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SHRP-LTPP Monitoring Data: Five-Year Report

Gonzalo R. Rada
PCS/Law Engineering
Beltsville, Maryland

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Program Manager: *Neil F. Hawks*
Project Manager: *Cheryl Allen Richter*
Five-Year Report Manager: *A. Robert Raab*
Program Area Secretaries: *Cynthia Baker, Francine A. Burgess*
Production Editor: *Katharyn L. Bine*

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Strategic Highway Research Program
National Research Council
2101 Constitution Avenue N.W.
Washington, DC 20418

(202) 334-3774

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EXECUTIVE SUMMARY

The U.S. Congressional Surface Transportation Act of 1978 directed the Secretary of Transportation to investigate "...the need for long-term or continuous monitoring of roadway deterioration to determine the relative damage attributable to traffic and environmental factors." In compliance, the Federal Highway Administration (FHWA) initiated the Long-Term Pavement Monitoring (LTM) program beginning with a LTM pilot study as a cooperative effort between FWHA and the American Association of State Highway and Transportation Officials (AASHTO). Selected pavements in eight (8) states were monitored beginning in 1982.

Concurrently, the Transportation Research Board (TRB) conducted the Strategic Transportation Research Study (STRS) to develop a strategy for a major research emphasis on key technological gaps with potential for high payoff. One of the primary recommendations of the study was the selection of long-term monitoring of in-service pavements as a high priority research need. The STRS report was approved by the FHWA and AASHTO and was developed further as the Strategic Highway Research Program (SHRP) with the Long-Term Pavement performance (LTPP) as a major research activity. The pilot LTM study, funded by the FHWA, was utilized as a transition activity for the SHRP-LTPP study prior to funding of SHRP. A major finding of the LTM pilot study was recognition of the absolute necessity for uniformity and consistency in data collection as the basis for analysis and accomplishment of objectives.

The overall objective of the SHRP-LTPP study is: To increase pavement life by investigation of various designs of pavement structures and rehabilitated pavement structures, using different materials and under different loads, environments, subgrade soil, and maintenance practices. The establishment of a national long-term pavement database to support LTPP analyses and future research needs was recognized as a major specific objective of the LTPP study. Sources of data for population of the National Pavement Database included General Pavement Studies (GPS), existing in-service pavements; Specific Pavement Studies (SPS), in-service pavements designed and built in accordance with selected criteria; Accelerated Pavement Testing (APT) in-service or other test sections subjected to accelerated loading; and additional sources as identified. Types of data collected under the GPS and SPS experiments are divided into the following categories:

1. Inventory - Generally constant data describing the test section;
2. Condition monitoring - Pavement condition data that changes over time and exposure to traffic and environmental conditions;
3. Traffic - Vehicle volumes and wheel loading data prior to and during the monitoring period;
4. Climate - Data necessary to characterize the environment in which the pavement has existed and continues to be exposed during the monitoring period;
5. Maintenance - Maintenance activities to which the pavement has been subject since construction and during the monitoring period;
6. Rehabilitation - Detailed data concerning any rehabilitation of the pavement during the monitoring period that essentially moves the section to a newly rehabilitated pavement; and
7. Materials Sampling and Testing - Actual field collected and laboratory test data of pavement layer materials at the beginning of the study.

This report summarizes the LTPP monitoring data collection activities for inclusion in the National Pavement Performance Database. The pavement condition monitoring data includes identification of surface distress, profile measurements, deflection testing results, and surface friction measurements. The report also describes traffic, climate, maintenance, rehabilitation, and seasonal monitoring and data collection. The report does not contain the normal research results or conclusions because:

- The data collection is intended to continue for a total of 20 years, of which this report describes the first 5 years;
- Data analysis involves interactions between the pavement condition monitoring data and other data elements of the National Pavement Performance Database; and
- Data analysis is the responsibility of other projects and reports. The primary end product of the 5-year data collection activity is the populated National Pavement Performance Database.

Some of the other results and products of the 5-year pavement condition monitoring activity are:

- Preparation and publication of the SHRP-LTPP Distress Identification Manual,
- Development and implementation of procedures for interpretation of pavement distress film records from the PASCO equipment;
- Development of SHRP modified Georgia Faultmeter that is being used in LTPP data collection;
- Development of Manual for FWD Testing;
- Development of FWD calibration procedures;
- Preparation of FWD quality assurance software;
- Selection of pavement back calculation software for use in LTPP analyses, and
- Development of computer programs to support the analysis of road profile data.

INTRODUCTION

The pavement community, faced in the 1970's with rapid deterioration of pavements nationwide, recognized the critical need for better understanding of those parameters that affect pavement performance, especially those related to rehabilitated pavements. It became apparent that the only chance of success was to mount an organized and massive study that could be continued for sufficient years to "let the pavements tell us how they perform" over their lifetime and over a diversity of environmental conditions, traffic, materials, designs, construction techniques and quality control, maintenance strategies, and other important parameters. This led to direction from the Congress of the United States in the Surface Transportation Act of 1978 to the Secretary of Transportation to study and investigate "...the need for long-term or continuous monitoring of roadway deterioration to determine the relative damage attributable to traffic and environmental factors." This offered an opportunity to begin a serious initiative, which was undertaken by the FHWA Office of Planning in the form of concepts for a "Long-Term Pavement Monitoring (LTM)" program, drawing strongly on the opinions and ideas from other offices of the FHWA. It was decided to approach LTM as a cooperative program between the FHWA, AASHTO, and participating state DOTs. An LTM pilot study was structured as a cooperative program between the FHWA, AASHTO, and eight selected states, and was implemented in 1982 to monitor selected pavements from those eight states.

Concurrent with the FHWA activities, the Transportation Research Board was conducting a study, called the "Strategic Transportation Research Study (STRS)", to develop a strategy for a major new research emphasis on key technological gaps with a potential for high payoff. The results of this study were published in TRB Special Report 202, "America's Highways, Accelerating the Search for Innovation." A key recommendation from the study was the selection of long-term monitoring of in-service as a high priority reseach need. This need was developed as the Long-Term Pavement Performance (LTPP) reasearch of SHRP. As it became clear that the major agencies involved in pavement design, construction, and management were recognizing the need for a national database to include long-term data from highway monitoring, these agencies joined together to develop these plans mutually and in cooperation.

AASHTO approved the recommendations of the Strategic Transportation Research Study and established the "Strategic Highway Research Program (SHRP)" to carry them out. As the result of broad-based enthusiasm for such a program expressed at a national workshop on long-term pavement monitoring sponsored by the FHWA in October 1984, the FHWA offered to fund "transition activities" to maintain the momentum until SHRP was approved by Congress and funded in its own right. A SHRP Advisory Committee for Pavement Performance was appointed to provide guidance for this transition planning to include experiment designs and implementation planning.

The objective for LTPP studies established by the "Strategic Transportation Research Study" and adopted by the advisory committee for pavement performance as their goal was:

"To increase pavement life by investigation of various designs of pavement structures and rehabilitated pavement structures, using different materials and under different loads, environments, subgrade soil, and maintenance practices."

The specific objectives developed by the advisory committee are:

- Evaluate existing design methods.
- Develop improved design methodologies and strategies for the rehabilitation of existing pavements.
- Develop improved design equations for new and reconstructed pavements.
- Determine the effects of (1) loading, (2) environment, (3) material properties and variability, (4) construction quality and (5) maintenance levels on pavement distress and performance.
- Determine the effects of specific design features on pavement performance.
- Establish a national long-term pavement database to support SHRP objectives and future needs.

It was their expectation that accomplishment of these objectives would resolve most of the difficulties currently experienced in implementing successful pavement management systems.

The research team and the Advisory Committee drew heavily on the previous work and planning on the Long-Term Pavement Monitoring Program to develop an overall LTPP Study Program with three potential types of studies. These included General Pavement Studies (GPS), Specific Pavement Studies (SPS), and Accelerated Pavement Testing (APT). The General Pavement Studies involve several experiments that embrace a large array of site selection factors, and are expected to produce a broad range of products and results. The Specific Pavement Studies has its own set of more limited goals, construction needs, and experimental approaches; and are generally aimed at more intensive studies of a few independent variables for each of a number of study topics. The other category of study is the Accelerated Pavement Testing Program. The APT could include either road tests, or the FHWA accelerated loading facility (ALF); however, neither of these are being considered for implementation at this time.

The great majority of test sections for the GPS have been selected from existing highways, but it is expected that most of the test sections used in the SPS will be specially designed and constructed pavements having characteristics needed for the specific studies. Both sets of test sections are, or will be, located on in-service highways throughout the United States and Canada, and hence subjected to "real" non-idealized traffic loadings, and a wide range of environmental conditions. All test sections are located in the outer (driving) lane of the highway, regardless of the number of lanes present, all testing is confined to the test section itself and the areas immediately adjacent to the test section in the same lane.

The types of data being collected under the GPS and SPS experiments can be divided into seven categories:

1. Inventory Data;

2. Monitor Data;
3. Traffic Data;
4. Climatic Data;
5. Maintenance Data;
6. Rehabilitation Data;
7. Materials Sampling and Testing Data.

Each of these categories and the data elements therein are described in more detail next.

Inventory Data

The basic inventory data includes that data necessary to: 1) identify the test section, 2) describe the geometric details of its construction and the material properties of its structural constituents, and 3) identify construction costs and costs of subsequent maintenance and repair prior to the long-term monitoring effort. All of this data, with the exception of certain material properties which change over time or environment such as subgrade strength and moisture content, should remain constant throughout the monitoring period unless the pavement is resurfaced or rehabilitated during the period. In the latter case, the test section becomes for practical purposes a new pavement structure with new surface conditions, so the basic inventory data must be revised to describe these new conditions, while retaining the original data for reference in long-term cost analyses and studies of the effects of rehabilitation on deterioration rates.

Monitoring Data

The monitoring data includes distress profile measurements, deflection testing results, and surface friction measurements. This data is being collected on a periodic basis to provide a historical database for developing relationships between distress, performance, traffic and axle loads, age, maintenance and other significant variables. Deflection, friction, distress, and profile measurements are typically made every one to two years, except when they may be required more frequently when the rate of deterioration is accelerating as damage becomes severe or on selected sections during critical seasonal changes such as spring thaw.

Traffic Data

Traffic data are being collected to describe the loadings to which the LTPP sections are subjected to. These data includes Average Annual Daily Traffic (AADT); percent heavy trucks; distribution of traffic by vehicle classes; and distribution of axle loads for single, tandem, and tridem axles. Both historical data prior to initiation of the monitoring activity, as well as the traffic collected throughout the monitoring period are included.

Climatic Data

The climatic data includes that data necessary to characterize the environment in which the pavement has existed since its construction and on through the monitoring period. The climatic data elements being collected include: weather station identification/location; average monthly temperature; average maximum daily temperature by month; average minimum daily temperature by month; average monthly precipitation; average monthly percent sunshine; average monthly wind speed; general type of environment; average annual number of days of precipitation; latitude; longitude; freezing index; average number of annual freeze-thaw cycles; elevation above sea level; average annual deicing salt application; highest monthly mean solar radiation; lowest monthly mean solar radiation; and Thornthwaite moisture index.

Maintenance Data

The determination of data elements to be collected to reflect maintenance activities on LTPP test sections was one of the more difficult tasks in planning the LTPP program. The complications include the wide variations in maintenance policy and data collection procedures among various Highway Agencies, and the need to coordinate maintenance activities within the test sections themselves. However, guidelines for the collection of these data are now in place and are included in the "LTPP Data Collection Guide" (Ref. 1); the required maintenance data elements are also included in this document.

Rehabilitation Data

The data being collected by LTPP pertain to rehabilitation that has occurred after initiation of monitoring for the test section. Most rehabilitation procedures such as recycling or overlay produce a test section having a modified pavement structure, while other procedures such as undersealing may be considered to restore the existing pavement structure. Reworking shoulders and placement of edge drains are other examples of improvements that may be made without changing the primary pavement structure; however, any such rehabilitation converts the pavement from an "original pavement" to a "rehabilitated pavement". The specific data elements to be collected for rehabilitation are included in the "LTPP Data Collection Guide" (Ref. 1).

Report Organization

This report focuses on the SHRP-LTPP monitoring activities. The specific topics covered, in order of presentation, are distress, deflection, profile, traffic, surface friction, climate, seasonal monitoring, maintenance, and rehabilitation. As applicable, the objectives, data collection equipment and procedures, quality assurance procedures, status and products are detailed for each monitoring activity. The reader is referred to the "LTPP Overview" report (Ref. 2) for a more detailed description of the LTPP program.

DISTRESS

Objectives

SHRP's efforts to monitor surface distress on the test sections under study in the Long-Term Pavement Performance (LTPP) research serve two primary purposes. The first is to provide a permanent, objective, high resolution record of pavement condition over the full length and width of the sections under study; the second is to provide detailed, distress-specific condition data for use in the development of pavement performance prediction models.

To achieve these objectives, SHRP is making use of the PASCO Roadrecon photographic distress survey technology, which provides for both high resolution 35mm surface distress photographs and photographic cross-profile measurements. Two Roadrecon units were constructed by PASCO in 1988 to perform pavement condition surveys for SHRP. In those instances where the PASCO units cannot be used, due to time constraints or the difficulty of getting the PASCO survey vehicles to the site, manual distress surveys serve as the backup data collection method.

Basis for Data Collection

The majority of the LTPP distress data is being developed from photography through a computer assisted interpretation process. However, distress surveys are performed by field personnel ("manual" surveys) from time to time to supplement the photographic data when special circumstances (equipment accessibility, scheduling conflicts, etc.) arise. The "Distress Identification Manual for the Long-Term Pavement Performance Studies" (Ref. 3) serves as the basis for both the manual distress surveys, and the reduction of distress data from the PASCO film. This manual provides the definitions and procedures for the actual identification, measurement, and recording of distresses, so necessary to achieve the desired consistency in distress data collection.

A draft version of the distress identification manual (DIM) was published by SHRP in June of 1989, and the final document was published in October 1990. While this document served as an excellent starting point for the collection of SHRP distress data, actual monitoring experience with LTPP pavements revealed that a number of distress type or severity level definitions were too vague. As a result, a follow-up effort was undertaken to remedy these problems. As part of this effort, numerous meetings were held with SHRP and Regional Coordination Office Contractor (RCOC) staff. A one-week distress workshop, involving SHRP and RCOC staff, was also held in Arlington, Texas in the Spring of 1991 to address problems associated with the DIM. The outcome of all this was an unpublished, revised document which has been in use by SHRP since the Summer of 1991 for the interpretation of distress photographs as well as for the conduct of "manual" distress surveys. Work is currently in progress to further improve the DIM; it is anticipated that this document will be published by SHRP in late 1992 or early 1993.

Photographic Distress Surveys

Equipment and Data Collection

The two PASCO Roadrecon survey vehicles used for the SHRP testing are each equipped with two camera systems; these units are shown in Figure 1. A distress camera system (Roadrecon RR-70) is mounted on the front of the vehicle, and includes a 35mm slit camera mounted on a boom which extends out over the pavement, and a series of lights mounted on the front bumper. A cross-profile camera system (Roadrecon RR-75), mounted on the rear of the vehicle, includes a boom-mounted 35mm pulse camera and a hairline projector located on the rear bumper. Both camera systems are controlled by computer from the front passenger seat of the survey vehicle. The vehicle operates at highway speeds, and all surveys are done at night, under controlled artificial lighting. The lights for the survey systems are sufficiently bright that incidental light from street lights and/or passing vehicles does not significantly affect the quality of the photographs.

The distress photographs obtained with the PASCO survey vehicle are continuous strips of 35mm movie film which provide 100 percent coverage of the full lane width, and a portion of the shoulder (16 feet (4.9 m) total). Resolution approaching 1 mm may be achieved when the equipment is adjusted correctly, and ideal pavement and lighting conditions exist. In general, however, a 2 mm resolution was achieved in the work done for SHRP.

Cross-profile photographs are taken at 50 feet (15.24 m) intervals on the SHRP sections, and, like the distress photos, cover slightly more than the full lane width. Because the first cross-profile photograph on each section must be triggered manually, the cross-profile measurements are rarely at exactly station 0+00, 0+50, 1+00, etc., although SHRP requires that they be within 10 feet (3 m) of those locations. The actual locations are identified from marks which appear on the edges of the distress film.

The (original) negatives and one set of positive copies of both types of film are being put into archival storage, to preserve them for future researchers. Additional positive copies are used in the data reduction process. In addition, the photographic images may be digitized and stored on optical disk for distribution to researchers at some point in the future.

Prior to the start of the field surveys, pilot tests were run to verify that the two survey vehicles to be used for the SHRP surveys could provide photographs of the required quality. In addition, both static and dynamic checks on the accuracy of the rut depth measurements obtained were conducted. In dynamic checks, cross-profiles derived from the PASCO photographs compared favorably with those from manual cross-profile measurements made with a string line, although small differences in the locations of the two measurements contributed to the differences which

Figure 1 - Picture of PASCO Units Showing Front and Back Cameras

did exist. Static rut depth measurements derived from PASCO cross-profile measurements and equivalent manual measurements agreed to within 1 mm.

Also, a number of quality assurance measures have been established for the collection of distress and cross profile photographs on the SHRP test sections. For example, a resolution test pattern with precision machined grooves ranging from 1 to 6 mm in width is used to verify the adequacy of the photographic resolution. As a rule, the 1-mm groove in the test pattern is visible. If resolution of 2 mm or better is not achieved, camera settings are checked and adjustments are made. Failure to achieve resolution of 3 mm or better triggers rejection of the film in addition to camera adjustments. Additional quality assurance measures include checks on linear distortion, lateral placement in the lane, location of cross-profile photographs with respect to the target location, and film processing quality. Reference 4 provides a more detailed description of these quality assurance measures.

Interpretation of Distress Photographs

The reduction of distress data from the PASCO film has been more problematic than originally anticipated. In planning for this activity, it was felt that the use of a relatively high degree of automation by a single contractor would maximize the efficiency and consistency of the data reduction. At present, no fully automated system for the reduction of detailed pavement distress data from photographic media exists, although a great deal of research is being done in this area. Hence, a "semi-automated" approach was adopted. The approach currently being used by SHRP to interpret distress data from film and to ensure its quality is summarized below; Reference 5 provides a more detailed discussion.

Examination of distress photographs for determining the types and extent of distress is accomplished using a computer software system and film handling system developed by PASCO USA, Inc. The distress film interpretation equipment is called the PAvement DIstress Analysis System (PADIAS) and consists of an IBM compatible 386 computer, a Film Motion Analyzer (FMA) for viewing and digitizing the images from the 35mm films, and a printer for preparing the reports. This system was especially adapted to SHRP's needs, and it has undergone revisions concurrent with changes in the SHRP Distress Identification Manual. Also, in May 1991, to alleviate problems with image clarity, PASCO modified the PADIAS from a back projection system to a downward projection one.

Photography, processing and organization of the film are accomplished by PASCO USA. The finished films are sent to the LTPP Technical Assistance contractor, where the PADIAS operator performs a quality review of each film roll to establish whether or not the images are satisfactory. The operator documents the results of the review on film log forms. Any irregularities in the pavement test sections noted during this review are brought to the attention of supervisory personnel for resolution. A copy of the film logs is then forwarded to SHRP for storage.

