrade and conducted the 20 ft. auger probe. A second crew operated a core rig mounted on a farm type tractor that obtained all of the 4 in. and 6 in. cores of pavement surfaces and bound base layers. The third crew was responsible for saw cuts for the test pit, removal of pavement slabs, preparation for nuclear tests, obtaining bulk samples of unbound layers and subgrade materials, and test pit clean-up.

Actual time of each activities were recorded by RCOC personnel and included in their report of the pilot study. The times required for each of the three drilling and sampling crews to

complete their assigned activities were uniform except for the test pit in the CRCP pavement. CRCP pavement had considerable steel reinforcing which had to be spliced prior to patching.

The drilling and sampling contractor had a total of nine people on the job full-time. With this crew size and complement of equipment, it was reasonable to complete all work on the asphalt concrete (AC) test section including repair of the test pit within one working day. The sampling of unreinforced concrete sections was also completed but data reporting forms were not completed. Test pit repair was deferred because on-site hot-mix AC patching materials were not available.

Much was learned from the pilot study including the feasibility of the planned sequence of field activities and the reasonableness of the time frame to accomplish the field operations on each pavement section. The pilot study also illustrated the reasonableness of the previous estimates of the amounts of sample materials planned to be collected and shipped, the problems associated with test pit excavation and other potential problems. Many of the problems hypothesized during field drilling and sampling did occur during the pilot study (such as late arrival of SHA personnel, inclement weather and questions about procedures and reporting forms). However, the general impression of all persons involved in the pilot effort was that it was very worthwhile and contributed to the overall success of this portion of the LTPP research. In addition, based on experiences gained during the pilot study, the Guide for Field Material Sampling, Handling and Testing (5) was enhanced and finalized.

To share this learning experience with a wider group than just the participants of the pilot test, a video was prepared in January 1989, entitled "A Guide for Taking LTPP Pavement Samples," (14), which captured the many aspects of the GPS sample operations. The video was useful to state DOT officials in defining the necessary coordination requirements, and explaining the sampling operations for the LTPP pavement test sections located in each state (4).

Field Material Sampling Guide

Evolution

A critical element in the drilling and sampling program was the development and evolution of the SHRP-LTPP Guide for Field Material Sampling, Handling, and Testing (5). The outline for later revisions of the Field Guide was begun in October 1987 with the issuance of the "Materials Sampling and Testing Guide for Long-Term Pavement Performance Studies, Draft" (11). This document was issued prior to the initiation of the SHRP-LTPP program and outlined the general materials sampling and testing plan for the GPS test sections identified at the time. Subsequent to this Guide, SHRP issued its first version of the field sampling guide in January 1989. This document was the "second generation" field guide and all work in the GPS program essentially followed the instructions presented in this version. This guide, designated as SHRP Operational Memorandum-OM-006 (5) provided explicit directions to the drilling and sampling contractors, SHRP Authorized Representatives and Regional Coordination Office Contractors and it also outlined the requirements of the GPS sampling

operations. The primary objective of the LTPP Field Material Sampling Guide was to achieve consistency and to maintain high quality in the field activities of the regional drilling and sampling contractors.

The drilling and sampling guide was provided to SHRP Regional Engineers, SARs accompanying the drilling contractors, the drilling contractors crew chiefs and others. In effect, the Guide served as the control for the drilling and sampling operations. This guide, which was revised in May 1990, based on lessons learned in the field, is the definitive source of information on the methodology used by SHRP in conducting field sampling and field testing operations.

Future Use

The drilling and sampling guide is an instrumental tool in the realization of SHRP's long-term pavement performance goals. The GPS field guide was also the primary document used for SPS materials sampling and testing program. In the future, this guide can be utilized by other organizations that wish to perform a similar field material sampling and testing program. Additionally, this guide will be used extensively in the SPS program for many years to come.

Conduct of Field Material Sampling

Each SHRP region conducted their field drilling and sampling operations under different schedules and with different drilling and sampling contractors. However, through the use of the SHRP-LTPP Guide for Field Material Sampling, Handling and Testing (5), the quality of specimens and field testing were consistent and similar results were provided. The number of test sections to be sampled ranged from approximately 135 in the North Atlantic region to 260 in the Southern region. The Western and North Central regions drilled and sampled approximately 180 and 200 test sections respectively. The approximate locations of the SHRP test sections are presented in Figure 2. As can be seen, these test sections were located throughout the continental U.S., Canada, Alaska, Hawaii and Puerto Rico. Such widely dispersed sites required a great amount of coordination and cooperation between many organizations and agencies. Drilling and sampling operations were begun in early 1989 and essentially completed in mid-1991. The scope of the GPS work and numbers of experiments by type are described in Appendix B of the drilling and sampling guide. The SHRP drilling and sampling contractors did not conduct operations outside the continental U.S. Sampling outside the continental U.S. was performed by state/province DOT forces.

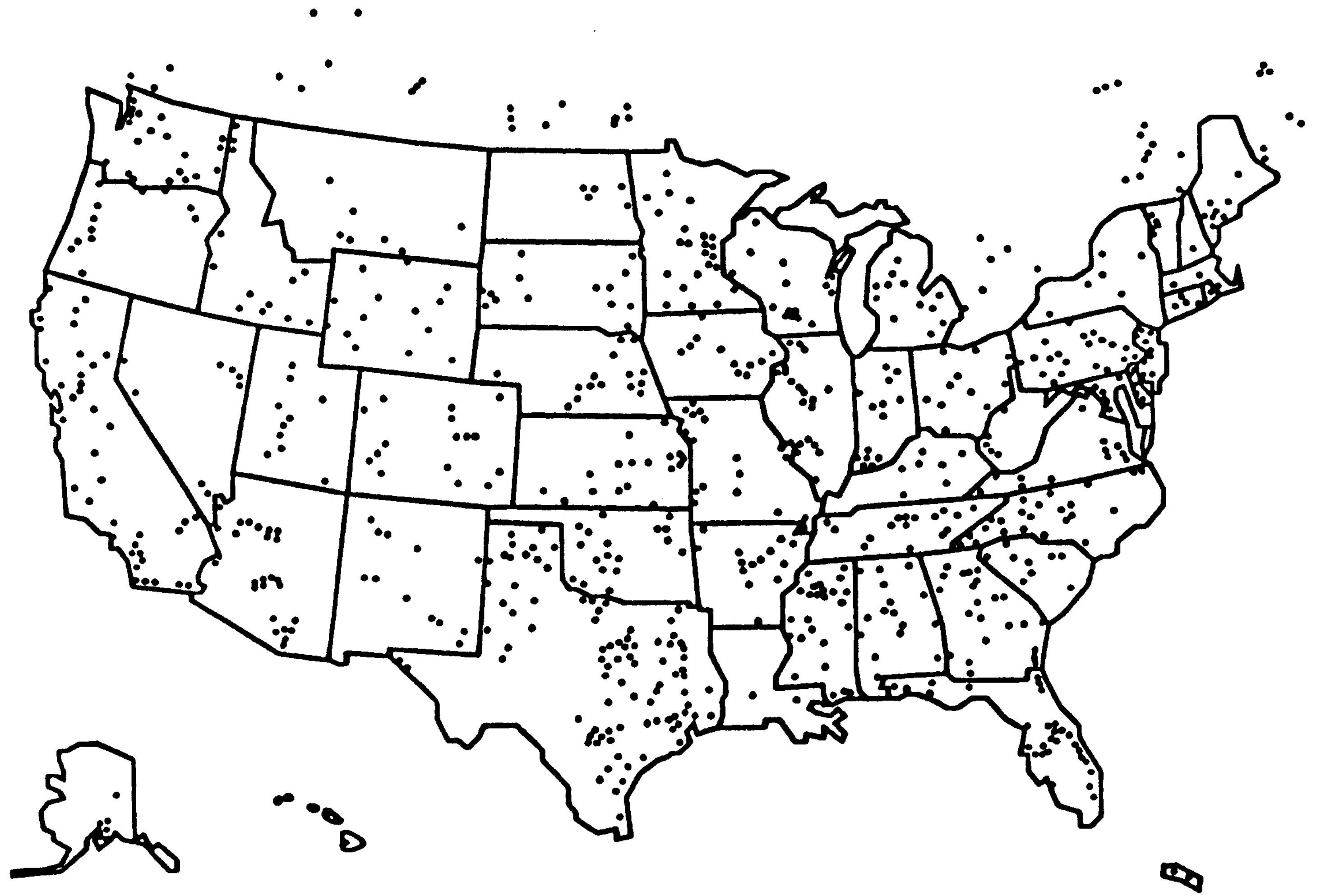


Figure 2. Location of Approved GPS Test Sections

The regional drilling and sampling contractors were under the operational control of the SHRP Authorized Representative from the SHRP Regional Coordination Office. The work on the designated pavements included, but not necessarily limited, to the following:

- cooperation and coordination with state highway agencies to provide traffic control, patching, and test pit restoration. In some areas and under some circumstances, the drilling and sampling contractors were required to provide all of the traffic control, patching, and test pit restoration services

- coordination with the SAR regarding schedule, scope of work, and other technical details

- layout of sampling and testing locations based on drawings and instructions provided in the drilling and sampling guide

- diamond bit core-drilling of asphaltic concrete, portland cement concrete, cement treated layers, bituminous treated layers, and other treated or stabilized pavement layers

- auger sampling of untreated bases, subbases, and subgrades

- Shelby (thinwall) tube sampling, if appropriate, and split spoon sampling of subgrade soils

- sawing and other methods of removal of asphalt concrete and portland cement pavement layers at test pit locations

- sawing and other methods of removal of treated layers at test pit locations

- in-place nuclear density and moisture tests of untreated base, subbase, and subgrade soils at test pit locations

- removal of bulk and moisture samples of untreated pavement layer materials and subgrade soils at test pit and other locations

- detailed logging of each exploration

- preparation of a summary report for each site

- careful marking, packaging, and shipping of all materials designated for laboratory storage and subsequent testing

- cleanup and disposal of excess material and debris from test pits, auguring and bulk sampling

A thorough understanding of pavement construction techniques, extensive pavement materials sampling, capability and experience by the drilling and sampling contractor and SAR were critical to the quality of the final product.

Certain general procedures were followed for each test site in all SHRP regions. Examples of a typical daily work plan for an AC pavement and PCC pavement are shown in Figures 3 and 4, respectively. During the day preceding the start of sampling and testing of a test section, the drilling contractor's crew chief and the SAR selected the location and estimated the time of arrival at the next test site. After traffic control was established, the drilling and sampling contractor would lay out the initial sample locations and commence the coring operation. The basic GPS sampling and testing sequence of operations consisted of the following:

- (a) sawing and removal of pavement at the test pit location
- (b) coring and auguring near the test pit location
- (c) coring and auguring at opposite end of test site
- (d) bulk sampling and moisture/density testing in the test pit as layers are removed
- (e) Shelby tube and split spoon sampling of subgrade material
- (f) auger probes in the shoulder if required

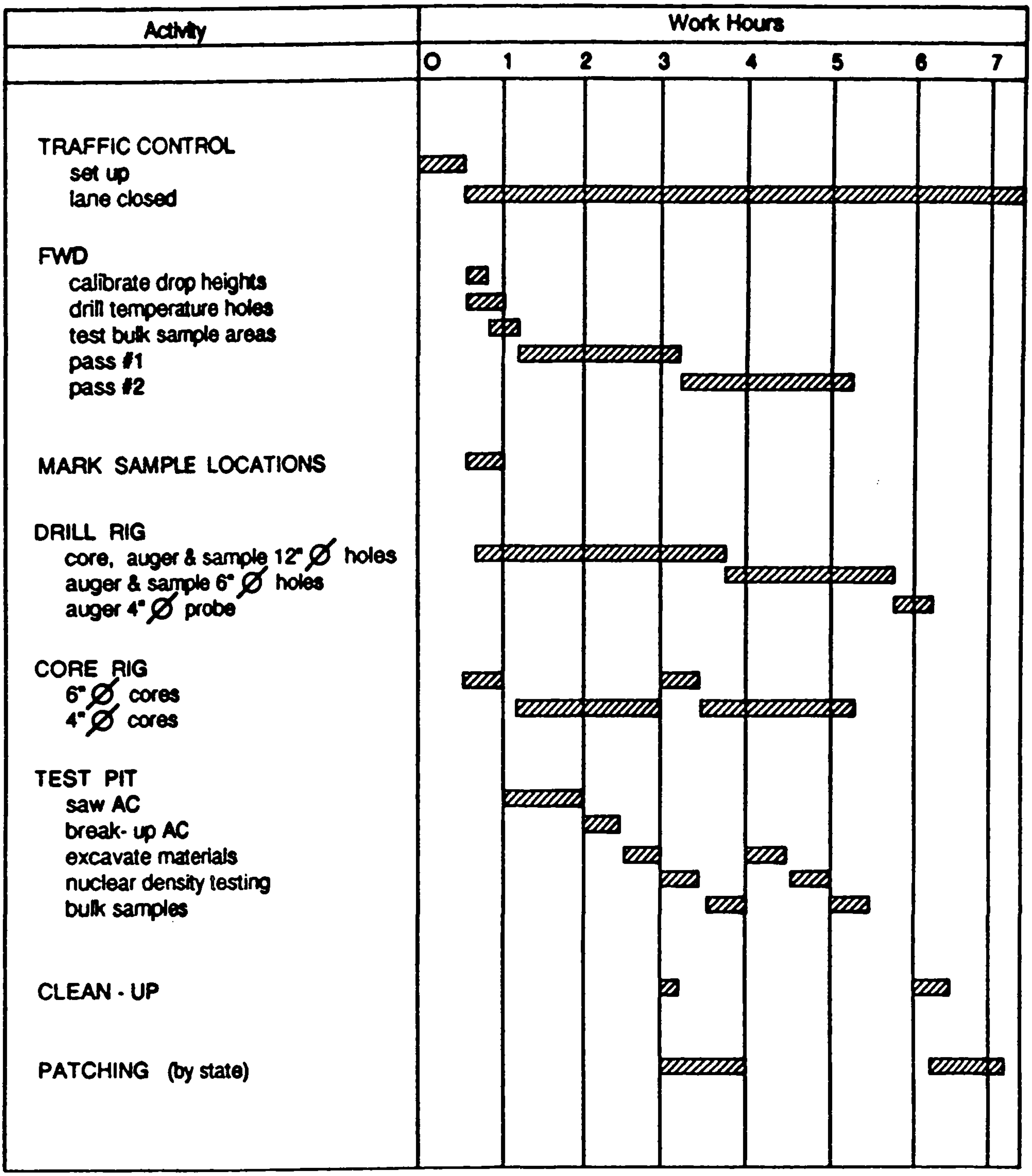
Variations in this sequence were adopted in some locations to optimize the efficiency of the operations.

The SAR distributed location maps to the drilling and sampling contractors in their regions during the initial start-up meetings and on an as-needed basis during drilling and sampling operations. The maps included the SHRP ID number and the specific test section location including highway/road designation, direction of traffic, lane number, and a landmark for each section. Preliminary inventory data sheets with entries for lanes for describing the expected conditions such as pavement type, layer materials, and layer thicknesses were also provided for each section. A GPS test section was 500 ft. in length and the field sampling and testing areas were located prior to and beyond the GPS test section resulting in a lane occupancy of approximately 600 ft.

Typical layouts for materials sampling points and field testing points are illustrated in Figures 5 and 6 and more detailed sampling and testing plans for each type of test section are shown in Appendix B of the SHRP-LTPP Guide for Field Material Sampling, Handling and Testing (5).

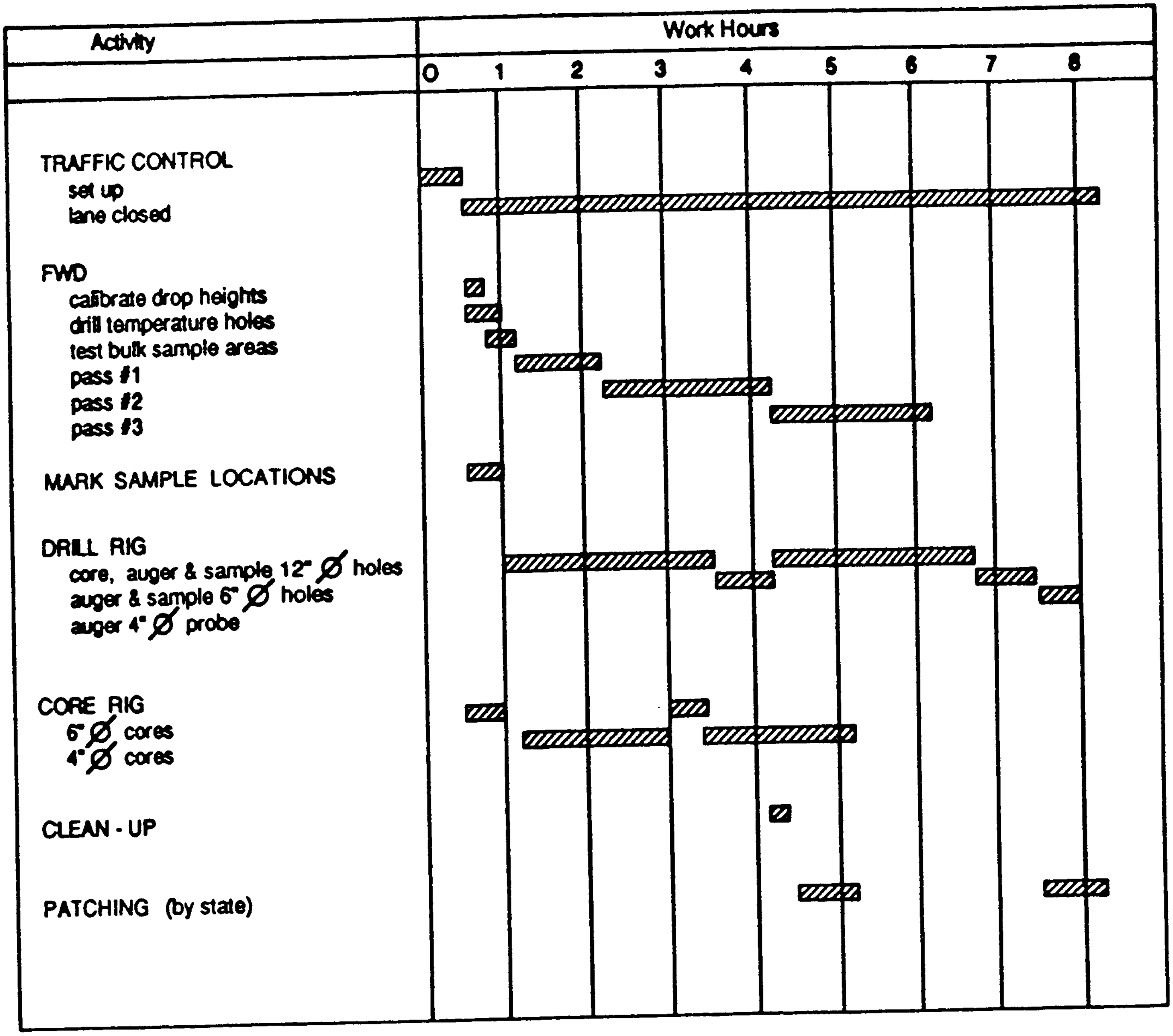
Coring

The acquisition of asphalt concrete and portland cement concrete cores was undertaken using 4, 6, and 12 in. diamond drill bits and water as a coolant. Special care was taken to ensure a minimum use of water so that the lower unbound layers of the pavement structure would not be contaminated during this operation. Coring was often performed with a truck-mounted drill rig or a tractor mounted drill rig for smaller diameter coreholes. The finished cores were extracted from the pavement using suction cups or wire pulls. For cores that were not going



NOTE: Actual times will vary depending on pavement type, thickness, number of layers and down time.

Figure 3. Typical Day of Drilling and Sampling, Flexible Pavement



NOTE: Actual times will vary depending on pavement type, thickness, number of layers and down time.

Figure 4. Typical Day of Drilling and Sampling, PCC Pavement

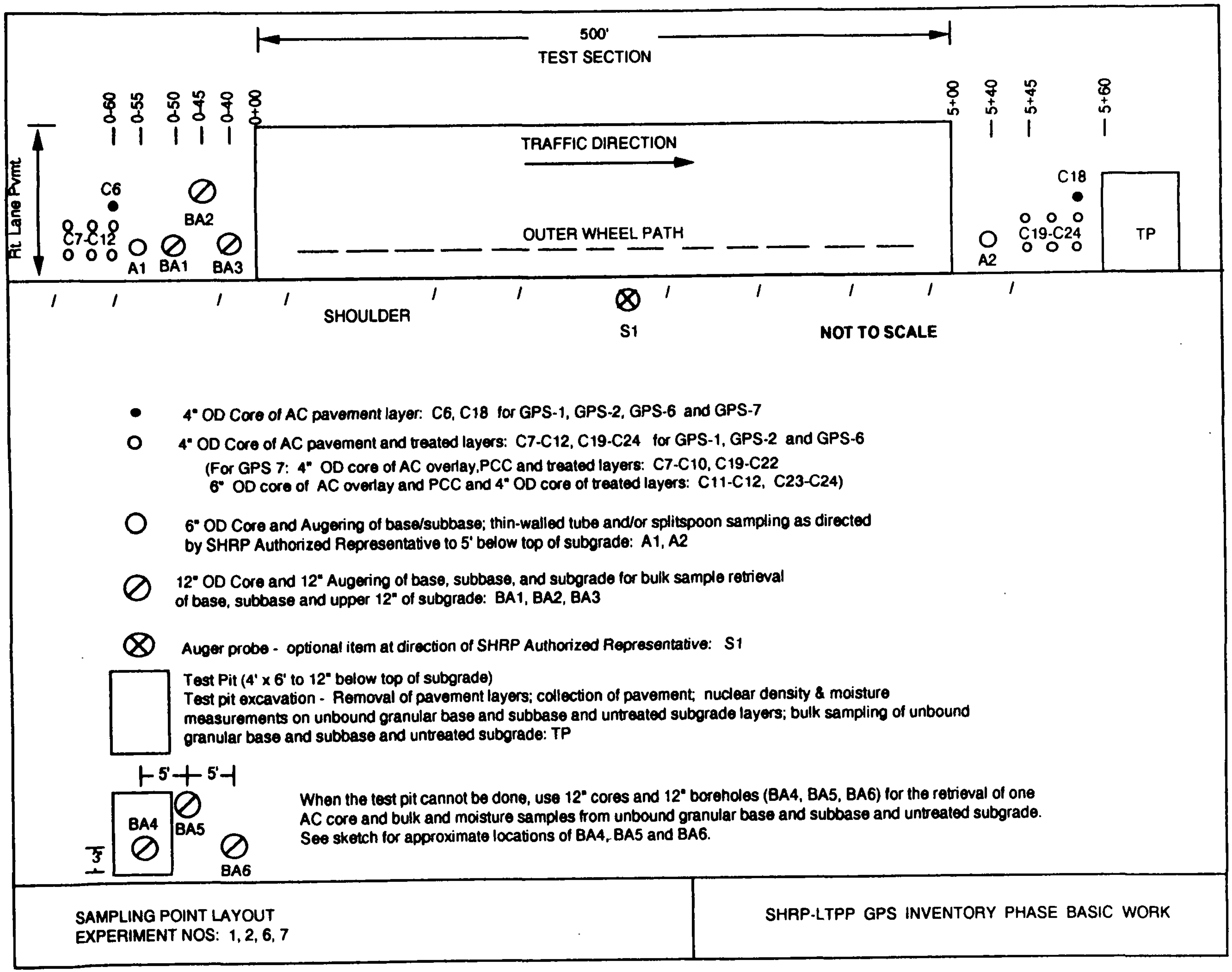


Figure 5. Typical Sampling Point Locations for GPS-1, GPS-2, GPS-6, and GPS-7 (Flexible Pavements)

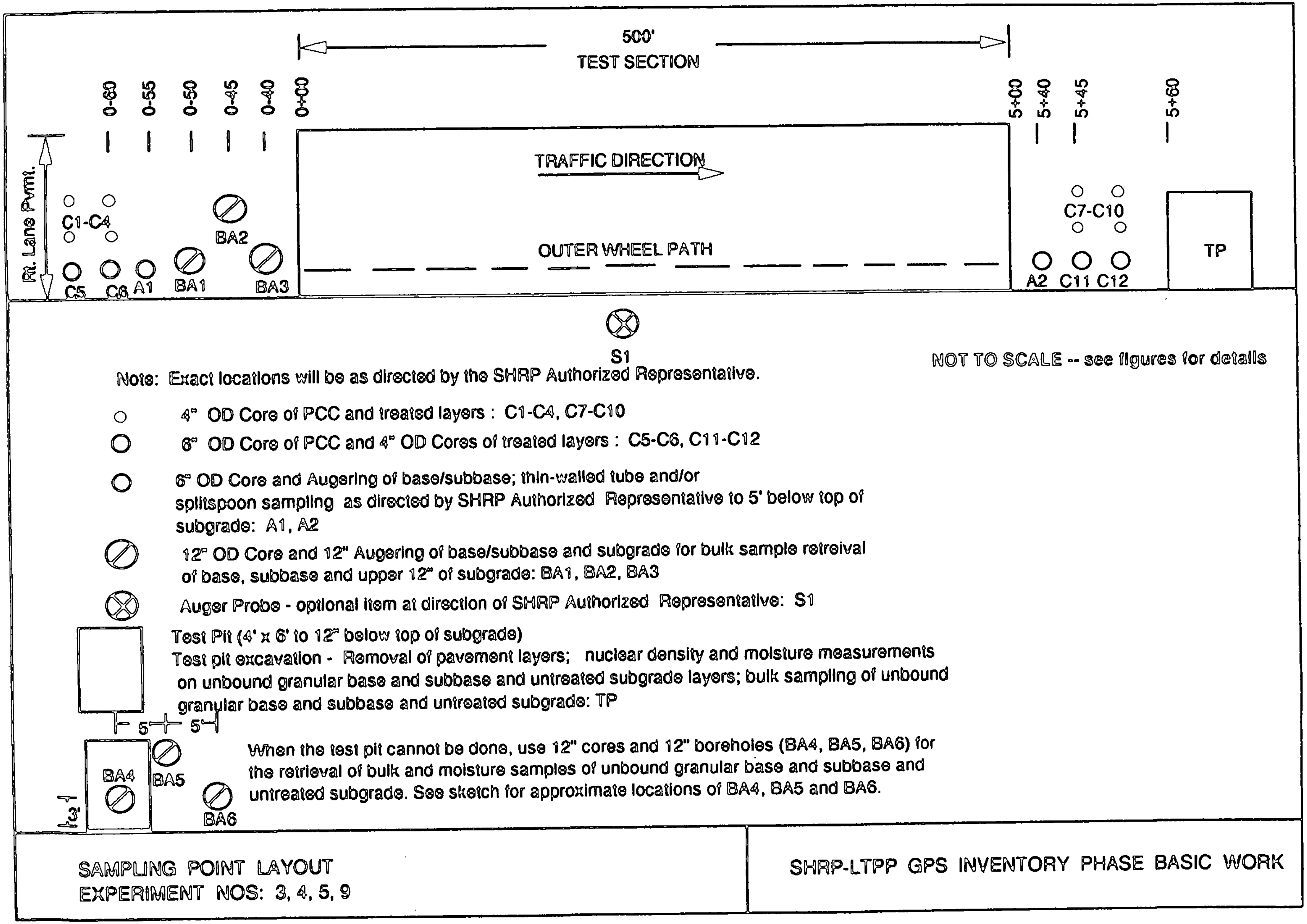


Figure 6. Typical Sampling Point Locations for GPS-3, GPS-4, GPS-5, and GPS-9 (Rigid Pavements)

to be used in laboratory testing (e.g., 12 in. PCC cores) a plug was inserted in the core to extract it from the pavement. Prior to extraction from the pavement, all cores were marked on the top with an arrow oriented to indicate the direction of traffic. This arrow was subsequently used in laboratory testing to align the cores appropriately. Layer thicknesses and the condition of extracted cores were recorded on the appropriate data sheet.

The coring and sampling operations for experiments GPS-6 and GPS-7 (asphalt concrete overlay over asphalt concrete and asphalt concrete overlay over jointed portland cement concrete, respectively) could have occurred at two different times; once before the overlay and once after the overlay. Consequently, the GPS-6 and GPS-7 pavement sections may have been sampled and tested as a specific case as follows:

(a) Case 1 - If the complete field material sampling and field testing program for a GPS-6 and GPS-7 test section was conducted after the AC overlay had been placed, this section would have been classified, sampled, and tested as a "Case 1." A case 1 designation meant that no field material sampling and testing had been conducted prior to the overlay.

(b) Case 2 - If the field material sampling and field testing program for a GPS-6 and GPS-7 test section was conducted in two stages; once before the AC overlay and once after the placement of the AC overlay. This section would have been classified, sampled, and tested as a "Case 2." A case 2 section would have had the majority of the field material sampling and field testing conducted before placement of the AC overlay, followed by a second round of field sampling conducted after placement of the AC overlay to acquire core samples of the AC overlay for laboratory materials testing. This case was not preferred because it required two rounds of field testing to be conducted.

The coring of the test sections was conducted utilizing AASHTO T24-86, "Obtaining and Testing Drilled Cores and Sawed Beams of Concrete."

Auguring

After removal of the bound layers for the 6 in. and 12 in. diameter coreholes, the remaining layers were investigated through auguring. This activity was conducted utilizing AASHTO T203-82(86), "Soil Investigation and Sampling by Auger Borings." and AASHTO M146-70(80), "Terms Relating to Subgrade Soil-Aggregate and Fill Materials." For the BA-Type sampling locations (i.e., 12 in. diameter cores), the untreated base, subbase and subgrade layers were augured separately to obtain uncontaminated bulk samples of each layer. The materials raised by the auger from immediately beneath any cores of pavement surfaces or bound layers was wasted due to possible contamination by water or fines from the coring operation. Any material from different layers which was mixed during the auguring operations was also wasted. Only uncontaminated materials from each layer was retained as a large bulk sample and shipped to the laboratory. The amount of bulk samples required are indicated in Table 1. A small jar sample was also taken from each unbound layer for moisture content determination in the laboratory.

Table 1. Weight Requirements for Bulk Samples of

Unbound Base, Subbase, and Subgrade Layers

Layer	Bulk Samples from 3-12" Auger Holes (BA1, BA2, and BA3)	Bulk Samples from Test Pit*
Unbound Base	Maximum 200 lbs. (100 lbs. Minimum)	200 lbs.
Unbound Subbase	Maximum 200 lbs. (100 lbs. Minimum)	200 lbs.
Subgrade		
Coarse Grain	200 lbs.	200 lbs.
Fine Grain	150 lbs.	150 lbs.

At the A-type sampling locations (i.e., 6 in. diameter cores), all unbound material above the subgrade was wasted. Undisturbed samples of the natural subgrade or fill material were obtained to a depth of 4 ft. below the top of the subgrade using, if appropriate, thin wall tube sampling.

Shelby tubes could not be used because of soil conditions, split spoon sampling was conducted using a 140 lb. hammer with a 30 in. drop. Blow counts were recorded on Form S02A contained in the drilling and sampling guide. Split spoon samples were opened and examined, and the length of recovery and description of the soil were logged.

Test Pit Excavation

The provision for a test pit in the field drilling and sampling phase afforded the best opportunity to obtain site-specific data and information unavailable from any other source. The SHRP drilling and sampling contractors used an excavation machine (usually a backhoe), a pneumatic pavement breaker, chisel and dump truck to perform the test pit excavations. During the test pit operations, motorist and worker safety during test pit excavation, sampling and testing were of major concern. In some cases the test pits were deleted at the discretion of the state highway agency for safety or other reasons. In such cases, bulk samples of untreated layers were obtained by 12 in. auguring at the test pit location. In these instances, nuclear density testing was not conducted.

The pavement and any treated layers were sawn to the specified overall dimensions. These pavement components were cut into smaller pieces as necessary for removal. Use of cooling water during sawing was minimized to reduce moisture contamination of layers. If saws of sufficient blade diameter to cut through all pavement surface and treated layers were not available, pneumatic spades and chisels were carefully used to minimize damage to underlying untreated layers. One 12 in. by 12 in. sample of an AC pavement surface was recovered intact for packaging and shipment to the laboratory. No samples of PCC pavement surface or treated layers were retained except for those cases where suitable test cores of the layers were not obtained elsewhere from the test section.

After removal of the surface and treated layers, the untreated layers, including the subgrade, were tested using the nuclear density gauge. Excavations of the subgrade continued to 12 ins. below the top of the subgrade or fill material. Bulk samples were obtained of all unbound layers in accordance with Table 1.

At the completion of the operations, the test pit was restored to "as near original condition" as possible by state highway department personnel and/or drilling and sampling contractor personnel. Test pits for asphalt sections and non-CRCP pavements were usually completed the same day as the drilling and sampling operations. For jointed concrete pavements, a procedure sometimes used by SHRP forces to restore concrete test pit locations was as follows:

- saw along all edges of the test pit completely through the concrete surface and place anchor plugs in the pavement slab to be removed

- place anchor bolts in the plugs and string steel cable through the eyelets

- with a backhoe or front end loader attached to the cable, lift the test pit slab in one piece and place beside test pit area

- complete regular sampling and testing activities

- replace sampled areas with suitable base and subbase material and compact with pneumatic tampers to maximum attainable density to a level even with the bottom of the concrete surface

- replace concrete slab, remove anchor bolts, and seal joints in accordance with appropriate state specifications

In continuously reinforced concrete (CRCP) or other instances where the procedure outlined above was not feasible, an overnight lane closure was initiated followed by permanent patching of the test pit area the following day or the placement of a temporary patch at the completion of the sampling and testing followed by permanent restoration at a later time was employed.

Auger Probe

An auger probe was employed at the shoulder of the section during the field drilling and sampling operations to determine if bedrock or other significantly dense layers existed within 20 ft. of the pavement surface. Auguring was performed with the drill rig mounted on a truck by a 6 in., continuous flight, solid, helical auger. Auguring was performed to a depth of 20 ft. or refusal, whichever came first. When refusal occurred prior to 20 ft., the probe was often continued at an adjacent location to insure that a hard layer was present. If refusal occurred at the second location, the auger probe activity was terminated and refusal was reported.

Sample Numbering, Packaging and Shipment

Prior to shipment to the laboratory, all samples were separately marked with a sample number after cleaning, drying, wrapping and packaging. Each sample was identified in accordance with the specifications in the drilling and sampling guide. Samples were shipped in wooden boxes of standard construction to the appropriate laboratory within 5 days of sampling.

Site Cleanup

At the conclusion of the drilling and sampling operations,the contractor was responsible for removing all material and debris created by their operations. All material was stored or disposed of off of the state right-of-way in accordance with state highway and local requirements. In most cases, state and provincial forces worked in concert with the drilling and sampling contractor to provide site cleanup activities.

Reporting

A set of reports were prepared by the drilling and sampling contractor for each site using SHRP standard forms described in the data collection portion of this document. These site reports were eventually stored in the NPPDB and the originals were stored in each RCOC office in archival form. In addition to these site reports, an as-sampled and tested field material sampling and field testing plan was attached that identified the actual locations of the drilling and sampling effort.

Data Collection Guidelines

The primary objective of the drilling and sampling program was to provide a comprehensive profile of the pavement layer structure and layer thicknesses of the pavement layer materials, as well as to provide high quality samples/specimens for further laboratory materials testing and characterization. To formalize and facilitate the collection of this data, standard data entry sheets and standard materials codes were developed to record all data collected in the field (**10**).

The guidelines for recording the data collected during the field material sampling program are contained in Appendix C of SHRP-LTPP-0G-006, "SHRP-LTPP Guide for Field Material Sampling, Handling and Testing, May 1990." Detailed instructions are provided in Appendix C of the Guide for completion of the forms and selection of standard SHRP comment codes that are used to record material classifications. These data collection sheets were principally completed by the drilling and sampling contractor's crew chief and were subsequently reviewed by the RCOC for completeness and accuracy prior to entry in the NPPDB.

Detailed descriptions of field material sampling and field testing operations and data collection were available in the reference previously cited (SHRP-LTPP-0G-006). This document and the LTPP Researcher's Guide (**15**) should be used to fully comprehend the data collection activities for the field materials characterization program.

The field material sampling and testing program consisted of the acquisition of 4 in. (AC) and 6 in. (PCC) cores of the pavement surface and treated layers, 6 in. auger holes, 12 in. diameter bulk sampling core holes and excavation of test pits. The results of this operation were primarily recorded on the field data collection forms shown in Table 2.

Table 2. Summary of Data Collection Sheets for Field Material Sampling

Form Number	Form Title	Entered in Database?
S01	Log of Pavement Core (Borehole Locations)	Yes
S01A	Log of Pavement Cores (C-type Locations)	Yes
S02A	Log of Bore Hole (A-type)	Yes
S02B	Log of Bore Hole (BA- type)	Yes
S03	Log of Test Pit	Yes
S03A	Log of Test Pit (Sketch)	No
S04	In Situ Density and Moisture Tests	Yes
S05	Log of Shoulder Probe	Yes
S06	Materials Sample Inventory	No
S06A	Materials Sample Inventory - Summary	No
S07	Project Site Report	No

A separate log was prepared for each core hole type (i.e., A, BA, and C-type sampling areas). The total depth of penetration into the pavement structure during each coring operation and the average length of the recovered core were recorded to the nearest tenth of an inch. Data sheets S01 and S01A were used to record these drilling operations and generally documented the bound layer material thicknesses and material classifications. The logs also included comments concerning the core cooling medium, difficulties encountered during coring and any defects (such as cracks, voids and disintegration) observed in the core.

A log was also completed for each auger hole (A and BA-type augers). The depth of penetration of each coring operation and the average depth of the sampling were recorded to the nearest tenth of an inch. Data sheets S02A (A-type augers) and S02B (BA-type augers) were used to record these drilling operations and to document the sampling of the unbound materials portion with the 6 and 12 in. bore holes. Form S02A also documented the results of the standard penetration test on the subgrade material. Additional comments concerning the presence and levels of water, if encountered, and the sample numbers and number of bags per sample if more than one was retrieved.