After the film quality review is completed, the distress interpretation process is initiated. To simplify film handling; interpretations are completed on a state by state (province by province) basis, as one state (province) is typically contained on a single roll of film. For GPS sections, the project information sheets from the nomination database are reviewed for the sections selected for interpretation to provide pertinent information on pavement type, lane width, underlying layers, etc. For SPS sections, pavement type is determined from the experiment number and test section numbers, both contained in the site ID. When available, section site verification videos are reviewed, as needed, to enhance the interpretation process.

The actual film interpretation is comparable to performing a typical condition survey; that is, the type, amount and severity of the distresses existing in the section are observed and recorded. Operation of the PADIAS distress interpretation program is described in Reference 5. Distress definitions and measurement guidelines are described in the SHRP Distress Identification Manual (Ref. 3). It should be noted, however, that a few common distress types cannot be identified consistently from the PASCO photographs, and will have to be measured in other ways during site visits. A summary of the distress types that can and cannot be identified from the PASCO photographs is presented in Table 1.

The function of the PADIAS program is to interpret and record pavement distresses within a test section from the 35mm RR-70 film using the film motion analyzer (FMA). This is accomplished by displaying the road surface on a frame by frame basis. In the PASCO film, a frame represents a 12.2 foot (3.7 m) length of pavement, thus there are normally 41 frames within a 500-foot (152.4 m) section. The FMA screen pointer (cursor) is used to designate and record distresses existing in the portion of the pavement section designated by the frame. After identifying all pavement distresses within a frame, the software-controlled FMA advances the film to the next frame. The distress identification process is continued until all frames have been interpreted.

Upon completion of the interpretation process, the operator generates reports summarizing type, amount, and severity of the distresses found in the section. This process is repeated for each section included on a state (province) film roll. The resulting summary reports, along with interpretation logs, for a completed film roll (state or province) are compiled and submitted to the quality assurance/quality control (QA/QC) engineer for review. The QA/QC reviewer examines all of the reports and selects sections to receive a detailed QA/QC review based on operator comments, pavement type and requirements for random quality control checks. All sections are looked at by the QA/QC reviewer, using the FMA, with a minimum of 25% of the interpreted sections being reviewed in detail. The selection procedure for the detailed QA/QC reviews is based on PADIAS operator comments concerning difficulty in interpretation, distress report complexity or anomalies, and film condition and clarity. If any discrepancies are noted in the quality control review, the section is corrected by the operator and discrepancies in interpretation resolved. If there are systematic discrepancies observed in the QA/QC review then an increasingly higher percentage of the interpretation film (i.e., 30, 40, etc.) is reviewed in detail by the QA/QC reviewer.

Table 1 - Summary of Distress Types that Cannot be Reliably Interpreted with the PADIAS

Pavement Type	Distress
AC Pavements	Shoving Bleeding Polished Aggregate Ravelling and Weathering Lane-to-Shoulder Dropoff Lane-to-Shoulder Separation Water Bleeding and Pumping
JPC Pavements	Transverse Joint Seal Damage Map Cracking and Scaling Polished Aggregate Lane-to-Shoulder Dropoff Lane-to-Shoulder Separation Water Bleeding and Pumping
CRC Pavements	Map Cracking and Scaling Polished Aggregate Lane-to-Shoulder Dropoff Lane-to-Shoulder Separation Water Bleeding and Pumping

The processed data is then forwarded to the RCOC's, who perform another QA/QC review of the film and distress reports. The RCOC distress quality control team utilizes a combination of projection viewing of the PASCO film, the nomination verification videotape, and/or spot checking of the actual section conditions in the field to confirm the PADIAS operator's interpretation of the section. If any discrepancies are noted, the RCOC and PADIAS team review the section and mutually resolve any discrepancies. Reports for edited sections are generated by the PADIAS contractor to replace the original reports sent to the RCOC's. Upon completing the QA/QC regional review process, the distress data is entered into the LTPP database.

Interpretation of Cross-Profile Photographs

The reduction of SHRP's cross-profile and rut depth data is done by PASCO, using equipment much like that used for the distress film. The cross-profile image is projected on a digitizing screen, and the data are reduced by digitizing a series of points on the hairline image in the photograph. For SHRP's purposes, 30 points are digitized at approximately 6 inch (15.2 cm) intervals. The X-Y coordinates resulting from this process are stored in computer data files, and used to produce cross-profile plots. The cross-profile represented by these coordinates is relative to a straight line connecting the two edges of the lane (i.e., the shoulder edge of the pavement and the inner edge of the lane), which is treated as being horizontal; no measurement of cross-slope is obtained.

After all sections in a state or province have been digitized, and accepted by the operator, they are passed to the PASCO quality assurance staff, who review the header information and the maximum rut depth data for accuracy. Any errors in the header information are corrected at this time. On completion, the magnitude of the maximum rut depth of each wheel path is compared to that of the previous year's survey. If the rut depth has decreased by more than 3 mm or increased by more than 4 mm, the section is flagged for further review -- the profiles for each year are compared by overlaying them on a computer screen to determine where discrepancies, if any, are located. If there are no discrepancies, the data is accepted. Otherwise, the profile for the current year is redigitized and the quality assurance process is repeated.

To date, the reduction of cross-profile data has been done by PASCO, who in addition has performed all quality assurance reviews and generated ASCII data files, summary reports, and transverse profile plots. The ASCII data files are generated for direct input into the LTPP database. The summary reports contain cross profile data for each section tested, including the associated statistics, while the plots are graphical representations of the transverse profile at each location tested in the section. Copies of all these are sent to SHRP and the LTPP technical assistance contractor for further review and storage.

Manual Distress Surveys

Collection of Distress Data

As noted earlier, distress surveys are performed by field personnel ("manual" surveys) from time to time to supplement the photographic data when special circumstances (equipment accessibility, scheduling conflicts, etc.) arise. Achieving the desired consistency in distress data collection requires a firm basis for the actual identification, measurement, and recording of distresses. Pavement distresses are defined and measurement and recording requirements established in the "Distress Identification Manual for the Long-Term Pavement Performance Studies" (DIM; Ref. 3).

Manual distress surveys are performed using the procedures published in the LTPP Manual for Distress Surveys (Ref. 6). This manual contains the standard forms and symbols used to record distress occurrences observed by the rater on the distress map prepared for the section being surveyed; see Figure 1 for a sample distress map. This map is reviewed in the field by the rater and all distress quantities are summarized and recorded on the distress survey sheets appropriate for the pavement type.

In addition to the above referenced documents, two other supplemental manuals have been prepared for use in the performance of manual distress surveys. They are: "SHRP-LTPP Manual for Dipstick Profile Measurements" and "SHRP-LTPP Manual for Faultmeter Measurements" (Ref. 7 and 8, respectively). The first manual provides operational field guidelines for the collection of transverse profile data using the Dipstick® Profiler manufactured by Face Technologies, Inc. These data are needed when such data cannot be obtained by the PASCO Roadrecon survey units. The latter manual provides field guidelines for the measurement of faulting (in jointed concrete pavements) and lane-to-shoulder dropoff (in all pavement types), using the Georgia DOT Faultmeter. Besides the field measurement procedures, these two manuals provide guidance for equipment calibration and maintenance.

Rater Accreditation

By definition, distress surveys performed by field personnel can not have the same level of detailed, thorough supervision and quality assurance checking as is available in the film interpretation process. Another important facet of the manual survey is the fact that no permanent objective records, such as the photographs obtained in a consistent and controlled manner, are left behind to supplement the hand-drawn maps and observations and interpretations (possibly subjective) of the rater.

As a consequence, an accreditation process to develop consistency among raters has been established by SHRP (Ref. 9). Specifically, the purpose of this accreditation process is to provide a means for ensuring, to the extent possible, the quality and consistency of distress data being collected for LTPP by the RCOC raters. Although the process is still in its early

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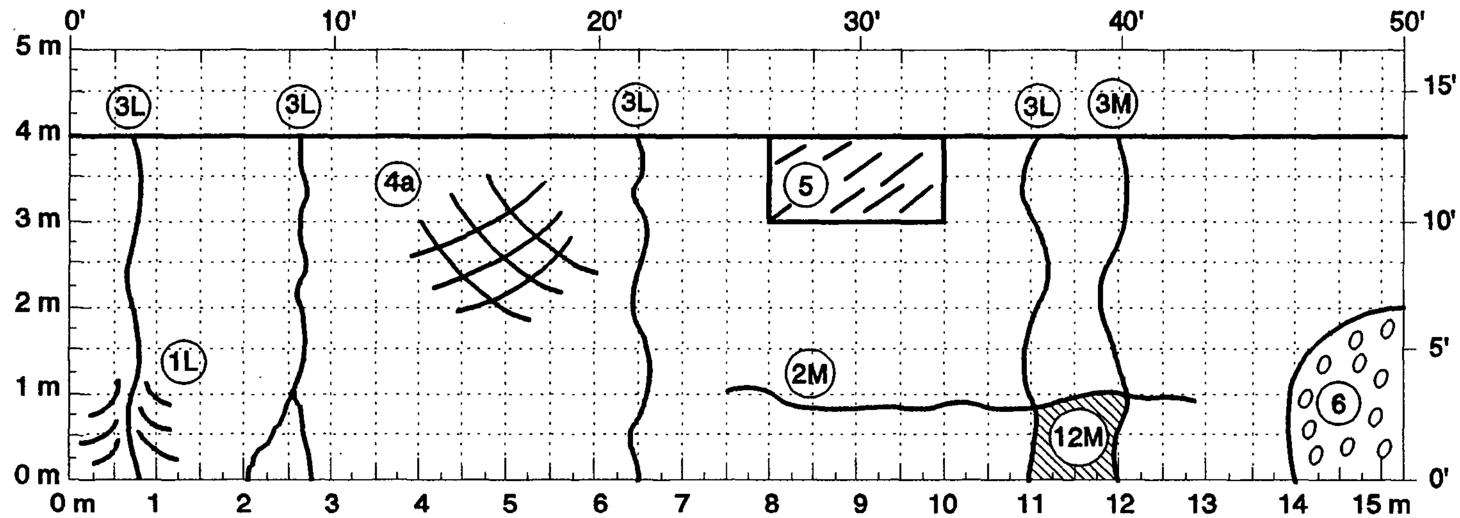
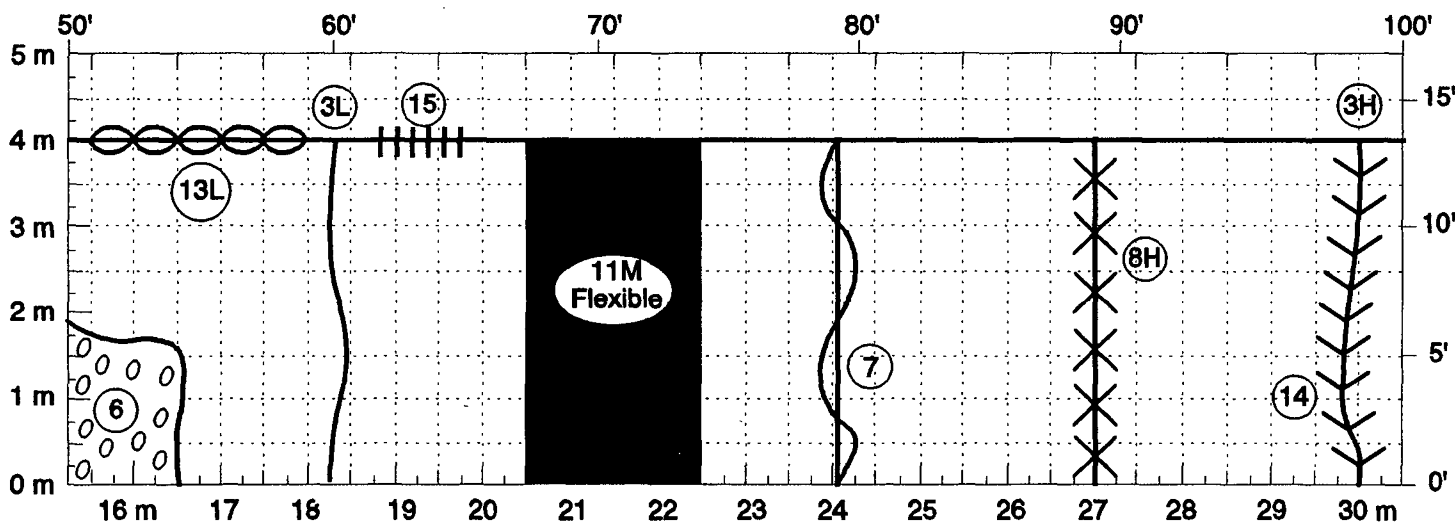


Comments: 4 m LANE WIDTH



Comments: CONSTRUCTION JOINT AT 0 + 27

Figure 2 - Sample Distress Map Showing Symbols and Other Information

implementation phase, it is SHRP's intent that all distress data for the LTPP study be collected by raters who have successfully completed the accreditation. Furthermore, it is SHRP's intent to have the RCOC raters re-accredited on a periodic basis -- every two to three years.

The accreditation process is being administered in a workshop situation. The raters are brought to a single location for one week of classroom and field work. Classroom training is limited in scope due to the level of experience required (discussed later) for attendance; the primary emphasis is on changes or revisions to the DIM along with any changes in field procedures. However, a general review of distress types is conducted using slides and video to reinforce the attendees knowledge of the most current DIM and field procedures. Field survey exercises are conducted to "calibrate" the raters. Sections in the early portion of the field exercises contain only a few distresses while more complex sections are used in later exercises. The objective of these surveys is to determine the individual rater's bias and as necessary, retrain or correct those biases.

The actual accreditation process consists of two major parts: a written examination and field surveys. The written examination is intended to test the general knowledge of the rater, in a closed-book situation, through identification of distresses from slide/video and by a series of questions covering a range of distress type and severity level definitions and measurement procedures. The field surveys are intended to measure the accuracy of the raters' observations on a series of pavement sections which have been carefully surveyed by a committee of experienced raters. The successful completion of the examinations will identify the rater as possessing the level of knowledge, competence, and accuracy in observation to provide distress data of acceptable reliability for inclusion in the LTPP database.

The written examination is worth 20% of the overall accreditation grade, while the field survey portion is worth 80% of the total score. To receive accreditation, a rater must achieve a combined 75% grade for the written and field examinations, but no less than 70% on either portion. The passing grades noted are expected to affirm the competence of the raters in distress data collection. The minimum examination grades, however, are not intended to suggest that errors in the field of up to 30% are in any way acceptable.

Finally, because of the importance of the distress data to the goals of the LTPP study, minimum levels of experience and expertise are required for the personnel performing surveys. To participate in the accreditation process, and hence future distress data collection activities, RCOC raters must have the following: high school education (or equivalent), previous training in distress surveys (either formal or informal), familiarity with LTPP DIM and field procedures. Previous field experience (minimum of 1 year) is highly desirable, but not mandatory.

Status of Distress Activities

To date, two rounds of distress surveys have been conducted on all current SHRP General Pavement Studies (GPS) test sections, and most of the existing Specific Pavement Studies (SPS) test sections. In addition, a third round of distress surveys on all SHRP GPS and SPS sections is nearly complete. Manual distress surveys have been required on a few test sections, due to their remote nature, or time constraints which made photographic surveys impossible. At present (Summer 1992), efforts are concentrated on completing the third round of photographic distress surveys.

Interpretation of the distress photographs has been completed for the initial round of GPS and SPS surveys, including all quality assurance checks, corrections where necessary, and report generation. Interpretation has also been completed for the second round of GPS and most SPS surveys, but quality checks have only been conducted on a subset of these sections. It is anticipated that all second round interpretation activities for both GPS and SPS sections will be completed by the Fall of 1992, and that work on the interpretation of the third round of surveys will commence shortly thereafter.

Significant effort has been and is currently being devoted to revising the SHRP distress identification manual and the manual for field distress surveys (Ref. 3 and 6). It is anticipated that final versions of these documents will be published by SHRP in late 1992 or early 1993.

Finally, the rater accreditation program is now in the process of being implemented. Three accreditation workshops were held in the Spring and Summer of 1992, in Reno, Nevada. In all, 29 RCOC raters have been accredited to date as a result of these workshops. Much valuable information has also resulted from these workshops in regards to rater variability and procedures for minimizing the same; i.e., improving the consistency among raters. Work is now underway to incorporate the knowledge gained from the first three workshops into future workshops.

Products

From the LTPP perspective, monitoring of pavement distress will provide the data necessary to achieve, in conjunction with the other monitoring activities, the objectives of the LTPP program, including the development of pavement performance models. These data will also provide a permanent, objective, high resolution record of pavement condition over time (generally 15 to 20 years), over the full length and width of the sections under study, for use by future researchers.

To the pavement engineering community as a whole, the "key products" of the SHRP distress activities include:

- Distress Identification Manual and Data Collection Procedures

  Distress data is a key indicator of pavement performance, and can, when used with other pavement data, provide insight into the condition of a pavement. Timely collection of accurate, detailed, and uniform distress data allows both assessment of pavement condition, and evaluation of the mechanisms behind any deterioration which may have occurred. Thus, distress data are an important means of monitoring pavement performance for the purposes of pavement management, pavement design, pavement maintenance, and pavement research.

Achieving consistency in distress data collection requires a standard basis for the actual identification, measurement, and recording of distresses. However, standard procedures for the collection of distress data have not yet (Summer of 1992) been adopted by such major standard setting organization as AASHTO or ASTM. As a consequence, SHRP has developed a Distress Identification Manual to ensure the validity of the data being collected for the LTPP sections. Pavement distresses are defined and measurement and recording requirements established in this manual. In essence, the manual provides the means needed to ensure the uniform and consistent collection of pavement distress data. The manual includes data collection guidelines for asphalt surfaced, jointed concrete, and continuously reinforced concrete pavements.

Although SHRP's principal means for the collection of distress data is through photographic distress surveys, manual distress surveys are performed by field personnel when special circumstances arise. Data collection procedures are detailed in LTPP Manual for Distress Surveys, which contains the standard forms and symbols used to record distress occurrences. In addition, two other manuals have been prepared by SHRP for use in the performance of manual distress surveys. The first manual provides operational field guidelines for the collection of transverse profile data needed to determine rut depths. The latter manual provides field guidelines for the measurement of faulting (in jointed concrete pavements) and lane-to-shoulder dropoff (in all pavement types), using the SHRP modified Georgia DOT Faultmeter. Both manuals also provide guidance for equipment calibration and maintenance.

Adherence to the distress identification manual and data collection procedures developed by SHRP offer the potential for greater uniformity in the collection of pavement distress data, which will lead to better maintenance and rehabilitation decisions by providing more uniform and accurate pavement conditions data.

- SHRP Modified Georgia Faultmeter

Fault measurements are a significant part of the regular distress evaluation of the LTPP portland cement concrete pavement test sections. Objective measurements are needed to document the performance of concrete pavements over time. These measurements are used to monitor the progress of distress, and to relate the rate of change to environmental conditions and traffic observed in the LTPP studies.