Test pits were logged as the excavations progressed using Forms S03 and S03A. These data sheets included the description of each layer, the thickness of each layer (to the nearest tenth of an inch), sample numbers and the number of bags per sample, any water seepage, sloughing, voids underneath the pavement and similar occurrences. The thicknesses were measured at a minimum of two points on each exposed face of the pavement layer. Form S03A was used to sketch the vertical test pit profile as it was sampled. The dimensions of the test pit, the depth of each layer and the material type of the layer were also illustrated. Photographs of the test pit taken by the SAR were keyed to the sketch to show the general pavement structure. Close-up pictures were taken if voids or similar discontinuities existed. The photographs and test pit sketches were transported to the RCOC for archival purposes.

In situ moisture and density tests (nuclear density gauge) were recorded on Form S04. In situ moisture and density testing was conducted in the test pit on the surface of all untreated base, subbase and subgrade layers. The measurements of moisture and density for each layer were also recorded on this form. The nuclear density gauges were calibrated using procedures described in a later portion of this document.

Form S05 was used to record the results of the pavement shoulder auger probe. The purpose of the auger probe was to determine whether bedrock or other significantly dense layers existed within 20 ft. of the pavement surface. Pavement layer thicknesses were recorded to the nearest inch and the depth to refusal (if reached) was recorded in feet. This information is expected to be extremely useful in the analysis of the LTPP data.

Forms S06, S06A, and S07 were used to record summary information for the material sampling information from a given test section. Specifically, Form S06 provided a detailed inventory of material samples for shipment to the regional laboratory and PCC testing laboratory. This included cores from C-type locations, cores from A, BA-type and test pit locations, thin-wall tube samples, split spoon samples, moisture samples and block samples from AC layers. Also, this form contained a note which described the sample type, condition and sample number.

Form S06A provides a summary using information from Form S06 for all samples collected from the pavement section. Layer numbers were assigned consecutively from the subgrade to the surface layer. The subgrade would be assigned as layer number 1 and the surface layer would be assigned the last (highest) number. A description of the pavement layer material and sample type was also provided on the form. The laboratory receiving the samples was also identified on the form.

The project site report (Form S07) documents a number of items concerning the pavement test site such as the weather conditions, equipment breakdowns, unusual conditions and other incidence which occurred on the job site. A summary of all drilling and sampling performed on the test section was also listed on this form.

All of the data entry forms were completed by the drilling and sampling contractor representative and approved by the SHRP Authorized Representative. They were organized in a sampling data packet and forwarded to the following personnel:

- SHRP Regional Engineer (originals)
- Regional Testing Laboratory Contractor
- National PCC Testing Contractor
- Regional Drilling and Sampling Contractor's Office

The data was checked for accuracy and completeness in the RCOC's office and entered in the regional pavement performance database (RPPDB). The original sampling and testing data packet along with all pertinent photos and other pertinent information were kept in the RCOC's office for archival storage.

Quality Assurance/Quality Control in the Field

The field material sampling and testing conducted for the GPS program was unprecedented in terms of geographic coverage, specificity of requirements and magnitude of work. Throughout this effort, SHRP required consistent, high quality field material sampling and field testing from all drilling and sampling contractors. To achieve this goal SHRP implemented uniform quality assurance (QA) and quality control (QC) procedures within each region (16). The definitions for quality, quality control (QC), and quality assurance (QA) for SHRP are as follows:

- Quality: conformance to requirements established by SHRP
- QC: insuring completion of work activities and assessing the results before releasing it to SHRP
- QA: verification of quality control measures, i.e. verifying that quality control is operational and adequate

The QA/QC procedures provided guidance within the scope of work that could impact the quality of field material sampling and field testing and were consistently followed to insure

the production of an acceptable quality of coring, boring, auguring, disturbed and undisturbed sampling, bulk sampling from the test pits and in situ field testing.

Specifically, the QA/QC program provided a methodology for the review, assessment and selection of corrective action in the following areas:

- overall project supervision
- locations of exploration holes, test pits and field tests,
- materials sampling
- handling of samples
- adherence to specified field testing procedures for in situ density and moisture measurements
- accuracy in measurements
- equipment maintenance and calibration
- data collection and recording
- preparation and submittal of reports

The first step in the QA/QC process was the adherence to the SHRP guidelines for Field Material Handling and Testing (**5**).

The commitment to QA/QC was consistent at all levels of the SHRP-LTPP program including the SHRP Authorized Representatives, SHRP Regional Engineer, RCOC staff, drilling and sampling contractors, field and office staff and state highway personnel. Assignments regarding appropriate QA/QC checks were made at every level of the LTPP pavement data acquisition process. Specific responsibilities and a flowchart of the QA/QC process are presented in Section 4 of the <u>SHRP-LTPP Guide for Field Materials Sampling, Testing and Handling, May 1990</u> (**5,16**).

Personnel

Quality assurance and quality control of field materials began during the development of the Technical Provisions that included detailed requirements for field drilling and sampling personnel. The presence of experienced and knowledgeable persons was the first and most important aspect of this program. The crew chief (i.e. on-site project supervisor) was a senior technician, geologist or engineer with a minimum of five years experience in subsurface explorations. This person was familiar with all aspects of the drilling and sampling contract, as well as his own and his crew member's responsibilities and specific duties. The crew chief was also responsible for maintaining and using copies of pertinent standards, memoranda, directives and the basic QA/QC manual (Field Sampling and Testing Guide) (**5**). A review of all logging, sampling and field test data was completed by the crew chief. A review by the SAR was subsequently conducted to verify the information on the data sheets for each test site.

Table 3 contains a list of personnel and their associated responsibilities for this effort. References to laboratory and database personnel are included in the table to provide an "overall picture" of field material sampling and testing QA/QC.

The SHRP Authorized Representative (SAR) was required to possess similar qualifications as the crew chief. The SAR was responsible for authorizing, inspecting and verifying the work conducted by the drilling and sampling contractor. This person represented a key element in the instrumental part of the QA/QC process. One of the more critical functions of the SAR was the review and approval of the field data packets prepared by the drilling and sampling personnel. This included verifying layer thicknesses, sample condition, sample types and sample locations. Additionally, the SAR inspected the samples prior to shipment to ensure compliance with SHRP standards.

SHRP RCOC personnel were responsible for checking the field data packets for completeness and reasonableness. This included checks of the documentation regarding sample receipt by the laboratories. These documents were cross-checked with the field shipping forms to ensure that the number, type and condition of the specimens shipped from the field reached the laboratory. In addition,the RCOC personnel coordinated activities between the SHRP drilling and sampling contractor and the appropriate SHRP laboratory. All of these activities were undertaken to avoid sampling error and to insure consistency and accuracy of the field sampling and testing data.

Equipment

As part of the QA/QC process, the drilling and sampling contractor was required to adequately maintain and calibrate the equipment so that quality samples and test data could be acquired. A preventative maintenance program was implemented to reduce the down time of the equipment on the project. The height of drop and weight of the drive hammer for the standard penetration test on the drill rig were checked for compliance with AASHTO T206-81 (17). Other equipment was inspected on a frequent basis to ensure efficient operation. Additionally, the SHRP Quality Assurance Consultant visited several drilling operations to ensure compliance with appropriate QA/QC procedures.

Periodically, the nuclear moisture-density equipment was checked to assure that the measurements on standard materials of known density and moisture were within acceptable limits. A program-wide verification/calibration program was established to assure the accuracy and consistency of the data obtained by these devices (18). This was essential because the in situ moisture and density data was collected on different material types in four geographic regions by four different contractors using different nuclear equipment. Materials of known density (traceable to the National Institute of Standards and Technology or NIST) were used to verify that the device was recording measurements within an acceptable range of the known density and moisture. The nuclear density gauges were calibrated based on the results of this verification procedure.

Table 3. Field Drilling and Sampling QA/QC Responsibilities

Agency/Person(s)	Responsible for
Regional Drilling and Sampling Contractor/Crew Chief/Project Manager	QC - Field Sampling and Field Testing Activities, Field Data Packet, Shipment of Samples to Laboratory QC - Implementation of SHRP Procedures and Directives in the Field
RCOC/SHRP Authorized Representative	QA - All Field Activities QC - Field Data Packet
Regional Laboratory Testing Contractor/Lab Chief/Project Manager	QC - Sample Receipt and Check of Samples
PCC Laboratory Testing Contractor/Lab Chief/Project Manager	QC - Sample Receipt and Check of Samples
SHRP Regional Engineer/RCO	QA - Regional Field Data QC - Regional Database
SHRP Quality Assurance Manager	QA - Field Equipment and Procedures
SHRP and P-001 Staff	QA - Interregional Field Data QA - Database

Summary Statistics and Information

At the completion of the field materials characterization work for the GPS program, the estimated overall quantities were:

- 775+ GPS sites sampled
- 14,000 cores of AC and PCC taken
- 450 test pits excavated
- 330 nuclear density tests performed
- 200 tons of bulk samples removed

All of this materials characterization information was transferred to the national SHRP database that represents an important and unique depository of information for highway pavement researchers. Perhaps, most important of all, SHRP has met its goal and provided present and future pavement researchers with high quality field materials characterization information, as well as other attributes of the pavement layers from the LTPP GPS pavements (**4**).

Status of GPS Materials Sampling and Testing

All of the GPS sites that were scheduled for initial drilling and sampling have been completed. Any future GPS sections that are added as the program continues will have to be drilled and sampled according to SHRP guidelines, probably utilizing state and provincial forces. Drilling and sampling of planned overlay experiments GPS-6B (AC overlay of AC) and -7B (AC overlay of PCC) test sections which have been overlaid after the initial round of drilling and sampling will have to be drilled and sampled to obtain the cores of the pavement overlay.

Most of the GPS drilling and sampling program has been completed and a major effort is not expected in this portion of the materials characterization program for the remainder of the LTPP program.

SPS Field Material Sampling and Field Testing

Introduction

The SPS experiments were developed to investigate the performance of selected flexible and rigid pavement structures, maintenance treatments of flexible and rigid pavements, rehabilitation treatments for flexible and rigid pavements, environmental effects in the absence of heavy loads, and asphalt mix performance generally within a factorial of subgrade type and environmental condition. The structural factors included different surface layer and base layer thicknesses, while rehabilitation and maintenance treatments ranged from crack sealing and minor repair to extensive surface preparation followed by asphalt or concrete overlay. The

SPS experiments consisted of individual sites with similar details and materials requirements according to the experiment requirements, but composed of multiple test sections.

The SPS sites were distributed among the climatic regions and subgrade soil types. The experimental designs and construction considerations for the experiments are described in the experimental design and research plan documents published for each experiment (**19,20,21,22, 23,24**). Construction features and details for the experiments are described in the construction guidelines documents also published for each experiment (**25,26,27,28,29,30**).

The guidelines for formulating field materials sampling and laboratory testing plans for the SPS experiments have been developed from experience gained during the GPS materials testing program. These guidelines were used by the SHRP regional offices and participating agency to develop a field testing and material sampling and laboratory testing plan tailored to the individual test site that meets the data needs of the experiment. Unlike GPS sections, the use of multiple test sections resulted in increased site length, and an expected greater variability. Since comparisons of performance will be conducted both between test sections at a site, and between sites within the regions, the need for thorough and reliable characterization of the engineering properties of the materials is critical. Therefore, a sufficient number of field tests must be performed and a sufficient number of samples must be acquired from each test site to enable adequate laboratory characterization of the pavement materials.

In this report, the field testing of SPS projects will be divided and discussed in the following two groups; 1) SPS-1, -2, -5, -6, -7, and -8, and 2) SPS-3 and -4. This is logical in that two different philosophies were used to develop the field sampling plans for each group. SPS-1, -2, -5, -6, -7, and -8 were based on new construction or rehabilitation treatments while the SPS-3 and -4 experiments involved pavement maintenance practices and did not require the level or intensity of sampling and testing required by the other experiments.

Development of SPS-1, -2, -5, -6, -7 and -8 Field Sampling and Testing Plans

Materials characterization using field and laboratory testing was designed to provide an adequate level of information on each pavement layer for inclusion in the NPPDB. The data requirements varied between experiments only to the extent that different construction processes were taking place or that different materials were used.

The testing plan for a particular experiment was defined entirely by the materials data requirements. For example, the required number of resilient modulus, creep compliance and thickness tests controlled the number of surface layer cores in an asphalt concrete pavement as follows:

- Resilient modulus. Six resilient modulus tests are expected to be performed on cores from the asphalt concrete surface. Also, three tests should be performed on cores from the asphalt treated base (ATB) layers and two tests on cores from the permeable asphalt treated base (PATB) layer. Three cores obtained from the same approximate location (adjacent to each other) are required for

each resilient modulus test. In addition, a core will be required for conduct of indirect tensile testing in conjunction with each resilient modulus test.

- Creep compliance. One creep compliance test will be performed on the asphalt surface course material. Three cores obtained from the same approximate location are required for this test.

- Thickness. Two cores acquired from locations adjacent to both ends of each test section will be needed to quantify the as-constructed thickness. These cores will be taken along the same transverse line at 3 ft. and 6 ft. from the edge of the travel lane.

In general, the development of the (materials characterization test plan) for the SPS experiments includes the following steps:

1. Review of project site layout and soil profile logs.

2. Formulation of a combined laboratory testing and field testing plan. The field sampling requirements will be based on the laboratory testing plan. This plan takes into account site conditions, construction schedule, and the laboratory material testing requirements. An adequate number of field tests must be performed and sufficient samples must be obtained to assure that all laboratory material characterization tests can be performed.

3. Development of a field sampling and testing plan report. This report specifies sampling area locations, field test locations, type and number of samples from each location and material, a table that identifies the tests to be performed on each sample, and a table that lists the field test to be performed at each location.

4. Field sampling and testing of materials. In reporting this activity, adjustments made in the field to the sampling and testing plan must be recorded.

5. Testing of material samples in the laboratory.

6. Compilation and storage of data. This includes compilation of field sampling, field test data and laboratory material test data and entry of this data into the National Pavement Performance Database.

Although the material properties sought for any SPS experiment site are similar, the details of the sampling and testing plan will differ depending on subgrade variability and geometric constraints at each specific project site. The sampling plan must be tailored for the specific site conditions to account for the distance between test sections, project length, subgrade variability, construction scenario (i.e., rehabilitation of an existing pavement or new construction), and other conditions unique to the site. The guidelines were developed to simplify the process of developing an appropriate plan for each experiment site.

Special Considerations for SPS Field Sampling and Field Testing

SPS experiments include both existing pavements and new construction. As a consequence, field sampling and testing plans must address the need to minimize destructive sampling and testing activities in both the existing and finished pavements as well as constraints on access caused by the construction schedule. GPS sampling and testing sought to maximize the information obtained while limiting the number of destructive test locations near the test section to prevent influences on pavement performance resulting from these activities. This same policy applies in SPS but is complicated by the number of sections at a site, the number of different pavement structures at a site and the desired objectives of sampling and testing during construction activities.

Experiments dealing with rehabilitation of existing pavements will require the same type of sampling as in GPS. An adequate number of core locations, a test pit, and shoulder probes will be distributed throughout the project site, based on the assumed subgrade variability. This is termed pre-construction sampling. The experiments requiring construction of new pavements will adopt a program of sampling and testing that is conducted during and throughout the construction process. As layers are completed sampling and testing are performed. Table 4 summarizes the type of construction and the approach to sampling and testing.

Pilot Study Testing in Iowa and Mississippi

Initial development of the approach and scope of materials sampling and testing for SPS projects was tested in a pilot study conducted in the summer of 1989 on the SPS-5 project on I-55 in Yazoo County, Mississippi. This initial work included experience gained from the effort and decisions undertaken in the development of the pre-construction sampling and testing plan for an SPS-6 in Iowa during the same period.

The test plan developed for the Mississippi SPS-5 project was intended to validate and revise the approach for multiple test sections which would be economical but provided for thorough sampling and testing. Laboratory testing requirements, (i.e., the number of test results needed) were based on the GPS experience. The influence of site length and subgrade variability then dictated the number of locations for sampling the existing pavement structure to properly characterize the site. The sampling methods were the same as GPS; however, the number of sampling locations were increased to provide information distributed throughout the site.

The Iowa SPS-6 preconstruction sampling plan was developed to quickly obtain as much pre-construction information as possible. This project occurred early in SPS implementation and preceded development of the testing guidelines. As a result, the GPS approach was implemented with attention to test section distribution along the project site.

The experience gained from the pilot sampling and testing resulted in definitive sampling and testing guidelines for each SPS experiment, exclusive of the maintenance effectiveness

Table 4. SPS Construction Type and Sampling Frequency

SPS Experiment	Sampling and Testing		
	PreConstruction	During Construction	Post Construction
1 New Flexible	Subgrade Layer	Each Finished Surface	Finished
2 New Jointed Concrete	Subgrade Layer	Each Finished Surface	Finished
5 Rehabilitation of Flexible	Entire Existing Structure	New AC only Surface	Finished
6 Rehabilitation of Jointed Concrete	Entire Existing Structure	New AC Surface	Finished
7 Bonded Concrete Overlay	Entire Existing Structure	Fresh PCC Surface	Finished
8 New Flexible and New Jointed Concrete	Subgrade Surface	Each Finished	Finished

experiments SPS-3 and SPS-4. Most of the assumptions, concerning the number of test locations and types of laboratory tests, incorporated in these pilot efforts were considered to be appropriate and have been included in the final guidelines for these experiments (**31,32,33,34,35,36**).

Sample Design of a Sampling and Testing Plan

The field testing and material sampling and testing plan will be prepared in a coordinated manner with the participating agency and contractor. In addition, the following documents will be reviewed prior to plan preparation:

1. Project plan and profile sheets
2. Soil profile sheets
3. Laboratory and field material testing requirements
4. Other documents or information related to the project which, for example, would help establish subgrade variability along the site

The variability of the subgrade will be investigated during the site selection process and will be a prime consideration in development of the final sampling and testing plan for the site. Plan and profile sheets will be used to establish the location of cut/fill sections and to define the expected variability in subgrade materials. The site location constraints imposed to avoid cut/fill transitions, bridges, culverts, substructures and side hill fills and the inclusion of supplemental test sections desired by the participating agency would require a longer project site to accommodate all test sections. The greater length of a test site will increase the potential for variability of the subgrade soils along the site. The actual number of subgrade sampling locations will, therefore, be based on the total site length and known variations.

In addition, the material sampling and testing plan will be tailored to the specific features encountered at each project site. The participating highway agency may also construct supplemental test sections at the site in addition to those required for the SPS experiment. Therefore, the sampling and testing plan must be site-specific. For illustration purposes, an example of the material sampling and testing requirements and a conceptual site plan for an SPS-8 project site with flexible pavement sections are presented.

The site in this illustration represents new construction and consists of two test sections, required for a given SPS-8 flexible pavement project site. The pavement cross sections conforming to the experiment design are illustrated in Figure 7. The sample SPS-8 test site layout shown in Figure 8 is extracted from the construction guidelines and will be used to illustrate the materials sampling and testing requirements. For this site, the 600 ft. test sections (50 ft. monitoring length and 50 ft. at each end for field sampling) are spaced 100 ft. apart. Locations for subgrade and base course testing are distributed throughout each test section. The sampling locations, which include bulk sampling locations and locations for coring, shall be contained within the sampling areas at each end of the test section outside the monitoring length, and numbered consecutively as illustrated in Figure 8.

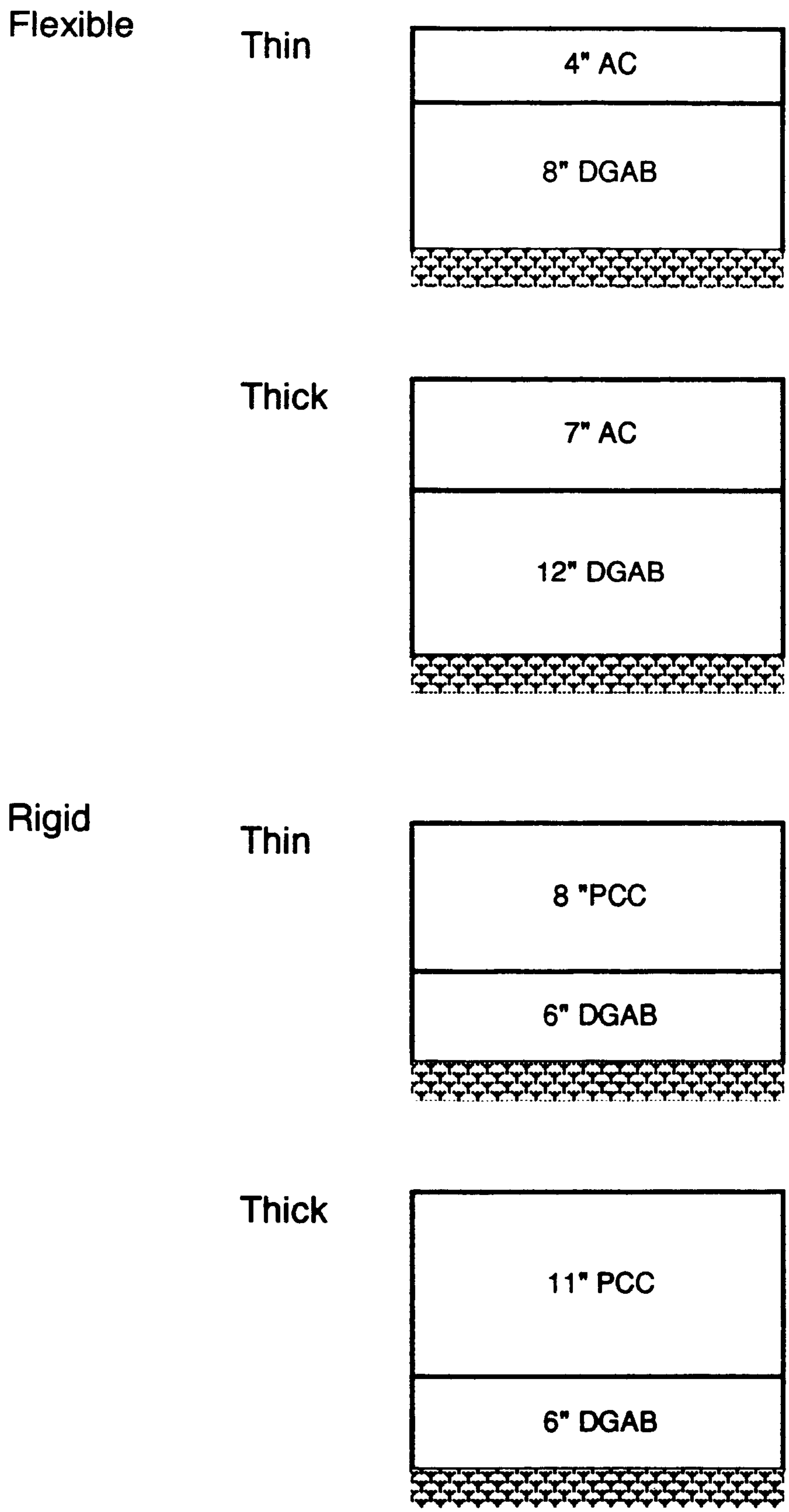
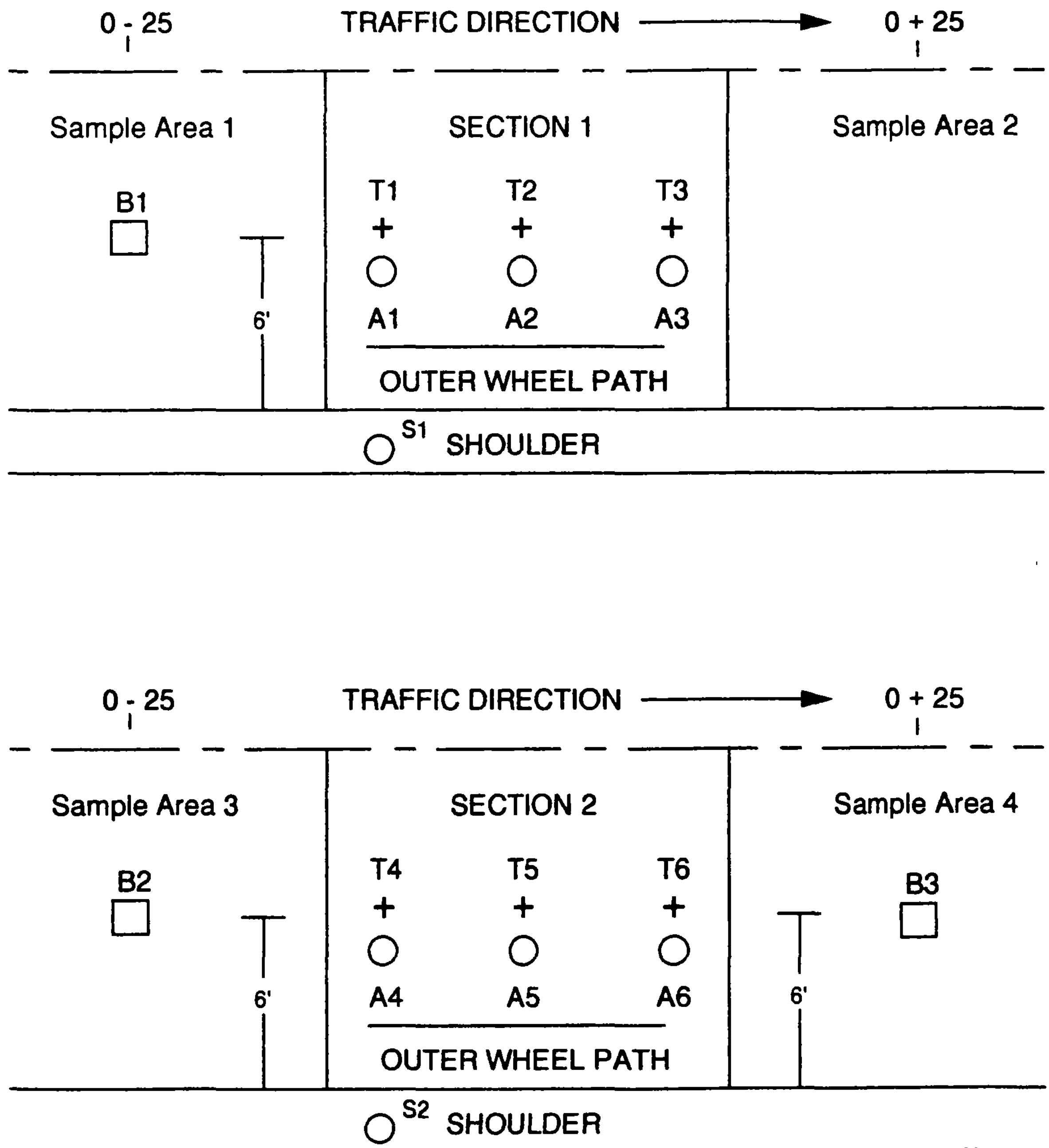


Figure 7. SPS-8 Pavement Cross-Section Layout Scheme



□ - Bulk sampling location 1 ft x 1 ft to 1 ft below surface
T1 - In-place density test location
A1 - Location of Shelby tube/split spoon sampling to 4 ft below surface
S1 - Location of augerprobe in shoulder

Figure 8. SPS-8 Test Site Layout

The layouts presented are based on the construction sequence, i.e. milestones such as completion of subgrade preparation, base course, and surface course. The first testing and sampling, shown in Figure 9, is of the prepared subgrade. After construction of the granular base layer, in-place testing for density, moisture content and bulk sampling is performed at the locations shown in Figure 10. Finally, cores are acquired from the finished surface course at locations shown in Figure 11. Bulk samples of the uncompacted asphalt mixtures are also obtained during construction.

Field Material Sampling and Testing Guidelines

Field materials sampling and testing guidelines have been published by SHRP for the SPS-1, -2, -5, -6, -7, and -8 experiments (31,32,33,34,35,36). These documents combine the sampling plans and instructions with the laboratory testing requirements for each experiment. The sampling procedures are based on the SHRP-LTPP Guide for Field Materials Sampling, Testing, and Handling (5).

Contents

The site specific field material sampling and laboratory testing plan developed according to the published guidelines for each SPS experiment site includes the following elements:

- Project layout plan
- Detailed sampling layout
- Detailed field testing layout
- Laboratory testing plan

Each guideline document provides information describing the experiment and test section requirements. This is followed by specific details for development of sampling and testing plans including site layouts for sampling locations, the types of samples required, and the testing needs. Activities including methods of sampling, reporting requirements, and materials shipping and handling are also described in order to standardize techniques, reduce variability, and maintain consistency.

The project layout plans are used to identify the location of testing and sampling areas relative to the test sections for each sampling and testing activity. Since sampling and testing is required at the different stages of construction, layouts must be developed for each stage, i.e. prepared subgrade, base course, surface course. The approximate transition lengths between test sections are indicated on the plan.

It is important to insure that the sampling areas are located in portions of the pavement that are constructed with the same materials and layer thicknesses as the adjacent monitoring portion and thus are representative of the test section. Therefore, 600 ft. long test sections are constructed with the same pavement structure and materials to allow for 500 ft. monitoring

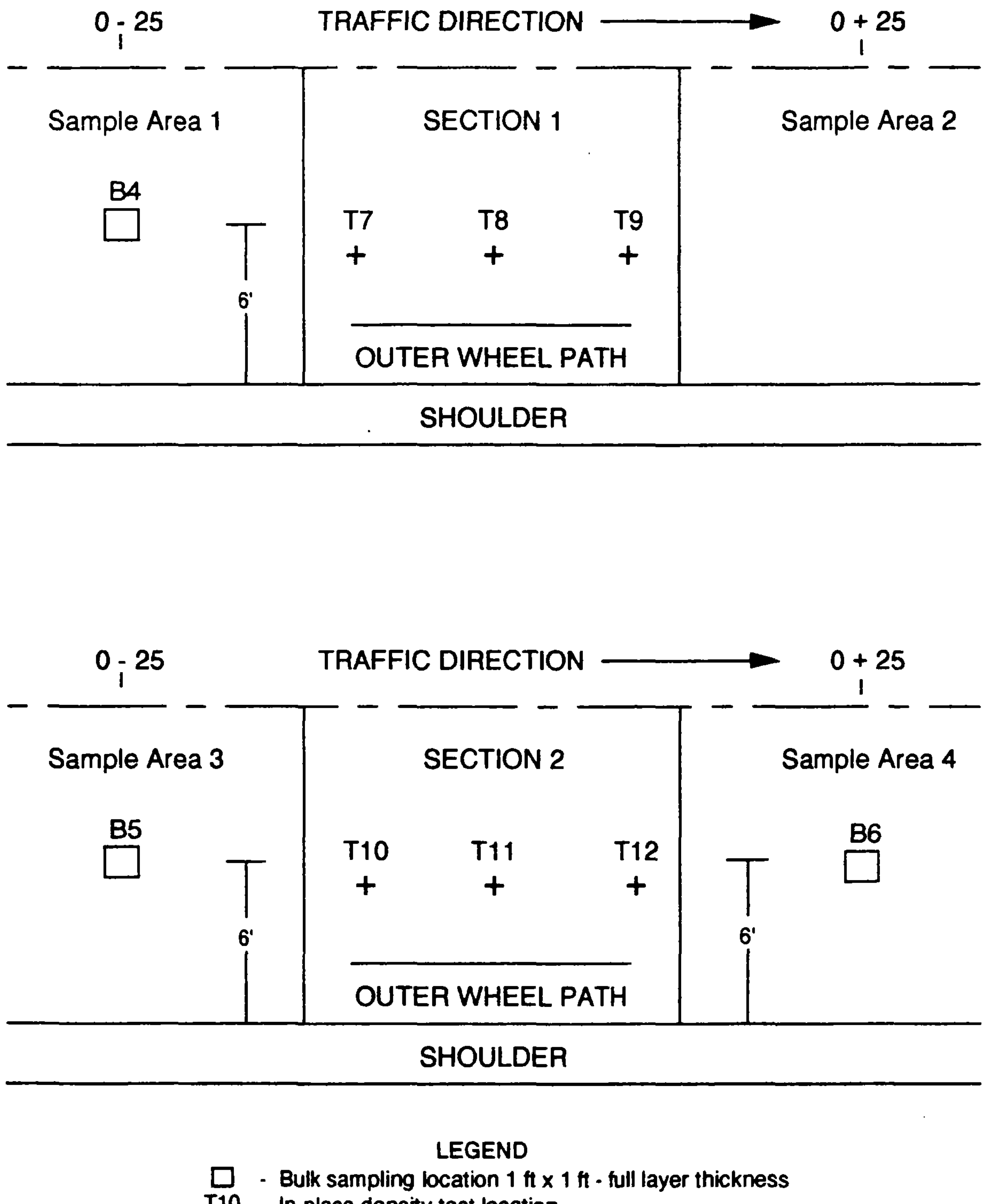


Figure 9. SPS-8 Field Sampling and Testing of Prepared Subgrade

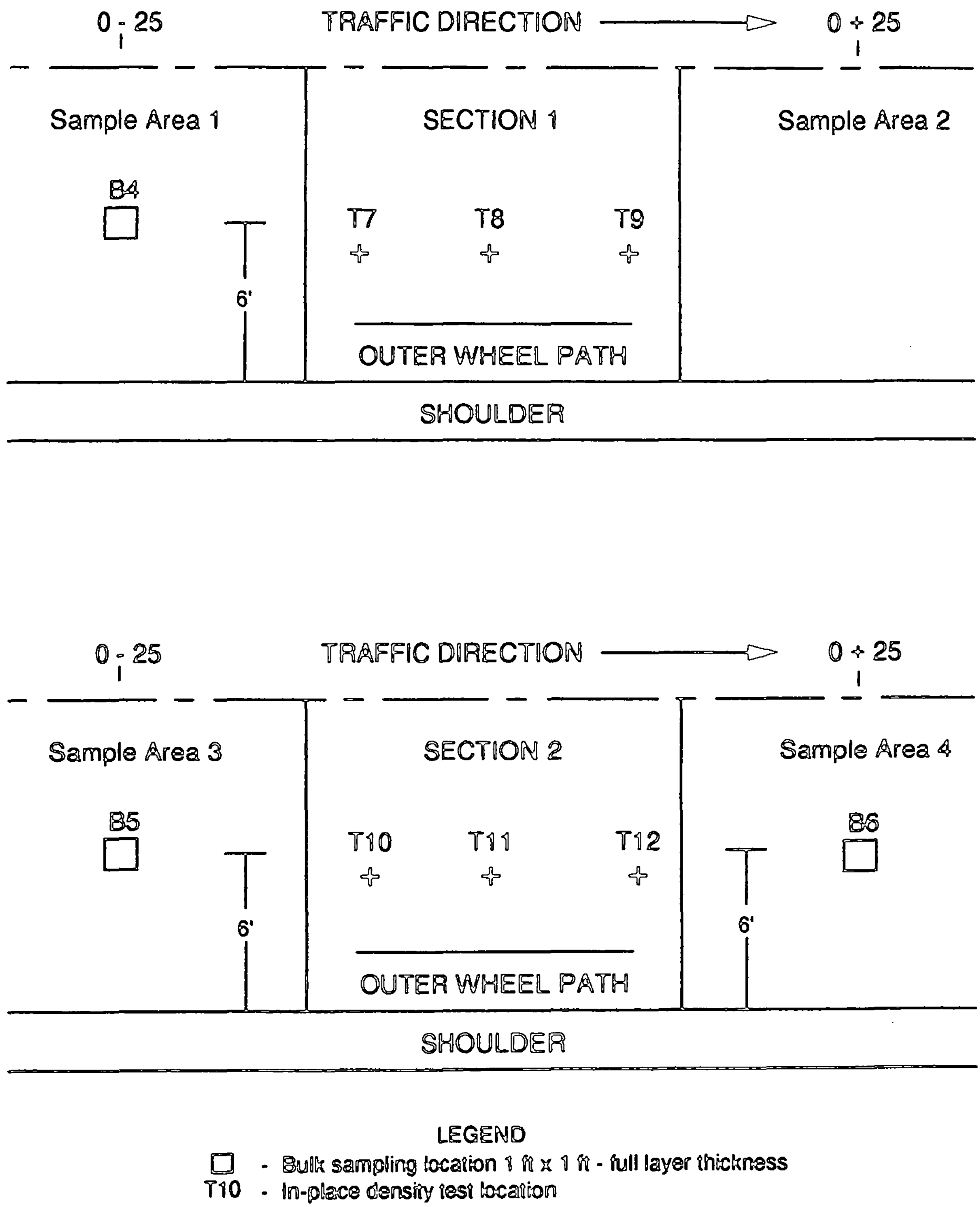


Figure 10. SPS-8 Field Sampling and Testing of Granular Base

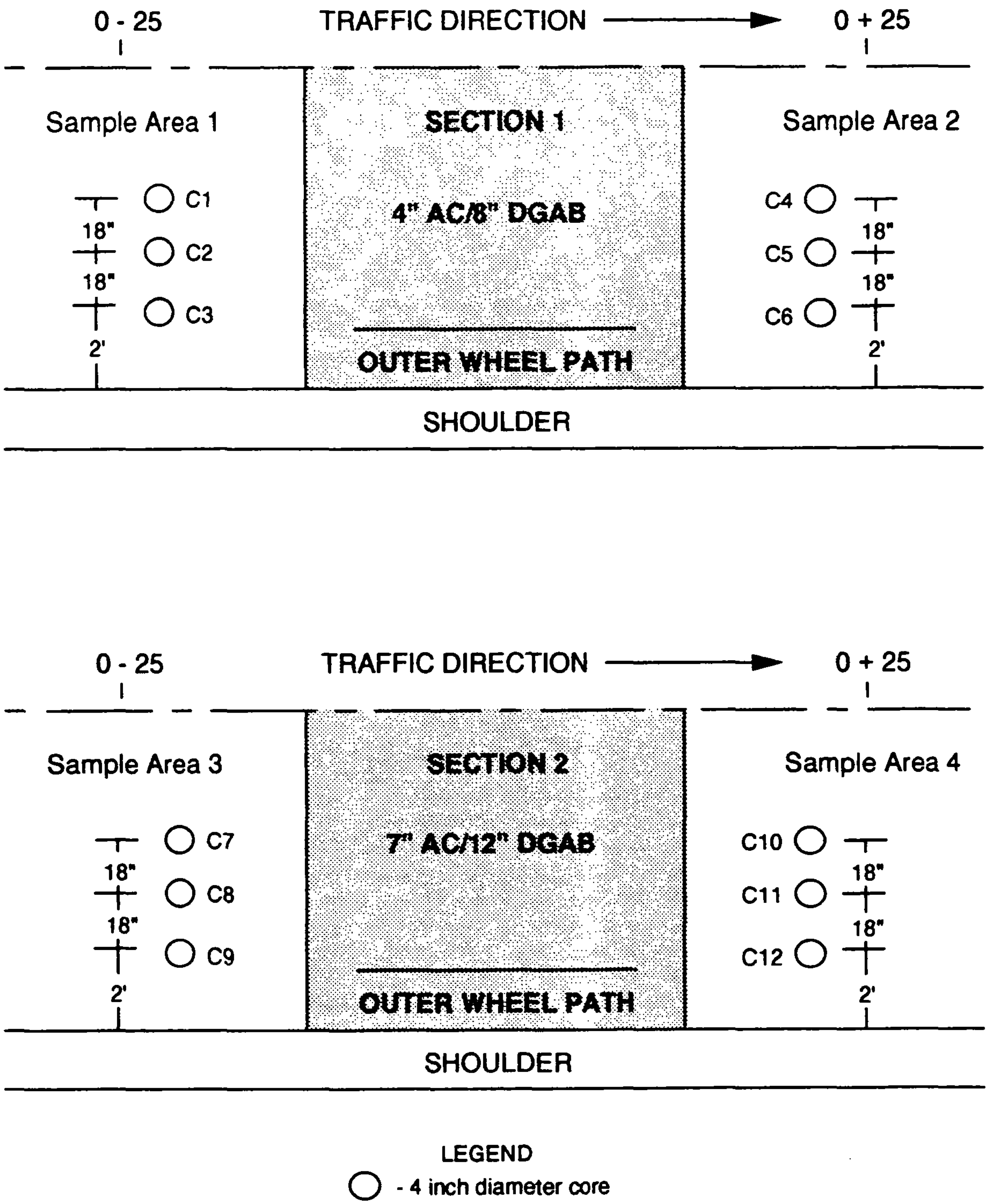


Figure 11. SPS-8 Field Sampling for the Surface Course

length and 50 ft. at each end for field sampling. The location and type of each sample is designated relative to the beginning and end of each test section.