A SHRP modified Georgia Faultmeter is being used in the LTPP program, to collect these data. This device is quicker, more repeatable and easier to use than conventional straight edge and scale. The speed at which the device works substantially reduces lane closure time. Because the operator is able to operate the faultmeter while standing, readings can be taken quickly and easily recorded. Data collection procedures have been published in the SHRP-LTPP Manual for Faultmeter Measurements (Ref. 8).

Highway agencies also require fault measurements for pavement management, rehabilitation design, and control and acceptance of construction on such projects. The calibration and data collection procedures used in the LTPP studies are readily adaptable to highway agency usage. More importantly, they provide highway agencies with the consistency needed to monitor the progression of faulting in pavement management.

An equally important by product will be the rater accreditation process. Such a process does not presently exist within most states, much less on a nation wide scale. Its implementation would go a great way towards improving the consistency and quality of distress data collected by highway personnel, which is particularly important since, unlike photographic surveys, no permanent objective records are left.

DEFLECTION

Objectives

Deflection testing with falling weight deflectometers provides the primary means for assessing structural capacity, and variations therein for the pavement test sections studied in LTPP. SHRP's deflection testing activities can be roughly divided into two phases. For the initial phase of data collection, which was completed in the Summer of 1992, the deflection testing was linked with the drilling and sampling to provide baseline information; the reader is referred to the "Materials Characterization" report (Ref. 10) for a more detailed description of the drilling and sampling program. Among the functions this data will serve are the following:

- Provide a basis for estimating the in-situ layer material properties (E_i - dynamic modulus)
- Assess the degree of load (stress) transfer across rigid pavement joints/cracks.
- Provide a basis for estimating the in-situ (effective) pavement structural capacity in terms of either the AASHTO Structural Number (SN) or PCC thickness.
- Provide a basis for "linking" test pit information (i.e., laboratory characterization) with the overall section properties (Materials Characterization - Vol. 5).
- Evaluate the degree of structural variability present in individual test sections.

In the second phase of data collection, which is just beginning to get under way, SHRP's deflection testing efforts will be directed toward the seasonal monitoring program (Ref. 11), SPS testing, and "routine" monitoring of each GPS section approximately once every five years. The purpose of the seasonal monitoring program is to provide the data needed to understand the magnitude and impact of temporal variations (both seasonal and diurnal) in pavement response and properties due to the separate and combined effects of temperature and moisture variations over time.

Data Collection

Equipment and Procedures

SHRP is using four (one for each region) trailer-mounted Dynatest Model 8000E Falling Weight Deflectometers (FWDs) to measure the deflection response of all GPS and SPS pavement test sections; one of these devices is shown in Figure 3. These devices are capable of producing loads ranging from 1,500 to 27,000 pounds force (7 to 120 kN). The load is applied by means of an 11.82 inch (30 cm) diameter load plate and it is measured by a load cell located above the loading plate. Seven seismic sensors (geophones) measure deflection response. A portable

Figure 3 - Picture of the SHRP Falling Weight Deflectometer (FWD)

computer controls the FWD operation, and serves as a high speed data acquisition and processing system.

In order to provide a uniform and standardized field deflection measurement procedure, a publication titled "SHRP-LTPP Manual for FWD Testing - Operational Field Guidelines" was released for use in January 1989 (Ref. 12); an updated version, which incorporates the experience gained by SHRP over the past three years, will be released in late 1992 or early 1993. Because this manual only considers deflection testing of GPS sections, a number of supplemental guidelines were subsequently prepared to address the various SPS experiments (Ref. 13 to 18). Both the FWD manual and supplemental guidelines also document the ancillary data collection -- measurement of temperature and joint/crack widths -- conducted in conjunction with the deflection testing.

SHRP is conducting two basic types of deflection tests: basin tests, which are conducted on all pavement types, and load transfer tests, which are conducted only on portland cement concrete (PCC) pavements. The full testing program for GPS and SPS sections is described in the above referenced documents. Pertinent details of the testing program for GPS sections are as follows. The testing program for the SPS experiments is very similar, though as a rule, fewer points per section are tested due to time constraints.

While the best sensor spacing for use on any given pavement structure is a function of the rigidity and layer composition of that structure, a uniform sensor configuration has been adopted for all pavement types to minimize the possibility of sensor location errors. For deflection basin tests, sensors are located at 0, 8, 12, 18, 24, 36 and 60 inches (0, 203.2, 304.8, 457.2, 609.6, 914.4 and 1524.0 mm). For load transfer tests, the sensor at $r = 8$ inches (203.2 mm) is moved to a location 12 inches (304.8 mm) to the rear of the loading plate.

A uniform drop sequence is used at all test points within a test section. This drop sequence begins with a series of three drops at a load of 12,000 to 14,000 pounds force (53 to 60 kN) for seating purposes, followed by four repeat drops at each drop height (load level) used. For flexible (i.e., asphalt concrete) pavements, four drop heights are used, producing nominal loads of 6,000, 9,000, 12,000 and 16,000 pounds force (26, 40, 53 and 71 kN). On rigid (portland cement concrete and continuously reinforced concrete) pavements, only three drop heights are employed, producing nominal loads of 9,000, 12,000 and 16,000 pounds force (40, 53 and 71 kN).

Testing within the section is completed in two or three passes at different lateral (transverse) locations in the lane: mid-lane, defined as 6.0 ± 0.5 feet ($1.83 \pm .15$ m) from the pavement edge; outer wheel path, defined as 2.5 ± 0.25 feet (0.76 ± 0.08 m) from the pavement edge; and pavement edge, where the load plate is located within 3 inches (7.63 cm) of the pavement edge. All testing in a given lateral location is completed in a single pass over the section for reasons of ease, efficiency, and error reduction. The mid-lane locations are tested first, followed by the edge locations where applicable, and the outer wheel path locations.

Deflection basin tests at two test pit locations, approximately 50 feet (15.24 m) outside the section boundaries, are also conducted for all pavement types in conjunction with drilling and sampling operations (test pits are optional in PCC -- state or provincial highway agency preference; large diameter cores can be used instead). The function of these tests is to provide a basis for "linking" test pit information (i.e., laboratory characterization) with the overall section response. Test pit locations (prior to excavating) are tested first (i.e., before the within section testing) so that drilling operations can commence.

All testing uses station 0+00 of the test section as the reference point for the FWD distance measuring instrument, to ensure that test locations can be accurately located in the future. The specific test pattern used on the test sections varies with pavement type. The approximate longitudinal test point spacing for all pavement types is 25 feet (7.62 m). This results in a maximum of 21 test points per pass per section.

In addition to the deflection data, air and pavement surface temperatures are monitored by sensors mounted on the FWD trailer, and these data are recorded with the deflection data for each test point. Additional temperature data are obtained by manual monitoring of temperatures at three depths (bottom, middle, and surface) in the pavement surface layer at two locations, one at each end of the test section, just beyond the section boundaries. These manual measurements are obtained at the start of testing and at hourly intervals during testing.

Other Related Issues

During the development of the FWD data collection guidelines and the conduct of deflection testing, a number of important issues surfaced which merit special attention. They include: sensor spacing, storage of load and deflection history data, noise in the FWD load pulse, and equipment availability. A discussion of these issues is presented below, along with its resolution.

The sensor spacing used in SHRP's deflection testing activities has been a topic of much discussion. There has been general agreement that the use of a single sensor spacing for all pavement types is necessary, to minimize the potential for errors associated with changing the spacing from one section to the next. However, agreement regarding the set of sensor locations that will best characterize pavement response for the set of pavements being studied has been harder to come by. The sensor spacing ultimately adopted for use in the SHRP deflection testing is a compromise, agreed upon as "reasonable" by the majority of the members of the SHRP-LTPP Expert Task Group (ETG) for Deflection Testing and Backcalculation. Consideration has been given to the use of one or two additional sensors, as it appears that all concerns could be satisfied in this way. However, this option was not available when data collection was begun, and has since been ruled out due to financial considerations.

The storage of load and deflection history data has been another source of considerable debate in the deflection testing area. Traditionally, only the peak magnitudes of the impulse load and resulting deflections have been recorded and used in the analysis of FWD data. However, the

FWD data acquisition system has the capability to record the full history of the load pulse and deflection response, and some researchers are currently working to develop improved analytical methods which make use of this data. Storage of the complete history is therefore desirable, but problematic by virtue of its volume. As a compromise, history data is being collected and stored for one fourth of the deflection tests at each test point and load level, but it is being stored "off-line", on optical disk, rather than in the main LTPP database.

Still another issue which has complicated the deflection testing program is the presence of "noise" in the FWD load pulse. Ideally, the FWD pulse is essentially half-sine in shape, with a smooth rise to the peak value. For reasons which are not fully understood, high frequency "noise" occasionally introduces a "bump" in the pulse, which is not necessarily transmitted to the pavement due to the configuration of the loading plate and buffers. It was believed that the nature of this phenomenon was such that when it occasionally coincided with the peak load magnitude, it would always result in a erroneously high peak load. To alleviate this problem, an optional digital filter was implemented in the FWD data collection software. However, a thorough study of the impact of this filter revealed that it had a far greater impact on the magnitude of both loads and deflections than originally anticipated, and it was unclear whether the "filtered" values were more correct than the "unfiltered" values or not (Ref. 19, 20). Hence, the use of the software filter was discontinued after the pilot data collection activities in December 1988.

Subsequently, the FWD manufacturer developed a modified, rounded buffer shape for the FWD loading mechanism, which resulted in a smoother load pulse. When advised that the rounded buffer shape was now standard, and shown data demonstrating the smoother load pulse shape, SHRP agreed to the manufacturers' offer to modify the original flat buffers on the SHRP FWD's to the new shape. The resulting buffers were rounded to a 50 mm radius; they were implemented during the early part of 1990. Shortly after delivery of these buffers it was found that the rebound of the loading assembly had been increased, resulting in impacts which caused breakage of the FWD lift mechanism. Consequently, the 50 mm buffers were subsequently replaced in the Spring of 1990 (except for the Western Region, where they were replaced in December of 1990) with buffers rounded to a 90 mm radius. The result of this series of exchanges was that deflection data was collected on SHRP test sections using three different types of buffers in the FWDs, each of which resulted in a slightly different load pulse. An evaluation of the differences between the buffer shapes is discussed in Reference 21.

A final area of difficulty in relation to the deflection testing has been equipment availability. At times, the need for deflection testing has exceeded the available capacity, due to concurrent demands for testing on GPS and SPS test sections. To solve this problem, SHRP has called upon the State highway agencies which have similar FWDs to fill in the gaps. The one major drawback to this is that the state or provincial highway agencies FWDs are generally uncalibrated and have not been involved in the rigorous comparisons conducted to ensure uniformity among the SHRP FWDs. This will be somewhat compensated for by calibrating these devices "after the fact" as discussed under quality assurance.

Quality Assurance

A number of measures have been implemented to ensure the quality of the SHRP deflection data. These measures include: initial acceptance testing, equipment comparison and calibration, standardized field testing procedures and field data checks, and quality assurance software.

Initial acceptance testing of the four SHRP FWDs, conducted in Florida in May 1988, revealed that normalized deflection measurements for one of the devices were significantly different from those for the other three. This problem was traced to an inaccurately calibrated load cell on the suspect FWD, and corrected by the manufacturer. Subsequently, a pilot calibration effort, in which measurements of load and deflection from the FWDs were compared with measurements obtained from independent reference systems, and additional comparative testing were conducted in November of 1988, resulting in the conclusion that all four SHRP FWDs were measuring and recording accurate and equivalent load and deflection data.

Periodic verification of the accuracy of the load and deflection measurement devices on the SHRP FWDs is essential to the integrity of the SHRP deflection data. In addition, because needs for deflection testing in the SHRP program will soon exceed that which can be done with just the SHRP FWDs by the Fall of 1992, it is essential to be able to calibrate state-owned FWDs to a SHRP standard, so that they may be use to supplement the testing which SHRP is able to do. Accordingly, SHRP developed methodology and equipment that allow for calibration of FWDs against an independent reference system (Ref. 22, 23). Using this technology, SHRP has recently completed the installation of one FWD calibration center in each of the four SHRP regions -- Harrisburg, Pennsylvania (North Atlantic); Reno, Nevada (Western); Austin, Texas (Southern); and Minneapolis, Minnesota (North Central). Thus, both SHRP and non-SHRP FWDs can now be checked for agreement with the SHRP standards. Annual calibration is anticipated for any device used in SHRP testing.

To ensure the continued reliability of the FWD measurement devices, the FWD operators are required to conduct monthly relative calibration checks of the deflection sensors. In these checks, the geophones are compared to each other in a statistically designed experiment. Since it is unlikely that all seven geophones would change in a systematic fashion, this provides a good, quick check that all are functioning properly. The procedure for this calibration is detailed in the FWD field manual (Ref. 12), and a computer program, FWDCAL (Ref. 24), has been developed to automate the data analysis and decision criteria, thus simplifying the process, and minimizing the potential for operator error.

The FWD data collection process is fully automated, and includes five data checks to alert the FWD operator of potential data errors or problems. They are:

- Roll-Off - an electrical check of the deflection sensors to verify that the signal attenuates with time.
- Decreasing Deflections - a check to verify that deflections are lower at increasing distances from the load.

- Out of Range - a check to verify that deflections are less than the maximum deflection that the sensor is capable of recording accurately.
- Load Variation - a check that the load for a particular drop is within a specified tolerance of the average load for that drop height at that location.
- Deflection Variation - a check that the normalized deflection for a given sensor for a particular drop is within a specified tolerance of the average normalized deflection for that sensor for that drop height at that location.

In order to implement the latter two checks, it was necessary to determine the level at which variation was indicative of problems, rather than simple random variation. To do this, data from the two rounds of comparative testing were evaluated. Based on analyses of joint probabilities, limits of $\pm$ 200 pounds ($\pm$ 890 N) and $\pm$ 0.24 mils ($\pm$ 6 microns) were established for the load and normalized deflection, respectively (Ref. 25). It is estimated that these values will result in the rejection of one in 1,000 test sequences, generally under the heaviest load used in the SHRP testing, and for the sensor at the center of the loading plate.

The field data checks built into the FWD data acquisition software are the first line of defense against invalid deflection data. The second line of defense is a computer program, called FWDSCAN (Ref. 26), which verifies the integrity, completeness, and compliance with the established test pattern of the field data after it is delivered to the SHRP regional office. All verification results are written to an output file as a permanent record of this process having been performed. In addition, a data file containing only peak deflection data is created for use with the next FWD quality assurance program.

For the final stage in the quality assurance process, a computer program called FWDCHECK (Ref. 27) has been developed to analyze deflection data for test section homogeneity, the degree to which test pit data is representative of the section, the presence of data outliers within the section, and overall reasonableness from a structural capacity viewpoint. As a rule, the checks embodied in FWDCHECK will not eliminate data, but rather flag potential problems. It is believed that remarks generated from these analyses will be of significant benefit to users of the SHRP database. The FWDCHECK program provides both tabular and graphical data displays for the four major factors evaluated.

The last set of checks in the FWDCHECK program -- overall reasonableness from a structural capacity viewpoint -- are based on a comparison of pavement structural capacity derived from the analysis of deflection data to what one might expect based on known layer thicknesses and material properties. In view of the temperature dependent nature of the asphaltic concrete modulus, a procedure to correct maximum measured deflections to a standard temperature was developed by SHRP to make the structural capacity comparison a valid one (Ref. 28). This procedure initially relied on pavement surface temperature data automatically recorded with the deflection data for each test point. Because differences of up to 40°F were found between mid-depth and surface temperatures, with obvious implications on the structural capacity computations, the program was later modified to use temperature data manually obtained at three depths in the pavement surface layer.

Initial Data Analysis

Like the rest of the LTPP data, the raw deflection data is being stored in SHRP's National Pavement Performance Database, and will ultimately be available to all researchers to use as they see fit. In the near term, SHRP is applying a backcalculation procedure to these deflection data in order to estimate the in situ elastic moduli of the pavement layer materials. SHRP is undertaking backcalculation for the sole purpose of meeting the immediate needs of the initial analysis of the LTPP data. The layer moduli derived from this endeavor will supplement, not replace, the raw deflection data stored in the National Pavement Performance Database. This endeavor has been undertaken with the full expectation that it will be the first analysis of this deflection data, but not, by any means, the last. Too much remains to be learned about the art and science of backcalculation for this analysis to be regarded as definitive.

In order to estimate in situ layer moduli, SHRP has developed a backcalculation procedure, consisting of an existing backcalculation program and a series of application rules. Before further discussions, it is important to clarify the terminology used. The term "backcalculation program" or "software", means just that -- the computer programs used in backcalculation. However, the manner in which a backcalculation program is used is as important, and in some cases, more important than which program is used. Hence, "backcalculation procedure" refers to not only the software, but also the "rules" by which that software is applied.

Selection of Backcalculation Software

The process that SHRP followed in the selection and development of a pavement backcalculation procedure for use in the LTPP data analysis involved the following steps. A more detailed and expanded description of this process is presented in Reference 29.

1. Software identification;
2. Development of preliminary software selection criteria;
3. Preliminary software selection;
4. Software evaluation;
5. Compilation of evaluation results;
6. Final software selection;
7. Procedure development and documentation.

The first three steps in the process outlined above were quite straight-forward. Software identification involved a review of the literature to identify a number of the programs available, and their pertinent features. The second and third steps were accomplished through discussions at a meeting of SHRP's LTPP Expert Task Group for Deflection Testing and Backcalculation in November, 1990. Based on ETG recommended criteria, six programs were selected for further evaluation. ELCON and ILLI-BACK were selected for rigid pavements, and ISSEM4, MODCOMP3, MODULUS, and WESDEF for flexible pavements.

The purpose of SHRP's backcalculation software evaluation exercise was twofold: (1) to provide a basis for selecting a program for use in the SHRP backcalculation; and (2) to provide a basis for development of the procedures to be used with that software. For this endeavor a group composed of ETG members, the software developers, and SHRP contractors was assembled. Each evaluator was requested to work independently of the others to run all of the backcalculation programs using the same data sets from a number of actual SHRP test sections.

Deflection data and other pertinent information from 16 SHRP pavement test sections, 8 flexible and 8 rigid, were extracted from the SHRP database for use in this software evaluation exercise. A primary consideration in the selection of these data sets was coverage of the wide range of pavement structures that make up the SHRP experiments. Other considerations included the distribution of these sections by climatic region, SHRP region and geographical location within the U.S.

On completion, an overview of the comments and recommendations provided by the evaluators was undertaken to determine how they viewed each program. Although the ranking of the programs varied from one evaluator to another, MODCOMP3, MODULUS and WESDEF were overwhelmingly ranked as the top three backcalculation programs. Furthermore, initial review of the backcalculation results provided information sufficient to cause the remaining three programs -- ELCON, ILLI-BACK and ISSEM4 -- to be eliminated from further study. Because the two programs specifically intended for the analysis of rigid pavements did not perform well enough to remain in the study, the remaining three programs were necessarily evaluated for the solution to rigid pavement structures.

In order to make the final software selection, numerous analyses were conducted using the backcalculation results. They included: (1) a broad program-to-program comparison, (2) an assessment of user sensitivity, (3) determination of reasonableness of results, and (4) analysis of deflection matching errors (goodness of fit), based on actual and simulated deflection data. Based upon the analyses results, it was concluded that MODCOMP3, MODULUS, and WESDEF, are useful tools for backcalculation, which can produce good results.

Overall, the performance of the MODULUS program was found to be somewhat superior to that of the other programs, although one or both of the other programs may have been better for an individual section. Thus, MODULUS was selected as the primary backcalculation program to be used in the initial analysis of the SHRP deflection data. It should be clearly understood, however, that SHRP's selection of backcalculation software does not constitute an endorsement, nor does it imply that the particular program selected is in any sense, the "best" program available. Indeed, given the present state of the art, it is probable that the "best" program for use in any given circumstance depends on a number of factors, including, but not limited to, the level of expertise of the user, the nature of the pavement being evaluated, and the intended use of the results.

Backcalculation Rules and Guidelines

In general, backcalculation is a laborious process, requiring a high degree of skill, and the results are known to be moderately to highly dependent on the individual doing the backcalculation. This comes about for a number of reasons, including the lack of a consensus standard addressing all aspects of the backcalculation process. In order to ensure that the backcalculation applied in the SHRP data analysis is as consistent, productive, and straight forward as possible, the SHRP backcalculation procedure combines the MODULUS backcalculation program with a rigorous set of application rules.

SHRP has a distinct advantage over most agencies which have done backcalculation in the past, in that the SHRP database contains a wealth of information which can and is being used in the backcalculation process. Indeed, the SHRP backcalculation rules rely on information stored in the LTPP database to generate the input for the backcalculation program. In addition, the initial backcalculation procedure has been automated to a high degree, thus reducing opportunities for operator error.

Detailed descriptions of the rules that have been incorporated in the SHRP backcalculation procedure are presented in Reference 30. These rules address three major areas: definition of initial (seed) layer moduli and moduli ranges, modeling of the pavement structure, and evaluation of the analysis results. The first group of rules focus on the definition of seed moduli required to run the MODULUS program. Dynamic modulus predictive equations that rely on material property and field temperature data stored in the LTPP database are used to establish the seed moduli for asphaltic concrete layers; the specific algorithm used depends on the available information. Seed moduli for portland cement concrete layers and other stabilized materials are determined based on laboratory test results, if available, or assumed otherwise. Similarly, seed moduli for unbound granular layers are estimated on the basis of material type. Outer deflection readings and Boussinesq's one-layer deflection equation are used to estimate the initial subgrade modulus.

The second set of rules address the modeling of the pavement structure for purposes of backcalculation. Because the MODULUS program is limited to a maximum of 4 unknown layers, prioritized guidelines for combining two or more layers or fixing layer moduli in complex pavement structures are established by this set of rules. The Poisson's ratio for each layer is fixed according to material type. Other items covered by these rules include the modeling of thin asphalt concrete layers (less than 3 inches (75 mm)) and the subgrade (e.g., treatment of stabilized subgrades, depth to effective rigid layer, etc.).

The third and final set of rules focus on the evaluation of the backcalculation results. Maximum allowable deflection matching error limits are established by these rules, both for the individual sensors as well as all sensors combined. Guidelines for checking the reasonableness of the results are also provided by these rules, along with procedures to be followed in case of bad or questionable data.

Despite these rules, the evolving nature of the science (or art) of backcalculation makes it likely that early experience with this procedure will bring to light areas where further refinement is needed. Hence, it is anticipated that the initial release of the SHRP backcalculation procedure will be followed up, as we learn more about the strengths, weaknesses, and requirements of the process.

Other Related Issues

During the development of SHRP's layer moduli backcalculation procedure, a couple of issues surfaced, which merit special attention. The first major issue deals with the storage of the backcalculation analysis results. Unlike most of the data stored in the LTPP database, layer moduli are not raw data, but rather data that has been derived from the analysis of deflection data. In addition, because backcalculation is still an evolving science (or art), it is anticipated that these layer moduli may change as advances in the state-of-the-art are made. Furthermore, SHRP is undertaking backcalculation for the sole purpose of meeting the immediate needs of the initial analysis of the LTPP data. Thus, it was generally agreed by members of the Expert Task Group on Deflection Testing and Backcalculation that these data should be stored in a "shadow" database, not readily accessible and with clear warnings indicating the temporary nature of the values stored therein.

The second major issue deals with material non-linearity, particularly that of the subgrade, but other unbound granular base and subbase materials as well. Several individuals expressed their concern over the fact that the MODULUS program, which has been selected for use in the SHRP backcalculation procedure, does not incorporate material non-linearity, per se. These individuals felt that SHRP was making a serious mistake in not accounting for non-linear pavement material response in the backcalculation process. They also felt that SHRP's failure to provide for non-linear material models in the backcalculation is sending the wrong signal to the pavement engineering community, and may lead to the false conclusion that stress dependency does not need to be taken into consideration in pavement design. Despite this concerns, SHRP concluded that the use of strictly linear models is the lesser of several evils. At present time (1992), the use of non-linear models is not feasible, and hence, it is better to use an imperfect model, than to do nothing.

Status of Deflection Activities

Since the initiation of the SHRP program, significant progress has been made in the deflection testing arena. Actual field testing of GPS sections was initiated in the early months of 1989. Over the past three years, the first round of testing on the GPS test sites identified to date has been completed, and second round testing is progressing rapidly. Also, most of the required deflection testing of SPS sections has been completed. At present, the focus of deflection testing is shifting from the initial inventory-type testing of GPS sections to the more intensive testing for the evaluation of moisture and temperature related variations in pavement response, testing of SPS sections as they are constructed, and long-term monitoring of GPS sections through testing at five-year intervals.

Development of SHRP's backcalculation procedure was completed in the Fall of 1992, thus the initial analysis of the deflection data collected to date will soon commence (Winter of 1992). The analysis will first be applied to the data from the test pit areas, where accurate layer thickness information and other data is available. Based on the results from this initial analysis, both typical and extreme layer moduli will be investigated, to provide a snap-shot characterization of the LTPP sections. In addition, the strengths and weaknesses, successes and failures of the SHRP backcalculation procedure will be assessed, and if necessary, changes to the procedure will be made. Once comfortable with the backcalculation procedure, SHRP will apply it to the remainder of the deflection data in order to obtain information on the within section variability.

All manuals and operational field guidelines for the collection of deflection data in GPS and SPS sections have been finalized (see Ref. 12 through 18). Likewise, final versions of all FWD quality assurance software for use with GPS sections have been completed (see Ref. 22 through 27); similar software for use with SPS sections are now being contemplated. Four (one for each SHRP region) reference calibration centers have been installed and they are now operational.

Products

Deflection data will provide a basis for estimating in-situ layer material properties, assessing the degree of load transfer across rigid pavement joints/cracks, estimating in-situ pavement structural capacity in terms of either the AASHTO Structural Number (SN) or PCC thickness, linking test pit information with overall section properties, and evaluating the degree of structural variability present in the LTPP test sections. As part of the seasonal monitoring program, deflection data will also provide information needed to attain a fundamental understanding of the magnitude and impact of temporal variations in pavement response and properties due to the separate and combined effects of temperature and moisture variations over time. Furthermore, in conjunction with the other LTPP monitoring activities, deflection testing will provide the data to support the overall LTPP objectives and future needs.

Key "by-products" resulting from the LTPP deflection activities include:

- Manual for FWD Testing (Ref. 12 through 18)

  Existing standards for deflection testing are very general, and lack the detail needed to ensure uniform data collection. The SHRP-LTPP Manual for FWD Testing provides guidelines needed to ensure the uniform and consistent collection of pavement deflection data with FWDs. The manual includes field data collection guidelines for asphalt surfaced, jointed concrete, and continuously reinforced concrete pavements. Issues addressed in the manual include: identification of test point locations for evaluation of structural properties (layer moduli) and joint condition; drop sequence; measurements of temperatures and joint openings to aid in data interpretation; field data checks (quality assurance); and relative calibration of the FWD deflection sensors.

Adherence to the deflection testing guidelines presented in the manual will help ensure consistent, uniform structural evaluation of pavements, thus providing the basis for sound pavement management and design decisions, which will result in better pavements, at lower cost.

- FWD Calibration Procedures (Ref. 22 through 24)

Regular calibration of FWDs ensures that the deflection data collected is (a) accurate, (b) unbiased, and (c) independent of the particular FWD used to collect it. However, standard procedures for the calibration of FWDs have not yet been adopted by the major standard setting organizations, and as a result, few FWD owners have calibrated their FWDs. As a consequence, the accuracy and uniformity of these devices is largely unknown, and much of the data that has been collected may be inaccurate.

To ensure the validity of the deflection data collected on the LTPP test sections, SHRP has developed FWD calibration procedures and related data collection software packages to provide for the calibration of the SHRP FWDs. These procedures have been implemented at four SHRP regional FWD calibration centers, hosted by state highway agencies in Minnesota, Nevada, Pennsylvania, and Texas, which are available for use by the state highways agencies.

Reference calibration is the first stage in the SHRP calibration process: the FWD measurement systems are calibrated against independent reference systems, which are themselves calibrated to National Institute of Standards (NIST) traceable standards. The outcome of this process is a set of adjustment factors, which can be entered into the FWD data collection software to "fine tune" the individual FWD so that its readings are comparable to other calibrated FWDs. SHRP has also developed a software package, FWDREFCL, to automate the data acquisition and processing for the reference calibration process.

SHRP's relative calibration procedure is a statistically rigorous procedure designed to calibrate the deflection sensors on a single FWD to a common estimate of truth. The relative calibration serves two purposes. First, it is the final step in the complete calibration of an FWD, and second, it serves as a quick means to verify the integrity of the FWD deflection sensors on a more frequent basis. This procedure is presented in the SHRP-LTPP Manual for FWD Testing (Ref. 12). Also, a computer program, FWDCAL, has been developed to automate the processing of the resulting data.

- FWD Quality Assurance Software (Ref. 26 and 27)

  FWD testing allows massive quantities of deflection data to be collected in a relatively short period of time for the purposes of structural evaluation of pavements. Given this quantity of data, the need to first verify the integrity and completeness of the data, and then evaluate the data for uniformity and overall structural capacity in a consistent fashion necessitates the use of automated processing procedures. SHRP has developed a suite of quality assurance software to fill these needs for the deflection data collected as part of the LTPP program. This software is equally useful in the pavement management activities of highways agencies.

  SHRP's FWDSCAN software provides a quick, reliable means to check FWD data, as it comes in from the files, for readability and completeness. Although specifically developed for use with the SHRP field manual for deflection testing, this software could easily be adapted for use with other deflection testing programs to quickly verify that the deflection data needed for pavement management activities has been collected, stored, and delivered for analysis, without being corrupt in any way.

  SHRP's FWDCHECK software is a tool for preliminary evaluation of deflection data. The checks embodied in this software include an evaluation of section homogeneity, the degree to which destructive sampling location are representative of the remainder of the section, the presence of "outliers" in the deflection data, and AASHTO structural capacity. Although originally developed to aid in the evaluation of the SHRP deflection data, this software has a great deal to offer the pavement management engineer.

  For example, budgetary limitations frequently force agencies to assume that data obtained from a limited amount of destructive sampling and laboratory testing is representative of long sections of pavements. The representativeness check embodied in FWDCHECK provides a means to use deflection testing to evaluate the validity of that assumption, and adjust pavement management decisions, accordingly. The section uniformity checks allow the pavement management engineer to try different subsection boundaries, and evaluate the statistical significance of differences in their response to deflection testing, so that reasonable subsection boundaries can be selected for tracking, design and contracting purposes. The check for outliers aids in the identification of atypical test points, which may indicate the need for localized remedial measures. Finally, results from the structural capacity analysis can be used to track changes in the pavement's structural condition over time, thus contributing to the engineer's ability to plan timely and effective maintenance and rehabilitation strategies.

Like FWDSCAN, FWDCHECK is somewhat specific to the SHRP data collection procedures and data file format. However, it can be readily adapted to accommodate the procedures and file format used by other highway agencies.

Finally, if it proves successful, the recently completed SHRP layer moduli backcalculation procedure will provide the first truly standard means to evaluate the structural capacity of pavements from deflection data. The rules and guidelines developed by SHRP for the backcalculation procedure will provide highway agencies with a tool to perform consistent, uniform pavement structural evaluations, thus providing the basis for sound pavement management and decision making.

LONGITUDINAL PROFILE

Objectives

Measurements of longitudinal profile will provide an objective, fundamental measure of pavement roughness for use in evaluating and quantifying pavement condition, and changes therein, for the SHRP test sections. The use of simulation algorithms with the SHRP profile data will allow the computation of a variety of different measures of pavement roughness (e.g., International Roughness Index or IRI, Root Mean Square Vertical Acceleration or RMSVA, Mays Index) to suit the needs of researchers using the SHRP data.

Data Collection

Equipment and Procedures

SHRP's primary profile measurement device is the K.J. Law Model 690 Digital Non-contact Profilometer®. Three of the four Profilometer®s used by SHRP are identical, having been manufactured specifically for SHRP; the fourth, on loan to SHRP from the Federal Highway Administration, is identical but for the vehicle in which it is mounted. The most obvious result of the use of two different vehicles is a difference in the distance between the profile sensors. The spacing for the SHRP Profilometer®s is 66 inches, center to center, while that for the FHWA Profilometer® is 54 inches. In instances where geographic and/or time constraints make the use of a Profilometer® infeasible (e.g., test sections in Hawaii and Puerto Rico), SHRP is using the Dipstick® road profiler, manufactured by the Face Company, as the profile measurement device. Details of SHRP's profile measurement procedures are given in SHRP's field manual for profile measurement (Ref. 31; which supersedes earlier, separate documents addressing Profilometer® and Dipstick® measurements: Refs. 32 and 33), and are summarized below.

The profilometers operate at a speed of 50 miles per hour (80 km per hour) when measuring profile, except where legal, geometric, or safety constraints dictate the use of slower measurement speed. Five repeat runs are made, to provide both a quality assurance check on the data (poor repeatability may be indicative of a malfunction in the measurement systems, or poor tracking on the part of the driver), and some measure of the transverse variability of the pavement profile. This measure of variability is important because the best driver will not be able to maintain exactly the same tracking from one year to the next.

The survey lines for the Dipstick® measurements are marked on the pavement in the wheel paths. A closed-loop survey is made by running the length of the section once, and then returning to the beginning of the section along the same path. By checking the closure of this loop, one can verify that reliable data has been collected.

Because both profile runs with the Dipstick® are made along the exact same survey line (to within the limits of human error), the Dipstick® measurements do not provide a measure of the transverse variability in the pavement profile. Time constraints associated with the need for lane closures to conduct Dipstick® measurements prohibit measurements along multiple lines to achieve a measure of transverse variability. Rather, for those sections where the Dipstick® is used repeatedly, SHRP researchers will endeavor to locate the same measurement line in successive years.

Although the differences are not believed to be important in the interpretation of the data, there are several basic differences between the data obtained with the Profilometer®s and those obtained with the Dipstick®s, which data analysts should be aware of. The most obvious difference is in the spacing of the profile data points, which is twelve inches for the Dipstick®, and six inches for the Profilometer®s. There are also two more subtle differences. Although the storage interval for the Profilometer® is six inches, the sample interval is actually one inch. What is recorded at the six-inch intervals is a data point representing a twelve-inch running average (i.e., the average of thirteen measurements taken at one-inch intervals). The data points stored for the Dipstick® are pure, un-averaged, relative elevation values. The final difference between the two data sets is that the Profilometer® software automatically applies a third order high pass filter of user-selectable wavelength to the data prior to storage. The mathematical form of that filter is as follows:

$$\textit{Filter Output} = \frac{S^3\ (\textit{Filter Input})}{S^3 + (2\zeta + 1)\,\omega S^2 + (2\zeta + 1)\omega^2 S + \omega^3}$$

Where:	S	=	Spatial LaPlace Operator
	ω	=	Spatial Filter Natural Frequency
	ζ	=	Damping Ratio
Units:	S	=	1/feet
	ω	=	radians/foot
	ζ	=	No Units
Values:	ω	=	6.28/300 = .0209333
	ζ	=	.5

For SHRP purposes, a 300-foot filter wavelength is used, on the grounds that longer wavelength features are not believed to be significant to profile-based indicators of pavement condition/performance. No filter is applied to the Dipstick® data as it is collected.

Quality Assurance

A number of measures have been implemented to ensure the quality of the SHRP longitudinal profile data. These measures include: initial acceptance testing, equipment comparisons and calibration, standardized field testing procedures and field data checks, and quality assurance software.

Initial acceptance testing of the SHRP profile measurement devices involved comparisons between SHRP Profilometer®s, and against rod and level surveys at sections in Michigan. Because the devices were delivered sequentially, the initial comparisons were done in pairs. A time lapse of roughly ten months between the delivery of the first two Profilometer®s and the last one was accompanied by a significant change in the profile of the pavement sections used in the acceptance testing, negating the validity of the rod and level survey comparison for the last device.

In February of 1990, after acceptance of the fourth (and final) Profilometer®, a comparison of all four Profilometer®s with each other, with rod and level surveys, and with Dipstick®s, was conducted in Austin, Texas. This comparison brought to light some previously unidentified problems with the last Profilometer® delivered. Those problems were corrected, and that device reran the test sections. The end result of this comparison was a conclusion that all four devices were providing comparable data, and that the data obtained with the Profilometer®s was comparable to that obtained with the Dipstick® and rod and level surveys. This conclusion was based on subjective evaluations of profile plots. Statistical evaluations had also been planned. However, a hurried data collection schedule and non-ideal lighting conditions resulted in a data set with many "saturation spikes," which prohibited valid statistical comparisons between devices. Rather than attempting to "cleanse" the data, it was decided to repeat the comparison at a later date, under conditions which allowed complete adherence to routine quality assurance measures.

A separate exercise, in which the Dipstick®s were compared with each other and with rod and level surveys was also conducted, with the conclusion that all are providing comparable, accurate data. Both profile plots and various profile statistics (IRI, RMSVA, etc.) derived from Profilometer® and Dipstick® data have been compared for a range of pavement types and roughness levels. The results for the two devices have corresponded closely, despite the differences in the equipment described above.

A second comparison of the four regional Profilometer®s was performed in Ann Arbor, Michigan in June of 1991. The experiment was established to determine the repeatability of the devices and to compare the devices. Data analysis on the left wheel path indicated that there was a statistical difference between the Profilometers. Using step-wise procedures, it was determined that the Southern Region Profilometer was the device which was different. To date, despite several thorough "checkups" the source of this difference has not been identified. The repeatability of the devices was, however, essentially the same as the other devices.

In addition to the equipment comparisons, field quality assurance measures for the profile data have evolved considerably since the initiation of data collection. The checks originally prescribed in the profilometer field manual (Ref. 32) involved relatively informal manual checks. When the January 1990 comparative testing made it evident that the profilometer sensors are prone to errors due to sensor saturation under certain ambient lighting conditions, it was decided that a more formal quality control process was in order.