To ensure consistency in data reporting, a layer numbering scheme is developed for each site when reporting data for the different pavement layers. In this scheme, each layer is designated by a number. The absence of a layer in a test section is be designated with a zero thickness.

Future Use

Participating agencies and FHWA will rely on the SPS sampling and testing plans in order to maintain consistency in the future.

Data Collection Guidelines for SPS Field Material Sampling

Data elements obtained as part of the field material sampling and testing activities for SPS experiments are classified in the following groups:

- Test Section Location Reference Table
- Construction Data
- Field Materials Sampling and Testing Data
- Laboratory Materials Testing Data

The data collection and reporting process for SPS test sites requires the completion of specific data sheets from the Data Collection Guide for Long-Term Pavement Performance Studies which were developed for GPS and additional data sheets developed specifically for SPS. The SPS project-specific data sheets address construction data and other aspects of the materials sampling and testing activities. Data collection guideline documents have been published for SPS-1, SPS-2, SPS-5, SPS-6, SPS-7, and SPS-8 (37,38,39,40,41,42).

Conduct of Field Material Sampling

The field material sampling and field testing activities provides pavement material samples for laboratory testing and will yield in-situ moisture and density data for each test site, density data for new asphalt concrete, air content of fresh concrete, depth to rigid layer, and modulus of subgrade reaction measurements. Field sampling and field testing operations are performed during the different phases of pavement construction to fully characterize the pavement structure in each test section.

For experiments on existing pavement structures typical samples will consists of a combination of the following:

- 4 in. OD cores of the pavement surface (asphaltic concrete surface and binder courses only or Portland cement concrete). These are designated on sampling plans as C-type cores and their locations are identified with small shaded circles.

- 4 in. OD cores of the pavement surface (asphalt concrete surface and binder courses or PCC), bound base layers and treated subbase layers. These are designated on sampling plans as C-type sampling areas also and their locations are identified with small unshaded circles.

- 6 in. OD cores of the pavement surface (asphaltic concrete surface and binder courses or PCC), bound base layers and treated subbase layers; augering of unstabilized base and subbase layers; thin-walled tube and/or split spoon sampling of subgrade layers to 4 ft. below the top of the untreated subgrade. These are designated on sampling plans as A-type sampling areas and their locations are identified with medium-sized unshaded circles

- 12 in. OD core of pavement surface courses, bound base layers and treated subbase layers; augering of unstabilized base, subbase and subgrade to 12 in. below the top of the untreated subgrade for bulk sample retrieval. These are designated on sampling plans as BA-type sampling areas and their locations are identified with large-sized unshaded circles with a single diagonal line crossing the circle.

- 6 ft. by 4 ft. test pit to a depth of 12 in. below the top of the untreated subgrade for collection of pavement slabs, bulk sampling of unstabilized layers and the subgrade and nuclear density and moisture measurements on unstabilized pavement layers and subgrade material. These are designated on sampling plans as TP-type sampling areas and their locations are identified with an unshaded square.

- 6 in. shoulder auger probes augered to a depth of 20 ft. through the shoulder to determine the depth to a rigid layer. These are designated on sampling plans as S-type sampling locations identified with a medium-sized unshaded circle with a bisecting "X." The purpose of the shoulder auger probe is to determine if bedrock or other significantly dense layers exist within 20 ft. of the pavement surface. This determination is extremely important for later analysis of deflection measurements. However, it is possible that under certain geological or construction conditions where rock occurs at very deep depths or deep fill areas are constructed, the need for shallow auger probes would not be warranted or justified. Maps from the United States Geological Survey (USGS) and the U.S. Department of Agriculture (USDA), county soil surveys, plus other information from soil borings for nearby bridges or other structures can be used to assess the need for this auger probe.

For the new construction experiments, layering is established prior to construction and sampling and testing is conducted as each layer is finished. Therefore guidelines for the

sampling and testing plan for the subgrade consists of the following (NOTE - some of these requirements are the same as for existing pavement structures):

- In general, bulk sampling areas should consist of a single shallow excavation, approximately 2x2 ft. and 12 ins. deep.

- Sampling locations, especially A-Type locations, should not be located in cut and fill transition areas. These sampling locations must always be located completely in either a cut or fill.

- Sampling areas should be located outside the monitoring portion of the test section but in areas which are considered representative of the test section.

- For a test section that is placed more than one mile away from another test section or group of test sections, sampling should include A-Type borings and at least one bulk sampling location.

- If a group of test sections is located more than a mile away from another localized group of test sections, each group shall be treated separately in determining sampling requirements.

- Sampling for supplemental test sections, such as those representing the agency's design practice, should be incorporated in the sampling and testing plan following the overall criteria established for the SPS experiment.

- Samples of embankment fill that are obtained as part of subgrade sampling should be clearly identified.

- Auger probes to a depth of 20 ft. through the shoulder should be included to determine the depth to a rigid layer. The purpose of the shoulder auger probe, designated as S-Type boring, is to determine if bedrock or other significantly dense layers exist within 20 ft. of the proposed pavement surface elevation. This information is extremely important for the analysis of deflection measurements. However, shallow auger probes would not be warranted at locations where rock is known to exist at very deep depths. Therefore, maps from the USGS and the USDA county soil surveys, and other information from soil borings for nearby bridges, pavement construction plans or other structures should be used to assess the need for these auger probes.

The test plan reflects the variation of the subgrade at a specific site. If there is a high degree of variability at the site, the number of bulk sampling locations as well as A-Type sampling locations is increased. Similarly, if the subgrade soil is relatively consistent, the number of sample locations may be reduced. The primary purpose of the plan is to characterize, as closely as possible, the integrity, physical properties and engineering behavior of the subgrade materials at the test site.

The sequence and frequency of field sampling and testing required for the base course depends on the base course material and its location within the pavement structure. Therefore, a different field sampling and test plan is required to characterize the properties of each of the base materials, such as dense-graded aggregate base (DGAB), lean concrete base (LCB), permeable asphalt treated base (PATB), and asphalt treated base (ATB) used in an experiment.

The field sampling and testing activities required to characterize the properties of a dense graded aggregate base material include the following:

- Bulk sampling of the uncompacted base material from B-Type sampling locations for laboratory testing
- Moisture and density testing throughout each test section
- Elevation measurements throughout each test section

The field sampling and testing activities required to characterize the properties of a permeable asphalt treated base material include the following:

- Bulk sampling of the uncompacted asphalt concrete material from the mix plant for laboratory testing
- Elevation measurements throughout each test section

The field sampling and testing activities required to characterize the properties of an asphalt treated base material include the following:

- Bulk sampling of the uncompacted asphalt concrete material from the mix plant for laboratory testing
- Density testing by nuclear methods throughout the test sections
- Elevation measurements throughout each test section

In addition, coring of the permeable asphalt treated and dense graded asphalt treated base is performed in conjunction with coring of an asphalt surface course to obtain samples for laboratory testing.

The field sampling and testing activities required to characterize the properties of an asphalt concrete surface course material include the following:

- Bulk sampling of the uncompacted mix from plant for laboratory testing
- Coring outside the monitoring portion of test sections to obtain samples of surface and underlying bound layers for laboratory testing
- Density testing by nuclear methods throughout test sections
- Elevation measurements throughout each test section

The field sampling and testing activities required to characterize the properties of Portland Cement Concrete materials include the following:

- Bulk samples of the fresh PCC. These are immediately formed into beams and cylinders for surface layers and cylinders only for lean concrete base materials.

Summary Statistics and Information

By the time the field materials characterization work for the SPS-1, -2, -5, 6, -7, and -8 experiments is complete, the estimated overall quantities will be as follows:

- 84 SPS sites sampled
- 7000 cores of AC and PCC retrieved
- 100 pavement test pits excavated
- 2500 nuclear density tests performed
- 165 tons of bulk sample removed.

Status of SPS-1, -2, -5, -6, -7, and -8 Materials Sampling and Testing

SPS field materials sampling and field testing will continue over the remainder of the LTPP program for as long as these projects are being built. Within the first five years of the LTPP program, approximately 10-15 projects will have been drilled and sampled. The guidelines developed for the SPS program will be followed for all of the remaining SPS sites as well.

SPS-3 and SPS-4 Field Sampling and Field Testing Plans

The purpose of the SPS-3 and SPS-4 studies was to develop a database which will permit increased understanding of selected maintenance treatments in extending pavement service life or reducing the evidence of pavement distress. This would include an evaluation of the effectiveness of the pavement maintenance treatments and establishment of a study methodology which can be followed by highway agencies in evaluation other maintenance treatments.

The study included six specific preventive treatments:

1. chip seals, thin overlays, slurry seals and crack sealing for flexible pavements
2. undersealing along with joint and crack sealing in rigid pavements

The study of these preventive treatments applied to flexible pavements has been designated SPS-3, and the study of preventive maintenance treatments applied to rigid pavements has been designated SPS-4.

Field Sampling, Testing, and Data Collection

There were four phases of field data testing, sampling, and data collection in addition to the standard condition monitoring. In the first phase, the initial conditions prior to treatment application were defined. This was a part of the site verification process. In the second, the materials to be used in the treatments were sampled. In the third, information was collected during the treatment application to determine the quality of the treatment process, including the materials being used at each site. In the fourth phase, tests were used to determine how the pavements change over time after treatment application.

SPS-3 Materials Sampling Prior to Construction

The first materials sampling occurred during the site verification process. During that period, the participating state/provincial agency provided the coring and drilling equipment to collect at least one 6-in. diameter core adjacent to each section and drill into the subgrade to identify the layer materials, layer thicknesses, and subgrade type. The Regional Coordinating Office Contractors (RCOC) were responsible for submitting cores to the LTPP Regional Testing Laboratory. The participating state or province assisted the RCOC by providing the equipment and crew to extract the core.

The core was acquired in accordance with the directions for the A-1 core of the Sampling Point Locations Before Test Section, GPS-1, Asphalt Concrete over Granular Base, Appendix F, of the LTPP Field Material Sampling and Field Testing Guide (5). Only the asphalt core was to be retained. The core hole was then used as the auger site to visually classify the base type and subgrade type. The hole was then filled in accordance with state/provincial requirements.

The cores were then marked, wrapped, packaged, and shipped in accordance with the SHRP-LTPP Field Material Sampling Guide requirements. The information concerning the field sampling, cores recovered, and classification of base and subgrade material was recorded in accordance with the LTPP Field Material Sampling and Field Testing Guide. The SHRP section ID number was the SPS-3 section ID number. The first core for each section was numbered CA01. If additional cores were taken, they were numbered CA02, etc. The Field Set was to be H to designate it as an H-101 core. The following sheets were required:

1. Field Material Sampling and Field Testing, Log of Bore Hole, Form S02, (to record base, subbase, and subgrade classification)

2. Field Material Sampling and Field Testing, Log of Pavement Core, (Only for Use at Bore Hole Locations), Form S01 (to record coring information)

The data from Forms S01 and S02 are then entered into the RPPDB. A copy of S01 was forwarded with the cores to the SHRP designated laboratory. The SHRP section testing number system for SPS-3 and -4 was provided to all RCOC's and Regional Engineers, as well as SHRP. Each sample was identified with the appropriate SPS section identification number.

SPS-3 Materials Acceptance Sampling

In each region, the RCOC travelled to the location of the materials sources, sampled the materials, packaged the materials and submitted the materials to the regional testing labs for appropriate testing.

All samples were to be marked, packaged, and shipped in accordance with the SHRP-LTPP Field Material Sampling and Field Testing Guide. They were accompanied by Form S06, Material Samples Inventory For Shipment To Laboratory. The sample location was designated SO01 when taken at the source at which the materials were produced. The crack sealant sample numbers were designated HC01 for H-101 crack sealing material. The aggregate sample numbers were designated HA01 for H-101 aggregate. The emulsified asphalt cement sample numbers were designated HE01 for H-101 emulsified asphalt cement. The sample material was designated AESL for emulsified asphalt for slurry seals and AECS for asphalt emulsions for the chip seal. The sample material was designated AGSL for aggregate for the slurry seal and AGCS for the aggregate for the chip seal. They were identified with the section identification number of the first section to be applied in the region when section identification numbers were required.

SPS-3 Construction Monitoring, Sampling and Field Tests

The RCOC collected the samples of the materials during the construction. These were then marked, packaged, and shipped to the regional testing lab in accordance with the SHRP-LTPP Field Material Sampling and Field Testing Guide (5). They were accompanied by Form S06, Material Samples Inventory For Shipment To Laboratory. The sample location was AD01 when taken from a distributor or slurry seal applicator. The sample location was TR01 when taken from a delivery truck. The crack sealant sample numbers were designated HC01 for H-101 crack sealing material. The aggregate sample numbers were designated HA01 for H-101 aggregate. The emulsified asphalt cement sample numbers were designated HE01 for H-101 emulsified asphalt cement. The sample material was designated AESL for emulsified asphalt for slurry seals and AECS for asphalt emulsions for the chip seal. The sample material was designated AGSL for aggregate for the slurry seal and AGCS for the aggregate for the chip seal. Slurry seal samples were defined as slurry seal. They were identified with the section identification number from which they were taken. When samples were taken other than in a section, they were identified with the section number of the next section to which they were to be applied. For the check samples, which are taken only once per state or province, the samples were taken at the first location in the state or province where the treatments were placed, and were identified with that section identification number.

Crack Sealing

To address the problem of changes in the material over time, a second set of material tests were conducted after approximately one half the sections in a region were completed.

Specification	Test Method SHRP	ASTM
Sampling	HF01	D 3405

Slurry Seals

Field check samples of the aggregate and emulsion were taken at each site. The total slurry seal mix was sampled once in each state or province.

Specification	Test Method SHRP	AASHTO
Emulsion	HF02	T 40
Aggregate	HF03	T 2
Slurry	HF08	

Chip Seals

Field check samples of both the aggregate and emulsion were taken.

Specification	Test Method SHRP	AASHTO
Emulsion	HF02	T 40
Aggregate	HF03	T 2

Measurements

The SHRP LTPP Regional Coordinating Office Contractor (RCOC) was responsible for monitoring the application process. A check list was prepared by the H-101 contractor. These checks included equipment calibration checks, temperature checks, distance measurements, area measurements, and other similar tasks.

Crack Sealing

The only physical measurements were the temperature of the air, temperature of the sealant, and width of cracks and sealant. Relative humidity was based on local weather information. Temperature of the sealant was based on the temperature gage on the sealant heating equipment.

Slurry Seals

The physical measurements included moisture content of the aggregate, ambient temperature and relative humidity. Relative humidity was based on local weather information. The application rate measurement was based on the equipment readings which varied with the type of machine.

	Test Method	
Specification	AASHTO/ASTM	SHRP
Application Rate		HF04
Aggregate Moisture	T 217	HF27

Chip Seals

The physical measurements included moisture content of the aggregate, ambient temperature and relative humidity. Relative humidity was based on local weather information. The emulsion application rate was based on measurements of the emulsified asphalt quantity in the distributor.

	Test Method	
Specification	AASHTO/ASTM	SHRP
Emulsion Apl. Rate		HF05
Aggregate Apl. Rate		HF06
Aggregate Moisture	T 217	HF27

Recording Data

All data were recorded on the appropriate data collection sheets and all data will subsequently be entered in the SHRP data base by RCOC personnel.

SPS-3 Materials Sampling After Construction

The final materials sampling occurred approximately two years after construction and will be repeated biennially until the section is removed from the study. The participating agency will provide the coring and drilling equipment to collect at least one 6 in. diameter core adjacent to each section. The Regional Coordinating Office Contractors (RCOC) will be responsible for submitting cores to the LTPP Regional Testing Laboratory. The participating state or province will assist the RCOC by providing the equipment and crew to extract the cores.

The cores will be taken in accordance with the directions for the A-1 core of the Sampling Point Locations Before Test Section, GPS-1, Asphalt Concrete over Granular Base, Appendix F, of the LTPP Field Material Sampling and Field Testing Guide, except that the core will be moved 2 ft. towards the test section location. Only the asphalt core will need to be retained. The hole will then be filled in accordance with state/province requirements.

The information concerning the field sampling and core will be recorded in accordance with the LTPP Field Material Sampling and Field Testing Guide. The following sheet will be required:

1. Field Material Sampling and Field Testing, Log of Pavement Core, (Only for Use at Bore Hole Locations), Form S01 (to record coring information).

The cores will be marked, wrapped, packaged, and shipped in accordance with the SHRP-LTPP Field Material Sampling Guide requirements.

SPS-4 Materials Sampling Prior to Construction

Assurance coring was part of the site verification process. The participating agency performed the coring in coordination with the SHRP RCOCs. Testing at the GPS site provided general confirmation of the pavement section for SPS-4. However, construction records were also reviewed to insure that there was no change in surface thickness. The participating agency provided the manpower and the coring and drilling equipment to acquire at least one 6 in. diameter core from the paved shoulder adjacent to each test section (NOTE - this requirement was waived at some locations). Drilling was extended into the subgrade and the material and thickness for each layer and the subgrade type were identified. Information concerning the field sampling, core, and classification of base and subgrade material was recorded in accordance with the LTPP Field Material Sampling and Field Testing Guide. The SHRP section ID number would be the SPS-4 section ID number. The following sheets were required:

1. Project Site Reports, Form S07
2. Field Material Sampling and Field Testing, Log of Bore Hole, Form S05

No laboratory testing was conducted on cores or materials obtained during verification sampling.

A distress survey was conducted within 90 days prior to application of the treatments. This and subsequent distress surveys were to include a measurement of faulting and edge drop off. FWD deflection and roughness testing were also conducted on the GPS and all SPS-4 sections prior to treatment applications and biennially thereafter. Standard loss of support testing for underseal sections was conducted using the Benkelman Beam (Field Protocol H32F) to determine which joints and cracks to underseal.

SPS-4 Materials Acceptance Sampling

The RCOC was able to assist with material sampling when enough advance coordination was provided. Either the participating agency or RCOC sampled, packaged, and submitted the joint and crack sealant material samples to Western Technologies, Phoenix, Arizona for testing. Joint and crack sealant sampling was required for each lot purchased. Sampling requirements for ASTM D 3405 liquid sealant and silicone sealant were specified in SHRP protocols H33F and H34F respectively.

All joint and crack sealant samples were marked, packaged, and shipped in accordance with the SHRP-LTPP Field Material Sampling and Field Testing Guide (5). They were accompanied by Form S06, Material Samples Inventory for Shipment to Laboratory. Sample locations were designated SO01 when they are taken at the source at which the materials were produced. Joint and crack sealant sample numbers were designated HC01 for H-101 joint and crack sealing material. The joint and crack sealant materials were designated CKSL for the ASTM D 3405 and CKSS for the silicone. Sample material was identified with the section identification number when section identification numbers were required.

SPS-4 Construction Monitoring Sampling and Field Tests

The participating agency was responsible for completing the quality assurance and construction monitoring checklist. The appropriate data collection sheets were provided. General items to be monitored included initial deflection tests, stability tests, equipment calibration, material volumes, locations, temperatures and other similar tasks.

Specific data required for joint and crack sealing activities included air temperature, relative humidity, temperature of the sealant, width of joint and cracks, depth of sealant below pavement surface, depth of backer rod, application pressure, and thickness of sealant. Relative humidity was based on local weather information. Temperature of the ASTM D3405 sealant was based on the calibrated temperature gage on the sealant heating equipment.

Required undersealing data included deflection measurements, air temperature, relative humidity, fluidity of the grout (Field Protocol H35F), volume of the grout pumped per hole, hole pattern distances, depth of holes, amount of materials, and pumping pressure. Relative humidity was based on local weather information.

SPS-4 Special Testing After Construction

A distress survey will be undertaken six months after application, one year after application, and on an annual basis thereafter. Initial and subsequent condition surveys are to include measurements of faulting and edge drop off. It has been requested that the deflection testing be conducted on the SPS-4 test sections biennially. Deflection testing of the underseal section should include Benkelman Beam testing (Field Protocol H32F) in addition to FWD testing (Field Protocol H30F) using the SPS-4 testing plan for these devices.

Laboratory Materials Handling and Testing

Introduction

In July 1987 an ETG was appointed to provide guidance, direction and oversight for SHRP's LTPP laboratory material testing efforts. A representative group of knowledgeable materials engineers was appointed from State DOT's, universities and the private sector. The group was chosen with a wide geographic distribution (i.e. representatives from the northeast, southern, central and western states) and age distribution (i.e. 30's - 60's). One of the first tasks of the ETG was to nominate likely materials tests that could serve the objectives of SHRP's LTPP program. Using the cited rules (see pages 6 and 7) along with several iterations of rating and ranking, and the reality of certain imposed budget constraints for the testing effort, an array of tests was selected (and others eliminated) that could best serve the LTPP needs within identified budgetary constraints. The final selected tests for the GPS sites (4) are presented in Table 5.

A somewhat different procedure was followed in establishing the materials sampling and testing program for SPS. Experts in the materials field were asked to identify appropriate materials characterization tests for each SPS experiment. The final selection of SPS materials tests was developed from recommendations by the expert group and technical assistance contractors is shown in Table 6. This section documents the intensive efforts to develop and initiate the LTPP laboratory materials characterization program and to share the lessons learned over the course of the first five years of LTPP.

GPS Laboratory Materials Handling and Testing

Organizational Structure

As illustrated in Figure 12, a number of people were involved in the LTPP GPS laboratory materials operations. Efficient and timely conduct of the laboratory materials testing operation required a clear understanding of the administrative, supervisory and operational responsibilities of the various personnel. The organizational structure is similar to that of the GPS field materials sampling and testing program.

Table 5. Laboratory Materials Characterization Tests for GPS

SHRP Protocol	Laboratory Test Title
	ASPHALTIC CONCRETE
P01	Core Examination and Thickness
P02	Determination of Bulk Specific Gravity
P03	Determination of Maximum Specific Gravity
P04	Determination of Asphalt Content (Extraction)
P07	Determination of the Resilient Modulus
	EXTRACTED AGGREGATE
P14	Gradation of Aggregate
P14A	Fine Aggregate Particle Shape Test
	TREATED BASE/SUBBASE MATERIALS
P31	Type and Classification of Materials and Type of Treatment
P32	Unconfined Compressive Strength of Treated Base/Subbase
P33	Determination of Dynamic Modulus of Treated Base/Subbase
	UNBOUND GRANULAR BASE/SUBBASE AND SUBGRADE
P41	Particle Size of Granular Base/Subbase
P41	Sieve Analysis (Washed) of Granular Base/Subbase
P42	Hydrometer Analysis (to 0.001 mm)
P43	Determination of Atterberg Limits
P44	Moisture/Density Relations
P46	Determination of Resilient Modulus
P47	Classification of Granular Base/Subbase
P49	Determination of the Natural Moisture Content
P51	Sieve Analysis of Subgrade Soils
P51A	Dry Sieve Analysis of Subgrade Soils
P52	Classification/Type of Subgrade Soils
P55	Moisture-Density Relations
	PORTLAND CEMENT CONCRETE
P61	Determination of the Compressive Strength of In-Place Concrete
P62	Determination of the Splitting Tensile Strength of In-Place Concrete
P64	Determination of the Static Elastic Modulus of In-Place Concrete
P66	Visual Examination and Length Measurement of PCC Cores

Table 6. Laboratory Materials Characterization Tests for SPS

SHRP Protocol	Laboratory Test Title	SHRP Test Designation(1)
	ASPHALTIC CONCRETE	
P01	Core Examination and Thickness	AC01
P02	Determination of Bulk Specific Gravity	AC02
P03	Determination of Maximum Specific Gravity	AC03
P04	Determination of Asphalt Content (Extraction)	AC04
P05	Moisture Susceptibility	AC05
P06	Creep Compliance	AC06
P07	Determination of the Resilient Modulus	AC07
	EXTRACTED AGGREGATE	
P11	Specific Gravity of Coarse Aggregate	AG01
P12	Specific Gravity of Fine Aggregate	AG02
P14	Gradation of Aggregate	AG04
P14A(3)	Fine Aggregate Particle Shape Test	AG05
	ASPHALT CEMENT	
P21	Abson Recovery	AE01
P22	Penetration at 77 °F and 115 °F	AE02
P23	Specific Gravity at 60 °F	AE03
P24	Viscosity at 77 °F	AE04
P25	Viscosity at 140 °F and 275 °F	AE05
	TREATED BASE/SUBBASE MATERIALS	
P31	Type and Classification of Material and Type of Treatment	TB01
P32	Unconfined Compressive Strength of Treated Base/Subbase	TB02
P33	Determination of Resilient Modulus of Treated Base/Subbase	TB03
	UNBOUND GRANULAR BASE/SUBBASE AND SUBGRADE	
P41	Particle Size of Granular Base/Subbase	UG01
P41	Sieve Analysis (Washed) of Granular Base/Subbase	UG02
P42	Hydrometer Analysis (to 0.001 mm)	SS02
P43	Determination of Atterberg Limits	UG04, SS03
P44	Moisture/Density Relations	UG05
P46	Determination of Resilient Modulus	UG07, SS07

Table 6. Laboratory Materials Characterization Tests for SPS (Continued)

SHRP Protocol	Laboratory Test Title	SHRP Test Designation(1)
	UNBOUND GRANULAR BASE/SUBBASE AND SUBGRADE (CONTINUED)	
P47	Classification of Granular Base/Subbase	UG08
P48	Permeability of Granular Base/Subbase	UG09
P49	Determination of the Natural Moisture Content	UG10, SS09
P51	Sieve Analysis of Subgrade Soils	SS01
P51A	Dry Sieve Analysis of Subgrade Soils	SS01
P52	Classification/Type of Subgrade Soils	SS04
P54	Unconfined Compressive Strength of Subgrade Soils	SS10
P55	Moisture-Density Relations	SS05
P56	Density of Subgrade Soils	SS08
P57	Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter	SS11
	PORTLAND CEMENT CONCRETE	
P61	Determination of the Compressive Strength of In-Place Concrete	PC01
P62	Determination of the Splitting Tensile Strength of In-Place Concrete	PC02
P63	Coefficient of Thermal Expansion	PC03
P64	Determination of the Static Elastic Modulus of In-Place Concrete	PC04
P65	Density of PCC	PC05
P66	Visual Examination and Length Measurement of PCC Cores	PC06
P67	Interface Bond Strength	PC07
P68	Air Content of Hardened Concrete	PC08
P69	Flexural Strength	PC09

NOTE: (1) Explanation of SHRP Test Designation Numbers
AC -- Asphaltic Concrete
AG -- Extracted Aggregate from Asphalt Concrete
AE -- Asphalt Cement
TB -- Treated (Bound/Stabilized) Base/Subbase
UG -- Unbound Granular Base/Subbase
SS -- Subgrade Soil
PC -- Portland Cement Concrete

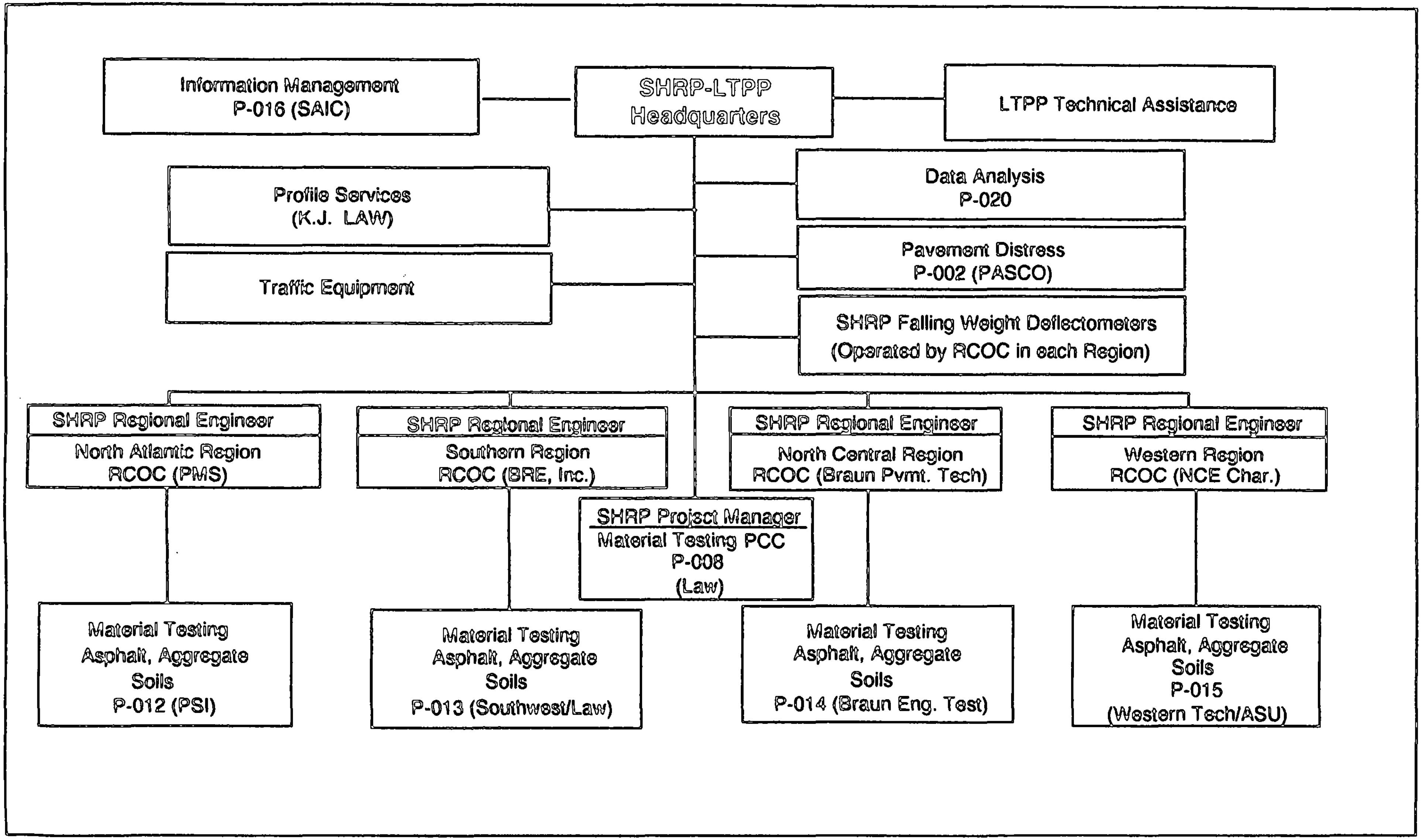


Figure 12. Agencies Involved in LTPP GPS Laboratory Operations

The SHRP Regional Engineer (SRE) was responsible for administration and management of all SHRP contracts in his region including the contract for the laboratory materials testing. He also provided coordination between the various regional contractors, state highway departments and technical assistance contractors. He also resolved questions and concerns that arose during the day-to-day operations of the laboratory materials testing program. The SRE was also responsible for supervision and approval of the SHRP Regional Coordination Contractor staff.

The SHRP Regional Engineer and RCOC provide coordination between the Regional Laboratory Materials Testing Contractor and the Regional Drilling and Sampling Contractor. The SHRP Regional Engineer and the designated RCOC staff worked with the Regional Laboratory Materials Testing Contractor to assure effective, efficient and safe operations in the materials laboratory at all times. The RCOC also works jointly with the SHRP Regional Engineer to insure data integrity and quality assurance throughout the laboratory testing program. Specific responsibilities included: checking field data packets for completeness and accuracy, transmitting incorrect field sampling data packets to the Regional Drilling and Sampling Contractor for correction, direct contact with the Regional Laboratory Material Testing Contractor to 1) resolve inconsistencies in the field sampling data packet, 2) approve pavement layering information and laboratory test assignments, and 3) perform other quality assurance checks.

The SHRP Project Manager for the Laboratory PCC Testing Contractor also worked in close coordination with the respective SHRP Regional engineers and the designated RCOC staff for 1) approval of laboratory test assignments and layering information, 2) approval of laboratory test data, and 3) implementation of quality assurance checks.

Frequent coordination occurred between the laboratory chief, other Regional Laboratory Material Contractor staff, the designated RCOC staff and the SHRP Regional Engineer. Comprehensive, continuing coordination was an essential element of the laboratory materials testing program.

Development of Technical Provisions

Development of the laboratory material testing technical provisions was undertaken over a period of time beginning in May 1986, with the issuance of the final SHRP Research Plans Report (**9**) and the June 1987, Data Collection Guide (**10**). Further development occurred in 1987 with the Draft Material Sampling and Testing Guide which proposed the laboratory materials testing plans of the SHRP GPS program. Based on a review of this documentation and with information concerning the proposed number of pavement test sections and the typical pavement layer types and thicknesses, the Technical Provisions were developed (**13,43,44**) and issued on May 6, 1988.

The technical provisions were based on a review of overall LTPP objectives, published test methods (AASHTO, ASTM, etc.) research on unit prices, consideration of needs of LTPP, review of information concerning the required number of laboratory tests for various levels of

reliability based on the probable variability of pavement materials. Some of the tasks performed were:

- develop assumptions, considerations and rationale for the laboratory testing requirements
- development of sampling plans for each GPS experiment showing the proposed types and numbers of laboratory materials tests
- preparation of assumed typical sections and field layout plans
- acquiring and analyzing unit prices for laboratory materials tests from laboratories across the United States
- development of cost summaries by experiment and SHRP region
- analyzing cost implications for different levels of laboratory testing
- development of concepts for the Program Announcements/RFQ's and laboratory testing contracts

These documents, entitled "Technical Provisions and Fee Schedules for Laboratory Testing of Soils and Bituminous Materials" (May 6, 1988) (43) and "Technical Provisions and Fee Schedules for Laboratory Testing of Portland Cement Concrete Pavement Materials" (May 6, 1988)" (44) along with the Program Announcement (June 1988) (13) were used by prospective laboratory materials testing contractors in submitting their proposals and bid prices to perform the required work. After receipt and processing of the proposals, the ETG members for laboratory materials testing independently rated and ranked the proposal. As in the field material sampling and testing work, the materials ETG was in general agreement as to the number 1 and 2 proposers for each of SHRP's four regions and the national PCC contractor. Contract awards were made on the basis of the summarized ETG recommendations, SHRP Executive Committee endorsement, negotiations with the Number 1 and Number 2 proposers and other standard requirements of SHRP. The contracts were awarded for each region and the National PCC testing contractor in the latter part of 1988 and in early 1989 as follows:

SHRP REGION	Laboratory Testing Contractor
North Atlantic	Professional Service Industries, Inc.
Southern	Joint Venture: Law Engineering Southwestern Laboratories
North Central	Braun Intertec Engineering, Inc.
Western	Western Technologies, Inc. Subcontractor: Arizona State University
All Regions	Law Engineering (all testing on portland cement concrete)

Following the award of these GPS testing contracts, an analysis of the total anticipated expenditures revealed large potential overruns of the budgeted amounts for the work. No other funds were available nor was the reallocation of funds deemed feasible. Therefore, a decision was reached to reduce the overall scope of the LTPP materials testing program. The service of the ETG for materials was again enlisted to provide guidance and to develop recommendations concerning possible reductions in the contracts. A questionnaire was developed listing all the planned tests and requesting the ETG members to independently rate the individual tests as "essential," "desirable," and "candidate for elimination." The ETG members were also asked to provide the rationales for their selections. Here again there was a very good consensus among the ETG members. They voted to eliminate the asphalt cement tests including abson recovery, viscosity, penetration and ductility. The rationale provided by the members indicated that these tests were of limited value in characterizing the properties of asphalt cements extracted from the typically older (7-15 years) in-service pavements being studied in the GPS experiments. Several other tests were voted as "candidates for elimination" on the basis that they were too empirical and did not characterize the basic properties of the material (i.e., CBR) or were not very relevant for aged AC materials (i.e., moisture susceptibility and creep).

The ETG recommendations were summarized by SHRP staff and presented to the LTPP Advisory Committee. This committee endorsed the recommendations and instructed SHRP staff to take immediate action to eliminate the selected tests from the original suite of tests to be performed on the GPS samples. As directed, the aforementioned tests were eliminated thereby bringing the anticipated expenditures more closely in line with the available budget (**4**).

Laboratory Materials Testing Guide

As was provided for the drilling and sampling operations, SHRP developed a comprehensive, detailed guide for materials testing. The guide entitled, "SHRP-LTPP Interim Guide for Laboratory Material Handling and Testing (PCC, Bituminous Materials, Aggregates and Soils)," (**45**) was first issued in November 1989, subsequently revised in February 1991, and finalized in August 1992. The guide gives very specific instructions regarding sample handling, storage, testing, reporting, and sample discarding. The guide consists of six sections and 12 appendices; approximately 1200 pages in all. This guide was organized as follows:

Section 1	Introduction
Section 2	Field Sampling and Laboratory Testing Operations
Section 3	Lab Testing of Bituminous Materials, Aggregates and Soils
Section 4	Lab Testing of Portland Cement Concrete
Section 5	Verification and Payment
Section 6	Laboratory Test Data Quality
Appendix A	Organizations and Personnel Contact Names
Appendix B.1	Lab Testing Program by GPS Experiment Type
Appendix B.2	Lab Testing Program by SPS Experiment Type
Appendix C.1	SHRP Standard Forms for GPS Laboratory Testing

Appendix C.2	SHRP Standard Forms for SPS 1,2,5,6,7,and 8 Laboratory Testing
Appendix C.3	SHRP Standard Forms for SPS-3 and SPS-4 Laboratory Testing
Appendix D	SHRP Terminology for Pavement Materials and Soils
Appendix E.1	SHRP Protocols for GPS Laboratory Testing
Appendix E.2	SHRP Protocols for SPS 1,2,5,6,7,and 8 Laboratory Testing
Appendix E.3	SHRP Protocols for SPS-3 and SPS-4 Laboratory Testing
Appendix F	GPS Field Sampling Plans
Appendix G	Laboratory Tracking Tables for the GPS Experiments

Each of these sections and appendices was considered necessary for the successful understanding and completion of the laboratory materials testing operations.

Section 1 of the Laboratory materials Testing Guide provides general organizational and coordination descriptions as well as an overview of the LTPP study. Field sampling and laboratory testing operations are described in Section 2. Section 2 also contains general descriptions of sample handling and record keeping as well as a description of laboratory test assignments. Section 3, one of the largest portions of the guide, contains detailed instructions and sample handling procedures for the testing of asphalt concrete (bituminous materials), aggregates and soils. This includes guidelines concerning initiation of testing, and directions concerning pavement layer summaries. Section 4 of the guide is similar to Section 3 in that it contains detailed instructions for the testing of portland cement concrete.

Section 5 of the laboratory testing guide, entitled, "Verification and Payment," provides guidelines which describe the conditions for payment of the laboratory testing contractors. this is primarily an administrative section of the guide and is useful for general information purposes. SHRP requires consistent, high quality, laboratory testing operations. To further this goal, Section 6 of the guide provided all participants with QA/QC assignments, methods with which to conduct the QA/QC program and a detailed discussion of SHRP requirements in this regard. This QA/QC section provided a methodology for the review, assessment and corrective action needed for all laboratory material testing activities.

The appendices contained in the Laboratory Material Testing Guide contain many useful items. Appendix A provides a list of all pertinent contact names and organizations involved in the LTPP program. This primarily included SHRP staff and SHRP contractors. Detailed materials testing plans and an overview of the GPS testing program is contained in Appendix B.1. Similarly, Appendix B.2 contains detailed laboratory testing plans for the SPS experiments.

Another critical element of the laboratory testing operations was the completion of data reporting forms. Appendix C.1 contains standard forms and instructions for completing the forms for the GPS pavements. In similar fashion, Appendices C.2 and C.3 contain laboratory testing reporting forms for the SPS projects. Appendix D contains SHRP standard terminology for the laboratory testing operations. This includes, for example, the definitions for fine and coarse aggregate as well as definitions for approximately four hundred other terms related to the SHRP materials characterization program.

One of the most important facets of the lab guide was the standardization of the test procedures which were used to conduct each laboratory test. These protocols outlined step-by-step instructions for each test procedure and included sections concerning sample handling and data reporting and other information related to SHRP needs (i.e., sample identification and location). This type of standardization was paramount to obtaining accurate, useable test data. These protocols are contained in Appendix E.1 (GPS), E.2 (SPS 1,2,5,6,7 and 8) and E.3 (SPS 3 and 4) of the Laboratory Material Testing Guide.

In order to provide the laboratory materials testing contractor with an overall view of the field sampling and testing process, Appendix F of the Guide presents an example field data packet which the laboratory could expect to receive from the drilling and sampling contractor. Finally, Appendix G of the Laboratory Material Testing Guide contains laboratory tracking tables for use by the contract laboratories. The tracking tables are based on the location numbers of the samples received from the field. Each sample is assigned a particular testing sequence and this testing sequence is used by the laboratory to define the testing of each specimen. Using these tracking tables, the laboratories were able to track each sample through the laboratory material testing program in a step-by-step manner.

There are several important items to remember when reviewing the laboratory materials testing Guide. The testing guide was initially and primarily developed for the GPS testing program. Sections concerning the SPS materials testing program were added at a later date. However, the materials testing program for the SPS experiments utilizes the same principles as the GPS program and the guide is very useful for SPS laboratory materials testing purposes. Other documents, as identified in subsequent sections of this report, contain more detailed SPS laboratory material testing plans than are available in the SHRP-LTPP Guide for Laboratory Material Handling Testing.

Protocol Development

All of the protocols developed for the SHRP-LTPP GPS testing program were prepared by an expert in the field of materials or a group of experts for the more complicated test procedures (i.e. resilient modulus). Development started in late 1988 and continued through 1992. The bulk of materials tests however, were completed in November 1989 and the associated protocols were issued with Version 1.0 of the SHRP-LTPP Guide for Laboratory Material handling and Testing. After that time, SHRP instituted a series of Materials Directives which were used to update the testing protocols in-between revisions to the Laboratory Material Testing Guide. Final development of all protocols was completed in September 1992 with the issuance of the latest version of the Laboratory Testing Guide.

Future Use

The Laboratory Materials Testing Guide is an instrumental tool in the materials characterization testing program for both the GPS and SPS experiments. In the future, this guide can be used by other organizations who wish to perform a similar laboratory testing

program. Additionally, this guide will undoubtedly be used extensively in the SPS program for many years to come.

The laboratory material testing guide was provided to SHRP Regional Engineers, RCOC's, the laboratory materials testing contractors and others. In effect, the Guide served as the control for the laboratory materials testing program. This guide represents the definitive source of information on the methodology used by SHRP in conducting laboratory materials testing operations (4).

Conduct of Laboratory Material Testing

Each SHRP region conducted their laboratory material handling and testing operations under different schedules and with different laboratory materials testing contractors. However, through the use of the SHRP-LTPP Guide for Laboratory Material Handling and Testing, the quality of testing and specimen handling was consistent and provided similar results. As previously stated, the laboratory materials testing program was a study in coordination and scheduling. Vast amounts of material were delivered to and tested by each laboratory. These laboratory specimens were subjected to a complex process of sample receiving, handling, testing and reporting. Laboratory materials testing operations began in late 1989 and continued through the end of 1991. Presently, only the resilient modulus testing (Protocols P07 and P46) remains to be completed for the GPS program. All other GPS testing was completed in mid-1993.

The regional laboratory materials handling and testing contractors are under the operational control of the SHRP Regional Engineer. In all four SHRP regions, a person from the Regional Coordination Office Contractor (RCOC) staff was designated to oversee and coordinate the laboratory operations for the region. This person was responsible for checking the data produced from the laboratory and general tracking of testing progress. A solid working relationship between this person and the laboratory materials testing contractor was essential to ensure accurate, thorough, and comprehensive materials testing data.

PCC Laboratory Material Testing

The National Laboratory PCC Testing Contractor was under the supervision of the SHRP contract manager in Washington, D.C. This laboratory conducted the testing for all portland cement concrete pavement layers. All other cement-treated materials (including econocrete, lean concrete, cement-aggregate, etc.) were tested by the Regional Bituminous Laboratory. Portland cement concrete testing was conducted by Law Engineering in Atlanta, Georgia.

The laboratory testing contractors were required to conduct and report their laboratory activities in the following sequence:

1. complete sample receipt reports
2. assign PCC laboratory test assignments

3. perform visual examination and thickness of PCC core testing (Protocol P66)
4. perform other PCC testing (compressive strength - Protocol P61), splitting tensile strength (P62), elastic modulus (P64)
5. submit data reporting forms and sample disposal logs to the PCC contract manager

The laboratory PCC Testing Contractor prepared a laboratory test assignment sheet using SHRP standard forms and submitted this form to the contract manager. These forms included such information as section I.D. numbers, specimen numbers, tests to be performed on each specimen and the condition of each test specimen. After receiving approval of Form L04, the laboratory proceeded with the remainder of testing beginning with the core examination and thickness test.

The PCC testing contractor followed precise specimen tracking tables which provided them with the following information and direction:

(a) Tracking of samples as they are taken from the field and tested in the laboratory
(b) Assignment of laboratory test numbers
(c) Laboratory test sequence for PCC pavement cores
(d) Dedicated specimen(s) for each test
(e) Designation of substitute specimens for appropriate laboratory tests
(f) Designation of extra specimens for future use
(g) Instructions for specimen storage
(h) Instructions for specimen disposal
(i) Special instructions and other remarks

Using these tracking tables, the contractor was able to trace each specimen through the Laboratory Materials Testing Program in a step-by-step manner. These tracking tables are presented in Appendix G of the Laboratory Material Testing Guide.

Table 7 contains a list of the laboratory tests and designated specimens required on PCC pavement cores by the laboratory PCC Testing Contractor.

Overall, the laboratory PCC testing program was undertaken smoothly and efficiently for the GPS testing program. All GPS PCC testing has been completed and results entered in the NPPDB.

Bituminous Treated and Unbound Materials Testing

The laboratory material testing for the entire GPS program (except PCC) was divided between four laboratory material testing contractors as identified in a previous section of this document. This testing consisted of laboratory tests for asphalt concrete, extracted aggregate from the asphalt concrete, bound base, subbase, subgrade and unbound granular

Table 7. PCC Laboratory Tests Required for GPS Pavements

Tests Per PCC Layer	Protocols	Sample Locations GPS-3, GPS-4 GPS-5, GPS-9	GPS-7
PC01. Compressive Strength	P61	C2, C8	C8, C20
PC02. Splitting Tensile Strength	P62	C5 (or C6)	C11 (or C12)
PC04. Static Elastic Modulus	P64	C1, C7	C7, C19
PC06. Visual Examination and Thickness	P66	C1, C2 C5 (or C6) C7, C8, C11 (or C12)	C7, C8 C11 (or C12) C19, C20 C23 (or C24)

PCC Cores from A1 and A2 locations are 6 inches in diameter. The diameters of PCC cores from C-type locations by GPS experiment are tabulated below.

GPS Experiment	Locations of 4-inch Diameter Cores	Locations of 6-inch Diameter Cores
GPS-3	C1 to C4, C7 to C10	C5, C6, C11, C12
GPS-4	C1 to C4, C7 to C10	C5, C6, C11, C12
GPS-5	C1 to C6, C7 to C12	---
GPS-7	C6 to C10, C18 to C22	C11, C12, C13, C14
GPS-9	C1 to C4, C7 to C10	C5, C6, C11, C12

base/subbase/subgrade materials. Appendix B of the Laboratory Materials Testing Guide outlines the complete laboratory material testing program by GPS experiment type.

To ensure consistency, uniform data and quality control in the laboratory materials testing process, each regional laboratory conformed to the set of SHRP laboratory testing protocols and all procedures contained in the Laboratory Testing Guide. The regional laboratories were required to keep close coordination with the SHRP Regional Engineers and RCOC from the time of receiving the samples from the field to final disposal of the materials. Timely transmission of information between the laboratory testing contractor and SHRP was achieved through the use of standard guidelines and forms contained in the testing guide. In addition, SHRP prepared standard definitions with which to describe the pavement materials.

Sample Receipt and Processing

The drilling and sampling contractor shipped the samples obtained from the field directly to the laboratory materials testing contractor along with a complete copy of the field data reporting sheets for each SHRP pavement section. Among other things, this data packet contained an inventory of the material samples shipped and the pavement layer numbers assigned in the field (field layer numbers).

Upon receipt of the samples, the samples were inspected by the Laboratory Chief for completeness of the shipment. They were inspected for damage, contamination, quantity and proper identification. The samples were subsequently logged in by the testing contractor. Various forms were completed to document the number, condition and planned laboratory testing for each sample. These forms were then approved by the SHRP Regional Engineer prior to initiation of testing. After the sample receipt process was completed, the samples were appropriately stored prior to further testing.

One of the more critical goals of the SHRP materials characterization program was the establishment of pavement structure layering for each test section. The pavement structure was initially established by the laboratory after completion of the sample receipt process. Pavement structures, layer descriptions and layer types were established early on in the laboratory testing process and refined at the completion of the laboratory testing activities. After the completion of this process, the appropriate forms were submitted to the SHRP Regional Engineer for review and approval. After this step, the laboratory began testing the pavement materials. A typical pavement structure and testing program for a flexible and rigid pavement are illustrated in Figures 13 and 14 respectively.

General Laboratory Testing

The regional soils and bituminous laboratory materials testing contractors completed testing on the following materials:

(b) GPS-2 Pavement over Other than Asphalt Treated Base (OTB)

Material Type and Code Based on Inventory Data	GPS-2 Selection Criteria	Example of LTPP Field Material Sample Data: Field Layer No.	Example of LTPP Field Material Sample Data: Material Code	Example of LTPP Laboratory Layering Information: Lab Layer No.	Example of LTPP Laboratory Layering Information: Material Code	Regional Laboratory Material Tests
Thin seal layer (71,72,73)	With or Without Seal Coat or Porous Friction Course			6 ☆	AC(700)	AC01,AC02,AC03,AC04,AC07,AG04
Dense-graded HMAC surface (01)	Dense-graded HMAC surface	4	AC(700)	5 ☆	AC (700)	AC01,AC02,AC03,AC04,AC07,AG04
Dense-graded HMAC (28)	None, one or more Dense-graded HMAC Layers			4 ☆	AC (700)	AC01,AC07
Bound Base (27 to 39, 42, 43, 44, 46)	Bound Base (Two or more lifts of same mixture considered as one layer)	3	Cement Aggregate Mixture (331)	3	Cement Treated Base (331)	TB01, TB02
Subbase (22 to 26, 42, or 43)	With or Without Subbase (Unbound or Treated)	2	Lime-Treated Soil (338)	2 ☆☆	Lime-Treated Subbase ☆☆(338)	TB01, TB02 ☆☆
Subgrade Soil (51 to 65)	+ Subgrade	1	Clay Subgrade (101)	1	Silty Clay (134)	SS01, SS02, SS03, SS04, SS05, SS07, SS09

NOTES: + A treated subgrade is considered a treated subbase layer.

☆ All specified asphaltic concrete tests to be done on cores from the top two maximum testable HMAC layers only. Only AC01 and AC07 tests to be done on other testable HMAC layers.

☆☆ Assign layer material code 321 and perform TB03 instead of TB02 test if this layer is asphalt treated layer.

Figure 13. Example of Laboratory Testing Plan for a Flexible GPS Test Section

Material Type and Code Based on Inventory Data	GPS-3, GPS-4, GPS-5 Selection Criteria	Example of LTPP Field Material Sample Data: Field Layer No.	Example of LTPP Field Material Sample Data: Material Code	Example of LTPP Laboratory Layering Information: Lab Layer No.	Example of LTPP Laboratory Layering Information: Material Code	Laboratory Material Tests
PCC Pavement JPCP(04), JPCP(05), CRCP(06)	PCC Pavement	4	PCC(730)	4	PCC(730)	PC06, PC01, PC02, PC04
Unbound or # Treated Base (21 to 24, 26 to 44, 46)	Bound Base	3	Asphalt Treated Base (321)	3 ++	Asphalt Treated Base (321) ++	TB01, TB03 ++
Subbase (21 to 44, 46)	With or Without Subbase (Unbound or Treated)	2	Lime-Treated Soil (338)	2 **	Lime-Treated Subbase (338) **	TB01, TB02 **
Subgrade Soil (51 to 65)	+ Subgrade	1	Clay Subgrade (101)	1	Silty Clay (134)	SS01, SS02, SS03, SS04, SS05, SS07, SS09

NOTES: + A treated subgrade is considered a treated subbase layer.

\# A seal coat and interlayers are permitted above an unbound granular base layer.

++ Exception - Perform AC01, AC07 tests instead of TB01, TB03; (a) if HMAC base (material code 319) is sampled and if the inventory data shows material code 28 and (b) if sand asphalt base (material code 320) is sampled.

** Assign layer material code 321 and perform TB03 instead of TB02 test if this layer is asphalt treated layer.

Figure 14. Example of Laboratory Testing Plan for a Rigid GPS Test Section

(a) Asphaltic concrete (for each layer including hot-mix, hot-laid, bituminous surface and other HMAC layers)

- Asphaltic concrete (AC) mixture
- Extracted Aggregate

HMAC mixtures were hot-mix, hot-laid, plant mixtures used for asphaltic concrete (AC) surface, including wearing and binder courses and other HMAC layers beneath the AC surface.

(b) Treated (or bound or stabilized) materials (for each layer)

These included asphalt treated material (ATB), and other than asphalt treated material (OTB). OTB materials included cement-treated material, econocrete, lean concrete, lime-treated materials and material treated or stabilized with chemicals.

- Treated Base
- Treated Subbase
- Treated Subgrade

(c) Unbound granular materials (for each layer)

These included soil-aggregate mixtures and naturally occurring materials used in base or subbase layers.

- Unbound Granular Base
- Unbound Granular Subbase

(d) Subgrade soils

These included all cohesive, non-cohesive and granular soils present in the top 5 ft. of subgrade. Typically these were untreated soils.

The laboratory testing contractors conducted and reported their laboratory activities in the following sequence:

(1) Submitted sample receipt reports (Forms L01, L02, L03) to the SRE/RCOC for review and approval.
(2) Performed pavement layer numbering and laboratory test assignments using Form L04.
(3) Performed visual examination and thickness of AC cores (Protocol P01). Steps 1, 2, and 3 were carried out simultaneously if agreed by SRE/RCOC.
(4) Performed a comparison of P01 test results with layer numbers assigned earlier on Form L04. Discrepancies in layer numbers were resolved in coordination with SRE/RCOC; layer numbers were corrected and a revised Form L04 approved by the SRE/RCOC. This approval was obtained before proceeding with other laboratory tests on asphalt concrete layers. A copy of approved Form L04 was sent to the Laboratory PCC Testing Contractor only if PCC pavement cores were tested.

(5) Performed laboratory tests of asphaltic concrete (Protocols P02, P03, P04, P07, P14).
(6) Performed laboratory tests of unbound granular base, and subbase materials and untreated subgrade soils (Protocols P41 through P55).
(7) Performed identification and thickness of the treated base and subbase materials and treated subgrade (Protocol P31).
(8) Performed other laboratory tests associated with the treated base and subbase materials and treated subgrade (Protocols P32 and P33).
(9) Performed detailed description of treated base and subbase materials and treated subgrade (Protocol P31).
(10) Submitted laboratory test results to SRE/RCOC for checking and approval.
(11) Prepared a summary of pavement layers (Form L05A) and sent to the SRE/RCOC.
(12) Prepared a sample disposal and storage record (Form L06) and sent to the SRE/RCOC.

Tracking of Laboratory Activities

Because of the complex nature of the laboratory materials testing program, tracking tables were developed to guide the regional laboratories through the process. These tables provided the materials testing contractors with the following information and directions:

(a) Tracking of samples as they are taken from the field and tested in the laboratory.
(b) Assignment of laboratory test numbers.
(c) Sample preparation and reduction of bulk sample to test sample sizes prior to testing.
(d) Laboratory test sequences for each pavement material type.
(e) Dedicated sample(s) for each test.
(f) Designation of substitute samples for appropriate laboratory tests.
(g) Designation of extra samples for future use.
(h) Instructions for sample storage.
(i) Instructions for sample disposal.
(j) Special instructions and other remarks.

Laboratory Test Procedures for Asphaltic Concrete

Asphalt concrete testing was conducted on core specimens and block samples retrieved from the pavement test section. Table 8 contains a list of AC core locations and the required test procedures for each specimen. Testing (except for core examination and thickness) was conducted on each AC layer. The AC Core Examination and Thickness Test was the first test performed on all AC core specimens. SHRP Protocol P01 was used in the performance of this test. This protocol covered the visual examination of the entire asphaltic concrete core and the measurement of the length of the entire core. It also covers the identification and determination of thickness of the individual layers within a core. Cores which contained more than one AC layer were sawed in the laboratory.

Table 8. Summary of AC Core Locations and Required Tests

Sample/Core Locations	Sample Size	Tests Per Each 1.5 inch or Thicker Layer	SHRP Protocol
All C-type A1, A2 cores	4 in. diam.	AC01. AC Core Examination and thickness	P01
C8, C9, C10 and C20, C21, C22 Cores (C7, C19 if needed)	4 in. diam.	AC07. AC Resilient Modulus	P07
A1, A2 cores (C12, C24 if needed)	6 in. diam.	AC02. AC Bulk Specific Gravity	P02
A1, A2 cores	6 in. diam.	AC03. AC Maximum Specific Gravity	P03
BA1 or other BA type core	12 in. diam.	AC03. AC Maximum Specific	P04
Block from Test Pit or BA type core, if no test pit	12 in. x 12 in.	AC04. AC Asphalt Extraction	P04

The Bulk Specific Gravity (test AC02) and Maximum Specific Gravity (test AC03) were conducted on 6 in. cores of asphalt concrete. Asphalt content tests were performed on block samples and 12 in. core specimens. The aggregate obtained from the AC04 test was used for sieve analysis using SHRP Protocol P14. Additionally the fine portion of the aggregate specimen was used to perform a particle shape test using SHRP Protocol P14A. This testing (P14A) was performed by the National Aggregate Association's Joint Research Laboratory (NAA-JRL). No testing was performed on extracted asphalt cement.

The Resilient Modulus and Tensile Strength Test, SHRP Designation AC07, was conducted on 4 in. core specimens from the pavement test section using SHRP Protocol P07. Appendices 1 and 2 of this report document the entire process undertaken for the resilient modulus testing program.

Laboratory Testing of Treated Materials

Treated materials testing was conducted on core specimens, chunks and pieces of pavement materials. Tables 9, 10 and 11 contain a list of treated material locations and the required test procedures for each specimen. SHRP Protocol P31, "Identification and Description of Treated Base and Subbase Materials, and Determination of Type of Treatment," were used for preliminary identification and detailed description of treated materials and treatment types. The thickness of these materials was also determined using this test procedure. Based on the results of the P31 test, laboratory tests using SHRP Protocol P32 or P33 (depending on material type) was required.

Protocol P32, "Compressive Strength of OTB Material," was used to test other than asphalt treated base materials (lean concrete, econocrete, soil cement, lime-treated soils and chemical stabilized soils). Protocol P33, "Resilient Modulus of Asphalt-treated Materials," was, of course, used to test asphalt-treated materials.

Laboratory Testing of Unbound Granular Base, Subbase and Untreated Subgrade Soils

Unbound materials testing was conducted on bulk samples of the material. These samples were taken from 12 in. diameter boreholes or the test pit location on the test section and were sent to the laboratory in bags. In the laboratory, these bulk samples were combined, prepared and reduced to a representative test size in accordance with procedures contained in the Laboratory Materials Testing Guide.

Layer thicknesses for these layers were determined by the laboratory from the field drilling and sampling logs provided by the drilling and sampling contractor. The thickness of the layer was then averaged from this information. The laboratory assigned a detailed classification for the soil after performing all designated tests on the samples. Table 12 lists the laboratory tests required for the unbound materials in the GPS program.

Table 9. Designated Sample Locations for SHRP Protocol P31 by GPS Pavement Type

Tests	Sample Core Location	GPS Experiment
Preliminary Identification (See Section 9 of Protocol P31 and Section 3.5.4 of this Guide)	C12 and C24 C6 and C12	GPS-2, GPS-6, GPS-7 GPS-3, GPS-4, GPS-5 GPS-9
Detailed Description (See Section 10 of Protocol P31 and Section 3.5.4 of this Guide)	C12 and remains of cores from C10 after P32 or C7, C8, C9, after P33	GPS-2, GPS-6, GPS-7
	C24 and remains of cores from C22 after P32 or C19, C20, C21 after P33	GPS-2, GPS-6, GPS-7
	C6 and remains of cores from C4 after P32 or C1, C2, C3 after P33	GPS-3, GPS-4, GPS-5 GPS-9
	C12 and remains of cores from C10 after P32 or C7, C8, C9 after P33	GPS-3, GPS-4, GPS-5 GPS-9

Table 10. Designated Sample Locations for SHRP Protocol P32 by GPS Pavement Type

Tests	Sample Core Location	GPS Experiment
Method A: (See Protocol P32)	C10 or C7, C8, C9	GPS-2, GPS-6, GPS-7
	C22 or C19, C20, C21	GPS-2, GPS-6, GPS-7
	C4 or C1, C2, C3	GPS-3, GPS-4, GPS-5 GPS-9
	C10 or C7, C8, C9	GPS-3, GPS-4, GPS-5 GPS-9
Method B: (See Protocol P32)	C10 or C7, C8, C9	GPS-2, GPS-6, GPS-7
	C22 or C19, C20, C21	GPS-2, GPS-6, GPS-7
	C4 or C1, C2, C3	GPS-3, GPS-4, GPS-5 GPS-9
	C10 or C7, C8, C9	GPS-3, GPS-4, GPS-5 GPS-9

Note: Protocol P32 shall only be used for OTB materials.

Table 11. Designated Sample Locations for SHRP Protocol
Protocol P33 by GPS Pavement Type

Section Location	Sample Core Location	GPS Experiment
Beginning of Test Section	C7, C8, C9 (C10 available)	GPS-2, GPS-6, GPS-7
End of Test Section	C19, C20, C21 (C22 available)	GPS-2, GPS-6, GPS-7
Beginning of Test Section	C1, C2, C3 (C4 available)	GPS-3, GPS-4, GPS-5 GPS-9
End of Test Section	C7, C8, C9 (C10 available)	GPS-3, GPS-4, GPS-5 GPS-9

Note: This protocol shall only be used for ATB materials (Asphalt Treated Materials)

Table 12. List of Laboratory Tests for Unbound Granular Base and Subbase Materials and Untreated Subgrade Soils

Laboratory Tests Per Layer *			SHRP Protocol
(a)	Unbound Granular Base Material		
	UG10.	Natural Moisture Content	P49
	UG01. and UG02.	Gradation	P41
	UG04.	Atterberg Limits	P43
	UG08.	Classification and Description	P47
	UG05.	Moisture-Density Relations	P44
	UG07.	Resilient Modulus	P46
(b)	Unbound Granular Subbase Material		
	UG10.	Natural Moisture Content	P49
	UG01. and UG02.	Gradation	P41
	UG04.	Atterberg Limits	P43
	UG08.	Classification and Description	P47
	UG05.	Moisture-Density Relations	P44
	UG07.	Resilient Modulus	P46
(c)	Subgrade Soils		
	SS09.	Natural Moisture Content	P49
	SS01.	Sieve Analysis	P51
	SS02.	Hydrometer Analysis	P42
	SS03.	Atterberg Limits	P43
	SS04.	Classification and Description	P52
	SS05.	Moisture-Density Relations	P55
	SS07.	Resilient Modulus	P46

* Recommended sequence of testing for each layer.

Bulk samples that weighed a maximum of 200 pounds were retrieved from each end of the test section. If bulk samples were received in excess of this weight, the extra material was discarded using appropriate procedures. If the total bulk sample weight was less than 200 pounds, alternative procedures were used to complete all of the designated laboratory tests. In many cases, one sample was used for more than one test procedure. The required weights for each test procedure are shown in Table 13. Figure 15 contains bulk sampling, handling and testing requirements for unbound base and subbase samples and Figure 16 contains handling and testing requirements for subgrade soils.

For subgrade soils, thin-walled tube samples were retrieved from sections containing cohesive subgrade soils. These tube samples were then used for resilient modulus testing using protocol P46. If tube samples were not available from a pavement test section, then bulk samples were reconstituted and used for this testing. Appendix 1 contains further details concerning the resilient modulus test procedures.

Quality Assurance/Quality Control in the Laboratory

As mentioned previously, a very important factor in awarding the SHRP laboratory contracts was the quality of the work to be accomplished under the contracts. High quality, accurate materials test data was of critical importance to the attainment of the objectives of the long-term pavement performance program. SHRP required that the testing contractors have their own in-house quality assurance (QA) programs as well as experienced and capable personnel committed to carrying out these internal checks and procedures. Another important step in the QA/QC process was the accreditation of each laboratory through the AASHTO Accreditation Program (AAP). All SHRP contract laboratories were accredited by AAP, thereby providing SHRP with important external QA checks (4).

During the production laboratory materials testing process, SHRP required consistent quality of all work. To achieve this goal, SHRP implemented uniform quality assurance and control procedures in each region. These controls were provided to the extent that is consistent with the importance of the activities necessary for acceptable quality of pavement material testing.

The laboratory material testing guide represented the first stage of the QA/AC process. Strict adherence to the Guide was intended to ensure regional data quality and interregional data consistency. The Guide contains all laboratory test data forms, protocols and other laboratory instructions. Strict conformance to the SHRP Protocols and sampling handling and storage requirements was essential to the success of the laboratory materials testing process.

The QA/QC program of each SHRP-LTPP testing contractor provided for the review, assessment and necessary corrective actions of the following:

1. Qualified personnel, proper equipment, references, and adequate facilities.
2. Project supervision.
3. Sample identification and receipt, storage and disposal.

Table 13. Approximate Weights of Test Samples

APPROXIMATE WEIGHT OF TEST SAMPLE FOR MAXIMUM SIZE AGGREGATES OF			
PROTOCOLS	1 INCH	2 INCH	3 INCH
(a)	Unbound Granular Base or Subbase Material Per Layer (Weight in lb.)		
P41	11	40	
*50 or 40			
P43	4	9	11
P47	+4	18	*50 or 40
P44	20	30	30
P46	10	30	65
TOTAL WEIGHT (a)	49	127	206
(b)	Subgrade Soils (Weight in lb.)		
P51	11	40	*50 or 40
P42	4	9	11
P43	4	9	11
P52	+4	18	*50 or 40
P55	20	30	30
P46	10	30	65
TOTAL WEIGHT (b)	53	136	217

Notes:

1. Approximate weights are based on the requirements of the pertinent Protocol and/or AASHTO and ASTM standards.

2. * indicates smaller test size permitted by the pertinent Protocol as compared to the test size requirement by the pertinent AASHTO/ASTM standards.

3. + indicates that the listed weight is a slight increase over the minimum weight required by the pertinent AASHTO/ASTM standards.

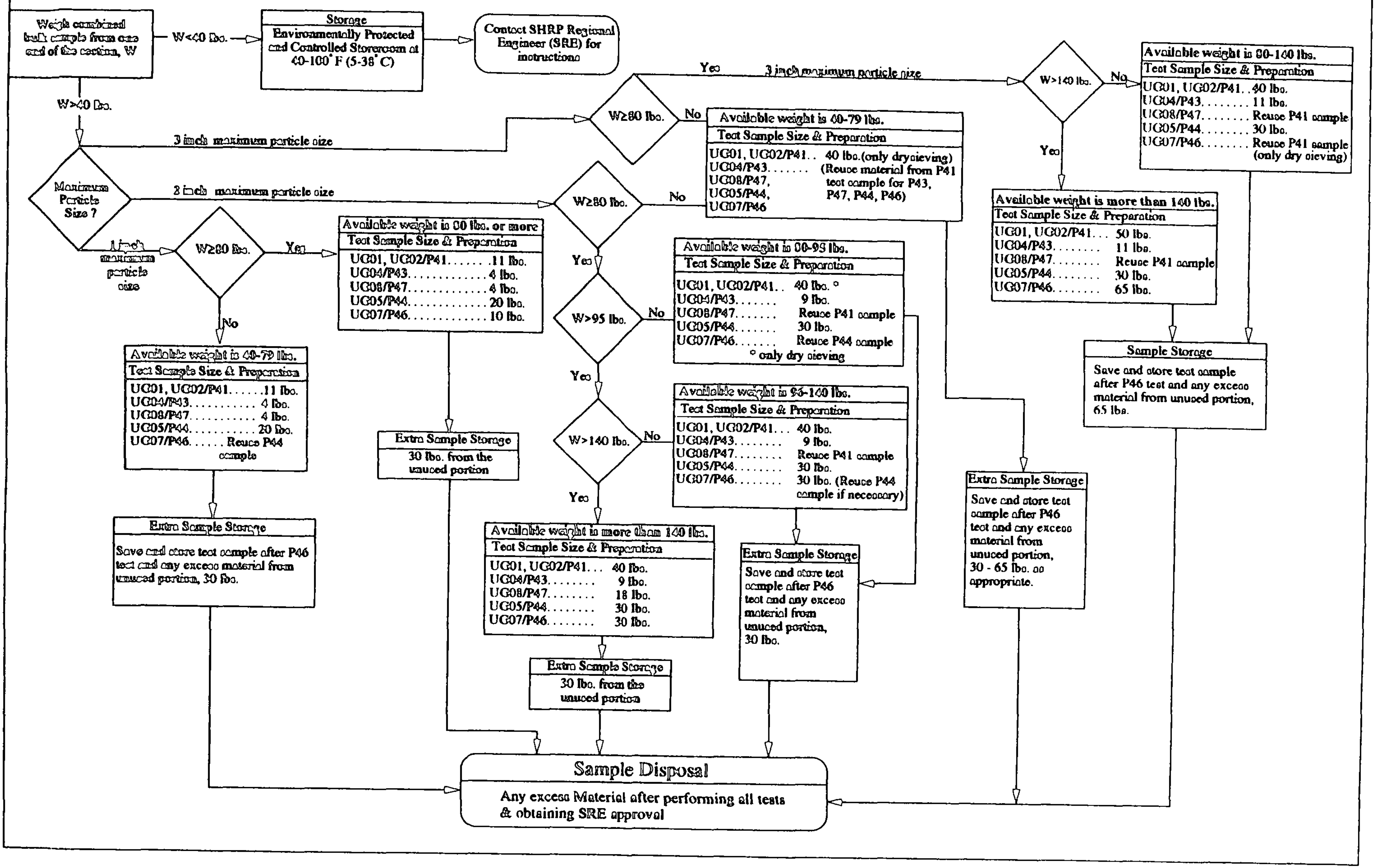


Figure 15. Bulk Sample Handling and Testing Requirements for Unbound Granular Base and Subbase

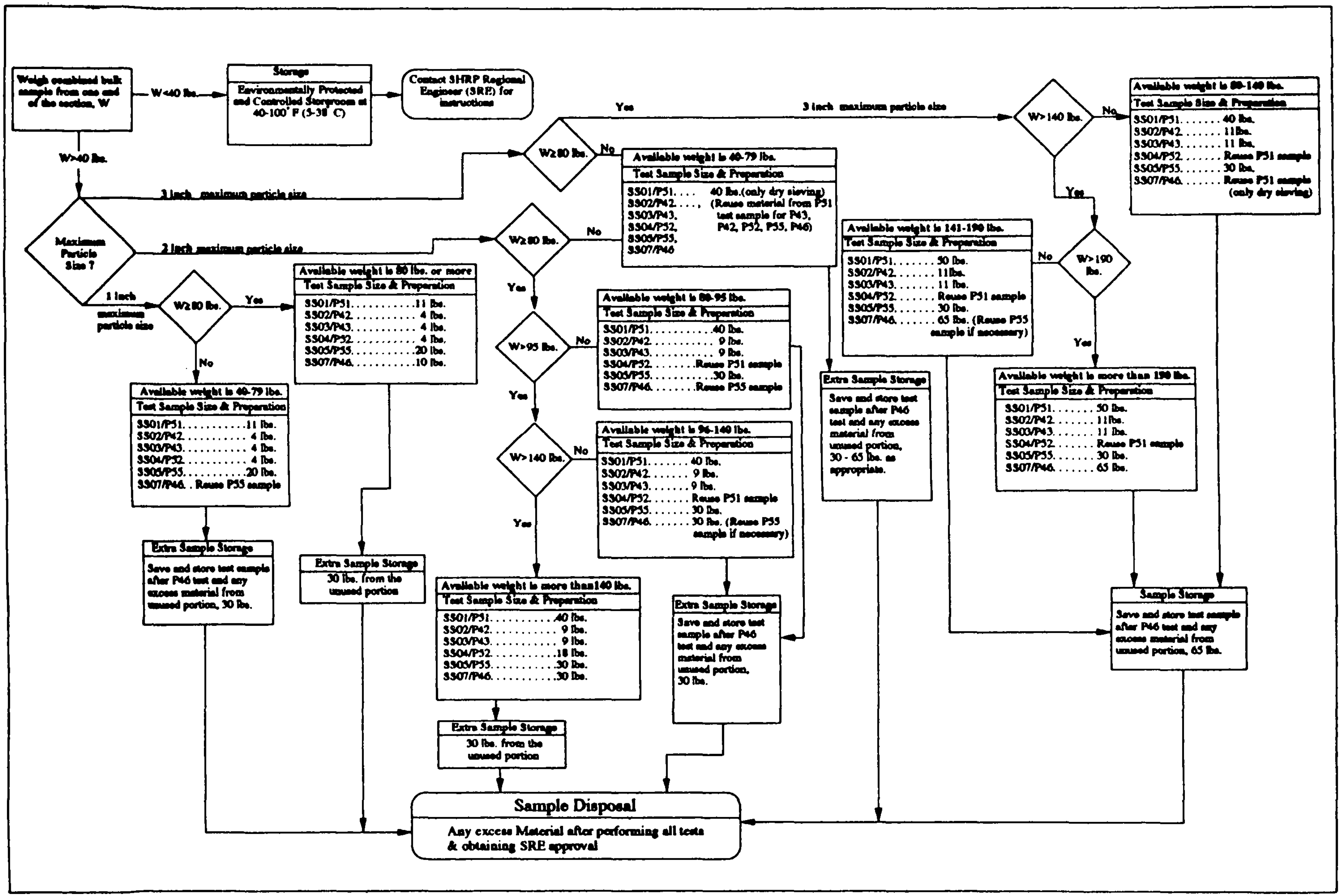


Figure 16. Bulk Sample Handling and Testing Requirements for Subgrade Soils

4. Laboratory handling of samples (cores, undisturbed subgrade samples and bulk samples.
5. Sample storage and disposal.
6. Pavement layering and laboratory test assignment.
7. Adherence to the specific laboratory testing protocols.
8. Accuracy in measurements.
9. Equipment maintenance and calibration.
10. Review and checking of data.
11. Presentation of data and reports.