Four computer programs (PROFSCAN, DIP, PROFCHK, and PROFCAL, Ref. 34) were developed to support the analysis of road profile measurements made with the K.J. Law Profilometer. These programs were then interfaced and coupled into a single module called PROFQUAL in a user-friendly micro-computer environment.

PROFSCAN was written to be used by the profilometer operator to review the data while on site. The profile data collection results from five (5) passes over the SHRP test site are analyzed to determine if additional runs are required for that site. The decision is dependent on a set of statistical summaries such as the mean International Roughness Index (IRI) value, standard deviation, and coefficient of variance. If the IRI value does not meet the statistical requirements, additional runs may be required to determine if variances in IRI are the result of technical problems or run to run variability do to variable pavement conditions. It should be noted that the final judgement remains with the operator as to the validity of the runs. The program also has the facility to scan the field data to identify the occurrence of "spikes" (rapid changes in elevation) and if they exist notify the operator as to their location along the test site. This can assist the profilometer operator in determining if these large deviations in profile are the result of technical problems (e.g., low sun angle) or pavement features (i.e., potholes, tented or lipped cracks, etc.). Header checks have also been incorporated into the software to verify the validity of entries.

The primary filed quality control measures for the dipstick are the daily calibration check and the closure check described in the field manual (Ref. 31).

The PROFCHK program is an extension of the PROFSCAN software intended to check the profilometer and/or dipstick survey data for completeness and readability, and generate an output file summarizing the results of the calculations checking process.

Before any profile summary statistics can be forwarded to SHRP for inclusion in the Regional and then National Pavement Database, the RCO personnel must check all profile data files to assess whether or not:

- the elevation data collected is out of range (e.g., occurrence of spikes, data outliers);
- the results are reasonable from a statistical viewpoint based on the stipulated tolerance criteria; and
- data is reasonable from a practical judgement stand point (i.e., indices values make sense based on historical comparisons, maintenance or changes in local conditions).

Based on the aforementioned conditions, the RCO can remove individual runs from the analysis or logically delete invalid data points (elevations) from the analysis (this is identified in the data set); to date (Fall 1992) this has been limited to a very small percentage of the data. Also, the RCO can assess the validity of the data that is collected and can identify anomalies in the data as being due to:

- Pavement features;
- Equipment related problems; and
- Unexplained.

It should be emphasized, however that the intended function of the PROFCHK software is not to discard data but rather flag potential errors and/or problems before processing the information further. An output file consisting of the database, a summary of the analysis results (IRI, RMSVA, etc.) and a summary of the check process is generated by the program for transfer to the Regional and the National Information Management Database System (RIMS/NIMS).

The DIP software was developed to provide input and processing capabilities for "Digital Incremental Profiler" (DIP) data. The software has two major sub modules: Longitudinal and transverse profiles. The first sub module allows manual entry of longitudinal profile measurements made with the digital incremental profiler in both left and right wheel paths at one foot sample intervals. The data can also be uploaded from ASCII text files using an interface program. Roughness indices and displacement are calculated from the longitudinal profile data using the same coding developed for the K.J. Law Profilometer. It should be noted that the differences in sample interval between the profilometer (6 inches) and digital incremental profiler (12 inches) are accounted for in the International Roughness Index (IRI) model by coefficients which are used to standardize the measurement results to a 10 inches (250 mm) sample interval.

The PROFCAL software is a utility program intended to assist in determining if the profilometer equipment is operating correctly and/or needs routine calibration checks. The program facilitates comparison of profile data obtained with the Profilometer at several speeds, and with the Dipstick. Significant differences between speeds, or between the profilometer and Dipstick data indicate the need for detailed evaluation of the equipment, and corrective measures, prior to the collection of additional data.

Status of Longitudinal Profile Activities

To date, essentially all of the SHRP test sections have been surveyed three times. Progress in this area has been better than expected, with most regions completing a full round of profile surveys in less than one calendar year, although an increasing work load will make this more and more difficult as SPS test sections are constructed. Future plans call for annual profile measurements on all test sections, with more intensive seasonal measurements on those sections included in the seasonal monitoring program. Profile measurements at the location of weight-in-motion (WIM) installations are also planned, to facilitate future analyses of the impact of pavement profile on dynamic loading, and vice versa.

TRAFFIC MONITORING

Background

The planners of the Long Term Pavement Performance (LTPP) project (Ref. 1) identified the need to retrieve historical traffic volume and axle-load data for each General Pavement Studies (GPS) test location prior to the initiation of the data monitoring phase, and to collect traffic and axle-load data at each GPS test location during the data monitoring phase of the LTPP research. In addition, traffic axle-load data is an essential element in the AASHTO design equations as an independent variable. Since the AASHTO designs are based on numbers of 18,000 pound equivalent single axle loads (ESAL) projected for a pavement, it is important in the GPS studies to evaluate pavement performance in light of actual accumulated ESALs experienced since it was opened to traffic in its present configuration.

Cumulative annual axle-load data (ESAL) can be obtained directly from permanently installed weigh-in-motion (WIM) equipment located and operating continuously at the test location, or can be estimated from a combination of traffic volume, vehicle classification data, and portable WIM measurements. The original SHRP plan for traffic data collection at GPS test locations involved "low-cost" weigh-in-motion devices operating continuously at each site (Ref. 35).

Subsequently it was determined that the use of piezo cable based "low-cost" WIM was not a viable option for truck weight studies but could be reliably used for vehicle classification studies (Ref. 36). Many State Highway Agencies (SHA) insisted that bending plates and load cells must be used in conjunction with WIM equipment to obtain valid weight data. The high cost of the higher quality WIM systems required a change in the original plan for SHRP.

Traffic Data Collection Requirements

To address this issue, a modified traffic data collection program was developed which recognized that it would not be possible to install a WIM device at each site, and further that it would not be possible to operate WIM (Ref. 36) continuously at each site. In this modified plan (Ref. 37) three levels of traffic data collection were established, including 1) a preferred approach that relied upon continuously operated WIM, 2) a desirable level that substituted automated vehicle classifiers (AVC) for WIM and added portable WIM measurements for a week each quarter, and 3) a minimum response that was similar to the desirable level but reduced the length of time for the portable WIM counts.

The modified plan continues to be the basis for traffic data collection by the SHA for the GPS experiments. The SHA were much more responsive to the "desirable" option that allows for the installation of automatic vehicle classifiers at GPS test sites and for making portable WIM measurements on a quarterly basis to collect weight data. As a result, over 60% of the GPS sites will include AVC rather than permanent WIM equipment. On the other hand, there will be over 270 WIM installations. That is a marked increase over the number of such installations in place across the U.S. and Canada prior to SHRP (Ref. 38).

The application of WIM technology by SHRP-LTPP spurred a heightened interest in traffic data collection by state highway agencies. The capability to collect continuous data on traffic volumes, vehicle classes, and individual truck weights through one device was a major breakthrough. Although WIM technology had been around since the early 1970's, its use had been minimal. Now, the expanded use of WIM required major changes to the data collection, processing, and summarization procedures used by highway agencies. SHRP lead the way in bringing about these changes and devising new procedures.

The SHRP data collection methodology involves a flexible framework, designed to provide the best possible traffic data within the limitations of each SHA. The SHRP traffic data collection plan requires minimum standards for traffic data collection at each LTPP site, but encourages SHAs to provide more and better data collection when fiscal and physical limitations could be overcome (Ref. 37). The plan identified three alternatives for traffic data collection and allowed each SHA the option of selecting any one of the three alternatives. Since the selection could be made independently for each LTPP site, this approach allowed the institution of differing levels of traffic data collection at the various LTPP sites located within a state or province.

The three alternatives for monitoring traffic data are further defined as follows:

- *Preferred* traffic data collection - permanent, year-round weigh-in-motion (WIM) equipment installed at each site and operated continuously.
- *Desirable* traffic data collection - a permanent, year round automatic, site specific, vehicle classifier, supplemented by and one week of weigh-in-motion measurements for each season at each study site.
- *Minimum* traffic data collection - a year-round vehicle classifier, counting a minimum of one full year during each five-year period, supplemented by one 48 hour weekend and one 48 hour weekday weigh-in-motion session conducted during each season of the year.

The SHRP plan allowed the SHAs more flexibility to better utilize their scarce resources and staffing limitations. At the same time, the traffic data collection requirements could provide enough information to SHRP researchers for development of reasonable estimates of traffic loadings at each LTPP pavement test sections.

Site Specific Versus Site Related - SHRP recommended that all traffic data collection take place immediately upstream or downstream of the LTPP pavement test sections (Ref. 39). Traffic loading estimates for a particular LTPP section must be based upon traffic data collected from the particular test location, since traffic loading characteristics can vary considerably between sites. The level of data collection activity would be identified in the traffic database.

This was found to be the case in early SHRP-LTPP research, when the Minnesota Highway Department and the North Central Regional Office of SHRP joined to conduct an analysis of truck volume and weight data that had been collected at four permanent WIM sites in Minnesota over the previous four years (Ref. 40). In comparing the variation of truck volumes with truck weight and ESAL calculations, several conclusions were reached, including these:

- The patterns for loading (ESAL) varied greatly from volumes for the "eighteen wheeler" class of trucks (3S2).
- Variation between the loading patterns at each of the four sites were significant.
- Low truck volumes on weekends actually resulted in higher loadings due to unusually heavy vehicles running on weekends.
- Location, direction, time of day, and classification of the highway also have significant impact on the number of trucks, weight of the trucks, and resulting ESAL.

For example, the data collected in Minnesota shows that 3S2 truck traffic (often assumed as the most "stable" of the truck volumes) not only varies over the course of a year, but the pattern of variation can be quite different from one location to another as shown in Figure 4. Similarly, ESAL applied by those trucks also change over the course of a year as shown in Figure 5. Even within the course of the "average" week, the patterns of 3S2 truck volumes and loads differ significantly and can be seen in Figures 6 and 7. Perhaps more importantly, the patterns for volumes and loads move in opposite directions on the weekends. (There are fewer trucks, but they weigh more).

These results demonstrated the need for site specific traffic and weight data collection equipment. After a series of traffic data collection workshops in all of the FHWA regions in the U.S. and in Canada, the SHA were convinced of this requirement, and plans to use statewide data to infer data at a given site were eventually abandoned. A typical traffic monitoring site layout is illustrated in Figure 8 (Ref. 39).

In locating the traffic data collection equipment, the objective was to locate it in a manner to assure that no interruption or interference in the traffic stream would develop between the LTPP pavement test section and the traffic data collection site. Where the traffic counting and weighing station is separated from the test location and the truck traffic varies between the two sites, additional traffic data must be collected at each site to document the relative difference in traffic loading at the two sites.

While SHRP's traffic data collection requirements provided more realistic traffic data collection options for the SHAs, it increased the difficulties that future LTPP researchers face when they analyze the traffic data because the amount and types of available traffic data will vary from one LTPP site to another. As a result, the analyst will need to establish a method for handling the differences in the available traffic data. As an aid to future analysts, the traffic data is assigned both a quantitative measure of variability and reliability and a qualitative description of the traffic data residing within the database.

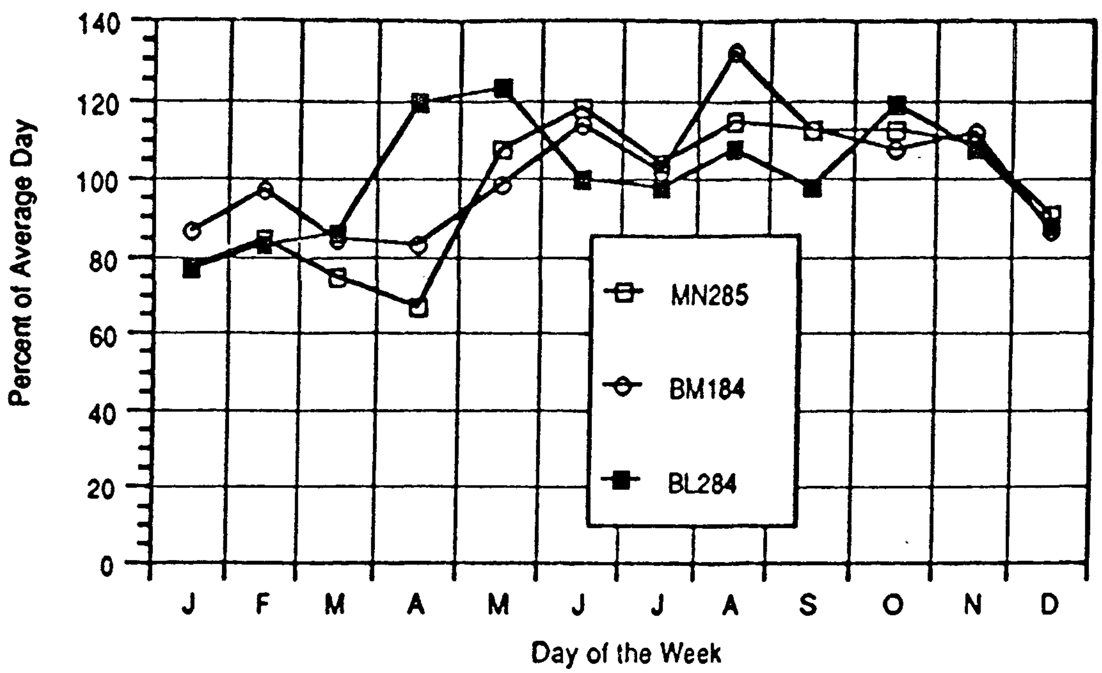


Figure 4 - Average Daily 3S2 Volumes by Month (Ref. 40)

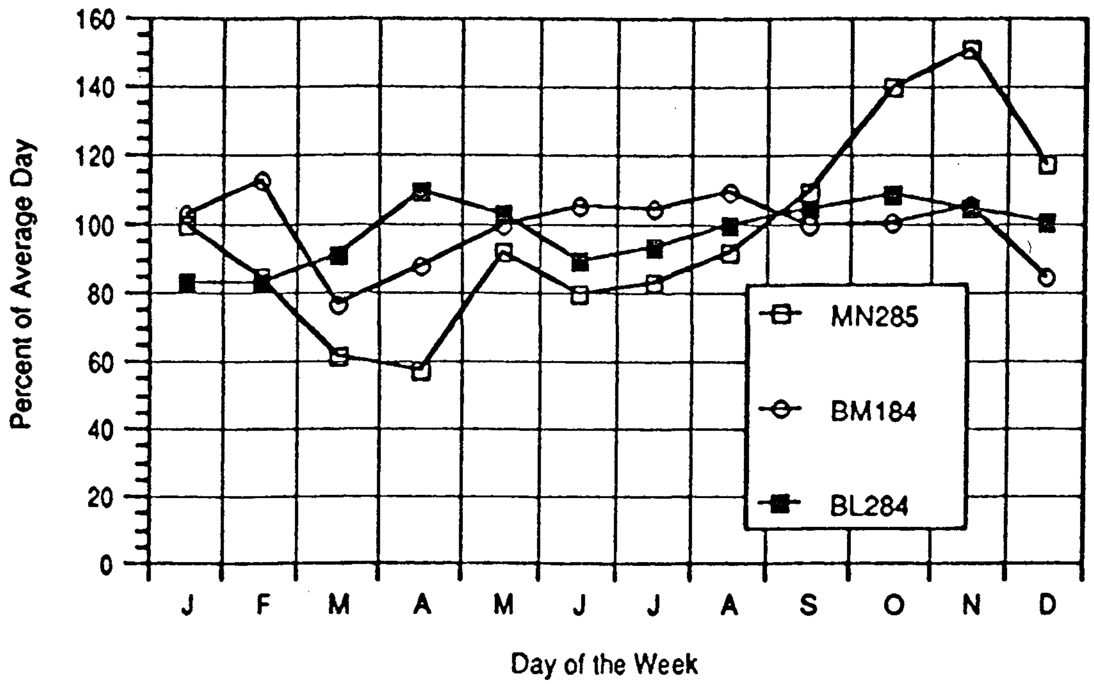


Figure 5 - Average Daily 3S2 ESAL by Month (Ref. 40)

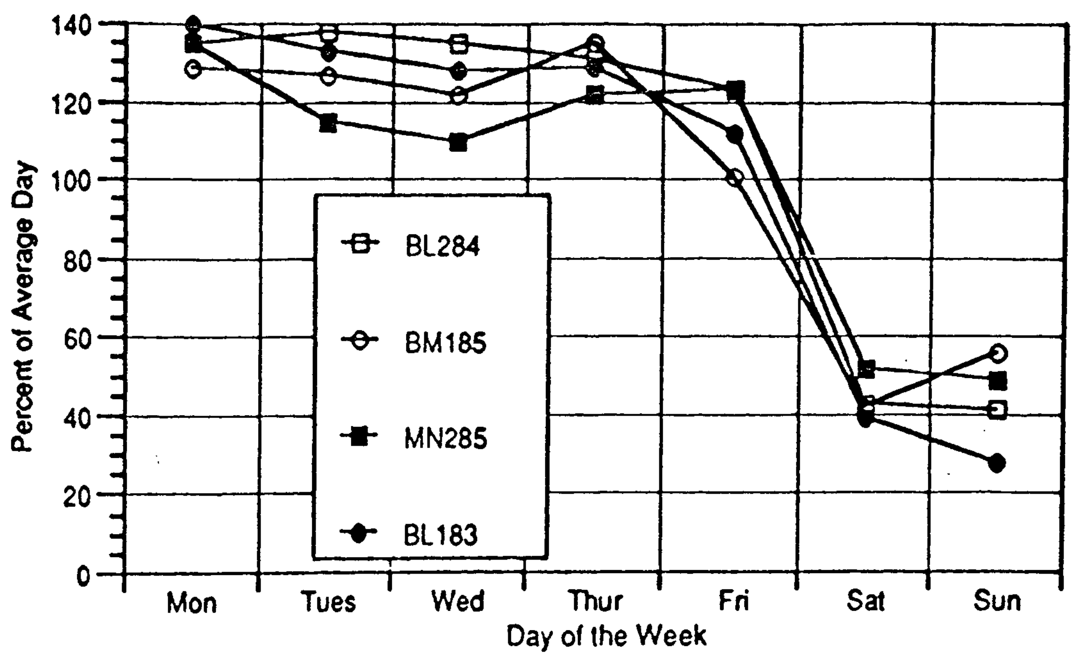


Figure 6 - 3S2 Volumes by Day of Week (Ref. 40)