The commitment to QA/QC ran throughout all levels of the SHRP-LTPP program including the SHRP Regional Engineer, SHRP Project Manager, RCOC staff, Laboratory Materials Testing Contractors and the SHRP Technical Assistance Contractors. All parties were committed to providing the highest quality laboratory materials testing data for the long-term pavement performance studies.

Personnel

Laboratory materials quality assurance and quality control began during the development of the Technical Provisions for the laboratory testing contracts (43,44). This document provided detailed requirements for laboratory testing personnel. The presence of experienced and knowledgeable persons was the first and one of the most important aspects of the program. The Supervisory Engineer was a licensed Professional Engineer with five years of demonstrated experience in the testing of pavement materials. The Laboratory Chief had a minimum of five years experience in materials testing and experience conducting laboratory testing.

All technicians were required to have a minimum of two years experience in the testing of soils, aggregates, and bituminous materials. The PCC testing contractor was also required to adhere to similar guidelines in the laboratory.

QA/QC Responsibilities

Each of the laboratory testing activities and the data generated by these activities were checked at various technical levels in order to insure quality. Designated persons were assigned specific QA and QC responsibilities in each SHRP region and at the national level. Table 14 contains a list of assignments which were made to implement quality management in the SHRP laboratory materials activities. References made to field materials sampling and database personnel are included to provide an "overall picture" of the QA/QC process.

Table 14. Laboratory QA/QC Responsibilities

Agency/Person(s)	Responsible For
Regional Drilling and Sampling Contractor/Crew Chief/Project Manager	QC - Field Sampling and Field Testing Activities, Field Data Packet, Shipment of Samples to Laboratory QC - Implementation of SHRP Procedures and Directives in the Field
RCOC/Authorized SHRP Representative	QA - All Field Activities QC - Field Data Packet
Regional Laboratory Testing Contractor/Laboratory Chief, /Project Manager	QC - Layering Assignment, Sample and Layer Identification, Laboratory tests, and Test Data, Layer Data and Sample Storage
PCC Laboratory Testing Contractor/Laboratory Chief, /Project Manager	QC - Sample and Layer Identification, Laboratory Tests and Data, Sample Storage
SHRP-PCC Project Manager	QA - Laboratory PCC Data
SHRP Regional Engineer/ Designated RCOC staff	QA - Approval of Layering Assignment Corrections if Necessary QA - Regional Field Data, QA - Regional Laboratory Data, PCC Data QC - Regional Data Base
SHRP Quality Assurance Manager	QA - Field Equipment and Procedures QA - Laboratory Tests and Calibrations
SHRP and P-001 (TRDF) Staff	QA - Interregional Field Data QA - Interregional Laboratory Data QA - Database

AAP Accreditation

Another, and most important step in the quality assurance and quality control in the laboratory was the laboratories adherence and completion of the AASHTO Accreditation Program (AAP). This required the laboratory to be accurate and proficient in the conduct of the laboratory materials characterization tests. For those tests which were to be completed by the SHRP laboratories but which were not part of the AAP, SHRP set up its own proficiency testing program as outlined in Appendix B of this document. The proficiency testing program initiated by SHRP ensured accurate, repeatable, results for a great number of laboratory materials tests.

SHRP Proficiency Testing Program

After extensive consultation and careful study of the AASHTO Accreditation Program (AAP) and SHRP's needs in the form of QA/QC practices, supplemental programs were identified and designed. The six programs, listed below, were approved for implementation.

1. Type 1 (Granular) Soil Proficiency Sample Program - Resilient Modulus
2. Type 2 (Cohesive) Proficiency Sample Program - Resilient Modulus
3. Soil Moisture Proficiency Sample Program
4. PCC Core Proficiency Sample Program - Static Modulus of Elasticity, Poisson's Ratio, Splitting Tensile Strength and Compressive Strength
5. AC Core Proficiency Sample Program - Resilient Modulus
6. Laboratory Molded AC Core Proficiency Sample Program - Resilient Modulus.

Each of the above programs was conducted independently of the other with the exception of the laboratory molded AC core proficiency testing program.. As noted previously, Appendix 2 contains a more comprehensive explanation of the SHRP Proficiency Testing Program.

Data Collection Guidelines

The primary objective of the laboratory materials testing program was to adequately and accurately characterize the layers contained within the GPS pavement structures. To facilitate the collection of this data, standard data entry sheets and standard materials codes were developed to record all of the data produced from the laboratory.

The guidelines for recording data generated from the laboratory materials testing work are contained in Appendix C of SHRP-LTPP-OG-004, "SHRP-LTPP Guide or Laboratory Material Handling and Testing," September 1992 (45). Appendix C.1 contains data collection guidelines for the GPS pavements studies and Appendix C.2 contains the SPS data collection guidelines. Appendix D contains SHRP standard terminology codes which are used on the data entry sheets to record materials classifications and descriptions. These data forms are primarily completed by the Laboratory Material Testing Contractor and subsequently reviewed

by the SHRP Regional Coordination Office Contractor (RCOC) for completeness and accuracy prior to entry in the Information Management System (IMS).

Detailed descriptions of laboratory materials testing operations and data collection are available in the reference previously cited (SHRP-LTPP-0G-004). This document, along with the LTPP Researcher's Guide (**15**) should be used to fully comprehend the data collection activities for the laboratory materials characterization program.

There are two types of laboratory data collection forms. The L-type form (Forms L01 through L07) is primarily general in nature and provides an overview of all of the laboratory materials testing activities for a given test section. One of the most important sets of data sheets in this group, Forms L05A and L05B, provides a summary of pavement layering for the test section. These forms provide the most up-to-date layer structure and material classification information available for a GPS test section. Table 15 contains a complete list of Forms L01 through L07.

The second type of laboratory data collection form is the T-type form (Forms T01A through T66). These data sheets are used to record individual test results for each layer in the test section as follows:

Forms T01A - T14A:	Asphalt Concrete Layers
Forms T31 - T33:	Treated Base/Subbase Layers
Forms T41 - T55:	Unbound Base/Subbase/Subgrade Layers
Forms T61 - T66:	Portland Cement Concrete Layers.

Table 16 contains a list of the data collection sheets used for Laboratory Material Handling and Testing.

All of these data entry forms, except Form L05B, are completed by the laboratory testing contractor's representative and sent to the SHRP RCOC for approval. The data were then checked for accuracy and completeness in the RCOC's office and entered into the RPPDB. The original data packet was kept in the RCOC's office for archival storage along with all other pertinent information.

Summary Statistics and Information

At the conclusion of the General Pavement Studies laboratory materials testing program, the estimated number of tests performed will be as follows:

Table 15. Summary of Data Collection Sheets for Sample Receipt and Handling in the Laboratory

General Laboratory Testing Forms		Entered in Database?
L01	Sample Receipt Report	No
L02	Sample Inspection Report	No
L03	Preliminary Laboratory Test Assignment	No
L04	Final Laboratory Test Assignments	No
L05A	Summary of Pavement Layers - Laboratory	Yes
L05B	Summary of Pavement Layers - RCOC	Yes
L06	Sample Disposal and Storage Record	Yes
L07	PCC Sample Disposal and Storage Record	Yes

Table 16. Summary of Data Collection Sheets for Recording Laboratory Test Results

Form	Description	Entered in Database?
Asphaltic Concrete Testing Forms		
T01A	AC Core Examination and Thickness Sht. 1	Yes
T01B	AC Core Examination and Thickness Sht. 2	Yes
T02	AC Bulk Specific Gravity	Yes
T03	AC Maximum Specific Gravity	Yes
T04	Asphalt Content	Yes
T07A	AC Resilient Modulus Summary	Yes
T07A - WKST	AC Resilient Modulus Worksheet	Yes
T07B	AC Resilient Modulus - ITS	Yes
T14	Gradation of Extracted AC Aggregate	Yes
T14A	NAA Test for Fine Extracted Aggregate	Yes
Treated Base/Subbase Testing Forms		
T31	Description of Material	Yes
T32	Compressive Strength	Yes
T33A	Resilient Modulus Summary	Yes
T33A - WKST	Resilient Modulus Worksheet	Yes
T33B	Resilient Modulus - ITS	Yes
Unbound Base/Subbase/Subgrade Testing Forms*		
T41	Gradation (B/SB)	Yes
T42	Hydrometer Analysis (SG)	Yes
T43	Atterberg Limits (B/SB/SG)	Yes
T44	Moisture-Density Relations (B/SB)	Yes
T46	Resilient Modulus Summary (B/SB/SG)	Yes
T46 - WKST	Resilient Modulus Worksheet (B/SB/SG)	Yes
T47	Classification and Description (B/SB)	Yes
T49	Natural Moisture Content (B/SB/SG)	Yes
T51	Sieve Analysis (SG)	Yes
T51A	Dry Sieve Analysis (SG)	Yes
T52	Classification and Description (SG)	Yes
T55	Moisture-Density Relations (SG)	Yes
Portland Cement Concrete Testing Forms		
T61	Compressive Strength	Yes
T62	Splitting Tensile Strength	Yes
T64	Static Modulus of Elasticity	Yes
T66	Core Examination and Thickness	Yes

* B = Base
SB = Subbase
SG = Subgrade

1.	Portland Cement Concrete	6,600 tests
2.	Asphalt Concrete	18,700 tests
3.	Extracted Aggregate	2,100 tests
4.	Treated Base/Subbase	1,800 tests
5.	Unbound Base/Subbase	17,000 tests
6.	Subgrade	13,000 tests
	Total:	59,200 tests

All materials characterization information will be recorded in the national SHRP database and will, in itself, be an important and unique depository of information for highway pavement researchers (4).

Status of GPS Laboratory Materials Testing

All of the GPS sites which have been drilled and sampled and had the samples shipped to the laboratory have had all testing completed (excluding resilient modulus). The resilient modulus testing program is underway and should be completed by mid-1993. All laboratory testing activities for the GPS testing program should be completed at that time. The main effort in this area is the transfer of the data from the laboratories into the National Information Management System so that the data may be used by researchers.

Appendix 1
Resilient Modulus Testing Program

A significant amount of data will be produced from the LTPP studies which can be used by the highway research community. One of the more important outputs from the materials characterization portion of the LTPP study will be resilient modulus (M_r) data for each layer of the pavement test sections. Relationships between this M_r data, other materials properties, environmental parameters, and falling weight deflectometer (FWD) data should be invaluable in evaluating the pavement performance of the LTPP sections.

This appendix offers an overview of the SHRP-LTPP test procedures involving resilient modulus testing of asphalt concrete (AC) cores (SHRP Protocol P07), asphalt treated base/subbases (SHRP Protocol P33), and unbound granular base/subbase and subgrade materials (SHRP Protocol P46). It is intended to provide a discussion of the fundamentals of the test procedures and to identify the results expected to be achieved from the performance of the resilient modulus test.

For each resilient modulus laboratory test, standard SHRP protocols have been developed for use by the laboratories. The intent of this process is to minimize the variability of material test data attributable to laboratory materials testing and handling techniques by standardizing these techniques as much as possible (**46**).

SHRP Protocol P07 (Resilient Modulus of Asphalt Concrete) and SHRP Protocol P07B (Resilient Modulus of Synthetic Samples) were developed to provide the SHRP contract laboratories with a standardized procedure for the testing of asphalt concrete. Protocol P33 (Determination of the Resilient Modulus of Asphalt Treated Base/Subbase Materials) was developed for the testing of asphalt treated base/subbase materials which could not be tested using Protocol P07. Lastly, SHRP Protocol P46 (Resilient Modulus of Unbound Granular Base/Subbase Materials and Subgrade Soils) and SHRP Protocol P46B (Resilient Modulus of SHRP Synthetic Specimens for Compressive Resilient Modulus) were developed for the unbound pavement layers. The P07B and P46B protocols are used as quality assurance/quality control devices for each resilient modulus test. Using these three protocols (P07, P33 and P46) most pavement layers can be tested and assigned a resilient modulus value. These determinations will be invaluable in the future analysis of the LTPP test sections.

In the materials testing program, there were four testing laboratories performing resilient modulus testing as follows:

SHRP Region	Laboratory	M_R Testing P07	P33	P46
Western	Arizona State University (Phoenix, AZ)	X	X	X
North Central	Braun Intertec Laboratories (Minneapolis, MN)	X	X	X
North Atlantic and Southern	Southwestern Laboratories (Houston, TX)	X	X	
North Atlantic and Southern	Law Engineering (Atlanta, GA)			X

These laboratories conducted all GPS testing for the SHPR-LTPP program. For the SHRP SPS resilient modulus materials testing program, it is anticipated that one or more laboratories will be utilized for all modulus testing.

Resilient Modulus of Asphalt Concrete - SHRP Protocols P07 and P07B

Development of Test Method

The development of the SHRP AC M_r test procedure evolved during most of the SHRP program. An outline and draft test procedure were originally developed by a group of materials testing experts under the direction of SHRP. The first draft of Protocol P07 was essentially based upon ASTM D4123-82 (1987) and preliminary findings of the Asphalt-Aggregate Mixture Analysis System (AAMAS) study. The first production version of P07 was issued in July, 1989. Subsequent revisions were instituted by the SHRP Technical Assistance Contractor in November, 1989, and the version currently in use for the resilient modulus pilot study was issued in July, 1992. Further refinement of the test procedure is expected as production testing continues. Resilient modulus testing of LTPP AC specimens under the SHRP program was completed in early 1993.

Summary of Method

The SHRP protocol for AC resilient modulus testing (SHRP Protocol P07) describes procedures for the determination of M_r using repeated load indirect tensile testing techniques. The procedure involves resilient modulus testing for a range of temperatures and loads. This test is completed on field cores obtained from SHRP test sections and is conducted through repetitive applications of compressive loads in a haversine wave form.

SHRP Proficiency Testing

Expert Task Group recommendations led to a decision in 1988 that a vital element in laboratory quality assurance would be the AASHTO Accreditation Program (AAP) (**4**). The laboratories under contract to SHRP were required to be accredited by AAP. Since the resilient modulus testing of asphalt was not covered under this program, it was decided that a separate proficiency testing program would be developed to assure the quality of the test data being collected.

Seventeen laboratories participated in an asphalt concrete resilient modulus testing program which involves two separate test series for the verification of M_r (resilient modulus) system calibration and proficiency. The first portion involved the verification of the system calibration and proficiency by testing a set of four synthetic reference specimens (ie. rubber, teflon, polyethylene and lucite) provided by SHRP, while the second portion involved establishment of further M_r proficiency on actual asphalt field cores.

In the first series, laboratory generated M_r results for the synthetic specimens were compared with the anticipated range in M_r results to identify acceptable or unacceptable results. If the measured responses did not fall within the anticipated range, then the agencies were advised to inspect their test system for possible equipment (load cell, transducers, etc.), alignment or specimen placement problems. Once system problems were corrected and acceptable M_r values were obtained, the testing agency was then released to begin the second series of the proficiency program involving asphalt core proficiency testing. It should be noted that there was considerable difficulty encountered by a number of laboratories in completing the initial proficiency test series.

The second proficiency test series involved M_r testing of asphalt cores obtained from the Penn State Test Track. The participating laboratories were provided with two sets of core specimens and requested to conduct resilient modulus testing utilizing SHRP Protocol P07 procedures including testing at 41 °F (5 °C), 77 °F (25 °C) and 104 °F (40 °C). Similar to the initial series, the M_r values generated by the participating laboratories were compared to a range of expected M_r values developed by SHRP quality control personnel. If measured responses fell outside this range then the agencies were advised to inspect their load apparatus, transducer placement and location for needed adjustments and to evaluate specimen marking, location and placement techniques of laboratory personnel.

Following the attainment of suitable resilient modulus values from the asphalt core proficiency testing series, the SHRP contract laboratories were cleared to begin pilot study testing.

The initial round of testing within the synthetic proficiency series produced a range of resilient modulus values from 25 percent to an order of magnitude greater than the accepted values for the reference specimens. These results illustrated that this testing program was indeed necessary and vital to the success of the LTPP program. This experience indicated that a less vigorous course of action may have resulted in the collection of unusable data at great cost to the highway community (**4**). A more detailed description of the proficiency testing program is provided in Appendix 2 of this document.

The AC Resilient Modulus Test

The repeated-load resilient modulus test of asphalt concrete cores is conducted through repetitive applications of compressive loads in a haversine waveform. The compressive load is applied along a vertical diametral plane of a cylindrical core of asphalt concrete (Figure 1-1). The resulting horizontal and vertical deformations of the core are measured and resilient modulus is calculated using the applied load, specimen dimensions and measured horizontal deformation information. In the present version of the M_r Protocol (P07), Poisson ratios are calculated from measured horizontal and vertical deformations. This value of Poisson's ratio is then used to calculate the resilient modulus of the test specimen.

Two separate resilient modulus values were obtained. One, defined as instantaneous resilient modulus, is calculated using the recoverable horizontal deformation that occurred during the unloading portion of one load-unload cycle. The other, defined as total resilient modulus, is calculated using the total recoverable deformation which includes both the instantaneous recoverable and the continuing recoverable deformation during the rest-period portion of one cycle.

For each resilient modulus test, the following general procedures are followed:

- The tensile strength is determined for a selected test specimen at $77 \pm 2\ ^{\circ}F$ using the procedures described in Protocol P07. The value of tensile strength determined by this procedure is then used to estimate the indirect tensile stress and the corresponding compressive load to be repetitively applied to the designated test specimens during the resilient modulus determinations.

- The test specimen(s) are tested along one diametral axis (axis in the direction of traffic), at one rest period (i.e., 0.9 seconds) and at testing temperatures of 41, 77 and 104 °F plus or minus two degrees F (5, 25, and 40 °C plus or minus one degree C). For each test temperature, repetitive haversine load pulses of 0.1-second duration are applied to the individual test specimens. The magnitude of load to be applied is based on a predefined percentage of the indirect tensile strength of a specimen. The general testing sequence included initial testing at 41 °F followed by testing at 77 °F, and final testing at 104 °F.

- After completion of resilient modulus testing at 104 °F, the test specimen is returned to 77 °F and an indirect tensile strength test is performed in accordance with standard procedures outlined later. This test is performed to determine the tensile strength of the specific specimen actually used in resilient modulus testing.

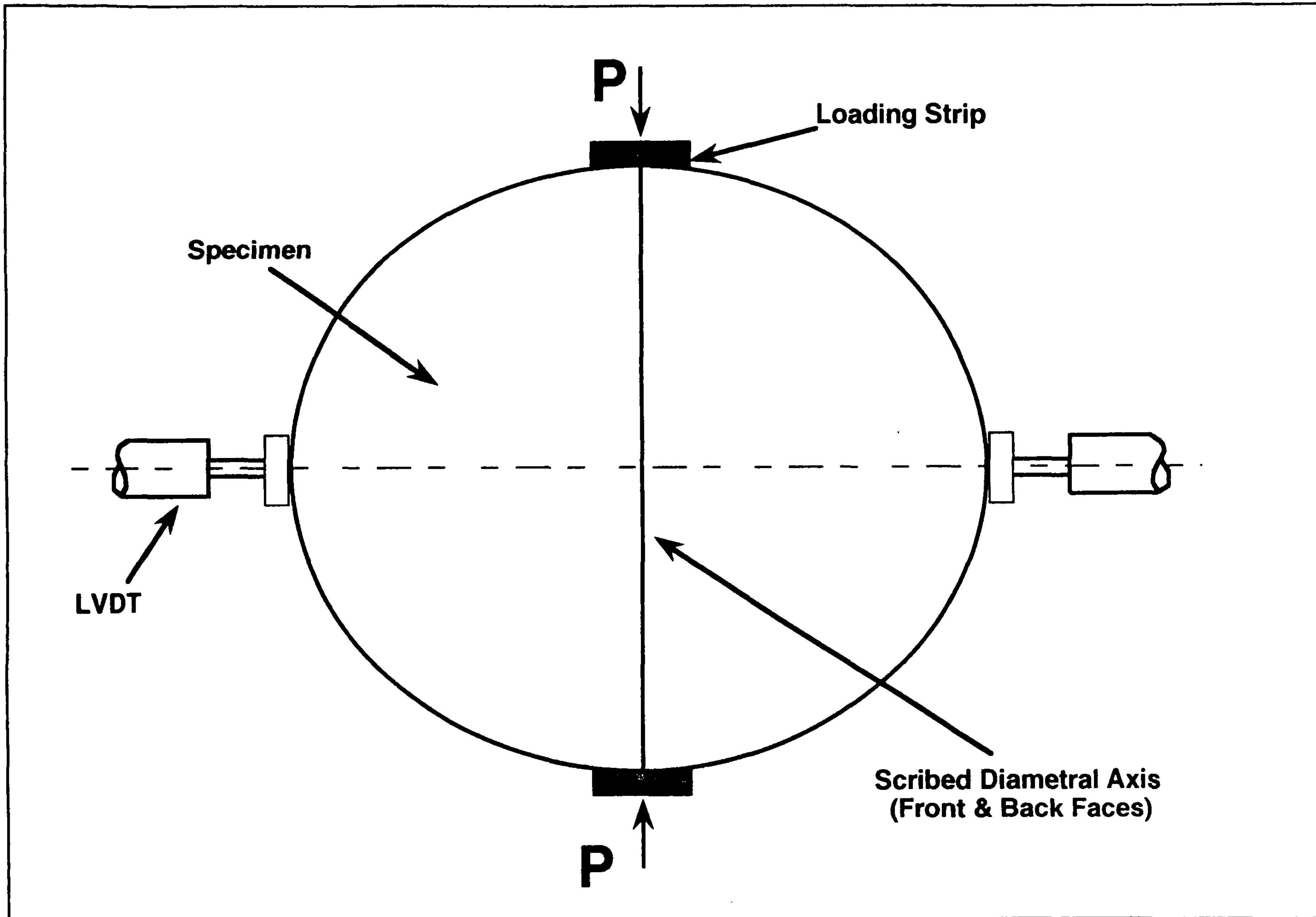


Figure 1-1. Project Loading of Asphalt Concrete Specimen

The resilient modulus test specimens are also subjected to testing for bulk specific gravity, maximum specific gravity and asphalt content using standard SHRP testing procedures.

Testing Machine

The testing machine used for SHRP resilient modulus testing is a top loading, closed loop, electrohydraulic testing machine with a function generator which is capable of applying a haversine shaped load pulse over a range of load durations, load levels, and rest periods (Figure 1-2).

Temperature Control System

The temperature-control system is capable of attaining temperature control ranging from 41 °F (5 °C) to 104 °F (40 °C) while maintaining the specified temperature within $\pm$ 2 °F ($\pm$ 1.1 °C). The system includes a temperature-controlled cabinet large enough to hold the load frame, one sample and the horizontal and vertical deformation transducers. In the systems used by the SHRP testing laboratories, carbon dioxide is the medium used for cooling the chamber and electric heating elements are used to raise the temperature in the chamber.

Specimen Holding/Loading Device

In addition to the closed loop system, a diametral load guide device was designed for SHRP testing. The loading device is a modified, commercially available (through special order) die set (Danly Die Set AS34BB, Modified by OEM, Inc., Box 831, Corvallis, Oregon 97339, Ph: 503-757-1100, Contact: Mr. Brad Whiting) with upper and lower platens constrained to remain parallel during testing (Figure 1-3). The top platen is counter-balanced by lead weights to minimize load effects for tests at elevated test temperatures. Attached to this load frame are two horizontal transducer holders positioned to provide a contact point of the transducer at the mid-height of the specimen. These transducer holders are adjustable in order to "zero" the transducers prior to testing. Steel loading strips with a concave surface having a radius of curvature equal to a nominal 4.0 inch diameter specimen is attached to the load frame to apply uniform loading to the diametral axis of the core. The outer edges of the loading strips have been rounded to remove sharp edges that might cut the core during testing.

This loading system was designed to insure that the load is applied evenly to the test specimen with no sample rocking or equipment flexure during testing.

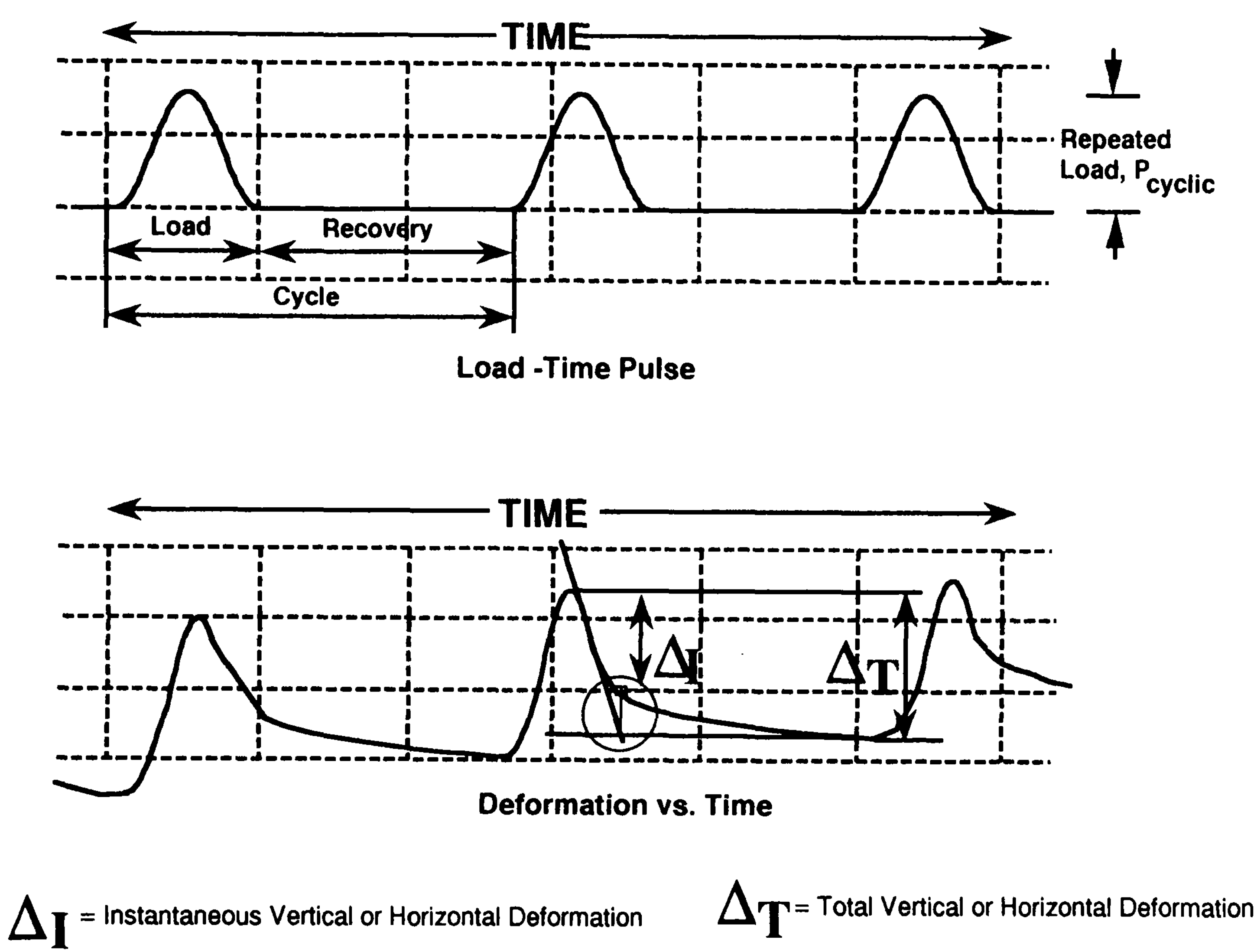


Figure 1-2. Typical Haversine Load and Deformation versus Time Relationships

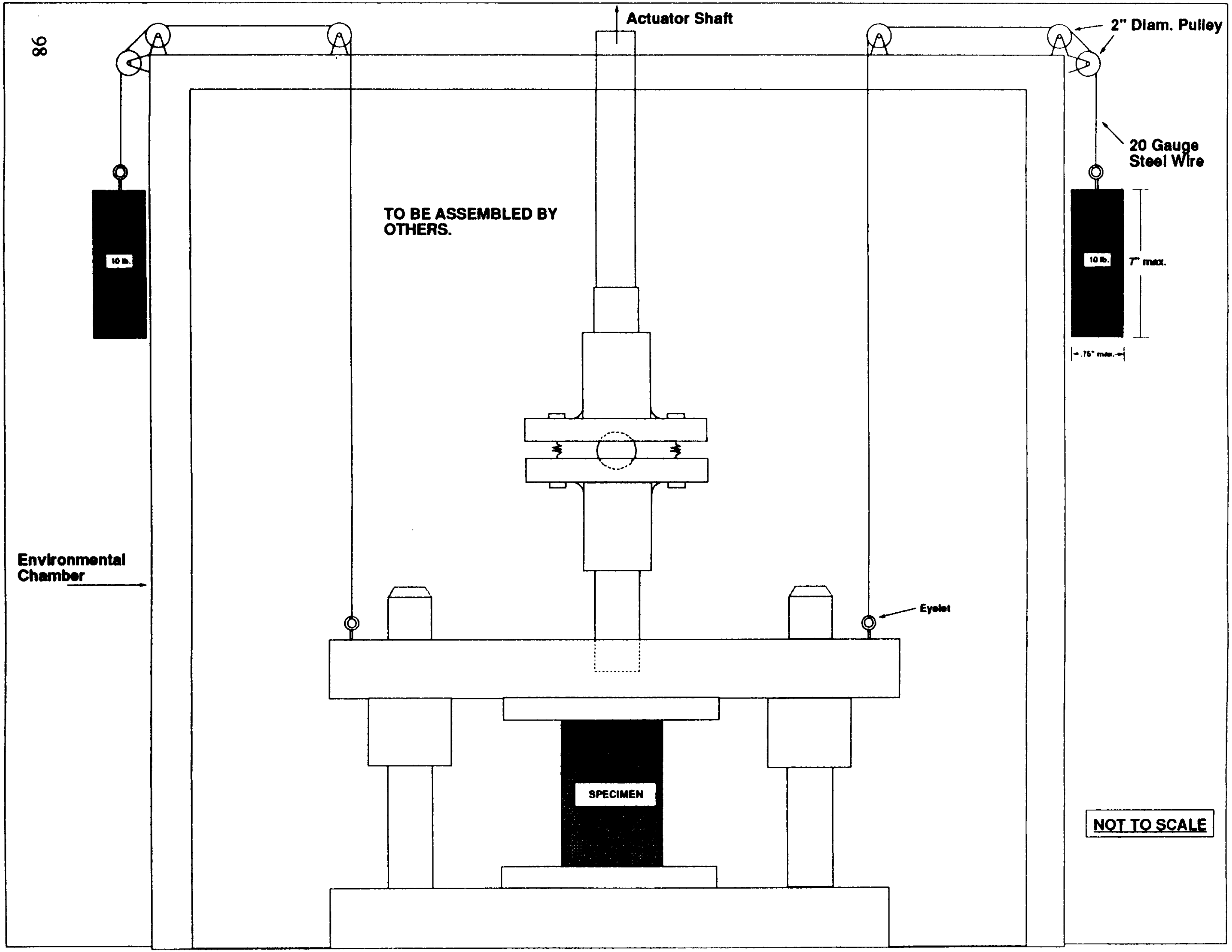


Figure 1-3. Illustration of Die Set and Counter Balance Device

Measuring and Recording System

The measuring and recording system includes sensors for measuring and recording horizontal and vertical deformations. The system is capable of recording horizontal deformations in the range of 0.000005 inch (0.00015 mm) of deformation.

The measuring or recording devices also provide real time deformation and load information and are capable of monitoring readings on tests conducted to 1 Hz. Computer monitoring systems are used to generate real time plots for viewing as the test progresses.

Horizontal Deformation Measurements

The transducers used to measure horizontal deformations are located at mid-height and opposite each other along the specimen's horizontal diameter (Figure 1-1). Positive contact between the transducer tip and specimen is maintained during the test procedure by using spring loaded transducers and the attachment of a suitable head ("half-moon" shaped) as a contact point. In addition, the two horizontal transducers are wired so that each transducer can be read independently and the results summed during the test program.

Vertical Deformation Measurement

The two transducers used to measure vertical deformations are located on opposite sides of the upper platen of the load frame (Figure 1-1). These two transducers are located equidistant from the actuator shaft and on a line coincident with the center of the two guide posts of the load frame and the center of the actuator shaft. The sensitivity of these measurement devices was selected to provide the level of deformation readout required. A positive contact between the vertical transducers and the upper platen of the load frame is maintained during the test procedure. In addition, the two transducers are wired so that each transducer can be read independently and the results averaged during the test program.

Sample Handling Preparation and Marking

Size Requirements

Resilient modulus testing is being conducted on asphalt concrete specimens that are extracted from a single pavement layer and are greater than 1.5 inches but less than 3.0 inches in thickness. The desired thickness for testing is 2.0 inches. If the thickness of a particular AC layer scheduled for testing is one inch or more greater than the desired testing thickness of 2 inches, then the two inch specimen to be used for testing is obtained from the middle of the AC layer by sawing the specimen. SHRP test samples which have projections or depressions higher or deeper than 0.1 inch were not tested unless there were no other suitable cores available. In addition, specimens with ends which are skewed (either end of the specimen

departs from perpendicularity to the axis by more than 0.5 degrees or 1/8 inch in 12 inches) were not tested. Cores which have smooth uniform curved surfaces as well as smooth and parallel top and bottom diametral faces were desired. Cores with ridges and grooves on the sides were not tested.

Specimens to be Tested

Six AC core locations were designated for the P07 test on every flexible pavement test section in the GPS study (Figure 1-4). The designated locations at the approach end of the section were: C7 (for indirect tensile strength test using Attachment A of Protocol P07); and C9 and C10 (for resilient modulus testing using Protocol P07). The designated locations from the leave end of the test sections were: C19 (for indirect tensile strength test using Attachment A of Protocol P07); and C21 and C22 (for resilient modulus testing using Protocol P07).

If any of the test specimens obtained from the specified core locations were damaged or untestable, other cores within the same grouping, but which have not been identified for other testing, were substituted for M_r testing.

Sample Storage Prior to Testing

Adequate moisture and temperature controlled storage of bituminous materials prior to testing was an important part of the resilient modulus process. Care was taken to insure that specimens did not deform or otherwise become unfit for testing due to high heat or other adverse conditions. Asphaltic concrete cores were stored between 50 °F and 70 °F with a flat side down and fully supported. Identification markings assigned to each sample were retained until the specimen was disposed of. Specimens were not disposed of until all tests were complete and the results had undergone appropriate QA/QC procedures to insure reasonable results.

Preparation of Specimens Prior to Testing

The test specimens designated for M_r testing are selected and prepared according to strict guidelines. If the field cores included two or more different layers, the layers are separated at the layer interface by sawing the field core with a diamond saw in the laboratory. Layers which contain more than one lift of the same material are tested as is. The lifts are not separated. Thin layers, (less than 1.5 inches in thickness) are removed from other testable layers. Any combination of thin layers which do not meet the testable layer criteria are separated from each other by sawing.

The diametral axis is marked on each test specimen to be tested using a suitable marking device (Figure 1-5). The axis is marked parallel to the traffic direction symbol (arrow) or "T" marked during the field coring operations. Slight adjustments in the marking locations are

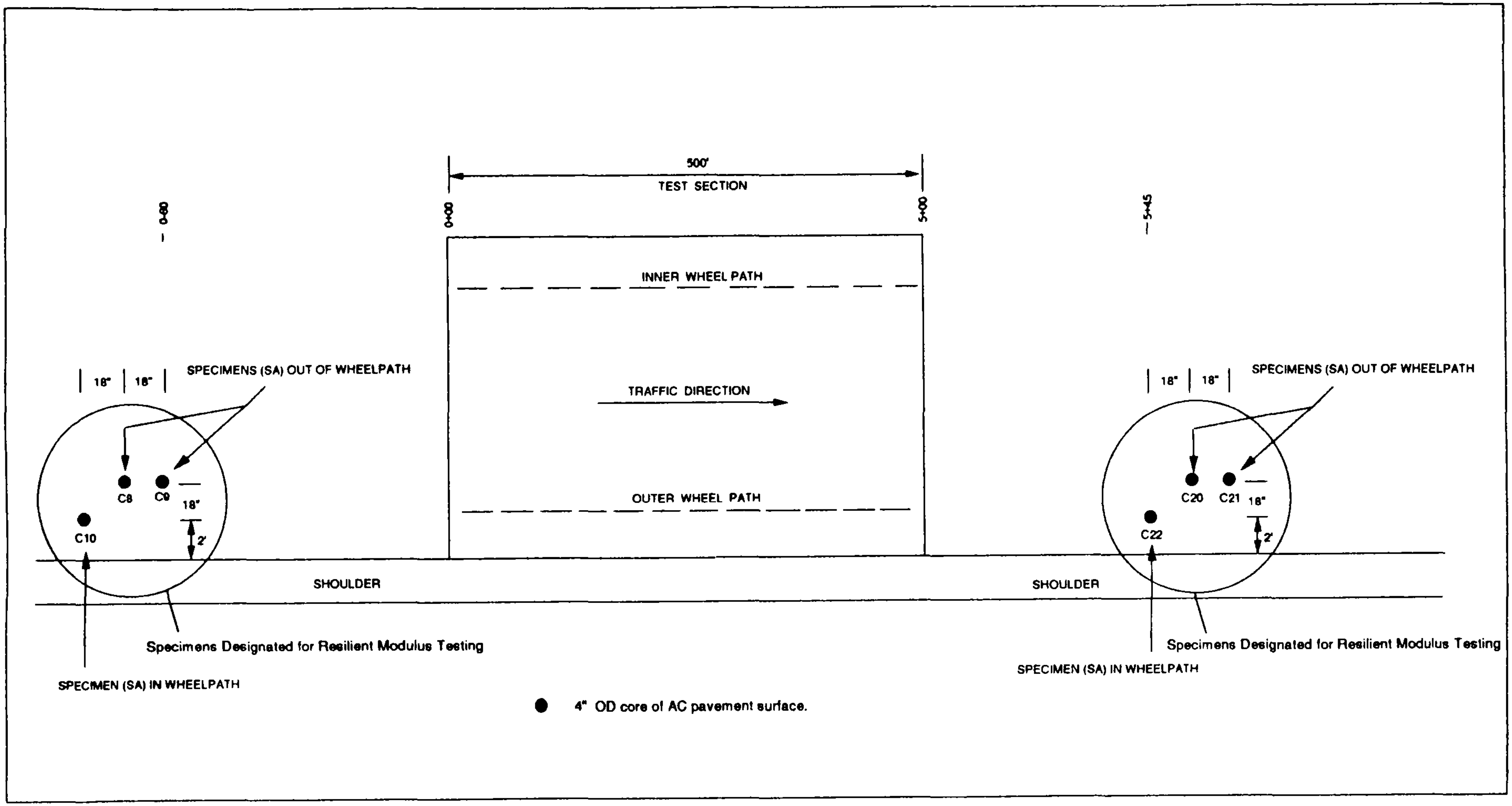


Figure 1-4. Location of Specimens Designated for Resilient Modulus Testing

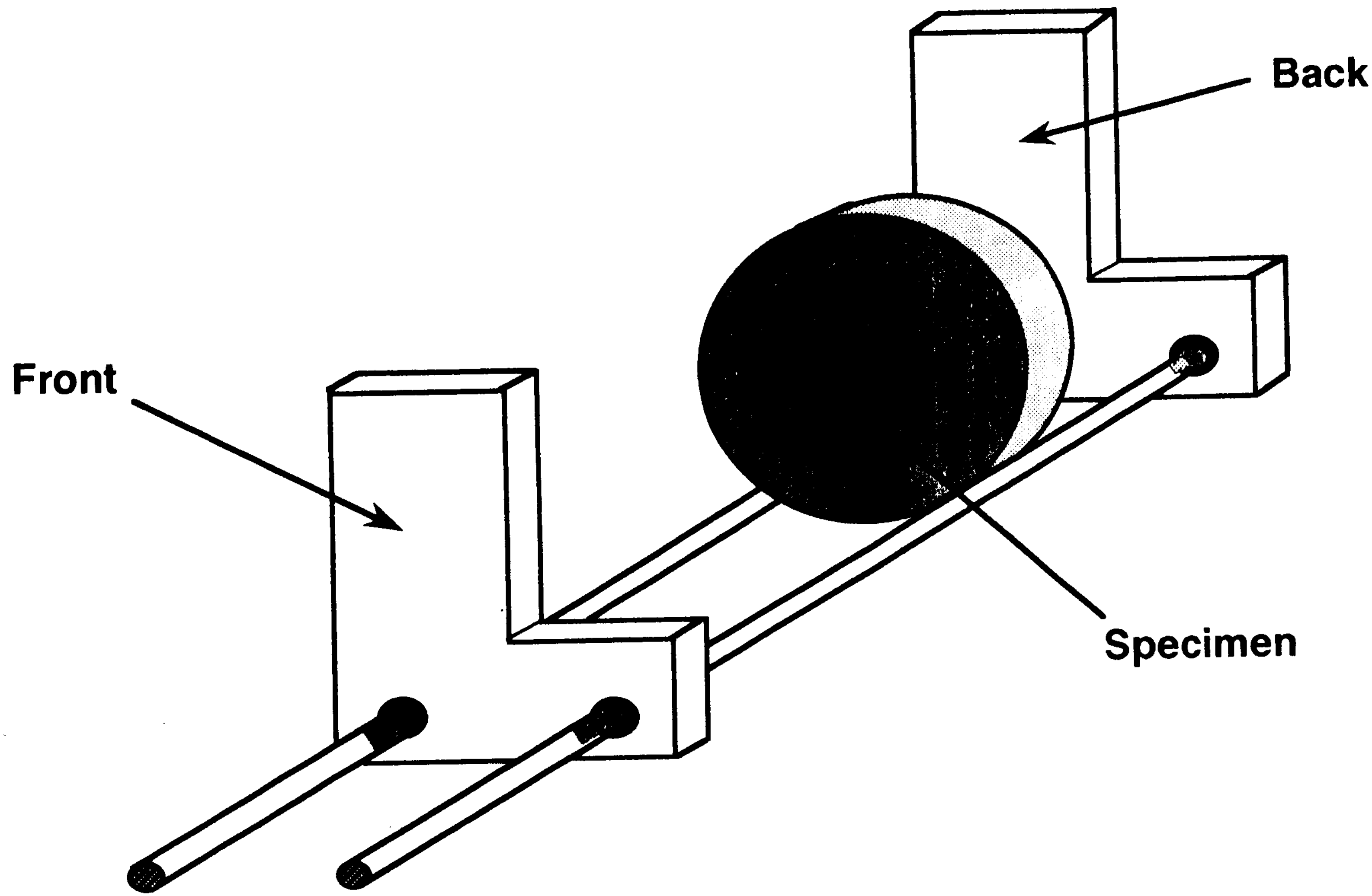


Figure 1-5. Illustration of a Suitable Specimen Marking Device

allowed to prevent the placement of the loading strips directly on exposed large aggregate particles. The thickness of each specimen is then measured to the nearest 0.01 inch (.25 mm). This thickness is determined by averaging three measurements taken equally spaced around the test specimen with a single center measurement.

The diameter of each test specimen is determined prior to testing to the nearest 0.01 inch (0.25 mm) by averaging a minimum of two diametral measurements. The diameter of the axis parallel to the direction of traffic is measured first. Subsequently, the diameter of the axis perpendicular (90 degrees) to this axis is measured. These two measurements are averaged to determine the diameter of the test specimen. If the average diameter of the core is less than 3.85 inches or exceeds 4.15 inches, the core is not to be tested. In this case, a replacement core is selected for the resilient modulus test.

Test Procedure

General

The asphalt cores are placed in a controlled temperature cabinet/chamber and brought to the specified test temperatures. Unless the core specimen temperature is monitored in some manner and the actual temperature known, the core samples should remain in the cabinet/chamber for a minimum of 24 hours prior to testing.

The tensile strength of the designated test specimens is determined at 77 ° ± 2 °F using the following procedure:

- The test specimen is marked, placed in the loading apparatus and positioned (this is a critical alignment and it is conducted with great care).
- A compressive load is applied along the axis marked parallel to traffic at a controlled deformation rate. A deformation rate of 2 inches (50.8 mm) per minute is used.
- The load is monitored during the entire loading time, or until the load sustained by the specimen begins to decrease. The indirect tensile strength is then calculated using the following equation:

$$S_t = (1.273 \times P_o)/t \times \{\sin (57.2958 / D) - (1 / [2 \times D])\}$$

or

$$S_t = 0.156 \times P_o/t, \text{ for a 4.00 inch diameter core.}$$

where:

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

Alignment and Specimen Seating

At each temperature, the test specimen is 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 (Figure 1-6). A check is also made to insure that the midpoint of the specimen in the lengthwise (or thickness) direction is located and coincident with a vertical line of action through the test machine actuator shaft and the shank of the Load Guide Device. The alignment of the front face of the specimen is 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 is similarly aligned. The head of the traffic direction arrow is always located at the top (twelve o'clock) position and the upper surface (i.e., the newer pavement surface) facing to the front.

Prior to testing the electronic measuring system is adjusted and balanced as necessary. After the horizontal deformation transducers are mounted in the holding device, adjustments are required in the relative position of the transducers in order to match the mechanical "null" position with the electrical "null" or a near zero voltage position (a similar "null" position is required for the transducers used to measure the vertical deformations during testing). When starting from the "null" position, the "travel" of the transducer shaft is sufficient to require no further adjustment in the transducer position for the duration of a test.

Preconditioning

Preconditioning and testing are conducted while the specimen is located in the temperature-control cabinet. Selection of the applied loads for preconditioning and testing at the three test temperatures is based on the tensile strength at 77 °F, determined as specified previously. Tensile stress levels of 30, 15, and 5 percent of the tensile strength, measured at 77 °F (25 °C), are used in conducting the resilient modulus determinations at the test temperatures of 41 ± 2, 77 ± 2 and 104 ± 2 °F (5, 25 and 40 °C ± 1 °C), respectively. Minimum specimen contact loads of 3, 1.5 and .5 percent of the 77 °F tensile strength value are maintained during resilient testing for test temperatures, respectively, of 41 ± 2, 77 ± 2 and 104 ± 2 °F (5, 25 and 40 ± 1 °C).

The sequence of resilient modulus testing consists of initial testing at 41 °F, followed by intermediate testing at 77 °F and final testing at 104 °F. The test specimens are brought to the specified temperature prior to each test (i.e. initial, intermediate and final). The test specimen is then 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

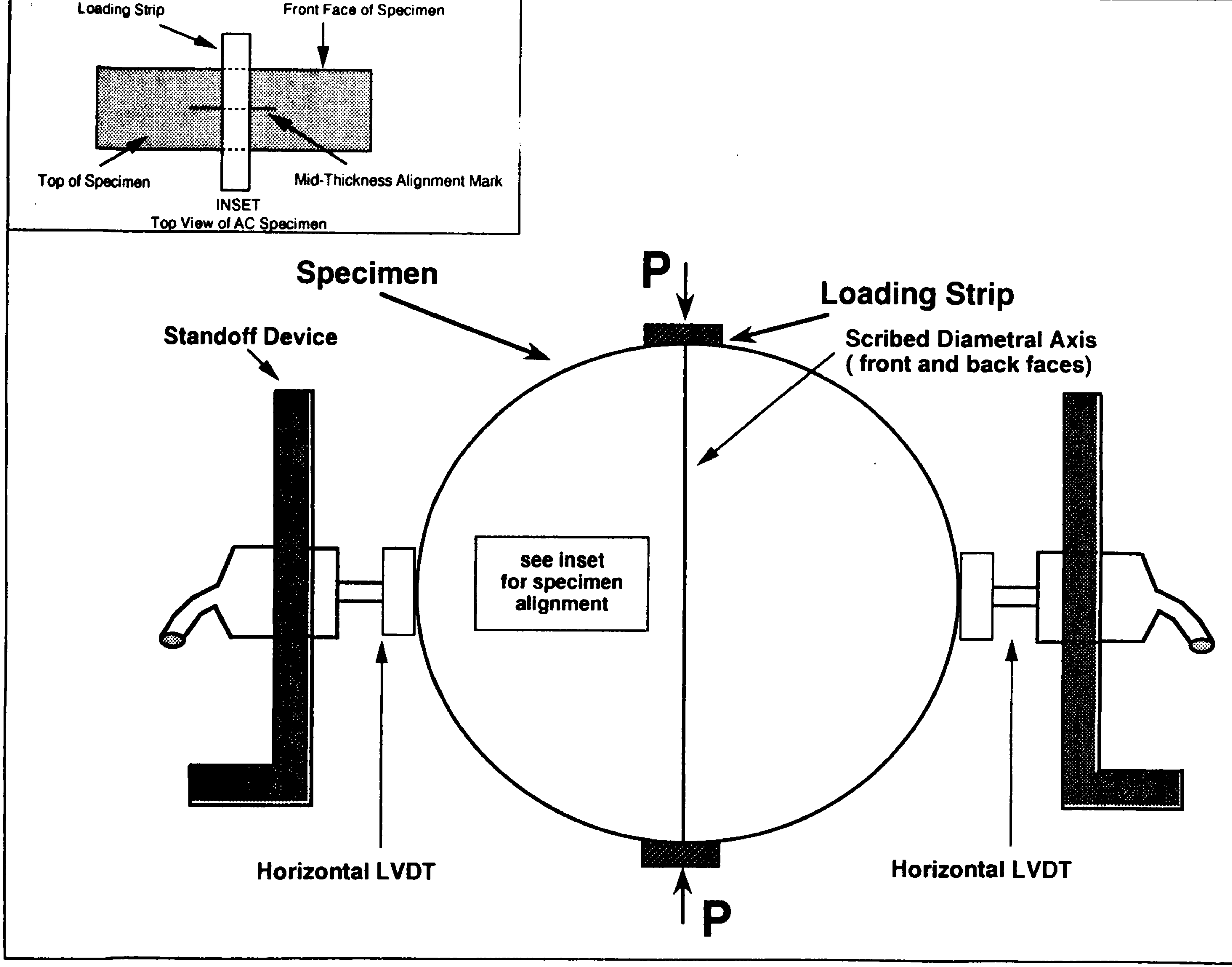


Figure 1-6. Positioning of Horizontal LVDTs and Illustration of Correct Specimen Alignment

minimum of ten successive horizontal deformation readings agree within 10 percent. The number of load applications to be applied depends 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. If adequate horizontal deformations (greater than 0.0001 inches) are not recorded using 5, 15 and 30 percent of the tensile strength measured at 77 °F (25 °C), then the loads are increased in load increments of 5 (i.e. 10, 15, 20, 25 percent).

Both the horizontal and vertical deformations are monitored during preconditioning of the test specimen. If total cumulative vertical deformations greater than 0.025 inch (0.625 mm) for 41 °F or 0.050 inch (1.25 mm) for 77 ° and 104 °F occur, the applied load is reduced to the minimum value possible at which adequate deformations for measurement purposes can be maintained. If use of smaller load levels does not yield adequate deformations for measurement purposes, the preconditioning is discontinued and an additional 10 load pulses are generated to use in the resilient modulus determination.

Testing

After preconditioning a specimen at a specific test temperature, the AC resilient modulus test is conducted as follows:

- A minimum of 30 load pulses (each 0.1-second load pulse with a rest period of 0.9 seconds) are applied and measured deformations are recorded. The application of load pulses continued beyond 30 until the range in deformation values of five successive horizontal deformation values (i.e. from lowest to highest value) is less than 10 percent of the average of the five deformation values.

- The recoverable horizontal and vertical deformations over the last five loading cycles are measured and recorded after the repeated resilient deformations have become stable. One loading cycle consists of one load pulse and a subsequent rest period. The vertical deformation measurements are also measured and reported. The resilient modulus is calculated along each axis for each rest period and temperature by averaging the deformations measured for the last 5 load cycles.

- When the specimen(s) have been tested along both axes, the specimen is placed in a chamber and raised to the next higher temperature.

- After testing is completed at 104 °F, the specimen is brought to a temperature of 77 ± 2 °F and an indirect tensile strength test is conducted.

Calculations

The M_r equation used in ASTM D4123 (**47**) is based to some extent on work by Hadley et. al. (**48**) in which the equations for the indirect tensile test developed by Hondros (**49**) were used to develop a direct method of estimating modulus. These equations, however, are based on uniform contact pressure or a "flexible" loading condition. The resilient modulus equation utilized in SHRP's P07 Protocol was developed by Hadley (**48**) to account for the use of the "rigid" curved steel loading strips used in applying the repeatedly applied load to the specimen. The P07 equation generally produces M_r values 20 to 25 percent greater than the ASTM equation (**50**). The results produced from this equation reflect a more practical resilient modulus value.

The resilient modulus of elasticity, E, in pounds-force per square inch is calculated as follows:

$$E_{RI} = \frac{P \times D(.080 + .297v + .0425v^2)}{H_I \times t}$$

$$E_{RT} = \frac{P \times D(.080 + .297v + .0425v^2)}{H_T \times t}$$

where:

E_{RI}	=	instantaneous resilient modulus of elasticity, psi.
E_{RT}	=	total resilient modulus of elasticity, psi.
P	=	repeated load, lbf., (P = applied load - minimum contact load)
t	=	thickness of test specimen, in.
D	=	diameter of specimen, in.
H_I	=	instantaneous recoverable horizontal deformation, in.
H_T	=	total recoverable horizontal deformation, ins.
v	=	Poisson's ratio

$$v_{RI} = \frac{.859 - 0.08R_I}{.285R_I - .040}$$

$$v_{RT} = \frac{.859 - 0.08R_T}{.285R_T - .040}$$

and

$$R_i = V_I / H_I$$

$$R_T = V_T / H_T$$

where:

V_I = instantaneous recoverable vertical deformation, in.

V_T = total recoverable vertical deformation, in.

Conclusion

Significant progress has been achieved in the development of the SHRP-LTPP asphalt concrete resilient modulus testing procedure. However, much can still be learned concerning actual production testing using this procedure. This project has the potential to bring the AC resilient modulus test procedures now being used, out of the university laboratories, into the mainstream at routine laboratory testing. This will only be accomplished by proceeding with production type testing for a long period of time. During this time, many factors will be evaluated and the procedure may be streamlined or modified to decrease the complexity of the test and its many processes.

Through the asphalt concrete resilient modulus testing program, it is believed that the impact on pavement performance of various materials and construction procedures currently in use can be established. This test has the potential to help reach may of the objectives set for the SHRP-LTPP program in 1987.

Resilient Modulus of an Unbound Material
SHRP Protocol P46

Similar to the SHRP AC M_r test procedure, the development of the unbound base, subbase and subgrade (SHRP Protocol P46) resilient modulus testing program evolved over most of the SHRP program. An outline and draft test procedure were originally developed by a group of materials testing experts under the direction of SHRP. The first draft of Protocol P46 was essentially based upon AASHTO T274-84 (subsequently withdrawn by AASHTO) and the experience of the experts. The first production version of P46 was issued in July, 1989. Subsequent revisions were instituted by the SHRP Technical Assistance Contractor in November, 1989 and the version currently in use for resilient modulus testing was issued in September 1992. Further refinements of the test procedure are expected as production testing continues.

Summary of Method

The resilient modulus of an unbound material was determined by repeated load triaxial compression tests on test specimens of the unbound material samples. Resilient modulus was defined as the ratio of the amplitude of the repeated axial stress to the amplitude of the resultant recoverable axial strain. SHRP Protocol P46 describes the methods and procedures for preparing and testing unbound granular base, subbase materials, and subgrade soils to estimate resilient modulus values representative of stress states beneath flexible and rigid pavements subjected to moving wheel loads.

The methods described in Protocol P46 are applicable to: undisturbed samples of natural and compacted subgrade soils, and to disturbed samples of unbound base and subbase and subgrade soils prepared for testing by compaction in the laboratory. The value of resilient modulus (M_r) determined from this protocol procedure is a measure of the elastic modulus of unbound base and subbase materials and subgrade soils recognizing certain nonlinear characteristics.

The resilient modulus (M_r) values generated by this test procedure can be used with structural analysis models to calculate pavement structural response to wheel loads and with pavement design procedures to design pavement structures.

The resilient modulus test provides a basic constitutive relationship between stress and deformation of pavement construction materials for use in structural analysis of layered pavement systems. It also provides a means of characterizing pavement construction materials, including subgrade soils under a variety of conditions (i.e. moisture, density, etc.) and stress states.

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

Testing Equipment

SHRP requirements for the modulus testing are very strict regarding equipment which shall be used. The apparatus consists essentially of the following:

- triaxial pressure chambers,
- loading device,
- load and specimen deformation response equipment,
- sample preparation equipment,
- miscellaneous apparatus.

The pressure chamber contains the test specimen and the confining fluid during the test. Figure 1-7 illustrates this apparatus. Air is used in the triaxial chamber as the confining fluid for all SHRP testing. The external loading device is capable of providing a variable magnitude of repeated loads for fixed cycles of load and rest period. A closed-loop electrohydraulic system is used for all SHRP testing.

The axial load measuring device used for SHRP testing is an electronic load cell located between the specimen cap and the loading piston. Test chamber pressures are monitored with conventional pressure gauges manometers or pressure transducers. Deformation measuring equipment consists of two linear variable differential transducers clamped to the piston rod outside the test chamber. Internally mounted transducers were found to be inefficient for production type resilient modulus testing.

A variety of equipment is required to prepare undisturbed samples for testing and to obtain compacted specimens that are representative of field conditions. Use of different materials and different methods of compaction in the field requires the use of varying compaction techniques in the laboratory.

Miscellaneous equipment used by the SHRP laboratories included calipers, micrometer gauges, steel rule (calibrated to 0.02 inch), rubber membranes from 0.01 to 0.031 inch thickness, rubber O-rings, vacuum source with bubble chamber and regulator, membrane expander, porous stones, scales, moisture content cans and data sheets.

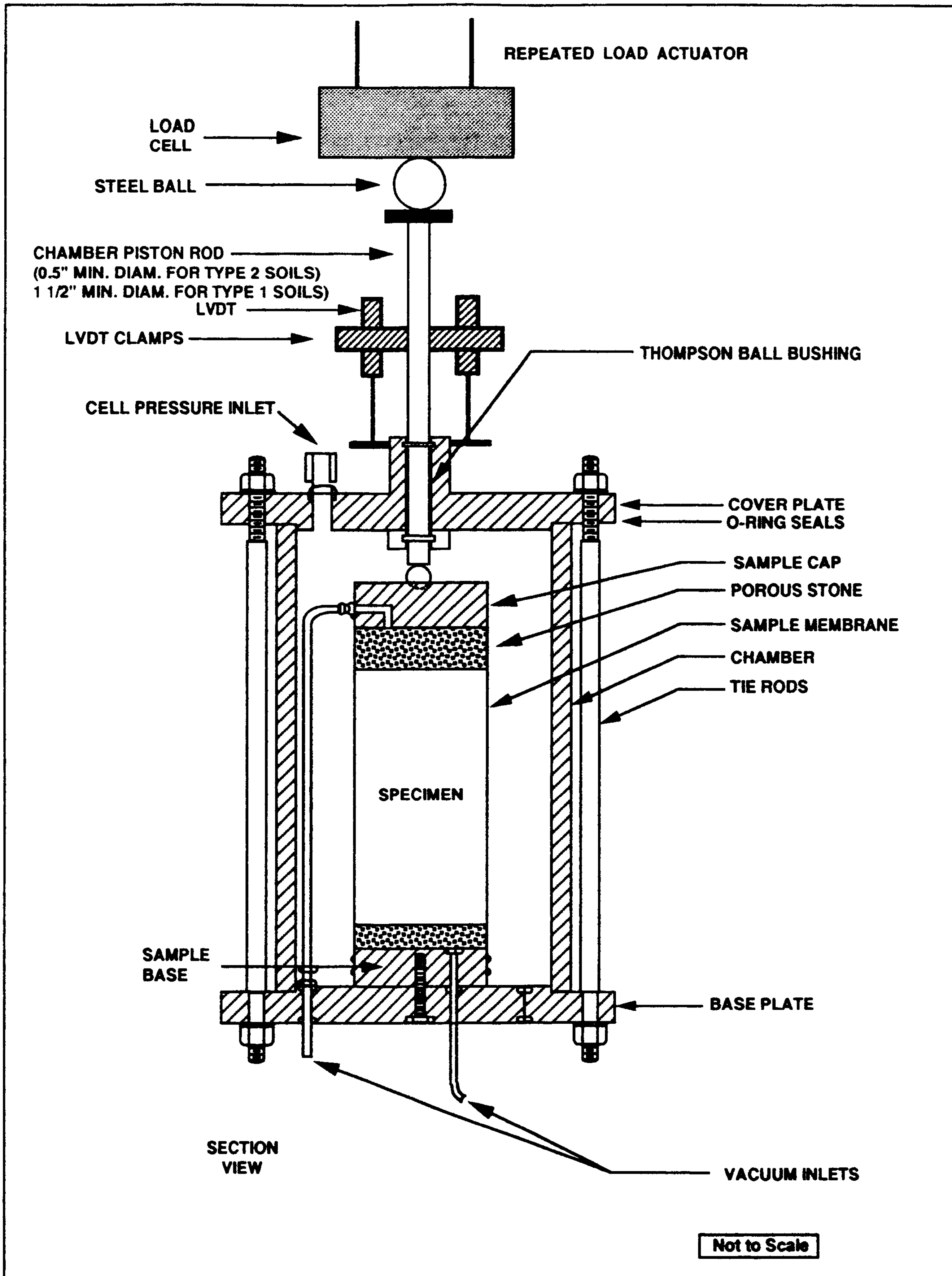


Figure 1-7. Triaxial Chamber with External LVDTs and Load Cell

Sample Types

For SHRP resilient modulus testing, soil types were divided into two classes, type 1 and type 2 soils. Type 1 materials include all unbound granular base and subbase material and all untreated subgrade soils which met the criteria of less than 70 percent passing the No. 10 sieve material and include all subgrade soils not meeting the criteria of Type 2 soils. Generally, thin-walled tube samples of untreated subgrade soils fall in the type 2 category. Testing parameters and compaction procedures used for type 1 soils are different from those specified for type 2 soils.

Type 1 Soils

Type 1 soils are prepared for testing by recompacting the soil in a six-inch split mold which has a height of 12 inches. Compaction forces are generated by a small hand-held air hammer. The compaction process is described in detail in the latest version of Protocol P46. Every type 1 soil sample must be recompacted to the approximate in situ density and moisture content. Moisture content values and density used for recompaction are obtained from in situ density measurements made during the field material sampling and testing program.

After the samples are compacted, they are inserted in the triaxial chamber, a confining pressure of 15 psi is introduced and 1000 applications of an axial deviator stress of 15 psi are applied using a haversine shaped load pulse consisting of a 0.1 second load followed by a 0.9 second rest period. After the preconditioning phase is complete, the confining pressure and deviator stress is reduced to 3 psi and the testing sequence begins. The entire testing sequence for Type 1 soils is shown in Table 1-1.

After completion of the resilient modulus test procedure, a check is made of the total vertical permanent strain that the specimen was subjected to during the resilient modulus portion of the test procedure. If the total vertical permanent strain did not exceed five percent, then a "quick shear" test procedure is conducted. If the total vertical permanent strain exceeded five percent, then the test is deemed complete. If the shear test is conducted, a constant axial strain is applied to the specimen until the load values decrease with increasing strain, five percent strain is reached or the capacity of the load cell is reached. The stress-strain curve for the specimen is plotted for the quick shear procedure. At the completion of all testing, the sample is subjected to a moisture content test in accordance with SHRP Protocol P49 and all results recorded on the appropriate data sheets.

Type 2 Soils

Type 2 soils are prepared for testing using procedures different than type 1 soils. Type 2 soils can either be thin-wall tube samples or bulk samples. If the thin-wall tubes are available and acceptable for the resilient modulus test, then <u>no</u> bulk sample is needed to reconstitute the test sample. The "undisturbed" thin-wall sample is then used for resilient modulus

Table 1-1. Testing Sequence for Type 1 Soils

Sequence No.	Confining S_3 psi.	Pressure Dev. S_d psi.	Stress $0.1S_d$ psi.	Contact Load Number of Load Applications
0 (preconditioning)	15	15	1.5	1000
1	3	3	0.3	100
2	3	6	0.6	100
3	3	9	0.9	100
4	5	5	0.5	100
5	5	10	1.0	100
6	5	15	1.5	100
7	10	10	1.0	100
8	10	20	2.0	100
9	10	30	3.0	100
10	15	10	1.0	100
11	15	15	1.5	100
12	15	30	3.0	100
13	20	15	1.5	100
14	20	20	2.0	100
15	20	40	4.0	100

determinations. If the thin-walled tube sample is not acceptable then bulk samples are used to reconstitute the test specimen for M_r testing.

For thin-walled tube samples, the SHRP laboratories trimmed the specimens using appropriate procedures. To be suitable for resilient modulus testing, a specimen approximately 5.6 inches long is trimmed from the thin-walled tube. The specimen is then placed in a rubber membrane and is ready for testing. If a good undisturbed subgrade sample is unavailable, a reconstituted specimen must be used. The compaction process used for type 2 soils is detailed in SHRP Protocol P46.

After the test specimens are recompacted to approximately in situ densities and moisture, they are inserted into the triaxial chamber, a confining pressure of 6 psi is introduced and 1000 applications of a deviator stress of 4 psi are applied using a haversine shaped load pulse consisting of 0.1 second load followed by a 0.9 second rest period. After the preconditioning phase is complete, the deviator stress is reduced to 2 psi and the testing sequence begins. The entire testing sequence for Type 2 soils is shown in Table 1-2. After completion of the resilient modulus test procedure, a check is made of the total vertical permanent strain that the specimen was subjected to during the resilient modulus portion of the test procedure. If the total vertical permanent strain did not exceed 5 percent, then a "quick shear" test procedure is conducted.

If the total vertical permanent strain exceeded 5 percent, then the test is deemed complete. If the shear test is conducted, a constant axial strain is applied to the specimen until the load values decrease with increasing strain, 5 percent strain is reached or the capacity of the load cell is reached. The stress-strain curve for the specimen is plotted for the quick shear procedure. At the completion of all testing, the sample is subjected to a moisture content test as per SHRP Protocol P49 and all results recorded on the appropriate data sheets.

Calculations

The resilient modulus is calculated using the following equation:

$$M_r = S_d/e_r$$

where:

S_d = repeated axial deviator stress and is the difference between the major and minor principal stresses in the triaxial test, and

e_r = resilient axial deformation due to the application of the deviator stress.

This value is calculated for each deviator stress and confining pressure. The values are reported on appropriate data sheets and subsequently entered into the NPPDB.

Table 1-2. Testing Sequence for Type 2 Soils

Sequence No.	Confining S_3 psi.	Pressure Dev. S_d psi.	Stress $0.1S_d$ psi.	Contact Load Number of Load Applications
0 (preconditioning)	6	4	0.4	1000
1	6	2	0.2	100
2	6	4	0.4	100
3	6	6	0.6	100
4	6	8	0.8	100
5	6	10	1.0	100
6	4	2	0.2	100
7	4	4	0.4	100
8	4	6	0.6	100
9	4	8	0.8	100
10	4	10	1.0	100
11	2	2	0.2	100
12	2	4	0.4	100
13	2	6	0.6	100
14	2	8	0.8	100
15	2	10	1.0	100

Summary

Significant progress has been achieved in the development of the SHRP-LTPP unbound materials resilient modulus program. Additional lessons will no doubt be learned as the test procedure is used in production style testing over a long period of time. Like the asphalt testing program, testing thus far has been accomplished on a very limited number of samples. However, this process of development and testing has proved very beneficial to SHRP-LTPP program and should go far in advancing the state-of-the-art for resilient modulus testing procedures.

SHRP-LTPP Resilient Modulus Pilot Study

The SHRP asphalt concrete resilient modulus pilot study was initiated to provide important supplemental information related to the SHRP resilient modulus testing program. The test sections represented all four SHRP regions, including twenty-eight states and four Canadian Provinces. Approximately six hundred specimens were subjected to a battery of standard SHRP tests including resilient modulus (**50**).

The results of this pilot study should have a significant impact on the SHRP M_r protocols of the future. An overview of the test procedure and the analysis of data from five of the test sections is presented in this appendix. This preliminary work established variations in modulus values for different test temperatures, varying rest periods, and tests along two different axes of the same sample. The pilot study testing program has yielded valuable results and insight for the resilient modulus test procedures of asphalt concrete.

As the pilot study proceeded limited information was available for the unbound base, subbase and subgrade resilient modulus protocol (Protocol P46). At this time unbound materials resilient modulus pilot study information is limited and is not discussed in depth herein.

The purpose of this testing program was to "debug" the resilient modulus testing procedures and equipment and ensure that the SHRP testing laboratories were performing the test in a competent manner.

Objectives of the M_r Pilot Study

Other primary objectives of this study were as follows:

- to evaluate the SHRP resilient modulus test procedures and determine factors of the tests which could be improved, streamlined, or eliminated
- to develop general resilient modulus testing experience prior to production testing of the specimens
- to allow for the institution and evaluation of in-house laboratory quality assurance/quality control programs prior to production testing
- to insure uniformity in resilient modulus testing between SHRP contract laboratories
- to determine the extent of construction variability present between ends of a test section
- to establish the extent of construction variability between SHRP sections within a state, states within a region, and between regions

In addition, the results of the pilot study were used to define areas in which the SHRP resilient modulus protocol for asphalt concrete could be improved, expanded, or streamlined. SHRP-LTPP asphalt concrete resilient modulus test requirements are defined in Protocol P07.

Pilot Study Testing

The 63 test sections were selected from the GPS-1 (hot mix asphalt concrete over granular base) and GPS-2 (hot mix asphalt concrete over bound base) SHRP experiments for potential use in the study and grouped based on moisture (wet vs. dry), temperature (freeze and no-freeze), subgrade type (coarse vs. fine) and base thickness (low vs. high). Figure 1-8 illustrates the experimental design. Based on these factors, fifty sections were chosen for testing. Test sections were chosen which had a minimum surface and asphalt treated base thickness of 1.5 inches in order to meet the minimum thicknesses required in Protocol P07. Traffic volumes and base types were not used as factors in the experimental design.

Three test specimens of all bound layers were obtained for resilient modulus testing from each end of the test section. Figure 1-4 illustrates the location of these specimens with respect to the pavement test section. Specimens were not obtained from the test section itself due to concerns of creating premature distress in the test section. As illustrated, two specimens were obtained from outside the wheelpath (specimens 1 and 2) and one specimen (specimen 3) was obtained from within the wheelpath. Additional specimens (not shown in Figure 1-4) were obtained from the same general area and were available as replacements for the previously identified specimens.

Initiation of Pilot Study Testing

Each SHRP contract laboratory was required to pass an AC resilient modulus proficiency/calibration testing program before they were cleared to begin pilot study testing. The proficiency program was a rigorous testing sequence performed on synthetic samples (teflon, polyethylene and lucite), as well as, asphalt core samples. The laboratory generated results must fall within a required range for each type of sample before clearance was given to begin pilot testing. See Appendix 2 for a complete description of this proficiency/calibration testing program.

After clearance, each laboratory was provided with a list of the designated specimens for pilot testing. The order of testing of these samples was randomized to minimize bias in the test results. The laboratory proceeded by testing each specimen in accordance with Protocol P07. The data from all the samples were eventually gathered and analyzed to achieve the stated objectives. The results of this pilot study were expected to impact the M_r test requirements (i.e. Protocol P07) since a critical analysis was going to be conducted to define variation in modulus values for different rest periods on the same sample and of the effect of testing two axes of each sample. This pilot study testing program yielded valuable results and insights into the asphalt concrete resilient modulus test procedure.

MOISTURE	WET				DRY			
TEMPERATURE	FREEZE		NO FREEZE		FREEZE		NO FREEZE	
SUBGRADE TYPE / BASE THICKNESS	F	C	F	C	F	C	F	C
LO	242401 (MD) 512004 (VA) 182008 (IN) 196150 (IA)	341638 (NJ) 541640 (WV) 261013 (MI) 271023 (MN)	223056 (LA) 052042 (AR) 412002 (AR)	124108 (FL) 479025 (TN)	382001 (ND) 836454 (MB) 307076 (MT) 901802 (SK)	322027 (NV) 829017 (BC) 201009 (KS) 327000 (NV)	067491 (CA) 404163 (OK) 062053 (CA) 062051 (CA)	321030 (NV) 404165 (OK) 371645 (NC) 068149 (CA)
HI	872811 (ON) 872812 (ON) 182009 (IN)	341033 (NJ) 341034 (NJ)	053071 (AR) 482108 (TX)	134112 (GA) 134113 (GA)	562017 (WY) 469187 (SD) 562020 (WY)	562019 (WY) 567772 (WY) 562037 (WY)	404154 (OK) 062004 (CA) 062647 (CA)	068201 (CA) 041062 (AZ) 041065 (AZ)

Figure 1-8. Pilot Study Experimental Design

Initial Pilot Study Results

Resilient modulus testing for the fifty test sections within the SHRP GPS program was undertaken and preliminary results of the testing program were analyzed. The testing program for all 50 sections, however, could not be completed because M_r testing for the 50 sections was not accomplished within the first five years of SHRP-LTPP.

Five sections were investigated in the initial analysis (Table 1-3) to: 1) establish initial estimates of variance (Mean Squares) in resilient modulus results for the surface and base layers, 2) establish the number of resilient modulus tests within ends required to fully characterize HMAC resilient modulus variance, and 3) evaluate the effects of test temperature, axis of test and rest periods on the resilient modulus of the surface and base layers. The resilient modulus data obtained from this study were also eventually used as one input in determining construction variability of the SHRP GPS test sections.

Resilient Modulus Mean Squares Estimates

Summaries of the individual resilient modulus mean squares estimates pertaining to the five SHRP sections are presented in Tables 1-4 and 1-5 for the surface and base layers respectively. Within each table, the mean squares associated with end-to-end and within-end variation are listed separately for test specimens extracted both within and outside the wheelpath. In general, it can be seen that the average mean squares for end to end variation outside the wheelpath are quite large when compared with variation within the wheelpath for both the surface (19.729 versus 1.335) and base (5.958 versus 1.729) layers. On the other hand, the within-end variation is fairly uniform for both layers either inside or outside the wheelpath.

A summary of the resilient modulus mean squares estimates for combinations of source, location, layer and section yielded values of 1.0×10^{10} $(\text{psi})^2$ or greater. It is interesting to note that the twenty combinations represent one-half of the total number (40) investigated for the five test sections. Fourteen of the combinations listed in Table 1-4 are related to the two Canadian sections and, in fact, the twelve higher mean squares estimates belong to the Canadian sections. At this stage of the analysis, there was no definitive explanation for the disparity in resilient modulus mean squares estimates between the two Canadian sites and the three southern United States sites. It is possible that the differences could be explained in an evaluation of mix design information including asphalt viscosity, since the mean resilient modulus estimates presented in Figure 1-9 indicate that the two Canadian sites (i.e., 872811 and 872812) have significantly greater resilient modulus values than the other sites (i.e.,

Table 1-3. SHRP Sections Included in Initial M_r Pilot Study Results

Section Number	SHRP Section Designation Province	State/
1	404154	Oklahoma, USA
2	512004	Virginia, USA
3	223056	Louisiana, USA
4	872811	Ontario, Canada
5	872812	Ontario, Canada

Table 1-4. End-to-End and Within-End Mean Squares for AC Surface Layer

SHRP Section	Surface Layer End-to-End out of WP	Within-Ends in the WP	S_1 vs S_3	S_2 vs S_3	Out of WP
223056	0.1142	0.0878	0.2435	0.0962	0.0391
404154	0.0959	0.6408	1.6636	0.7713	2.2850
512004	0.3181	0.6597	0.0111	0.3232	0.4515
872811	15.9920	0.3279	1.3439	6.4107	10.2324
872812	82.1270	4.2366	7.6856	6.6660	1.3586
Average	19.72944	1.33456	2.189540	2.85348	2.87332

S_1, S_2, S_3 represent specimen locations at the ends

Table 1-5. End-to-End and Within-Ends Mean Squares for AC Base Layers.