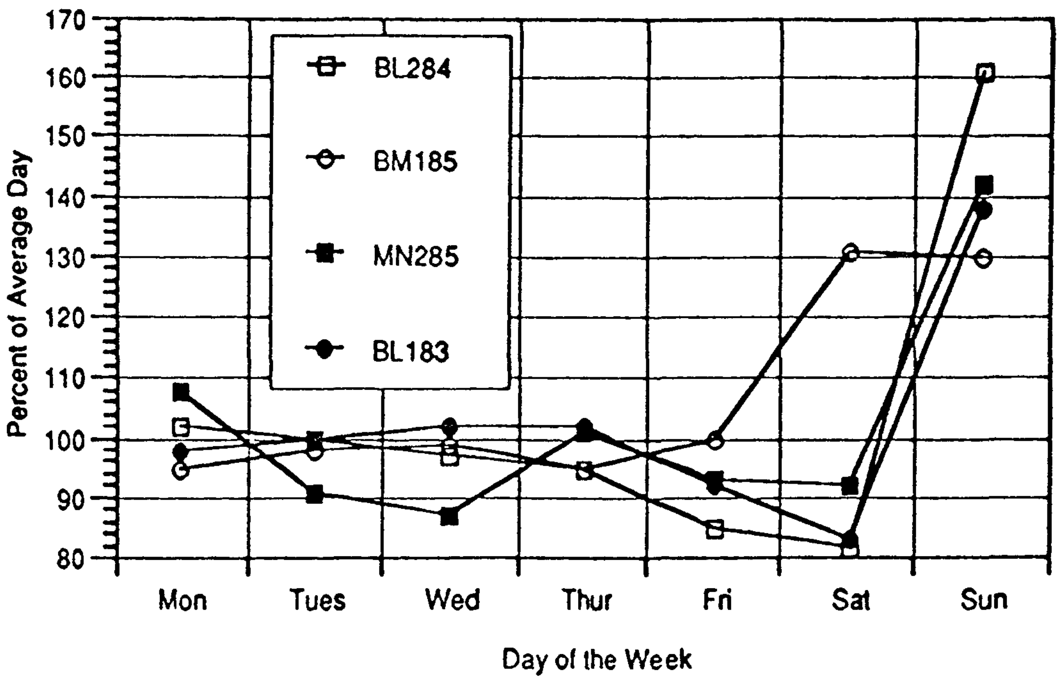


Figure 7 - ESAL Loads for 3S2's by Day of Week (Ref. 40)

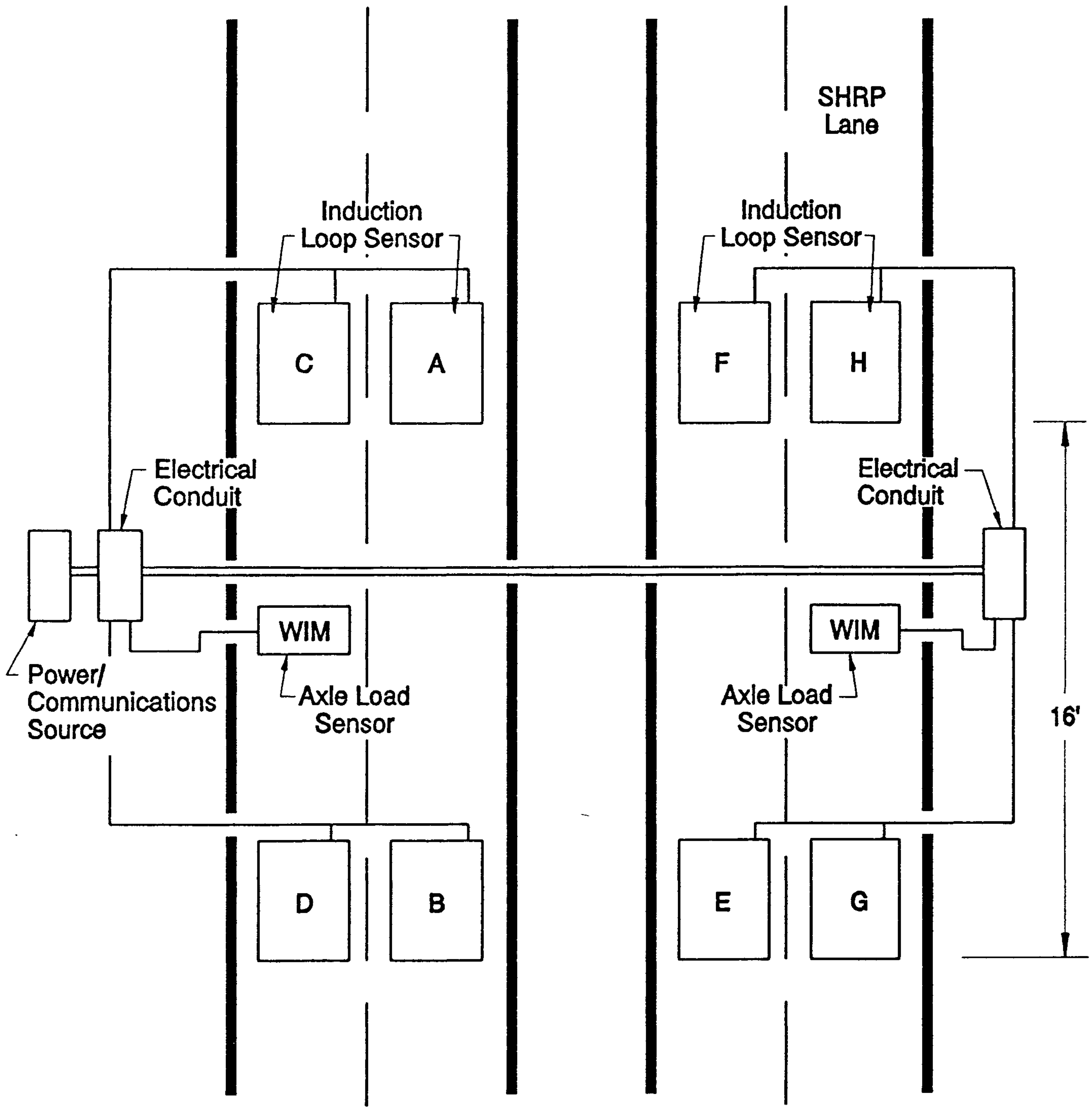


Figure 8 - Site Monitoring Layout (Ref. 39)

Traffic Data Collection Plans

Because of the variety of options available to the SHA in installing traffic data collection equipment and measuring traffic and axle-load data, the Traffic ETG requested that each SHA prepare a Traffic Data Collection Plan. A set of guidelines for the preparation of Traffic Data Collection Plans were developed and issued to the SHA in November, 1989 (Ref. 39). Each SHA was asked to submit plans to the SHRP Regional Office outlining their specific plans for collecting traffic data at each GPS test section in the state or province. Location, type of equipment, frequency of operation, SHRP funds required, persons responsible, and method of transmitting the data were summarized in the plan. Maps and installation schedules were also included along with other pertinent information.

The Traffic Data Collection Plans that were received from each of the 62 SHAs were reviewed by the SHRP Technical Assistance Contractor and the respective Regional Office staff to ensure that they met the standards set out by SHRP. If problems were noted, the regional representative discussed the matter with the SHA and reached a resolution. After all issues had been addressed, the SHRP Regional Engineer issued a letter of concurrence, authorizing the SHA to receive SHRP funds for traffic data collection, and encouraging the SHA to begin the implementation phase. The initial activity involved the retrieval and reporting of historical data, and that was followed by the installation of traffic data collection equipment at each site.

Historical Data

The requirements for retrieving and reporting historical data for each GPS test location were specified in Chapter 4 of the SHRP-LTPP Data Collection Guide (Ref. 41). This document provided background information, an explanation of the historical and monitoring traffic data requirements, historical data forms, monitoring data formats, and baseline information about collecting and processing of traffic data.

Historical data was initially retrieved from the files for two sites in each SHA and submitted to the SHRP regional office for review and verification of the output. After receiving feedback from the SHRP region, the SHA collected the historical data for all other GPS sites in the SHA. Historical traffic data was received for over 95% of test locations. This data is an important element in a number of early data analysis studies.

Traffic Data in the LTPP Database

The specific traffic data elements included in the LTPP National Pavement Performance database (NPPDB) consist of the Level 1, Primary Loading Estimates illustrated in Figure 9, from the LTPP Central Traffic Database (Ref. 42). These Level 1 records represent the "best estimate" of the traffic loads experienced at each LTPP site for each calendar year since the particular LTPP site was opened to traffic. The loading estimates will be given as the number of axles by

Study site location _________
Year _________
Data Availability Index (3 digits) _________
Study site lane volume _________ Standard Dev. Of Volume Est. _______
Sample Size (N) for Vol. Est. ______

Single axle weight distribution
Single axles counted _________ Single axles weighed ________
Single axles estimated for the year _________
weight category 1: Definition _____ Number of Axles ______
weight category 2: Definition _____ Number of Axles ______
etc.

Tandem axle weight distribution
Tandem axles counted __________ Tandem axles weighed _________
Tandem axles estimated for the year _____
weight category 1: Definition _____ Number of Axles ______
weight category 2: Definition _____ Number of Axles ______
etc.

Triple axle weight distribution
Triple axles counted __________ Triple axles weighed _________
Triple axles estimated for the year _____
weight category 1: Definition _____ Number of Axles ______
weight category 2: Definition _____ Number of Axles ______
etc.

Quad + axle weight distribution
Quad + axles counted ________ Quad + axles weighed _________
Quad + axles estimated for the year ________
weight category 1: Definition _____ Number of Axles ______
weight category 2: Definition _____ Number of Axles ______
etc.

Total Number of Truck & Combinations _________
Std Dev. of Truck Vol. Est. _________ Sample Size for Truck Vol.Est. ____

Annual ESAL for study site this year _______ Std Dev. of ESAL Est. _____
Weighted N for ESAL estimate __________

SN (structural number) for study site this year _________
D (Depth of concrete pavement) __________
Number of historical modifications (version number) ___________
Code for method used to estimate AADT ____________
Date this update was created _________
Comments

Repeat this record once for each year since the pavement section was opened for traffic. The entire set of records is then repeated for each study site.

Figure 9 - LTPP IMS Traffic Data

weight range and axle type, (i.e., singles, tandems, tridems, and quadrens) that the LTPP pavement test section was exposed to that year. Additionally, the combined Equivalent Single Axle Loads (ESALs) for this traffic data will be computed, using the current American Association of State Highway and Transportation Officials (AASHTO) ESAL formula. The estimates will also be based on the pavement structure identified in the National Pavement Performance Database (NPPDB) and information stored in the two databases (Ref. 43). A number of supporting variables will also be included in the traffic data information stored in the NPPDB.

At present (Fall 1992), the development of the traffic database is in its infancy. A minimum amount of monitored traffic data has been secured. However, over 60% of the GPS sites will include automatic vehicle classifiers (AVC) and 270 GPS sites will have permanent Weight-In-Motion (WIM) installations.

Maintenance of the pavement loadings by axle load and axle group will provide SHRP researchers with the capability to evaluate alternative ESAL computational formulas. On the other hand the availability of the current AASHTO ESAL values within the NPPDB will provide researchers with a quick, convenient and consistent traffic load estimate for limited, specific analyses.

The NPPDB and Traffic databases will contain descriptions of the traffic data collected at each LTPP site (Ref. 42). These narratives will be helpful to future researchers by defining the traffic data available in the NPPDB, and by identifying the number and type of traffic data used to calculate the annual ESAL loadings. This information is stored in the "Data Availability Matrix" for each LTPP site as illustrated in Figure 10.

FHWA Monitoring Standards

One major action taken by the ETG was to recommend the adoption of the FHWA HPMS and Traffic Monitoring Guide (Ref. 44) as basic documents for the development of a SHRP-LTPP traffic database, including the adoption of the FHWA 13-Class vehicle classification system and the standard FHWA formats for reporting traffic volume, classification, and weight data. This provided a standard that was known to all states. With the adoption of the FHWA standards, FHWA committed to provide funding support, personnel support, and assistance at all levels of the organization in the development and implementation of the LTPP traffic data collection program.

Role of the Regional Offices

The traffic database is currently (Fall 1992) housed at the four regional offices and the data is received, entered, checked, summarized, processed, reported, and stored at the regional level (Ref. 45). The regional representatives also work directly with the SHA in obtaining traffic and

SITE NUMBER: __________

Year	Short Volume Counts	Continuous Volume Counts	Short Vehicle Class Counts	Continuous Vehicle Class Counts	Short WIM Counts	Continuous WIM Counts	Data Availability Code
85	two						2
86	four						2
87	four		one		one		6
88			two				6
89		by lane		by lane		by lane	9
90		by lane		by lane		by lane	9

Figure 10 - Matrix of Available Traffic Data

load data for the GPS experiments. This includes reviewing and approving data collection plans, verifying the installation of traffic data collection equipment at each site, and receiving and entering traffic data from the SHA on a monthly basis.

International Traffic Data Requirements

The traffic data requirements for international GPS test locations are to be the same as those set for U.S. and Canadian sites. To facilitate understanding of these requirements by the coordinators from the various countries, an International Traffic Data Collection Handbook was compiled incorporating the most important SHRP technical memoranda, reports, and documents. The handbook was distributed initially at the International Coordinators meeting in England in November, 1990 (Ref. 46).

Current Status of Traffic Data Collection

Monitored traffic data gathered by the states is just beginning (Fall 1992) to be received at SHRP Regional offices. Traffic data collection activities should increase significantly since most states have completed data collection plan for their LTPP sites. The types of equipment scheduled for installation or presently installed are summarized in Table 2 (Ref. 13). In addition, the location of the traffic data collection equipment with respect to the LTPP pavement test sections is identified in Table 3 as Site Specific, Site Related, or Other.

Table 2 - Type of Traffic Data Collection Equipment

Region	WIM	AVC	Other or Unknown	Total Sites
North Atlantic	58	59	18	135
Southern	53	209	0	262
Western	54	129	0	183
North Central	108	88	2	198
Totals:	273	485	20	778
Percentage:	35%	62%	3%	100%

Table 3 - Site Specific

Region	Site Specific	Related	Other	Total Sites
North Atlantic	101	8	26	135
Southern	243	18	1	262
Western	159	24	0	183
North Central	168	21	9	198
Totals:	671	71	36	776
Percentage:	86%	9%	5%	100%

SURFACE FRICTION

The pavement condition monitoring program within the Long-Term Pavement Performance (LTPP) study included periodic surface friction data collection on GPS and SPS test sections. This is accomplished through friction measurements of LTPP sections by the individual participating highway or transportation agencies.

Friction Data Collection Frequency and Timing

Routine Monitoring Frequency - Routine monitoring was performed on GPS test sections and SPS test sections during normal monitoring cycles, as long as, no major maintenance or rehabilitation action (i.e. an overlay, seal coat or porous friction course) has been undertaken on the test section. Routine friction measurements are taken <u>once every two years</u>, or more frequently if desired by the participating agency.

Timing of Friction Measurements and Seasonal Variation - Each agency selected the more appropriate time of year for conducting friction measurements in their area based on the local experience and consideration of seasonal variation. The friction data was collected for the same time of year with each round of routine monitoring cycles.

Monitoring Before and After Rehabilitation/Maintenance Treatment - Additional friction measurements are performed on the GPS and SPS test sections before and after a major maintenance or rehabilitation action (e.g. overlay, seal coat or porous friction course) has been completed.

The following guidelines are used for timing of friction measurements in these cases;

<u>Before Treatment</u>	<u>After Treatment</u>
$<$ 12 months (for all types of overlays, seal coat, and surface treatment)	3 to 12 months (for thick [$\geq$2 inch] Asphalt Concrete overlay)
$<$ 6 months (if low friction is a major consideration for overlay selection)	3 to 6 months (for thin [$<$ 2 inch] Asphalt Concrete overlay on surface treatment) (NOTE: Measurements on surface treatment may be performed prior to 3 months)

Friction Measurement Procedure and Equipment

Equipment - A locked-wheel friction tester, used in accordance with AASHTO T242, ASTM E274, supplemented with Appendix B of FHWA Technical Advisory T 5040.17, was the preferred method for obtaining friction measurements. The SHAs were responsible for friction testing, utilizing available equipment.

Operating Speed and Air Temperature - The friction data and air temperature were collected with a calibrated locked-wheel friction tester at 40 miles per hour. Tests could be conducted at a lower speed if the legal maximum posted speed was less than 40 miles per hour. For quality assurance/quality control restrictions, friction measurements were not conducted when the air temperature fell outside the range of 32°F to 110°F.

Friction Data Collection on 500 Foot GPS Sections - The friction data was collected on 500-foot GPS test section at two locations. Since the SHRP sections were marked at 100-foot stations, the first friction measurement was completed on the first half of the section between stations 0 and 2, while the second friction measurement was obtained near the end of the section between stations 3 and 5. All measurements were obtained from the center of the inner wheel path. Skid Data Sheet 1 (Ref. 48) was used to record the friction data for 500-foot LTPP sections.

Friction Data Collection on 1000 Foot SPS Test Sections. The friction measurements were conducted at four locations within the 1000 foot SPS sections including:

(1) First measurement (at the beginning) between stations 0 and 2.
(2) Second measurement (interior) between stations 3 and 5.
(3) Third measurement (interior) between stations 5 and 7.
(4) Fourth measurement (near the end) between stations 8 and 11.

All measurements were conducted in the center of the inner wheel path. Skid Data Sheet 2 (Ref. 48) was also used to record the friction data for 1000-foot SPS sections.

Data Reporting

Skid Number - The surface friction data were reported as a Friction Number (FN) which is a ratio of the frictional force to the test wheel load multiplied by 100.

Other Data Elements - The following data elements were also recorded on the skid data sheets; section identification and operator data, date and time of measurements, equipment brand and model, agency equipment number, date of last calibration, pavement surface type, air temperature and comments.

Skid Data Sheets - Instructions for Skid Data Sheets 1 and 2 and sample data sheets are provided in Section 3.2 of the SHRP Data Collection Guide for Long Term Pavement Performance

Studies (Ref. 1). Skid Data Sheet 1 was used for friction data collection on 500-foot GPS test section. Skid Data Sheet 2 was used for friction data collection on 1000-foot SPS test sections. The participating agencies used these data sheets to report friction monitoring data.

Quality Control/Quality Assurance Checks

Quality Control (QC) - The friction data was collected and reported by the individual highway agencies. The friction number measurements were subjected to the following quality control (QC) checks (Ref. 49).

1. Strict compliance of the distress data collection and reporting by the equipment operator with the designated SHRP-LTPP data collection sheets and instructions; checking by the supervisor.

2. SHRP Regional Coordination Office Contractor (RCOC) logical review of the friction data submittal by the participating highway agency. This was performed while entering the friction data in the LTPP database. This consisted of a rational checking of each data item, verifying correctness of units and accuracy of the reported SN values, speed and air temperature data. Problems were resolved by communication and coordination between friction data reporting agency and RCOC personnel. The following QC checklist was used by the RCOCs for logical review of the submitted skid data sheets.

QC Checks	Expected Entries/Permissible Data Range
1. Use of appropriate data sheet...	Data Sheet 1 for 500 foot GPS section. Data Sheet 2 for 1000 foot SPS sections.
2. Section identification data...	As previously established database entries.
3. Operator's name...	Clearly shown.
4. Date and time of measurement...	Working hours (0600 to 2000).
5. Number of test locations...	2 for Data Sheet 1; 4 for Data Sheet 2.
6. (a) SN values... (b) Difference between average SN values at different locations...	30 to 70 ±5
7. Operating speed...	40 mph ±5
8. Equipment brand, model, and agency number...	Provided
9. Date of last calibration...	Required

QC Checks	Expected Entries/Permissible Data Range
10. Pavement surface type of the test section...	Required; it should match with the surface type entry in the database.
11. Air temperature at the time of measurement...	32 to 110°F

Quality Assurance (QA) - The following friction data quality assurance (QA) checks were established to ensure friction data quality and consistency in transferring the friction data to the National Pavement Performance Database (NPPDB).