SHRP Section	Surface Layer End-to-End Out of WP	Within-Ends in the WP	S_1 vs S_3	S_2 vs S_3	Out of WP
223056	1.0156	3.6999	0.2764	0.0632	0.3058
404154	0.8084	0.0387	0.8657	0.7402	0.5087
512004	0.0067	0.0112	1.4947	0.3344	3.2418
872811	20.5669	0.3500	2.1844	8.0490	2.9291
872812	7.3914	4.5489	0.0268	3.8410	4.4151
Average	5.957800	1.72974	0.96960	2.60556	2.2801

S_1, and S_2 out of wheel path, S_3 within the wheel path.

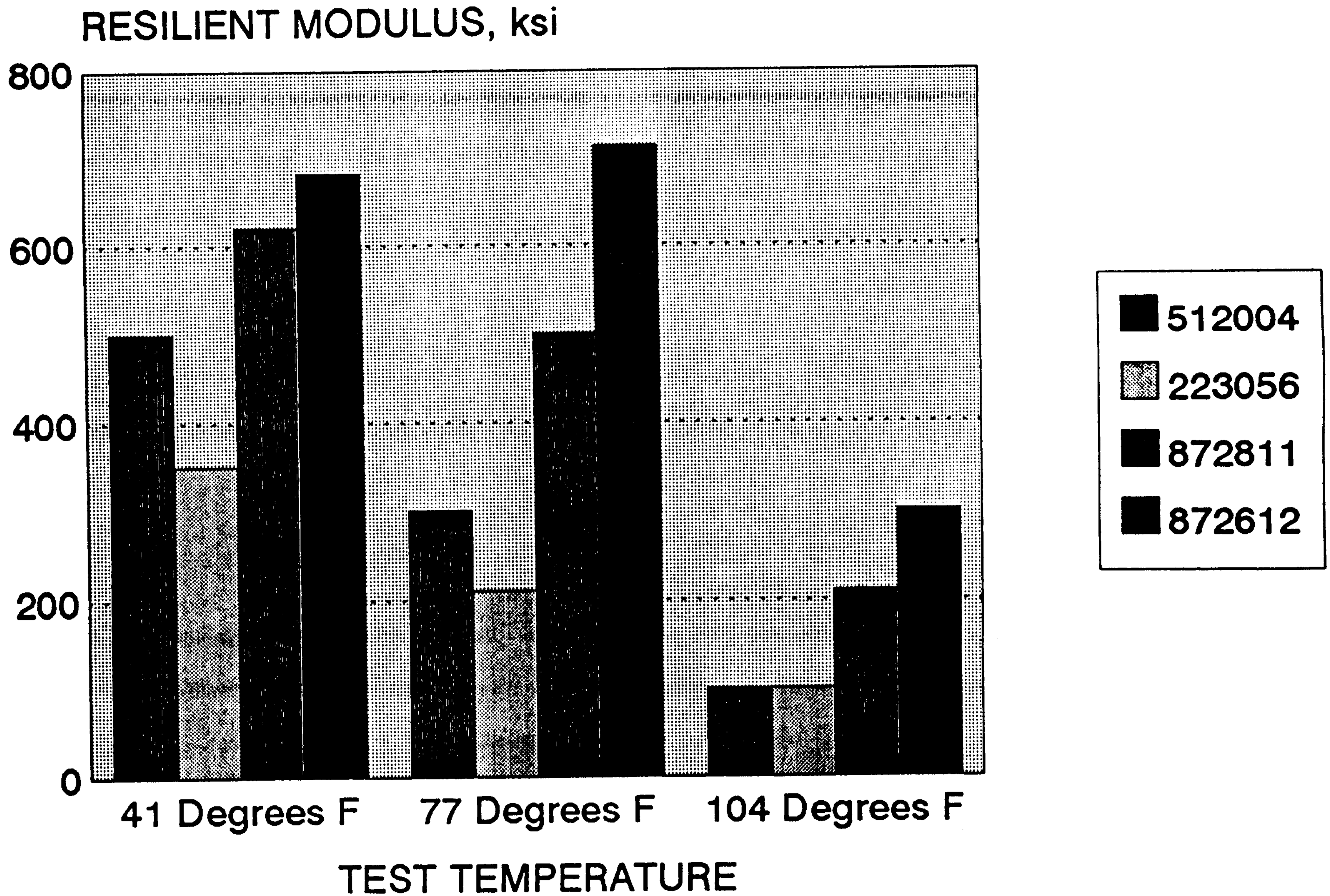


Figure 1-9. Modulus versus Temperature

512004 and 223056). This illustrates one of the goals of the pilot study in that an effort was being made to determine construction variability parameters between test sites within a state or province, between states or provinces and between climatic regions.

In addition, seven of the twenty combinations listed in Table 1-6 are related to end-to-end variation, while the remaining 13 combinations are related to the within-end variation. It should also be noted that the top three higher values represent end-to-end variation. On the other hand, the mean of mean squares estimates for end-to-end variation is 19.424×10^{10} while the mean for within-end mean squares is 4.408×10^{10}.

The combinations in Table 1-6 are distributed almost equally between outside the wheelpath, OWP, and inside the wheelpath, IWP. The eleven combinations for OWP share an average mean squares estimate of 13.786×10^{10}, while the nine IWP combinations have an average of 4.626×10^{10}.

Finally, the combinations for surface and base layers are also about equally distributed with nine surface entries with an average mean squares of 19.666×10^{10} and 11 base entries with an average of 5.571×10^{10}. Based on this information, the end-to-end, within wheelpath and surface layer mean squares estimates appear to be critical. However, some individual combinations involving within-ends, outside the wheelpath and base layer also yielded high mean squares estimates. As a result, the information must be investigated further to establish the resilient modulus testing needs relative to the number of samples within the end of the test section, as well as, to define the significant testing criteria (ie. temperature, axis and rest periods).

Number of Tests Within Ends

The Burr-Foster Q test for homogeneity was used to investigate the equality of variances in the end-to-end variance inside and outside the wheelpath. This method was also used to investigate the end-to-end and within-end variances along the wheelpath and the within-end variances both inside and outside the wheelpath. The results of this investigation are presented in Table 1-7.

The basic hypothesis offered in all cases was that the variances were homogeneous. In four of the cases, the hypothesis was accepted and equal variances were considered realistic for: 1) end-to-end variation both inside and outside the wheelpath for the surface layer (layer 1), 2) end-to-end and within-end variation for the base (layer 2), and 3) within-end variation for inside and outside the wheelpath for both the surface and base layers.

On the other hand, the hypothesis of equal variances for end-to-end within the wheelpath for surface and equality of variances for end-to-end and within-end resilient modulus results for the surface layer could not be accepted.

From this information, it is apparent that there are differences in end-to-end resilient modulus results and within resilient modulus results, particularly for the surface layer (layer 1). Based

Table 1-6. Summary of Mean Squares Estimates of Resilient Modulus, M_r

Source	Location	Layer	Section	Ms $[10^{10} (psi)^2]$
End-to-End	OWP	Surface	872812	82.1270
End-to-End	OWP	Base	872811	20.5669
End-to-End	OWP	Surface	872811	15.9920
Within-Ends	OWP	Surface	872811	10.2324
Within-Ends	IWP	Base	872811	8.0490
Within-Ends	IWP	Surface	872812	7.6856
End-to-End	OWP	Base	872812	7.3914
Within-Ends	IWP	Surface	872811	6.4107
End-to-End	IWP	Base	872812	4.5489
Within-Ends	OWP	Base	872812	4.4151
End-to-End	IWP	Surface	872812	4.2366
Within-Ends	IWP	Base	872812	3.8410
Within-Ends	IWP	Base	223056	3.6999
Within-Ends	OWP	Base	512004	3.2418
Within-Ends	OWP	Base	872811	2.9291
Within-Ends	OWP	Surface	404154	2.2850
Within-Ends	IWP	Surface	404154	1.6636
Within-Ends	IWP	Base	512004	1.4947
Within-Ends	OWP	Surface	872812	1.3586
End-to-End	OWP	Base	223056	1.1056

Table 1-7. Example of Analysis of Variance for Surface layer OWP vs IWP
SHRP Section 404154, Surface Layer: SA1 vs SA3; ANOVA

Source	df	MS10^{10}(PSI)^2]	F_{calc}
E	1	.0239	
S	1	.3733	00.50
ExS*	1	.7412	
T	2	20.7300	58.15
ExT*	2	.3565	
SxT	2	.0544	00.03
ExSxT*	2	1.8475	
A	1	.6730	19.12
ExA*	1	.0352	
SxA	1	.2680	00.10
ExSxA*	1	.3687	
TxA	2	.0213	00.03
ExTxA*	2	.7438	
R	2	.0164	00.92
ExR	2	.0178	
SxR	2	.0045	00.38
ExSxR*	2	.0118	
TxR	4	.0169	02.35
ExTxR*	4	.0072	
AxR	2	.0154	00.77
ExAxR*	2	.0020	

E = ENDS, S = Wheel path
OWP = Sample obtained outside the wheel path
IWP = Sample obtained inside the wheel path
T = Temperature, A = Axis, R = Rest period

* Appropriate mean squares error term based on end to end variation

From this information, it is apparent that there are differences in end-to-end resilient modulus results and within resilient modulus results, particularly for the surface layer (layer 1). Based on these results, it seems prudent to conduct testing on a minimum of two specimens from each end of each layer (surface and base) in order to define the within end variation. One sample should be obtained from within the wheelpath while the second should be obtained from outside the wheelpath. This approach will allow for development of resilient modulus information at a point (or within batch information) as well as end-to-end (or batch-to-batch information).

Evaluation of Test Parameters

The key element in this portion of the initial study was the determination of the correct random variable to use as an error term in investigating the effects of axis of test, rest period and test temperature on resilient modulus values. There are essentially two possibilities: the end-to-end variation and the within-end variation. Since the overall mean squares average for end-to-end variation (ie. 19.424×10^{10}) is so much larger than the overall mean squares average for within-end variation (4.408×10^{10}) that the random variable selected for continued evaluation was the end-to-end variation.

With the end-to-end variation accepted as the random variable, all interaction terms (ie. various cross products of axis, temperature, rest period and wheelpath) including end-to-end variation formed the error terms used to test the influence of the main effects (ie.. axis, temperature, wheelpath, and rest period individually) and interactions (ie. cross products) of the main effects or factors. The F test is the basis for deciding which factors and combinations of factors (i.e., interaction) influenced the resilient modulus values. In this type of analysis, if it can be ascertained that certain factors can be eliminated as being influential on resilient modulus, it would follow that the M_r test criteria and requirements could be revised and/or reduced to produce a more efficient test procedure. For example, if rest periods are found to be not significant, then future asphalt specimens resilient modulus testing will be conducted with a single rest period instead of the three presently specified.

An example of this type of analysis of variance (ie. ANOVA) is presented in Table 1-7 for the surface layer of SHRP section 404154. In the table, the first column identifies the main effects (e.g., S is wheelpath) and interactions (e.g., E x S is interaction of ends with wheelpath), column 3 presents the mean squares estimates while the fourth column includes the calculated F values. As an example, the calculated values for wheelpath, S, is obtained by dividing the mean squares for wheelpath by the mean squares for the interaction of end variation, E, with wheelpath, S (eq. $F_{calc} = .3733/.7412 = 0.50$). In this type of ANOVA, the significance of the main effects and their interactions is established by comparing the calculated F values with critical F values appropriate for the conditions. If the calculated F values of a main effect or interaction exceed or equal the critical F values, then that particular main effect or interaction would be considered as significant or influential, on resilient modulus test results.

For the ANOVA presented in Table 1-7, the original F value is 40 and the resulting comparisons between the calculated F values and the critical F values yield only test temperature as a significant variable. Since a single ANOVA for a particular layer of one SHRP section would not be considered definitive, a series of 20 separate ANOVA's were developed and analyzed. The 20 analyses include four for each of the five SHRP sections. The four analyses per section are further divided as two for each of the surface and base layers. For each layer, the two remaining analyses involved combinations of the three samples obtained from each end. In both instances, (sample 1 vs. sample 3 and sample 2 vs. sample 3) the combinations include comparisons of locations inside the wheelpath (i.e., samples 1 and 2) and outside the wheelpath (i.e., sample 3).

The results from the 20 separate ANOVA's are summarized in Table 1-8. The table includes only the main effects of wheelpath, test temperature, axis of test and rest period since no significant interaction effects were established. The significant or non-significance of the main effects are defined with a "Y" (Yes, significant) or a "N" (Not significant) in the four columns to the right.

From a review of the tabulated results, it is obvious that temperature is a significant main effect while it is equally obvious that axis of loading is not significant (100 percent "N"'s). In addition, the wheelpath with only two Y entries (10 percent) is likewise considered not significant. The decision concerning the main effects of rest period however, was not as clear cut and required further consideration. In particular, attention was given to the amount of increase or decrease in resilient modulus with the three rest periods. An example of this approach can be seen in Figure 1-10 where a small linear increase of about 10 - 15 percent was observed for SHRP section 223056. All sections exhibited similar results for rest period. For comparison purposes, the effect of test temperature on resilient modulus for the same section is illustrated in Figure 1-11 and for four of the sections in Figure 1-10. The differences in the effects of temperature and rest period are obvious.

The rest period phenomena was investigated further to ascertain if a systematic bias could be confirmed from the data gathering/extraction process conducted during the resilient modulus testing. In this investigation, it was found that the data gathering extraction program used the same number of sampling points for each of the rest periods. When the fixed data point problem was considered further, it was realized that the sampling rate for the three rest periods were different. The sampling rate for the 1.9 second rest period would be one-half the 0.9 second rest period while the sampling rate for the 2.9 second rest period would be one-third of the initial rest period. These sampling rate differences can result in off-peak data extraction errors of about 10 percent and 15 percent respectively. In other words, the peak (maximum) deformation values are highly likely to be obtained with the lower rest period than the higher rest peiods.

Since the calculated differences in the resilient modulus estimates essentially matched those changes in resilient modulus expected because of data extraction/sampling errors, and since the effect of rest period was minimal at best, the effect of rest period was judged to be not significant. Based on this, one level of rest period would be sufficient. However, the lower level rest period (ie. 0.9 second) would be retained in order to more accurately determine the load and deformation because of a much higher sampling rate.

Table 1-8. Results of Analysis of Variance Results for Five SHRP Sections

Section	Layer	Samples	Significant Effect of Wheel Path	Temp.	Axis	Rest Period
404154	Surface	1,3	N	Y	N	N
	Base	1,3	Y	Y	N	N
	Surface	2,3	N	Y	N	Y
	Base	2,3	N	Y	N	N
512004	Surface	1,3	N	Y	N	Y
	Base	1,3	N	Y	N	N
	Surface	2,3	N	Y	N	Y
	Base	2,3	N	Y	N	Y
223056	Surface	1,3	N	Y	N	Y
	Base	1,3	N	Y	N	Y
	Surface	2,3	N	Y	N	Y
	Base	2,3	N	Y	N	N
872811	Surface	1,3	Y	Y	N	Y
	Base	1,3	N	Y	N	Y
	Surface	2,3	N	Y	N	Y
	Base	2,3	N	Y	N	Y
872812	Surface	1,3	N	Y	N	Y
	Base	1,3	N	Y	N	N
	Surface	2,3	N	Y	N	N
	Base	2,3	N	Y	N	Y
	TOTAL		2/20	20/20	0/20	13/20

Y = Significant effect; N = Not significant effect

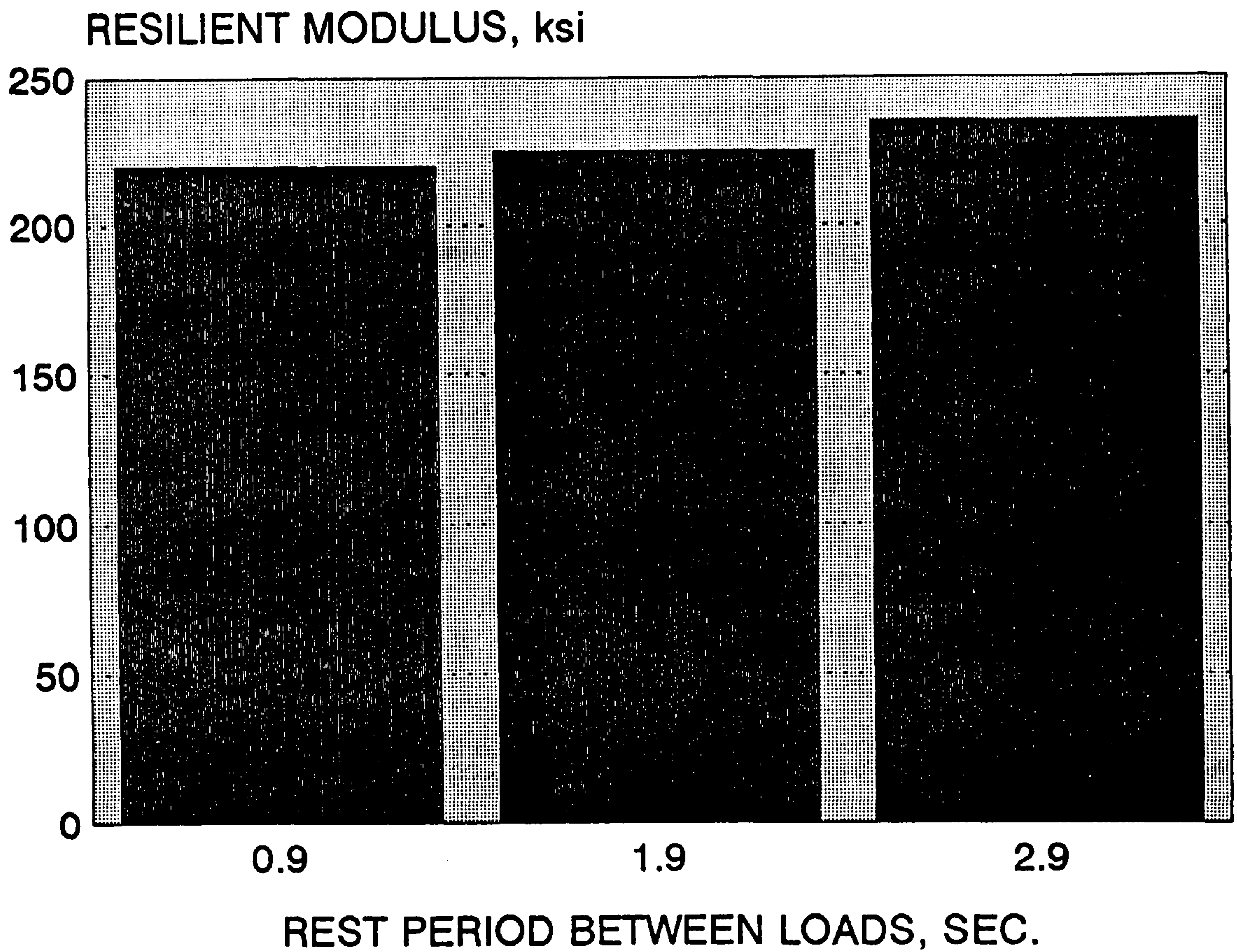


Figure 1-10. Modulus versus Rest Period - Section 223056

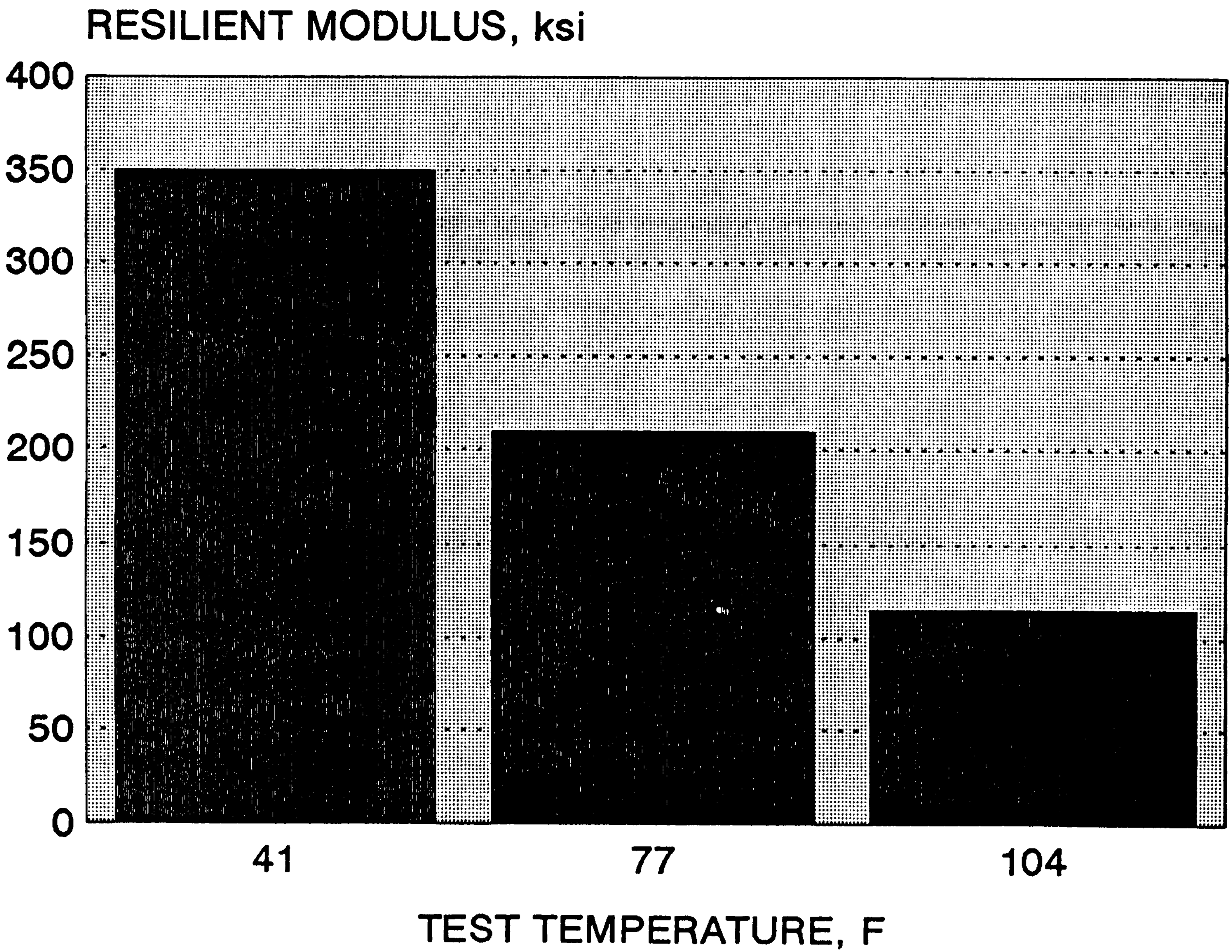


Figure 1-11. Modulus versus Test Temperature - Section 223056

Conclusions

As a result of this initial analysis of pilot study testing data, many of the objectives of the study were achieved. The foremost product was the identification of areas in which the SHRP resilient modulus protocol could be streamlined or certain requirements eliminated. These areas are as follows: 1) two specimens (instead of three) from each end of the test section (one inside the wheelpath and one outside the wheelpath) need to be tested, 2) one rest period (instead of three) is sufficient, and 3) one axis (instead of two) is sufficient. Additionally, it was determined that the three test temperatures are significant and must be retained in the protocol.

As the pilot study progresses, the variability in resilient modulus values will be evaluated between 1) test section sites in a state or province, 2) between states or provinces, and 3) between regions. The results of the resilient modulus testing and other factors will lead to a better understanding of construction and modulus testing variability in the United States and Canada.

A significant amount of data will be produced from the SHRP-LTPP studies which can be used by the highway research community. Relationships between the resilient modulus data, other materials properties, distress and deflection data should be invaluable in evaluating the pavement performance of the LTPP sections.

Appendix 2
SHRP Verification and Proficiency Sample Program Report

Introduction

SHRP management plans, at the inception of the Long Term Pavement Performance (LTPP) research project, included initiatives to insure that appropriate quality management measures would be an integral part of the implementation process. In general, quality management for a project of this magnitude has three recognizable parts, (1) a system used by those performing the work to control the quality of the work performed, (2) a system used by those accepting the work to show that the work conforms with expectations, (3) and a system independently administered which indicates how well the other two systems are performing and concurrently whether modifications to said systems should be considered by management. The supplemental programs discussed in this appendix were planned and approved as components of the third system.

Planning

Expert Task Group and SHRP staff recommendations led to a SHRP decision in 1988 that a vital element in laboratory Assurance (QA) would be the American Association of State Highway and Transportation Officials (AASHTO) accreditation program (AAP). 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 included on-site inspections of equipment and procedures, and participation in applicable proficiency sample series. However, a few critical tests in the SHRP LTPP studies were not included in the accreditation program. After extensive consultation and careful study, it was determined that supplemental programs should be designed to provide assurance of quality test data in a manner similar to that provided by AAP for other tests.

Further, it was recognized that analyses of in situ moisture and density test data from SHRP Long Term Pavement Performance (LTPP) field sections would be desirable on a national (rather than regional only) basis. Since existing standardization and precision requirements for nuclear test equipment is primarily directed toward individual nuclear gauges, it was determined that a supplemental program should be designed to allow variations in response between gauges used in different regions to be entered into SHRP records.

Materials tests requiring supplemental programs were:

- Type I Soil: Resilient modulus (M_R)-triaxial, moisture content, in-situ nuclear moisture/density.
- Type II Soil: M_R-triaxial, moisture content, in-situ nuclear moisture/density.
- Portland Cement Concrete (PCC) Cores: Static modulus of elasticity, Poisson's ratio, splitting tensile strength, compressive strength.
- Asphalt Concrete (AC) Cores: M_R-diametral.
- Laboratory molded Asphalt Concrete: M_R-diametral.

Implementation

A verification program for the in-situ nuclear tests and proficiency sample programs for each of the remaining tests was designed to provide the data necessary for evaluation of test quality. The seven programs, listed below, were approved for implementation.

1. Type I Soil Proficiency Sample Program
2. Type II Soil Proficiency Sample Program
3. Soil Moisture Proficiency Sample Program
4. Inter-Regional Nuclear Gauge Verification Program
5. PCC Core Proficiency Sample Program
6. AC Core Proficiency Sample Program
7. Laboratory Molded AC Proficiency Sample Program

Each program was conducted independently with one exception. The Laboratory Molded AC Proficiency Sample Program utilized certain information developed as a part of the AC Core Proficiency Sample Program. A summary of each of the seven programs is outlined below in the order shown. Three, the 3rd, 4th, and 5th listed, have been completed and a final draft report prepared. One, the 6th listed, should be completed by the end of the fifth year of SHRP-LTPP. The remaining testing programs (1st, 2nd, and 7th listed) should be completed at approximately the same time that tests of LTPP field samples are finished. Researchers or practitioners desiring completely detailed information should obtain a copy of the final research report for the program(s) of interest.

Summaries

Type I Soil

The objectives of the triaxial M_R test program for 6 in. diameter by 12 in. length specimens were as follows: 1) verify calibration and stability of test systems, 2) determine the components of variance of the test attributable to materials, samples, testing, laboratories, 3) prepare within laboratory and between laboratory precision statements in AASHTO/ASTM format, 4) determine the testing proficiency of SHRP contract laboratories, and 5) provide all participants with AMRL type reports on performance.

The Type I Soil Proficiency Sample Program has two separate parts.

Part 1

The first part involved rotation of a set of SHRP reference specimens 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) the acceptable range of reference values had been revealed. The intent of this procedure was to provide participants with an opportunity to verify the calibration of a 6 in. diameter by 12 in. length triaxial resilient modulus (M_R) test system by testing the SHRP set of three synthetic reference specimens using standardized parameters. One additional synthetic specimen was provided for each SHRP contract laboratory to be used for in-house quality control during production testing. These specimens were prepared for SHRP by the Vulcan Materials Company's Laboratory. If a system's response was not within the anticipated range, recalibration of the system was indicated. When response was within the anticipated range, SHRP contract laboratories were requested to test the in-house synthetic specimen furnished by SHRP and to maintain a record of the data for comparison with results obtained from daily quality control checks during the production testing of LTPP field samples. It was also suggested to other participating laboratories that a synthetic test block be obtained for the same purpose.

Part 2

The University of Nevada-Reno (UNR) was retained to conduct the second part of the Type I Soil Proficiency Sample Program. This part contained two rounds of proficiency samples, each consisting of 8 in. samples of type I soil (2 materials - 4 samples/material). Each participant fabricated two 6 in. diameter by 12 in. length specimens for triaxial M_R tests from each sample received (16 specimens). Instructions which accompanied round 1 included details for testing (P46) and directions that proficiency samples were to be tested only after successful verification of system calibration using the SHRP synthetic reference set.

SHRP quality assurance decisions concerning M_R testing of type I soil from LTPP field sections were largely based on results of the analysis of tests from this program. Fourteen laboratories have participated in the program.

Type II Soil

The objectives of the triaxial M_R test program for 2.8 in. diameter by 5.6 in. length specimens are as follows: 1) verify calibration and stability of test systems, 2) determine the components of variance of the test attributable to materials, samples, testing, laboratories, 3) prepare within laboratory and between laboratory precision statements in AASHTO/ASTM format, 4) determine the testing proficiency of SHRP contract laboratories, and 5) provide all participants with AMRL type reports on performance.

The type II soil proficiency sample program also had two separate parts.

Part 1

The first part involved rotation of a set of SHRP reference specimens 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) the acceptable range of reference values had been revealed. The intent of this procedure was to provide participants with an opportunity to verify the calibration of a 2.8 in. diameter by 5.6 in. length triaxial M_R test system by testing the SHRP set of three synthetic reference specimens using standardized parameters. These specimens were prepared for SHRP by the University of Texas at Austin. Correspondence, prepared by the Office of Materials and Research, Maryland State Highway Administration, with review and assistance from the University of Texas at Austin was circulated with instructions for testing and data reporting.

If a system response was not within the anticipated range, recalibration of the system was indicated. When response was within the anticipated range, it was suggested that SHRP laboratories obtain, test, and maintain a record of results, on a minimum of one 2.8 in. diameter by 5.6 in. length in-house synthetic specimen for comparison with daily quality control checks performed on the in-house specimen during the testing of LTPP field samples. It was also suggested to other participants that a synthetic test block be obtained for continued verification of test system stability.

Part 2

The Maryland State Highway Administration's Office of Materials and Research was retained to conduct the second part of the type II soil proficiency sample program. This part contained four proficiency sample rounds, each round consisting of eight samples of type II soil (2

materials - 4 samples/material). Each participant fabricates two 2.8 in. diameter by 5.6 in. length specimens for M_R tests from each sample received (16 specimens). Instructions sent with round 1 included details for testing (P46) and directions that proficiency samples were to be tested only after successful verification of system calibration using the SHRP synthetic reference set.

SHRP quality assurance decisions concerning M_R testing of type II soil from LTPP field sections are based on results of data generated by the 16 laboratories which have participated in this program.

Soil Moisture

The objectives of the soil moisture program were as follows: 1) determine the components of variance of the test attributable to materials, samples, water, testing, laboratories, 2) prepare within laboratory and between laboratory precision and bias statements in AASHTO/ASTM format, 3) determine the testing proficiency of SHRP contract laboratories, and 4) provide all participants with AMRL type reports on performance.

The Soil Moisture Proficiency Sample Program was completed and the final report can be obtained from by SHRP. The program was designed to provide precision and bias data concerning standard tests for moisture content of subgrade soils and base course aggregates and was modeled after the familiar AASHTO Materials Reference Laboratory (AMRL) proficiency sample programs at the National Institute of Standards and Technology (NIST). AMRL was retained to conduct the program for SHRP.

Two different cohesive soils and two different base course aggregates were supplied, respectively, by the Maryland Department of Transportation and the University of Nevada-Reno. These materials were from the same sources that were used in the Type II and Type I Proficiency Sample Programs. The Type I materials were obtained from the SHRP reference material sources, Watsonville Granite at Monterey, California and Kaiser at Pleasonton, California.

AMRL blended, then split each of the four primary materials into two approximately equal parts, one part to eventually provide material for dry samples and the other part to eventually provide material for wet samples. Each of these eight parts was then split again into two approximately equal portions designated as split A and split B. Each of the 16 splits (8A and 8B) was then split to yield 64 test samples.

Eight of the sets of 64 samples were finally processed for distribution in an air-dried condition and the other eight sets were processed for distribution in a wet condition. Finally, 20 groups of 3 test samples each were randomly selected from each of the 16 sets of 64 test samples and identified for shipment to each participating laboratory. Every participant received a total of 48 test samples (16 groups of 3 test samples each).

The data was collected and, after collation, transmitted to the SHRP Statistician for analysis and determination of test precision and bias.

Precision and bias statements were drafted in the standard AASHTO\ASTM format for use by standards writing committees as they deem appropriate. The statements, along with a_list of the 17 participating laboratories, and other details of the program are included in the final report available from SHRP.

PCC Cores

The objectives for the PCC 4 in. diameter by 8 in. length core program are as follows: 1) verify the testing proficiency of the SHRP contract laboratory, 2) determine the within laboratory and between laboratory precision for PCC core tests, 3) prepare precision statements in AASHTO/ASTM format, and 4) provide participants with AMRL type reports on performance.

The PCC Core Proficiency Sample Program is complete and the final report is available from SHRP. Modeled after the Cement and Concrete Reference Laboratory (CCRL) proficiency sample programs at the National Institute of Standards and Technology (NIST), this program was conducted for SHRP by the Iowa Department of Transportation Office of Materials.

Two different PCC mixes were prepared and cast into forms that would allow 4 in. diameter by approximately 9 in. length cores to be obtained for testing. All cores were taken, cured and shipped in accordance with standard practice. Twelve cores were sent to each participating laboratory for testing at age 56 days, six from each mix.

Instructions to the laboratories directed that two cores from each mix be tested in compression, two from each mix be tested for splitting tensile strength, and two be tested for static modulus of elasticity and poisson's ratio. Explicit directions were included concerning procedures to be followed for each test. Thirteen laboratories participated in the program.

The test data were collected and, after collation, transmitted to the SHRP Statistician for final analysis and determination of test precision.

The SHRP authorization to proceed with tests of LTPP field samples of PCC pavement was issued based on results of the proficiency sample tests.

Precision statements were derived and drafted in the standard AASHTO\ASTM format for use by standards writing committees as they deem appropriate. The precision statements, a listing of the 13 participating laboratories, and other program details were included in the final report.

AC Cores

The objectives of the diametral M_R test program for 4 in. diameter by 2½ in. length cores are as follows: 1) verify calibration and stability of test systems, 2) determine the components of variance of the test attributable to materials, samples, testing, laboratories, 3) prepare within laboratory and between laboratory precision statements in AASHTO/ASTM format, 4) determine the testing proficiency of SHRP contract laboratories, and 5) provide all participants with AMRL type reports on performance.

The AC Core Proficiency Sample Program was composed of two distinct parts.

Part 1

The first part centered on the rotation of a set of SHRP reference specimens 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 had been revealed. The intent of this procedure was to provide participants with an opportunity to verify the calibration of a diametral M_R test system by testing the SHRP set of four synthetic reference specimens using standardized parameters.

An additional set of synthetic specimens was provided for each SHRP contract laboratory to be used for in-house quality control during production testing. These specimens were prepared for SHRP by the Chevron Research Company. When response was not within the anticipated range, recalibration of the system was indicated. When response was within the anticipated range, SHRP contract laboratories were requested to test the SHRP furnished in-house set of synthetic specimens and maintain a record of the data for comparison with results obtained from daily quality control checks during the production testing of LTPP field samples. It was suggested to other participating laboratories that they use one or more in-house synthetic test blocks for the same purpose.

Part 2

SHRP retained the services of Nittany Engineers and Management Consultants of State College, Pennsylvania to conduct the second part which included furnishing and distribution of AC proficiency cores and the analyses of test data from both the synthetic reference set and the AC proficiency cores. Two sets of core specimens (5 per set) were obtained, prepared for testing, and 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 SHRP synthetic reference set.

Interim results from this program were the principal component in SHRP decisions concerning standardization of certain test system components used in the SHRP contract laboratories,

revision of SHRP protocol P07, issuance of SHRP protocol P07B, and authorizations for contract laboratories to proceed with pilot testing of LTPP field samples. Twenty-two laboratories have participated in this program.

Laboratory Molded AC

The objectives of the diametral M_R test program for 4 in. diameter by 3 in. length and 4 in. diameter by 1½ in. length laboratory molded specimens are as follows: 1) verify stability of test systems, 2) determine the components of variance of the test attributable to materials, samples, testing, length of specimens, laboratories, 3) prepare within laboratory and between laboratory precision statements in AASHTO/ASTM format, 4) determine the testing proficiency of SHRP contract laboratories, and 5) provide all participants with AMRL type reports on performance.

The Oregon State Highway Division Highway Materials Laboratory is conducting the Laboratory Molded AC Proficiency Sample Program for SHRP. A prerequisite for participation in this program is successful completion of part 1 (part 2 not required) of the AC Core Program (synthetic specimen tests).

The Laboratory Molded Proficiency Sample Program includes four rounds of proficiency samples. Each round contains eight samples, four of one material and four of a second material. The materials (aggregates from two quarries and two different asphalt cements from each of two refineries) are from SHRP reference library sources. Two 4 in. diameter by 3 in. length and two 4 in. diameter by 1½ in. length specimens are fabricated from each sample by the participating laboratory and tested in accordance with SHRP Protocol P07 as set forth in correspondence distributed with round 1.