1. Internal database quality checks as part of the Information Management System (IMS) Level 1 QA/QC checks of the National Pavement Performance Database. This is primarily based on the availability of critical elements (i.e. skid numbers for each section, speed, temperature checks, etc.), permissible ranges and variations listed in the above QC checklist test.

2. Inter-regional friction data consistency will be accomplished as part of the IMS Level 2 QA/QC checks. Review and evaluation of the regional databases submitted by the RCOCs is accomplished through IMS QA/QC checks.

CLIMATE

Objectives

Although the effects of climatic factors on pavement performance have long been recognized as important, those effects remain largely unquantified, because individual pavement research projects to date have generally been restricted to limited geographic areas with more or less uniform climatic conditions, and relatively short time spans, making it difficult to separate the effects of climatic factors from those of loading. By virtue of the relatively broad geographic and climatic distribution of the test sections involved, and its long-term nature, the LTPP program will rectify this situation. The SHRP climatic database is intended to provide the weather and climatic information needed to characterize the environment in which each LTPP test sections has existed, from the time of construction through the LTPP monitoring period. The development of the SHRP climatic database has recently (Summer 1992) been completed, but work is still in progress to ensure the quality of the data contained therein.

Data Collection

Data Collection Plans

Early plans for the collection of climatic data (previously referred to as "environmental data") are documented in the draft "Data Collection Guide for Long-Term Pavement Performance Studies" (Ref. 1). Those plans identified a list of climatic data elements to be collected in conjunction with the GPS experiments, with the assumption that the primary source of climatic data for use in the LTPP studies would be the U.S. Department of Commerce's National Climatic Data Center (NCDC), in part because the NCDC is the only source of nationwide, historic climatic data known to be available. Later efforts resulted in the addition of a few data elements, and additional statistics to the list originally proposed, but the focus remained on the GPS experiments, and the NCDC remained the primary source of climatic data for use in the LTPP experiments.

With the draft data collection guide information as a starting point, a preliminary plan for using the NCDC (and, for the Canadian sites, the Canadian Climatic Center (CCC)) data was developed under SHRP's LTPP Technical Assistance Contract. This plan was then reviewed by SHRP's Environmental Data Expert Task Group. The ETG generally endorsed the concept of using the NCDC and CCC data, and recommended an "interpolation" algorithm for deriving site specific estimates of climatic data from the weather station data; i.e., the development of virtual stations for each site. However, they also advised that some on-site weather stations be established to provide "ground truth" data which can be used to evaluate the reliability of site specific estimates of weather data derived from off-site weather stations.

Climatic Data

The bulk of the climatic data stored in the SHRP climatic database was obtained from the databases of the National Climatic Data Center (NCDC) and the Canadian Climate Center (CCC). Because weather stations are rarely found in close proximity to SHRP test sites, data from up to five nearby weather stations were used to estimate site specific climatic conditions. Plans for site specific, "ground truth" weather stations are discussed in a later section.

Weather stations for use in the development of SHRP climatic database were identified in the vicinity of the pavement test section using the following criteria.

For each site identify:

- at least one active first order weather station;
- the closest active cooperative weather stations satisfying the following criteria:
  1) At least 50% data coverage for the record length to be used;
  2) Record length at least equal to the pavement age or five years after the pavement construction date;
  3) The following data elements recorded as a minimum: minimum daily temperature; maximum daily temperature; daily precipitation; and daily snowfall, (if applicable);
- the three closest active or inactive (with at least part of the record length covering years after the pavement construction date), first order or cooperative weather stations other than those included in a) and b);
- at least one station with a record length of 10 years or more.

It should be noted that the designations "First Order" and "Cooperative" apply to U.S. weather stations. For the Canadian sites, equivalent categories of weather stations were used. Also, the identification process was global --- not limited by state or provincial borders to allow the consideration of weather stations close to a site but located in a neighboring state or province.

After the initial weather station identification, the four SHRP regional contractors were asked to assist in an evaluation of the degree to which the five weather stations identified for each section in their region were believed to represent conditions at the site. To aid the regional contractors, guidelines for this evaluation were prepared -- e.g., input from state climatologist, weather station-to-site distance, elevation difference, and terrain considerations, etc. In all, close to 300 first order weather stations and 2000 cooperative weather stations were selected for use in the initial development of the SHRP climatic database.

On completion of the weather station identification and selection process, climatic data for each of the final stations was obtained from NCDC and CCC. Specifically, the following data elements were acquired, where available, for each station:

- Maximum Daily Temperature,
- Minimum Daily Temperature,

- Mean Daily Temperature,
- Daily Precipitation,
- Daily Snowfall,
- Daily Occurrences of Weather,
- Daily Average Wind Speed,
- Peak Gust Wind Speed and Direction,
- Percent of Possible Sunshine,
- Average Sky Coverage Sunrise to Sunset,
- Average Sky Coverage Midnight to Midnight,
- Daily Minimum Relative Humidity, and
- Daily Maximum Relative Humidity.

Due to the limitations associated with the NCDC data collection procedure, only the first six data fields listed above were available from cooperative weather stations and the rest were available only from first order weather stations. Also, the first five elements in this list were generally available for the entire time span, while the remaining eight were predominantly available only after 1984.

For the above data elements, with the exception of the daily occurrences of weather, monthly average, standard deviation, skewness, and kurtosis (degree of flatness or peakedness of frequency distribution curve) were calculated for each year covered in the database. Where some daily data were missing, the monthly statistical parameters were calculated using the available data only, without substitution for missing data. In addition, the following "derived" data were calculated and stored in the SHRP climatic database:

- Total monthly precipitation;
- Total monthly snowfall;
- Number of air freeze-thaw cycles per month calculated using the mean daily temperature and a basis of 32°F cumulatively; the average of the maximum and minimum daily temperatures were used in the calculation of air freeze-thaw cycles where average daily temperature is not available;
- Maximum daily temperature range, and mean, standard deviation, skewness, and kurtosis thereof;
- Number of wet days (precipitation above 0.01"); and
- High intensity precipitation occurrences (>0.5"/day).

In addition to the weather data, the following information were stored in the SHRP climatic database to characterize the weather stations:

- Weather station name, number, and type (first order or cooperative),
- distance from applicable SHRP test site,
- elevation with respect to test site,
- bearing with respect to test site,
- data coverage for temperature and moisture.

Finally, the data for the virtual (i.e., statistical or composite) weather station was derived, as recommended by SHRP's Environmental Data Expert Task Group, using a $1/R^2$ weighting scheme, where R is the distance from the weather station to the site. Thus, the closer the weather station is to the site, the greater its effect is on the composite parameters for the virtual station. As an example, any weather station three times as far from the pavement site as the closest weather station will only contribute 10% to the composite parameter based on the distance weighting used. And, if the numerical difference in a given data element at weather stations separated such is 20%, then the impact of the far station is only about 2%.

It should also be noted that the choice of five weather stations, as recommended by SHRP's Environmental Data Expert Task Group, to represent climatic conditions at a given site was somewhat arbitrary and may yield a misleading impression of data coverage for a given site. In fact, one "good" station is all that is needed for a given site. The final figures are that only 24 GPS sites nationwide are represented with fewer than three weather stations; every GPS site is represented by at least one weather station.

Climatic Database

Database Organization

The SHRP Climatic Database is arranged in three levels, the lowest being the raw NCDC and CCC climatic data, and the highest being the summary information stored in the National Pavement Performance Database. Details of the database organization are as follows.

RAW CLIMATIC DATA. The lowest level of the database consists of daily NCDC and CCC data, cleansed of unnecessary codes and flags, and stored "off-line" on long-term storage media. The data is stored in its original system of units (U.S. customary for NCDC data, and SI for CCC data) for individual weather stations, without direct linkage to individual pavement test sites. Statistical parameters are not stored at this level.

DAILY DATA, STATISTICAL PARAMETERS, AND DERIVED DATA. The second level of the database includes daily data for individual weather stations and a "composite" weather station corresponding to each test section, as well as the calculated statistical parameters and derived data for all of these stations. Data at this level is stored in U.S. customary units for weather stations associated with U.S. GPS pavement sections, and SI units for weather stations associated with Canadian GPS pavement sections. Data in this level is stored "on line", and is associated with specific test sites for easy recovery.

MONTHLY SUMMARY DATA: The final level of the database contains monthly summary data (calculated statistical parameters and derived data) from the individual weather stations and the composite station. Data at this level are stored in U.S. customary or SI units, depending on the location (U.S. or Canada, respectively) of the

GPS pavement section. This portion of the Climatic Database is included in the National Pavement Performance Database (NPPDB).

As the storage scheme outlined above was being developed, consideration was given to processing the data, and retaining only the final "virtual" or "composite" values in the National Pavement Performance Database, with the thought that researchers desiring more detailed data could always go to NCDC and CCC for the original data. The members of the Environmental Data ETG felt strongly that this was not an appropriate course, because they felt that a significant number of researchers were likely to want the raw data, and it would be foolish for them to have to duplicate SHRP's efforts in acquiring the data. They also felt that it was important to have the "real" weather station data along side the composite data, so that researchers could evaluate the viability of the composite data for themselves, in light of the individual weather station values. Also, it was suggested that the use of data from the closest weather station would be preferable to the use of "composite" data in some instances. Thus, both raw and composite data are stored in the National Pavement Performance Database.

Quality Assurance

To ensure the reliability of the data ultimately stored in the climatic database, only data flagged as valid from NCDC and CCC was used in the development of the database. Additional quality control procedures included verification that all ordered and available data had been obtained and a thorough checking and review of the software used in the development of the database.

The complete database consists of 38 9-track tapes (over 3 gigabytes of data); 17 tapes for raw and daily data and 4 tapes for the monthly summary data. As there is a substantial amount of data in each level of the database, the following checks are currently being performed separately on each level:

- RAW CLIMATIC DATA (17 tapes): Check that all tapes are readable and compare the weather stations to the list of selected stations; the entire list of selected weather stations should have been included in the tapes.
- DAILY DATA, STATISTICAL PARAMETERS, AND DERIVED DATA (17 tapes): Check that all tapes are readable and compare the weather stations and parameters to the list of selected stations; the entire list of selected weather stations should have been included on the tapes. Also, check that the expected range of years of data has been obtained by comparing to the weather station selection list. In addition, read the link records and compare them to the separately obtained lists of GPS sites and their selected weather stations; all GPS sites and their selected weather stations should be represented.
- MONTHLY SUMMARY DATA (4 tapes): For monthly statistical data, check that all tapes are readable and compare the weather stations and parameters to the list of selected stations; the entire list of selected weather stations should have been included on the tapes. Also, check that the expected range of years of data has been obtained by comparing to the weather station selection list. For GPS

site location data, compare the recorded data to the separately obtained list of GPS sites; all GPS sites should be represented. For weather station site location data, compare the recorded data to the separately obtained list of selected weather stations; all selected weather stations should be represented. For GPS to weather station link data, compare the recorded data to the separately obtained list of GPS site and weather station combinations; all combinations of GPS site and selected weather station should be represented.

Finally, for a small group of GPS sites and their selected weather stations, the entire statistical generation process will be duplicated in order to check individual statistical values.

Ground Truth Weather Stations

Despite the effort that went into the development of the SHRP climatic database, there are gaps in the data for a number of the weather stations selected. Furthermore, data obtained from the selected weather stations may not be representative of the actual, on-site weather conditions for a number of sites. To overcome these shortcomings, SHRP is now (Fall 1992) in the process of preparing a plan for obtaining ground truth weather data. By implementing this plan, SHRP hopes to achieve the following:

- Evaluate the degree to which estimates derived from NCDC and CCC weather data are representative of actual, on-site weather conditions
- Provide weather data for those sites where no representative weather stations have been identified, or to fill in gaps in the available data.

This plan is described in Reference 50.

Status of Climatic Data Activities

To date (Fall 1992), SHRP has completed the development of the climatic database for GPS sections, as well as the various data quality checks. The final database has been uploaded into the National Pavement Performance Database. Reports documenting the development of database and describing the database contents have also been finalized.

Work is now (Fall 1992) in progress to develop plans for the implementation of ground truth weather stations for purposes of verifying the contents of the GPS climatic database and, if necessary, replacing questionable data. Plans are also being finalized for the development of the climatic database for SPS sections.

Products

The climatic database will provide the weather information needed to characterize the environment in which each LTPP test sections has existed, from the time of construction through the LTPP monitoring period. Along with the pavement performance data stored in the LTPP database, these climatic data will help accomplish many of the LTPP study objectives; e.g., quantifying the effects of climatic factors on pavement performance. This, in turn, will lead to more accurate pavement performance models, thus providing the basis for sound pavement management and decisions making.

Other "by products" anticipated from this endeavor include various reports outlining data collection and quality assurance procedures, which can be used by highway agencies and other researchers in the development of climatic databases. It is also anticipate that recommendations regarding equipment needs and installation of on-site weather stations will provide valuable information to both highway agencies and researchers.

SEASONAL MONITORING

Objectives

SHRP's seasonal monitoring program is intended to provide the data needed to define and describe the magnitude and impact of temporal variations (diurnal, seasonal and annual) in pavement response and properties due to the separate and combined effects of temperature and moisture variations over time. Among other things, it will provide a means to link properties derived from deflection measurements made at a random point in time to design (e.g., AASHTO "effective") conditions. Models developed and/or validated with data obtained on the limited number of sections initially studied in the seasonal monitoring program are expected to be applicable to similar SHRP test sections. The applicability of the models will be broadened as more sections are added to the program in future years.

To achieve these objectives, SHRP is pursuing a two-level monitoring effort, involving a core experiment comprised of sections to be monitored by SHRP with assistance from the sponsoring state and provincial highway agencies, supplemented by sections to be monitored by the states and provinces. Because SHRP's resources are limited, core experiment sites have been selected to fit a specific experimental design, and achieve a reasonable balance in terms of the pavement (e.g., type, thickness) and environmental (e.g., moisture, temperature) factors considered.

For supplemental sections to be monitored by the states, the only requirements are that the section(s) under consideration be a LTPP test section, and that the state provide all necessary equipment (including the falling weight deflectometer and subsurface moisture and temperature sensors), and adhere to all aspects of the data collection protocols established by SHRP. Successful completion of an FWD calibration process equivalent to that implemented in the SHRP calibration centers will be required for participation in this activity.

An overview of the seasonal monitoring program, an in particular the core experiment, is given in this section of the report. An expanded, more detailed presentation of the program is given in References 51 and 52.

Data Collection

To date, full-scale testing has been limited to two "pilot" sites -- an asphalt concrete pavement near Syracuse, New York and a concrete pavement in Boise, Idaho -- although monitoring of deflection and profiles has been initiated at other sites. The reason for this, as discussed later, is that SHRP is currently (Fall 1992) evaluating various moisture, temperature, and frost depth measurement devices, prior to proceeding with the instrumentation of the remaining 62 sites. It is anticipated that a final decision on the instrumentation for the core experiment will be made late in the Fall of 1992, and that the actual instrumentation of the remaining sites will commence shortly thereafter.

In general, the seasonal monitoring program involves more frequent collection of pavement data currently collected as part of routine LTPP monitoring. In addition, a number of data collection activities which are not a part of the general LTPP monitoring program are required.

Deflection testing with falling weight deflectometers will provide for the evaluation of structural properties (i.e., layer moduli) on all pavements and load transfer on rigid pavements. In many respects, the FWD deflection testing procedure will be identical to that currently used for routine GPS monitoring (Ref. 12). Major changes to this procedure include: reduced number of test points (only portion of the section is tested); multiple test cycles per day; and, increased monitoring frequency.

Pavement surface and air temperature, surface layer temperature profile, subsurface moisture and temperature profiles, depth of frost/thaw, depth to ground water table, joint openings and joint faulting will be collected in conjunction with the FWD testing. Instrumentation for temperature and moisture content of the surface, base, subbase, and subgrade materials will provide the necessary data on how these factors vary over time. Frost and thaw depth will be measured where applicable, to allow complete definition of the pavement structure at any given time. Joint faulting and joint opening measurements will be made to monitor the effects of temperature variations on joint condition.

Surface elevation, longitudinal profile, and transverse profile will be measured to obtain information related to soil volume changes (due to frost heave or expansive soils), pavement rutting and roughness, and slab warping/curling (rigid pavements only). Rod and level surveys will be used to determine pavement surface elevations, transverse profiles in flexible pavements, and slab warping/curling conditions in rigid pavement sections. Profilometer readings will be taken to measure the longitudinal profile of the pavement sections. In addition, annual distress surveys will be conducted as a part of the routine monitoring of these sections.

Data collection plans for the core experiment are driven by the goal of collecting as much of the data as possible to meet the experimental objectives, as well as logistical considerations. For the state supplemental sections, reductions in the data collection have been allowed to facilitate state participation as part of their routine monitoring efforts. While it is hoped that many participating agencies will collect all of "optional" data, in addition to that which is required, it is felt that the required data is sufficient for the monitoring to be worthwhile.

Site Selection

For reasons noted earlier, the total number of sites comprising the core experiment of the seasonal monitoring program has been limited to 64 sections; 48 of the 64 sections are flexible pavements and the remaining 16 are rigid pavements. In turn, 24 of the 48 flexible pavement have a thin AC surface (<4") and the remaining 24 have a thick AC surface (>4"). Likewise, 8 of the 16 rigid pavement sections are jointed plain concrete (JPC) while the remaining 8 sections are jointed reinforced concrete (JRC) pavements. Also, the total number of sections is equally distributed throughout the four SHRP regions; i.e., 16 sites per region. Details on the distribution of these sections within the experimental design are given in Reference 51.

Due to resource limitations, and for experimental design reasons, only test sections in the GPS-1, GPS-2, GPS-3 and GPS-4 experiments have been considered at the start of this program. From this subset of GPS sections, the following site selection criteria was used to identify candidate pavement sections and to select the final sites for use in the study. These criteria are presented in two prioritized sets. The first set includes those items that were used in the nomination process:

- Pavement sections should be in good to excellent condition; i.e., as little cracking and other distress types as possible.
- Thin surface flexible pavement (GPS-1) sections should have an AC surface thickness of 4 inches or less.
- Thick surface flexible pavement (GPS-1) sections should have an AC surface thickness of 4 inches or greater.
- Jointed plain concrete pavement (GPS-3) sections should have a uniform joint spacing in the 12 to 20 foot range.
- Jointed reinforced concrete pavement (GPS-4) sections should have a uniform joint spacing in the 35 to 45 foot range.
- Travel distances as they affect the RCOCs schedule.

The second set includes those items that were used in deciding which of the nominated sites to accept:

- Achieve the target number of sites for each cell within the experimental design. If all cells have not been filled, it may be necessary to interchange sites between SHRP regions or, in some cases, relax the criteria for those cells which have not been filled.
- Once all applicable sites have been identified for each experimental cell, every effort will be made to select sites with a range of frost depth and ground water table levels. Because this information is not currently being monitored as part of the SHRP GPS study, existing national and local (site specific) literature, the experience of RCOC personnel (e.g., shoulder borings for ground water table location), and/or geography will be relied upon to address these factors.