Quality assurance decisions concerning M_R testing of AC samples and the minimum length of such samples will be strongly influenced by data generated in this program. Sixteen laboratories have participated in the work. Data is collected and collated, then forwarded to a SHRP statistician for a components of variance analysis.

Nuclear Moisture/Density

The objectives of the nuclear moisture/density program: 1) verify calibration of test gauges, 2) determine the variance of tests attributable to different gauges; prepare a comparative report, and 3) provide SHRP contract laboratories with the verification data.

Troxler Electronic Laboratories, Inc. conducted the SHRP Inter-Regional Verification Program for Nuclear Test Gauges. The program required that nuclear test gauges used by SHRP field contractors on LTPP test sections be shipped to the Troxler Southwestern Branch Laboratory at Arlington, Texas during the October 1989 to March 1990 period for verification of calibration. The procedure involved derivation of data by all gauges on the same series of

calibration blocks in the same laboratory under the same environmental conditions during a relatively short time period.

Five SHRP field contractors participated in the SHRP Interregional Verification Program for Nuclear Test Gauges. Detailed information concerning the verification program, including comparative results, is fully documented in the final report which will be distributed by SHRP at a later date.

M_R Test Participant Experiences

Practitioners, who have not previously been involved with M_R determinations should be aware that the systems and procedures for M_R tests are sufficiently complex that considerable care and attention must be directed toward the calibration, stabilization, and verification of test systems and procedures, if reliable data is to be produced. Concerns and problems (and potential resolutions) experienced by participants in the SHRP proficiency sample programs are summarized in the brief compilation below. The listing is not exhaustive, but will provide considerable assistance to those interested in the initiation of M_R testing. Each of the items included have been reported by one or more (usually more) participants in the SHRP programs as factors in their progress toward achieving an acceptable level of confidence in their M_R test systems.

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1. PROCEDURES

- COMMUNICATIONS

Within laboratory: laboratory engineers and technicians should understand laboratory manager's expectations; managers should understand test system capabilities.

Between laboratories: personnel should be authorized to communicate with peers in other labs concerning comparable work.

- PROTOCOLS (test standards)

Availability: the protocol for tasks to be performed should be readily available to all personnel involved in the performance of the task.

Reading: the protocol should be read by those directly involved in performance of the task.

Understanding: understanding protocol requirements is mandatory for personnel assigned responsibility for tasks described therein.

Following: compliance with protocol requirements by personnel performing tests is mandatory.

2. SOFTWARE

° CONTROL OF TEST SYSTEM

Systematic: control mechanisms are activated or deactivated too early or too late; this occurs each time the system is operated using the same parameters; program should be modified to yield intended action; the modification is usually relatively easy to define but may or may not be difficult to implement.

Indeterminate: control mechanisms are activated too early or too late; this occurs at seemingly random times that do not have a readily apparent common cause; program usually must be modified to eliminate the problem; modification process will probably be difficult.

° EXTRACTION and ANALYSIS of TEST DATA

Systematic: applications program yields results consistently higher or lower than results that are properly determined manually; program must be modified to yield correct results; the modification may or may not be difficult depending upon the complexity of the software and in-house ability to carry out revisions.

Indeterminate: applications program yields inconsistent results that may or may not be equivalent to results derived manually; replacement of the program may be more economical than modification depending on the specific circumstances involved.

3. HARDWARE

° LOAD CELLS

Range: test load too close to the lower or upper limit of the load cell range; range of load cell used should be appropriate for the load to be applied.

Position: position of the load cell in the system can affect results.

Deformation: when a load cell is positioned so that the deformation measurements include any load cell deformation, such deformations should be determined and, if significant, used in the calculation of results.

Verification: load cell calibration should be verified at appropriate intervals between required calibration times; the first verification should be immediately following a calibration; verification can be done using either weights or load rings.

- LVDTs

Sensitivity: measurements and recording of same at the 1×10^{-5} level is required (P07)- generally then, the instrument should be sensitive to movements at the 1×10^{-6} level (microinch).

Noise: noise can significantly affect deflection readings, particularly when applications programs are used; noise should be minimized by thorough and adequate electrical grounding and appropriate signal enhancement.

Verification: calibration should be verified by means of machinist's blocks or micrometers (not hand held) which have been calibrated with machinist's blocks; the range of such devices should be appropriate to the range of measurement used in the system.

Nullpoint: arrange for the mechanical and electronic nullpoints to coincide; if this is not practical, verify that the voltage output signal is reading as intended throughout the full range of the instrument.

Contact shoe: the contact shoe should be designed to minimize the probability of movement or penetration of the specimen, or of being significantly affected by local variations in the specimen.

Contact load: the load (usually spring induced) should be adequate to provide a positive contact throughout the test, but should not cause any significant deformation of the specimen surface at the specimen temperatures required.

Data Recording: signals from the two horizontal LVDTs must be arranged to allow monitoring of each independently before averaging; this allows significant differences to be continually detected and corrective action taken; misalignment is a likely cause of major differences.

- LVDT HOLDER

Attached to specimen: several designs are available for yokes that attach directly to the specimen, some contact the ends of the specimen by means of spring loaded shoes adjusted by screws; one lab determined that a torque screw driver calibrated to provide 2 psi loading at the specimen/shoe contact area was optimum; i.e., the yoke did not slip during the test and specimen deformation (due to the shoe loads) during the test was not detectable.

Attached to load frame: any deformation, bending, rotation, vibration, pitching or other movement will be likely to affect the required deformation measurements; such movements, which may be in the microinch range, may be multiplied through attachment arrangements to magnitudes that significantly affect the final results.

Attached to pedestal: both load frame and pedestal movements will affect the required measurements.

° LOAD FRAME

Load strips: the beam section modulus should be adequate to preclude bending in the microinch range at load magnitudes used in the system.

Width: width must be 0.5 inches for 4 inch diameter specimens, 0.75 inches for 6 inch diameter specimens.

Radius: the concave surface must have a radius of curvature equal to the nominal radius of the test specimen.

Edge relief: edges of the concave surface should be rounded to prevent damage to the specimen during testing.

Parallelism: the central longitudinal axis of the concave surface of the load strips and the center longitudinal axis of the specimen should be parallel and lie in the plane of the specimen diameter to be loaded.

Homogeneous longitudinal load distribution: load distribution transmitted from the load strip to the specimen should be homogeneous; proper machining tolerances, adequate section moduli of the load frame, and proper alignment is mandatory.

Specimen cradle: a cradle that provides 2 supplemental contact surfaces which are parallel to the longitudinal axis of the concave surface in the bottom load strip, and which lie in the circumferential plane of the specimen can assist in providing rapid positive alignment of the specimen in the load frame.

° ELECTRONIC COMPONENTS

Controls

Dials, slides, knobs: settings may not be yielding the intended results; resetting, recalibration, or replacement of component parts may be required.

Keyboard: keyed instructions may not be yielding intended results; programming modifications may be required.

Servomechanisms

Valves: partial, early, or late operation may occur; this can affect intended loading magnitudes, durations and timing; maintenance or replacement may be required; worst case situations may require system modification.

Relays: early, late, or incomplete signals may be transmitted; appropriate operational and electrical system checks should be performed when system response indicates a potential problem.

Charts: charts used for monitoring or manual output checks should be verified at appropriate intervals; paper should be compatible with the device; problems may result from mismatch of voltage, mechanism wear or defects, improper settings, wrong paper.

Data gathering: faulty connections, mismatched voltage, excessive noise level, circuit board defects, or mismatched components may cause significant errors; repair, replacement, and/or noise level reduction measures are required as indicated by system operational and electrical checks.

Data storage: loss and/or contamination of data may be caused by malfunctioning disk or tape drives, defective or worn disks or tapes, voltage surges, magnetic fields, hardware program errors, and software program errors; storage devices should have continuous surge protection; data storage should be backed up at frequent intervals either automatically or manually; electromagnetic storage media should be protected at all times from stray electromagnetic fields and from rough handling.

- SYSTEM STRAIN

Significant: when system loads (same order of magnitude as loads to be used in tests) result in system strains at the microinch level or greater, said strain will likely have a significant affect on test data; modify system to reduce strain to non significant level; alternatively load/strain relationship should be determined and, if constant, used in data reduction.

Not significant: when system loads consistently cause system strains less than the order of measurement required in the test protocol, said strains will not likely have a significant affect on the test data and may be ignored.

- SYSTEM STABILITY

Monitoring: many of the previously listed problems can adversely affect system stability; use 1 or more of the synthetic quality control specimens(that were correlated with the SHRP synthetic reference specimens) on a daily basis when production testing is underway.

Closure

Initial blind test data derived by participating laboratories on synthetic reference specimens, prior to final verification of the calibration of their M_R systems, ranged from one-half the reference values to an order of magnitude greater than the reference values. This experience indicated that a less rigorous course of SHRP quality management would have resulted in the collection of unusable data at great cost to the highway community. More importantly, this "once in a generation" research opportunity would have been seriously compromised.

The SHRP verification and proficiency programs have continually demonstrated their effectiveness as components of a carefully planned and technically sound program of quality management.

Appendix 3
SHRP-LTPP Asphalt Resilient Modulus Pilot Study

Background

An asphalt material resilient modulus (M_r) pilot study was undertaken in SHRP-LTPP program to provide proof testing of the specified test equipment protocols, confirmation of testing, and to generate data useful in identifying essential test requirements (e.g., evaluation of temperature, load axes, and rest periods). In addition, the pilot study was structured to yield, through statistical means, significant factors influencing the various resilient modulus.

In this paper the results of an analyses of combined data from two of the four SHRP-LTPP regions are presented. M_r information was not yet available from two of the regions at the termination of the 5-year SHRP program. The M_r data used in this study is based upon vertical deflection compliance factors identified in the October 1992 version of the SHRP Mr Protocol P07.

Selection of Test Sections

Initially, 63 test sections were selected from the General Pavement Study (GPS) experiment (asphalt concrete [AC] over granular base) and GPS-2 (AC over bound base) experiments for potential use in the study and grouped based on moisture (wet versus dry), temperature (freeze and nonfreeze), subgrade type (coarse versus fine), and base thickness (low versus high). Based on these factors, 40 sections were chosen for testing (see Figure 3-1). Test sections were chosen which had minimum surface thicknesses of 1.5 ins. in order to meet the minimum thicknesses required in Protocol P07. Traffic volumes and base types were not considered factors in this experimental design.

The original intent of the pilot study was a full factorial investigation of the regional environmental effects (i.e., moisture, temperature, subgrade), asphalt base thickness, and associated mix design (i.e., asphalt content) and construction (i.e., air voids, bulk specific gravity) variables on the M_r values of the asphalt surface and base layers.

MOISTURE	WET				DRY			
TEMPERATURE	FREEZE		NO FREEZE		FREEZE		NO FREEZE	
SUBGRADE TYPE	F	C	F	C	F	C	F	C
BASE THICKNESS								
LO	242401 (MD) 512004 (VA) 182008 (IN) 196150 (IA)	341638 (NJ) 541640 (WV) 261013 (MI) 271023 (MN)	223056 (LA) 052042 (AR)	124108 (FL) 479025 (TN)	382001 (ND) 836454 (MB) 307076 (MT) 901802 (SK)	322027 (NV) 829017 (BC) 201009 (KS)	404163 (OK) 062053 (CA)	404165 (OK) 371645 (NC)
HI	872811 (ON) 872812 (ON) 182009 (IN)	341033 (NJ) 341034 (NJ)	053071 (AR) 482108 (TX)	134112 (GA) 134113 (GA)	562017 (WY) 469187 (SD)	562019 (WY) 567772 (WY)	404154 (OK) 062004 (CA)	068201 (CA) 041062 (AZ)

Figure 3-1. Pilot Study Experimental Design.

The analysis approach was subsequently modified because only half of the pilot test program was completed in time for the study to be completed in the first 5 years of the SHRP-LTPP program. In fact, the test data was only available for the Southern and North Atlantic SHRP regions.

The study goal was then more sharply focused to include an investigation of the impact of the associated material and construction properties on M_r of core specimens extracted from the ends of the SHRP-LTPP GPS sections. An analytical approach was then defined to aid in identifying significant variables for use in the subsequent development of regression analysis relating M_r estimates to the variables. One of the critical elements in the approach was the discovery of the error term appropriate for the assignment of significance.

Pilot Study Testing

Each SHRP contract laboratory must pass the AC proficiency/calibration testing program before they are cleared to begin pilot study testing. The proficiency program was a rigorous testing sequence performed on synthetic samples (teflon, polyurethane, lucite, and rubber) as well as core samples. The laboratory results must fall within an acceptable range of results for each type of sample before clearance to begin pilot testing.

After clearance, each laboratory was provided with a list of the designated specimens for pilot testing. The order of testing these samples was randomized to minimize bias in the test results. The laboratory proceeded by testing each specimen in accordance with the SHRP-LTPP resilient modulus (P07) protocol.

Analytical Approach

The overall analytical procedure undertaken in this investigation consisted of the five distinct phases listed below:

1. Regression analysis to develop equations for M_r based on indirect tensile strength ratio (ITSR)*, asphalt content (AC), bulk specific gravity (BSG), and air voids (AV) for each layer (surface, base) and at each temperature (41, 77, 104 °F). The objective was to define those combinations of effects, layer, and temperature that yielded the highest coefficient of determination, R^2.

2. Tests to assess homogeneity of state (or state highway agency) variances with regions (Southern and North Atlantic) for indirect tensile strength ratio (ITSR), asphalt content (AC), bulk specific gravity (BSG), and air void (AV). This task would provide an

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* The indirect tensile strength ratio is the ratio of the post M_r tensile strength (strength of actual M_r specimen) to pre-M_r tensile strength (strength of adjacent core specimen used to define applied cyclic load [stress] levels). Since the ratio represents actual/presumed strengths, the ITS is indicative of the relative cyclic stress applied to the M_r specimen.

indication of homogeneity of variation in mix properties (ITSR, AC, AV, BSG) across the two regions.

3. Selection of the "best" test temperature for analysis of each layer complete analyses of variance tests (ANOVAs) for indirect tensile strength ration (ITSR), asphalt content (AC), bulk specific gravity (BSG) and air void (AC) results based on regions, states, and SHRP-LTPP sections. This activity would identify significant differences in the mix variables between region, states within regions, and sections within states.

4. Analysis of variance (ANOVAs) tests for resilient modulus based on regions, states, sections, and test temperature to identify which of these factors should be used in the subsequent development of predictive equations for resilient modulus.

5. Regression analysis for resilient modulus of each asphalt layer type (surface or base) based on regions, indirect tensile strength ratio (ITSR), asphalt content (AC), bulk specific gravity (BSG) and their interactions (or cross products).

In all these analyses, the four samples obtained from each layer (two per layer at each end) within each section are considered to represent that section. Furthermore, the sections investigated within a given state are considered to represent that state, while the states within a given region are expected to represent conditions in that region. With this assignment, the sections and the states within any region are considered random. Since the states represent the largest units, they are the units that will be used to make inferences about the regions.

Phase 1 Analysis - Initial General Regression Analyses by Layer and Test Temperature

Selected Model for Analysis:

Resilient Modulus (M_r) = function of [indirect tensile strength ratio (ITSR), asphalt content (AC), bulk specific gravity (BSG), and air voids (AV)]

Results of These Regressions:

Test	Coefficient of Determination, R^2	
Temperature	Surface Layer	Base Layer
41	.29	.43
77	.44	.56
104	.45	.31

Conclusion

Since the coefficient of determination, R^2, for the surface layer M_r at a test temperature of 77 °F (.44) was, a) practically identical to the R^2 at a temperature of 104 °F (.45) in

the surface layer and, b) the largest R^2 (.56) for the base layer, a temperature of 77 °F was selected as the basis for the subsequent ANOVAs completed for indirect tensile strength ratio (ITSR), asphalt content (AC), bulk specific gravity (BSG), and air voids (AV).

Additional Statistical Requirement

In order to use the states within regions as the basis for testing the hypothesis that regions have equal responses in M_r for the variables ITSR, AC, BSG, and AV, it will be necessary to test for the equality of the variances between states within regions.

Phase 2 Analysis - Homogeneity of Variance Tests on States within Regions

Using appropriate mean squares for states within regions, the following F-tests were conducted:

Homogeneity of Variance Tests (F Test) of States within Regions for *Surface Layer*

Indirect Tensile Strength Ratio (ITSR)

$$F_{5,5} = \frac{\text{Mean Squares (Southern Region)}}{\text{Mean Squares (North Atlantic Region)}} = .209/.033 = 6.3$$

Not significant at a probability, *p*, of .01.

Asphalt Content (AC)

$$F_{5,5} = \frac{\text{Mean Squares (Southern Region)}}{\text{Mean Squares (North Atlantic Region)}} = 3.76/.83 = 4.5$$

Not significant at *p* of .01.

Bulk Specific Gravity (BSG)

$$F_{5,5} = \frac{\text{Mean Squares (Southern Region)}}{\text{Mean Squares (North Atlantic Region)}} = .0304/.0202 = 1.5$$

Not significant at *p* of .01.

Air Voids (AV)

$$F_{5,5} = \frac{\text{Mean Squares (Southern Region)}}{\text{Mean Squares (North Atlantic Region)}} = 51.35/11.59 = 4.4$$

Not significant at *p* of .01.

Comment

Even though the homogeneity of variance tests do not reject the hypothesis, it should be noted that the larger observed variances all occurred in the Southern region.

Homogeneity of Variance Tests of States Within Regions for the Base Layer

Indirect Tensile Strength Ratio (ITSR)

$$F_{4,5} = \frac{\text{Mean Squares (Southern Region)}}{\text{Mean Squares (North Atlantic Region)}} = .183/.046 = 4.0$$

Not significant at p of .01.

Asphalt Content (AC)

$$F_{4,5} = \frac{\text{Mean Squares (Southern Region)}}{\text{Mean Squares (North Atlantic Region)}} = 7.95/.797 = 10.0$$

Not significant at p of .01.

Bulk Specific Gravity (BSG)

$$F_{4,5} = \frac{\text{Mean Squares (Southern Region)}}{\text{Mean Squares (North Atlantic Region)}} = .035/.017 = 2.1$$

Not significant at p of .01.

Air Voids (AV)

$$F_{4,5} = \frac{\text{Mean Squares (Southern Region)}}{\text{Mean Squares (North Atlantic Region)}} = 87.09/12.26 = 7.1$$

Not significant at p of .01.

Comment

All hypotheses of homogeneity of variances between the two regions are accepted; however, the asphalt content (AC) variable has an observed "states" variance 10 times larger in the Southern region than in the North Atlantic. It should be noted that the bulk specific gravity (BSG) is the only variable with an observed "states" variance larger in the North Atlantic region.

Phase 3 Analysis - Analysis of Variance (ANOVAs) for Indirect Tensile Strength Ratio (ITSR), Asphalt Content (AC), Bulk Specific Gravity (BSG), and Air Voids (AV)

Surface Layer Analyses of Variance

ITSR = Indirect Tensile Strength Ratio

Source	df	MS	F
RG[1]	1	.1796	3.75
St(RG)[2]	10	.0479	1.40
S(St*RG)[3]	7	.0342	2.41
Remainder	54	.0142	2.41

None are significant at *p* of .01.

1 (RG) represents regions.
2 St(RG) represents states in regions
3 S(St*RG) represents sections in states in regions.

AC = Asphalt content, %

Source	df	MS	F
RG	1	.0165	<1
St(RG)	10	1.0117	3.14
S(St*RG)	7	.0342	8.10**
Remainder	56	.0142	

Sections are significantly different at *p* of .01.

BSG = Bulk Specific Gravity

Source	df	MS	F
RG	1	.03179	2.09
St(RG)	10	.01519	1.05
S(St*RG)	7	.01453	69.01**
Remainder	57	.0142	

** Sections are significantly different at *p* of .01.

AV = Percent Air Voids

Source	df	MS	F
RG	1	21.481	1.50
St(RG)	10	14.301	2.90
S(St*RG)	7	4.923	9.83**
Remainder	57	0.501	

** Sections are significantly different at *p* of .01.

Conclusion for Surface Layer Properties

In general, section-to-section variation within states seems to be the significant source. When compared to the state-to-state variation within regions, the region-to-region variation does not appear to be different for indirect tensile strength ratio (ITSR), asphalt content (AC), bulk specific gravity (BSG) and air voids (AV).

Base Layer Analyses of Variance

ITSR = Indirect Tensile Strength Ratio

Source	df	MS	F
RG	1	.0689	1.31
St(RG)	9	.0527	1.13
S(St*RG)	7	.0466	4.48**
Remainder	57	.0104	

** Sections are significantly different at *p* of .01.

AC = Asphalt content, %

Source	df	MS	F
RG	1	0.5079	<1
St(RG)	9	1.6203	2.08
S(St*RG)	6	0.7799	17.36**
Remainder	51	0.0437	

** Sections are significantly different at *p* of .01.

BSG = Bulk Specific Gravity

Source	df	MS	F
RG	1	.00099	<1
St(RG)	9	.02210	<1
S(St*RG)	6	.03167	50.81**
Remainder	51	.00062	

** Sections are significantly different at *p* of .01.

AV = Percent Air Voids

Source	df	MS	F
RG	1	25.707	1.05
St(RG)	9	19.706	<1
S(St*RG)	6	17.886	39.55**
Remainder	51	0.705	

** Sections are significantly different at *p* of .01.

Conclusion for Surface Layer Properties

In general, section-to-section variation within states seems to be the significant source of variation. The region-to-region variation does not appear to be different for any of the four properties when compared to the state-to-state variation within regions.

Phase 4 Analysis for Resilient Modulus Based on Regions (RG), States within Regions (St(RG)), and Sections within States within Regions (S(St*RG))

Surface Layer Analysis of Variance (ANOVA)

Source	df	MS	F
RG	1	262.157	6.68*
St(RG)	10	39.233	1.01
S(St*RG)	7	38.799	11.59**
Error "a"	57	3.345	

T (Temperature)	2	924.505	88.86**
RG*T	2	10.404	1.30
St(RG)*T	20	7.996	1.01
S(St*RG)*T	14	7.883	3.19**
Error "b"	114	2.475	

** Significant at p = .01: * Significant at p = .05.

Conclusion

Temperature of test and interaction of sections (in states in regions) * temperature or S(St*RG)*T are significant.

Base Layer Analysis of Variance (ANOVA)

Source	df	MS	F
RG	1	333.637	8.39*
St(RG)	9	39.777	1.01
S(St*RG)	7	51.422	20.67**
Error "a"	54	2.488	
T (Temperature)	2	891.878	40.54**
RG*T	2	22.001	2.85
St(RG)*T	18	7.772	<1
S(St*RG)*T	14	8.125	3.98**
Error "b"	108	2.043	

** Significant at p = .01: * Significant at p = .05.

Conclusion

Temperature of test and interaction of sections (in states in regions) * temperature or S(St*RG)*T are significant.

Comments

The results of the ANOVA's for M_r indicate that the regions represent the major source of variation if one level of test temperature is selected. It must be pointed out, however, that the section-to-section variation within states is at least an order of magnitude greater than the samples within sections. The variation between states within the regions is relatively small. Based on these results the best unit for predicting resilient modulus from indirect tensile strength ration,

asphalt content, bulk specific gravity, and air voids would be the section, because of its enormous variation.

Additional Statistical Requirements

It is understood in the conduct of this type of regression analysis, that individual samples within a section could not be used as the observational unit. It should be noted that a regression analysis utilizing both sections and samples in the same analysis is not straightforward since it involves the use of two errors, sections and samples in sections. To avoid this difficulty, the analyses in Phase 5 was undertaken using samples in sections as the error. This is a reasonably good approximation at this stage of data availability in LTPP. However, in the final analysis (when all of the LTPP data are used) care should be taken to utilize the section-to-section variation.

Phase 5 Regression Equations to Predict M_r from Regions, ITSR, AC, BSG, AV, and Their Interactions

The SAS regression procedure used to obtain the so-called "best" equation is the Stepwise MAXR procedure. All regressions were conducted assuming that the data were obtained from a completely random sample design. The MACR utilizes the Mallows C_p value which should be small and approximately the same size as the number of x-variables in the equation, while the p-values are less than 0.05 or nearly 0.05 when the "best" equation is obtained. The standardized variables, RG, ITSR, AC, AV, and BSG are used for the following cases. The standardized values for the terms included in equation 1-6 (e.g., RG, ITSR, AC) are presented in an appendix to this memorandum.

Regressions Combining Both Regions

Note: Regions; 1 = Southern, 2 = North Atlantic

Surface Layer M_r Regression Equation (77 °F)

$$M_r = 0.6267 - 15.1921*RG + 10.4205*ITSR + 38.8101*AC + 7.3464*BSG + 10.1303*AV + 1.2532*(RG*ITSR) - 3.2811*(RG*AC) + 17.5036*(RG*BSG) - 9.8641*(ITSR*BSG) - 3.3376*(ITSR*AV) - 35.6043*(AC*BSG) - 7.6842*(AC*AV) \quad \text{(EQ 1)}$$

$R^2 = .81$, $C_p = 11.64$
All x-variables have $p<.05$.

Base Layer M_r Regression Equation (77 °F)

$$M_r = - 0.2376 - 2.6998*ITSR + 0.8464*(RG*AC) - 0.6546*(RG*AC) + 2.4582*(ITSR*BSG) + 1.3026*(ITSR*AV) - 0.2466*(AC*BSG) - 0.7777*(BSG*AV) \quad \text{(EQ 2)}$$

$R^2 = .74$, $C_p = 9.02$
All x-variables have $p<.05$ except AC*BSG which has $p = 0.539$.

Regression Analyses by Regions

Southern Region, Surface Layer M_r (77 °F)

$$M_r = - 0.0954 - 1.5567*ITSR + 24.5916*AC + 4.1989*BSG + 2.3871*(ITSR*AC) - 25.4652*(AC*BSG) - 3.4101*(AC*AV) + 3.0524*(BSG*AC) \quad \text{(EQ 3)}$$

$R^2 = .42$, $C_p = 6.77$
Only the intercept has $p > .05$ (.56).

Southern Region, Base Layer M_r (77 °F)

$$M_r = - 0.7838 - 23.4523*AC - 5.0405*BSG - 7.4978*AV - 0.2615*(ITSR*AC) + 24.0436*(AC*BSG) + 2.0326*(AC*AV) + 5.1254*(BSG*AV) \quad \text{(EQ 4)}$$

$R^2 = .57$, $C_p = 6.24$
Only BSG*AV has $p > .05$ (.12).

North Atlantic, Surface Layer M_r (77 °F)

$$M_r = 1.2799 + 15.2958*ITSR + 30.9379*AC + 8.8290*BSG + 14.7159*AV - 13.9640*(ITSR*BSG) - 4.22666*(ITSR*AV) - 27.6815*(AC*BSG) - 11.5483*(AC*AV) \quad \text{(EQ 5)}$$

$R^2 = .87$, $C_p = 7.50$

North Atlantic, Base Layer M_r (77 °F)

$$M_r = 0.4080 - 5.6554*ITSR - 2.4496*AC + 21.0192*AV + 2.2374*(ITSR*AC) + 4.2211*(ITSR*BSG) - 21.4196*(BSG*AV) \quad \text{(EQ 6)}$$

Note: One could force ITSR in the equation.
$R^2 = .82$, $C_p = 3.93$
Only ITSR*AC has $p > .05$ (.10).

Conclusions

All regression equations shown here are based on a design for the pilot study investigation that is completely randomized for the sample cores. It is known that within the regions, the states are expected to represent the regions and are also considered random. Since the variation between states was found to be almost the same as the between sections within states (as illustrated in phases 3 and 4), there is no concern about states variation representing regions.

It is important to note that the section variation is almost an order of magnitude greater than the variation of the core samples within sections. This condition shed some doubts on the actual equations presented in Phase 5; however, this method of analysis is considered to be a good approximation of the method which would account for the section variation. Once the complete pilot study data is available, then another analyses should be undertaken to account for the section variation.

Utilization and Interpretation of a Pilot Study Regression Equation

An overall equation for resilient modulus based on the results of the pilot study, was developed and is based upon results for both regions for all three test temperatures. It should be noted, however, that there is no layer term in the equation since it was generally found that the surface and base layer moduli were comparable. Each of the independent terms included in the equations was standardized (or normalized) in order to depict the relative effect of each of the terms on the value of M_r. The standardization is attained by subtracting the mean value for the term from the individual value and then subtracting by the standard deviation in the same term.

For example, considering all individual values of bulk specific gravity (BSG), a mean value of 2.3436 is obtained and a standard deviation of 0.0443 can be calculated. The standardization of the bulk specific gravity term would then become BSG_s = [(BSG - 2.3436)/.0443].

The standardized term, BSG_s, is then considered an independent variable in the development of a regression equation for resilient modulus. All other independent variables (e.g., region, test temperature, air voids, asphalt content, etc.) were likewise standardized. The general regression equation for resilient modulus is presented below:

$$
\begin{aligned}
M_r \text{ in psi} = \quad & 534768 + 101483*[RG + .0270)/1.000762] - 281965*[(TEMP\text{-}2)/.8183418] \\
& + 32114*[(BSG\text{-}234376)/.0443] - 58316*[AV\text{-}5.002)/2.3207] \\
& - 31284*[RG+.0270)/1.000762]*[(TEMP\text{-}2)/.8183418] \\
& + 35892*[(RG+.0270)/1.000762]*[BSG\text{-}2.3436)/.0443] \\
& - 30041*[(TEMP\text{-}2)/.8183418]*[(BSG\text{-}2.3436)/.0443] \\
& + 47137*[(TEMP\text{-}2)/.8183418]^2 \qquad \text{(EQ 7)}
\end{aligned}
$$

R^2	=	.754
RMSE	=	199438
CV	=	33.29
df	=	430

where

RG =	Region Designation
	Southern -1
	North Atlantic +1
TEMP =	test temperatures, °F
	1 40
	2 77
	3 104
BSG =	bulk specific gravity
AV =	air voids in %

The advantage of the standardization process is that the coefficient for the standardized independent variable represents the amount of increase (positive) or decrease (negative) in the resilient modulus which could be expected with a unit change (i.e., change in 1 standard deviation of the original value) in the variable. For example, an increase of 1 standard deviation in air void content (or 2.32%) would more than likely produce a decrease of 58320 psi in the resilient modulus estimate.

In a review of the coefficients included in the equation it can be inferred that the resilient modulus is increased with:

- Region 2 (North Atlantic) results compared to Region 1 (Southern)
- Lower test temperature
- Higher bulk specific gravity values
- Lower air voids

It should be noted that there are four main effects (region, test temperature, bulk specific gravity and air voids), three interactions or cross product terms (i.e., region by test temperature, region by bulk specific gravity and test temperature by bulk specific gravity) and a single quadratic term (i.e., test temperature). The interaction terms involving region infer that there is some reversal in effects of test temperature and bulk specific gravity between the two regions. This can be seen in the next two equations which were generated form the overall M_r equation (Equation 7) by substituting the Southern Region (-1) and the North Atlantic Region (+1) codes in it.

M_r (Southern Region) (RG = -1)

$$M_r = 436100 - 251540*[(TEMP-2)/.818] - 2780*[BSG-2.33)/.044] - 58320*[AV-5.00)/23210] - 30040*[(TEMP-2)/.818]*[(BSG-2.34)/.004] + 47140*[(TEMP-2)/.818]^2 \quad \text{(EQ 8)}$$

M_r (North Atlantic Region) (RG = +1)

$$
\begin{aligned}
M_r = {} & 638910 \\
& - 314070*[(TEMP-2)/.818] + 68950*[BSG-2.34)/.044] \\
& - 58320*[AV-5.00)/23210] - 30040*[(TEMP-2)/.818]*[(BSG-2.344/.004] \\
& + 47140*[(TEMP-2)/.818]^2
\end{aligned}
\qquad \text{(EQ 9)}
$$

In comparing these latter two equations, it can be seen that the air void main effect, test temperature by bulk specific gravity interaction and test temperature quadratic term are common to both. However, the test temperature main effect has a significantly greater effect in the North Atlantic region (-314070 coefficient value) when compared to the Southern region (-251540 coefficient value). In addition, the main effect of bulk specific gravity is minimal in the Southern region (coefficient value of -2780) when compared with its impact in the North Atlantic region (coefficient value of +68950). Finally, the constant term in the North Atlantic region form of the equation (i.e., 6389101) is significantly higher than the constant term in the Southern region form of the equation (i.e., 436900).

The difference in these constant values implies that for the same mix and temperature conditions (i.e., same test temperature, BSG and AV), the resilient modulus value in the North Atlantic region would always be higher than that in the Southern region. In fact, at the mean values of the independent variables, all terms would reduce to zero and the resilient modulus estimated value for the Southern region would be 436,100 psi while the M_r estimate in the North Atlantic region would be 638,910 psi. These two values would represent the resilient modulus estimate sat a temperature of 77 °F, air void of 5%, and bulk specific gravity value of 2.343.

Conclusions for Utilization/Interpretation of Regression Equation

From the overall M_r regression equation (EQ 7) it can be inferred that there is a significant difference between M_r result for the two regions (i.e., Southern and North Atlantic). Since the testing was conducted by the same testing agency (i.e., Southwestern Testing Laboratories), there is no reason to suspect any testing bias. The difference could well be the type and viscosity of asphalt cement used in these regions. This "region" factor should be investigated further when all pilot study data is made available.

In addition, it can be inferred from Equation 7 that the factors influencing overall M_r values for the two regions are test temperature, bulk specific gravity, and air voids. It should be noted, however, that the analysis of M_r results at a 77 °F test temperature (EQ 1 through 6) indicated that the indirect tensile strength ratio (ITSR) and asphalt content (AC) variables were important factors. This letter result becomes important in mix design and/or construction quality control if a normal laboratory test temperature (i.e., 77 °F) is used in the testing/evaluation program.

The overall M_r equation offers the best opportunity, at present, for estimating resilient modulus of HMAC for a variety of temperature, bulk specific gravity, and air voids. It is

believed that equation can be used to define modulus estimates for use in a variety of data analysis studies.

APPENDIX

Standardized Variables

Means and Standard Deviations (Original Units)

a. <u>By Layer - Equations 1 and 2</u>

1. Surface Layer - Equation 1

	Mean (M)	Standard Deviation (SD)
RG(Region)	1.47	0.50
MR	573067	257818
ITSR	1.10	0.15
AC	4.26	0.45
BSG	2.37	0.06
AV	5.35	1.74
x1 = RG*ITSR	1.65	0.66
x2 = RG*AC	6.28	2.33
x3 = RG*BSG	3.50	1.23
x4 = RG*AV	7.60	3.22
x5 = ITSR*AC	4.66	0.86
x6 = ITSR*BSG	2.59	0.38
x7 = ITSR*AV	5.87	2.03
x8 = AC*BSG	10.07	1.13
x9 = AC*AV	22.44	6.82
x10 = BSG*AV	12.58	3.96

Note: Standardized Value = $\dfrac{\text{X-Mean}}{\text{Standard Deviation}}$

e.g. $AC_s = (AC - 4.26)/0.45$

2. Base Layer - Equation 2

	Mean (M)	Standard Deviation (SD)
RG(Region)	1.50	0.50
MR	571298	289000
ITSR	1.11	0.14
AC	5.19	0.58
BSG	2.35	0.08
AV	4.51	2.43
x1 = RG*ITSR	1.68	0.66
x2 = RG*AC	7.69	2.89
x3 = RG*BSG	3.46	1.20
x4 = RG*AV	6.86	4.60
x5 = ITSR*AC	5.68	0.86
x6 = ITSR*BSG	2.58	0.34
x7 = ITSR*AV	5.04	2.91
x8 = AC*BSG	12.20	1.49
x9 = AC*AV	22.81	11.85
x10 = BSG*AV	10.45	5.35

b. By Regions and Layer - Equations 3 - 6

1. Southern Region: Surface Layer - Equation 3

	Mean (M)	Standard Deviation (SD)
MR	425312	109881
ITSR	1.046	0.1674
AC	4.198	0.4769
BSG	2.342	0.0402
AV	5.817	1.6735
x5 = ITSR*AC	4.343	0.8043
x6 = ITSR*BSG	2.452	0.4024
x7 = ITSR*AV	6.182	1.9909
x8 = AC*BSG	9.830	1.1155
x9 = AC*AV	24.098	6.5477
x10 = BSG*AV	13.580	3.7712

2. Southern Region: Base Layer - Equation 4

	Mean (M)	Standard Deviation (SD)
MR	415917	131074
ITSR	1.068	0.1238
AC	5.097	0.6181
BSG	2.344	0.0486
AV	4.082	2.5706
x5 = ITSR*AC	5.420	0.7526
x6 = ITSR*BSG	2.503	0.2856
x7 = ITSR*AV	4.415	2.8159
x8 = AC*BSG	11.963	1.5772
x9 = AC*AV	19.665	10.9199
x10 = BSG*AV	9.465	5.7139

3. North Atlantic Region: Surface Layer - Equation 5

	Mean (M)	Standard Deviation (SD)
MR	737240	276241
ITSR	1.151	0.1194
AC	4.329	0.4106
BSG	2.391	0.0761
AV	4.815	1.6863
x5 = ITSR*AC	4.998	0.8049
x6 = ITSR*BSG	2.746	0.2966
x7 = ITSR*AV	5.540	2.0447
x8 = AC*BSG	10.336	1.0937
x9 = AC*AV	20.550	6.7242
x10 = BSG*AV	11.444	3.9094

4. North Atlantic Region: Base Layer - Equation 6

	Mean (M)	Standard Deviation (SD)
MR	726678	320284
ITSR	1.148	0.1535
AC	5.300	0.5118
BSG	2.354	0.1044
AV	4.995	2.1950
x5 = ITSR*AC	5.980	0.8872
x6 = ITSR*BSG	2.662	0.3718
x7 = ITSR*AV	5.739	2.8976
x8 = AC*BSG	12.475	1.3512
x9 = AC*AV	26.358	12.0087
x10 = BSG*AV	11.568	4.7622

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