When more sections than required had been identified for a given experimental design cell, the following criteria was used to make the final selections:

- Uniform pavement sections were given a higher priority assuming all other criteria had been satisfied. Uniformity checks were based on deflection and roughness data collected as part of the SHRP GPS study.

- Sites closest to first-order weather stations were given a higher priority assuming all other criteria had been satisfied.
- Sites having more accurate, detailed traffic data were given a higher priority assuming all other criteria had been satisfied.

Test Frequency

The 64 sites identified have been subdivided into two groups of 32 sections each. Each group of sites is to be tested on a two year cycle; e.g., the first group of sections will be tested at years 1, 3, 5...etc., and the second group at years 2, 4, 6..etc. Both the annual and daily testing frequency vary according to the parameter being measured.

Deflection testing in non-frost areas will be performed on a monthly basis (i.e., 12 test days per year). In frost areas, due to the effect of freeze-thaw conditions, the monitoring program will be repeated at least twice a month during the thaw and recovery period, and on a monthly basis for the remainder of the year (14 test days per year). The FWD test cycle sequence will be repeated a minimum of four times per test day for flexible pavements (at 1.5 to 2.0 hour intervals) and a minimum of three times per test day (at 2.0 to 2.5 hour intervals) for rigid pavements. In non-frost areas, FWD testing and related data collection will be repeated on a monthly basis (12 test days per year). The collection of related data (e.g., temperature, moisture, etc.) will performed in conjunction with the FWD testing.

Rod and level surveys will be performed on four to five different occasions throughout the year depending on the temperature regime, but always concurrently with an FWD test day. For the ensuing test years, only one survey will be required for each non-frost site (during mid-summer) and two in the frost areas (one during the late winter - fully frozen condition - and one during mid-fall). Longitudinal profile surveys will be conducted four times per test year for each site in the non-frost areas (one survey per season) and on five different occasions (one survey during the middle of each season and one additional survey during the late winter period) for sites located in frost areas. Readings are to be scheduled so that the time between FWD and profilometer surveys is minimized. For those experiment sites in the frost areas, the late winter survey will be conducted within one week of the corresponding FWD testing.

Instrumentation

SHRP is currently (Fall 1992) in the process of finalizing the instrumentation needs for the core experiment of the seasonal monitoring program. Toward this end, SHRP has instrumented two pilot sites to explore installation techniques, costs and effectiveness of different sensors presently available for the measurement of moisture and temperature related factors. One of the pilot sites, a flexible pavement, is located near Syracuse, New York and the other one, a rigid pavement, is located near Boise, Idaho. The installation of sensors at both of these sites was completed in the Fall of 1991, and approximately 6 months worth of moisture and temperature data has been collected since then, on a bi-weekly basis.

The equipment installed at each site includes instrumentation to measure temperature, moisture, frost depth, and depth to water table (an equipment cabinet and frost free bench mark were also installed). Specifically,

- Thermocouple and thermistor temperature sensor strings were installed to measure the temperature gradient through the pavement and into the subgrade.
- Two recently developed types of moisture sensors were included in the pilot studies: one using Time-Domain Reflectometry (TDR), and the other using Frequency-Domain principles. Four types of TDR sensors were used: two-prong, flat sensors; two-prong, curved sensors; three-prong, flat sensors; and three-prong, curved sensors. In addition to the TDR sensors, a Troxler Sentry 200 Moisture monitor, which is a non-nuclear moisture measurement system based on the frequency-domain sensor, was used.
- Instrumentation for measurement of frost penetration, as well as other soil characteristics, included a resistance probe and, in the case of the Idaho site, a resistivity probe.
- A piezometer to measure the water depth tables was installed at both sites.

A more complete description of the above sensors and their installation is provided in References 53 and 54. Final decisions regarding what sensors to use at the other core experiments sites will be made late in the Fall of 1992, after the analysis of the data collected to date has completed. Purchasing of equipment and installation of the instrumentation at the remaining sites will commence shortly thereafter.

Status of Seasonal Monitoring Activities

At present (Fall 1992), site selection and recruitment, and plans for data collection have been developed. The installation of instrumentation at the two pilot sites was completed in the Fall of 1991, and data collection activities have been carried out since. In addition, work is currently in progress to finalize the instrumentation needs. Once established, purchasing of equipment and installation of the instrumentation at those GPS sections comprising the seasonal monitoring program will commence. Seasonal monitoring of deflection and profile has been initiated at many sites, in an effort to identify potential problems prior to full-scale implementation of seasonal monitoring plans.

Products

For the pavement engineer, SHRP's seasonal monitoring program will result in the ability to apply in cost effective fashion, for the purposes of routine pavement design,the AASHTO concepts of effective modulus. The products of the seasonal monitoring program will also include validated models which can be used to effectively and precisely describe the daily, seasonal, and year-to-year changes in a pavement structure. In conjunction with other aspects of the LTPP research, these models will result in flexible new pavement design tools which will help meet the demand for highly reliable and precise pavement design.

For the pavement management engineer, SHRP's seasonal monitoring program will lead to increased flexibility with respect to the timing of routine monitoring activities, and better information on which to base pavement rehabilitation decisions. The models developed to describe temporal variations in pavements will provide the ability to relate pavement evaluation results obtained at any given time to some base condition, with the result that routine monitoring for an entire network can be spread over the year. The mechanistic models developed for pavement design can also become powerful pavement management tools, by allowing the pavement management engineer to predict the need for rehabilitation well in advance of the onset of measurable distress, and evaluate the implications of various rehabilitation schedules and strategies.

For the materials engineer, the seasonal monitoring program will result in greater knowledge of the in situ properties of pavement materials. This knowledge will likely reduce the amount of testing required to characterize pavement materials for design procedures such as the current AASHTO procedures and mechanistically-based procedures. In addition, the increased flexibility of the design procedures developed as a result of this endeavor will likely give the materials engineer greater flexibility in specifying, or accommodating, alternative materials.

Other important products that will result form the seasonal study include an assessment of existing moisture and temperature related measurement sensors, as well as recommendations and procedures for the installation of these sensors. Both of these activities will completed by the end of 1992.

MAINTENANCE

Introduction

The maintenance activities undertaken on the LTPP sections will no doubt influence and/or effect the results of the pavement studies. To meet the objectives of the Strategic Highway Research Programs (SHRP) Long Term Pavement Performance (LTPP) studies, the maintenance performed on a test section should be limited to that which would maintain the pavement in a safe and serviceable condition (Ref. 1). In addition any previous maintenance performed on an LTPP section can impact the pavement performance. Both ongoing and historical maintenance information is essential to the pavement performance evaluations of SHRP-LTPP data. Finally revisions in the type and level of maintenance or even specific deferment or elimination of maintenance strategies could bias pavement performance results (Ref. 55). To minimize the impacts of such action, it was necessary to establish maintenance guidelines for the SHRP-LTPP program.

Maintenance Policy

A maintenance policy was developed for the GPS test sections to establish a set of rules that permit a "reasonable" level of maintenance to be performed on the monitoring sections. The policy was to be based on representative SHA preventative or routine maintenance (Ref. 56). It is essential that these monitored sections not receive an artificially high or low amount of maintenance attention simply because of a designation as a national pavement test site. It is also desired that any maintenance treatments applied to a section be placed in response to an observed pavement need and not due to an edict to expend all apportioned maintenance funds to justify future budget requests.

Scope and Objective

Maintenance guidelines were developed to assure application of the same routine maintenance action to a SHRP-LTPP section as would be initiated at any similar site not included in the SHRP program. Specific guidelines were developed to insure that maintenance actions were limited to those which would not influence the structural response of the pavement. In particular, limitations were placed on those activities that would reduce, limit, or mask the type and amount of pavement performance information which could be obtained from the test site. Non-pavement related maintenance activities including guard rails, lighting, and signs were not to be restricted by the guidelines (Ref. 55).

The objective of the maintenance guidelines was the definition of the extent of preventative or routine maintenance activities which could be considered representative of the typical practices of U.S. and Canadian highway agencies. The desired end result of the maintenance policy was the assurance that the LTPP monitored sites would receive maintenance attention in response to observed pavement need rather than its designation as a national pavement test site (Ref. 55).

Maintenance Control Zone

A maintenance control zone illustrated in Figure 11 was established for each SHRP-LTPP monitored test section to coordinate maintenance activities at the site and to reduce the influence of other types of maintenance activities on the performance of the pavement sections (Refs. 55 and 56). The zone was delineated to restrict maintenance within the confines of the zone to specifically designated activities. The SHRP-LTPP maintenance guidelines were, therefore, only to be applicable to maintenance activities performed within the maintenance control zone (Ref. 56).

Maintenance Requirements

The SHRP Regional Coordination Office Contractors (RCOC) were to be advised, prior to commencement of a maintenance operation in the control zone, of any actions that would cover the pavement surface and "hide" distresses or change the structural characteristics (Ref. 55). This coordination effort would provide the RCOC the opportunity to schedule any required monitoring activities (i.e. distress survey, deflection and profile testing etc.) prior to initiation and completion of the maintenance activity.

Maintenance treatments within the control zone were to be completed using the highway/transportation agencies standard procedures and materials. Details concerning all maintenance activities for the LTPP monitored sites were to be recorded on appropriate SHRP maintenance data forms.

Safety-related maintenance could be performed at any time in accordance with the governing highway authority standards. Safety-related maintenance activities included in this category are:

- spot patching of potholes,
- punchouts,
- blowups, and
- other surface defects and restoration of skid resistance.

For slowly-deteriorating safety conditions, it is desirable that the SHA notify the SHRP RCOC in advance of any corrective action so that an assessment of the pavement condition prior to application of the treatment could be made. To assure the attainment of the greatest amount of structural performance information from a test section, use of hot mixed asphaltic concrete

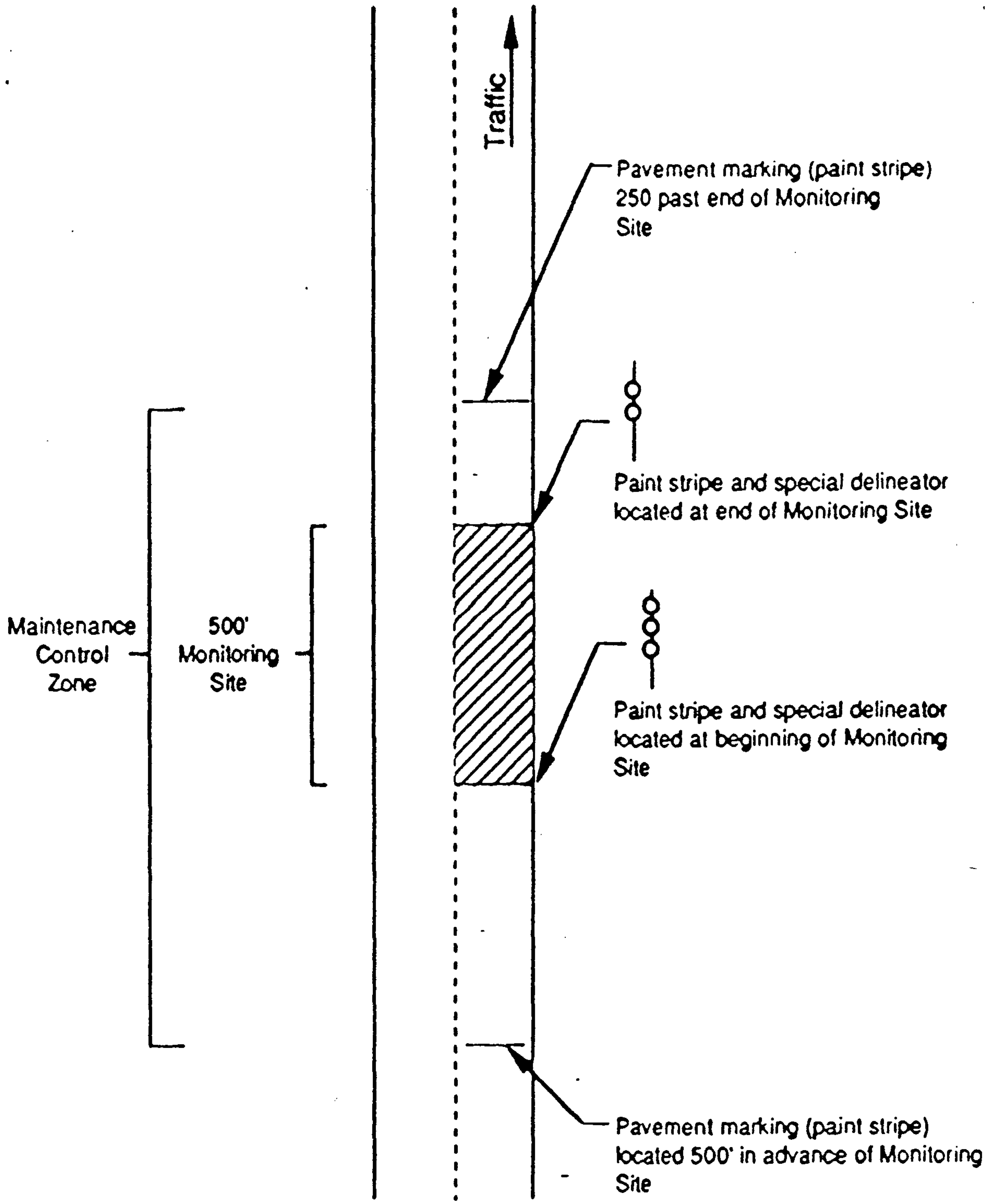


Figure 11 - Illustration of GPS Monitoring Site Maintenance Control Zone

(HMAC) overlays to restore skid resistance in the control zone was discouraged. Maintenance activities involving seal coats were allowed.

Routine or Preventative Maintenance

The types of "routine" or "preventative" maintenance activities that were allowed on a SHRP monitored section included:

- crack sealing
- joint cleaning/sealing, and
- isolated spot pavement repairs.

These activities could be performed without prior notification of the SHRP Regional Coordination Office Contractor (RCOC).

Other types of maintenance activities that were allowed on the SHRP monitored sections included application of the following types of seal coats:

- sand seal
- chip seal
- aggregate seal
- slurry seal
- fog seal

Since the application of these latter types of treatments could mask and hide surface conditions, their placement were to be coordinated with the SHRP RCOC prior to conduct of the work. In these instances a lead time was needed to allow the SHRP staff time to visit the site and document the surface condition prior to application of the treatments.

Restoration or Rehabilitation Treatments

Maintenance, restoration, or rehabilitation treatments which should not have been applied at the SHRP pavement monitored sections in their first performance period (non-overlaid), include:

- milling, grinding, use of heater-planer,
- undersealing,
- overlays, HMAC or PCC,
- slab jacking,
- retro-fitted underdrains or edge drains, and
- other specialized types of maintenance activities that affect the structural response or performance of the test section.

If these measures were applied to the pavement beyond the limits of the maintenance control zone, the transition distance between the termination or initiation of these treatments and the monitored section should be of sufficient lengths to ensure that performance of the test section is not influenced by the maintenance activity. If any of these types of treatments were planned for the pavement surrounding a monitored section or for adjoining lanes or shoulders, the SHRP Regional Coordination Office Contractor was to be notified as early as possible to enable adequate monitoring of the pavement condition to be conducted prior to treatment application.

Maintenance Data Collection

The proposed maintenance data collection plan addresses two separate time periods referred to as (1) historical data and (2) SHRP accumulated data. Historical data consists of information collected on or near the monitoring site prior to the time of initiation of site specific SHRP maintenance data collection program. SHRP accumulated data is defined as the information collected any time after the initiation of SHRP monitoring of the site. The SHRP maintenance data is accumulated using the collection system described in the remainder of this document. Historical maintenance information is recorded on maintenance data sheet 1, while the SHRP accumulated data is described in maintenance data sheets numbers 2 through 17.

In brief, it is the intent that the maintenance sheets be used to record those data items concerning maintenance activities that reasonably identify:

- existing pavement conditions prior to treatment,
- properties and quantities of materials used, and
- construction techniques applied during treatment.

The maintenance data collection sheets are provided in the following order:

DESCRIPTION	SHEET #
Historical Maintenance Information	1
Maintenance Location Summary	2
Seal Coat for AC Pavement	3-4
Crack Sealing of an AC Pavement	5
Patching of AC Pavement	6
Partial Depth Patching of PCC Pavement	7-9
Joint Resealing of PCC Pavement	10-11
Grinding, Milling and Grooving	12
Full Depth Repair of PCC Pavement	13-16
Cost Data	17

For each specific treatment (or work) type the appropriate data sheets, listed in Table 4, should be completed. The maintenance data sheets do not include descriptions of pavements to be repaired and/or rehabilitated; however, the "State Code" and the "SHRP Section ID" connect

Table 4 - Maintenance Data Sheets to be Completed

WORK ITEM	WORK TYPE CODE*	MAINTENANCE DATA SHEETS
Crack Sealing (linear ft.)	01	5
Transverse Joint Sealing (linear ft.)	02	10-11
Lane-Shoulder, Longitudinal Joint Sealing (linear ft.)	03	10-11
Full Depth Joint Repair Patching of PCC (sq. yards)	04	13-16
Full Depth Patching of PCC Pavement Other than at Joint (sq. yards)	05	13-16
Partial Depth Patching of PCC Pavement Other than at Joint (sq. yards)	06	7-9
PCC Slab Replacement (sq. yards)	07	13-16
Grinding/Milling Surface (sq. yards)	12	12
Grooving Surface (sq. yards)	13	12
Mechanical Premix Patch (using motor grader and roller) (sq. yards)	21	6
Manual Premix Spot Patch (hand spreading and compacting with roller) (sq. yards)	22	6
Machine Premix Patch (placing premix with paver, compacting with roller) (sq. yards)	23	6
Full Depth Patch of AC Pavement (removing damaged material, repairing supporting material, and repairing) (sq. yards)	24	6
Patch Pot Holes - Hand Spread, Compacted with Truck (no. of holes)	25	6
Skin Patching (hand tools/hot pot to apply liquid asphalt and aggregate) (sq. yards)	26	6
Strip Patching (using spreader and distributor to apply hot liquid asphalt and aggregate) (sq. yards)	27	6
Surface Treatment, single layer (sq. yards)	28	3-4
Surface Treatment, double layer (sq. yards)	29	3-4
Surface Treatment, three or more layers (sq. yards)	30	3-4
Aggregate Seal Coat (sq. yards)	31	3-4
Sand Seal Coat (sq. yards)	32	3-4
Slurry Seal Coat (sq. yards)	33	3-4
Fog Seal Coat (sq. yards)	34	3-4
Prime Coat (sq. yards)	35	3-4
Tack Coat (sq. yards)	36	3-4
Dust Layering (sq. yards)	37	3-4
Partial Depth Patching of PCC Pavement at Joints (sq. yards)	54	7-9

* Work Type Codes are taken from Table A.17 in Appendix A of Data Collection Guide (Ref 1).

this information to other more descriptive data (i.e. inventory, distress, materials sampling, etc.) for the test section within the National Pavement Performance Database (NPPDB).

On many of the data sheets, "Other" codes are provided for use in those instances where a product or technique is not specifically identified with a code. As maintenance practices change and new materials become available, it will be necessary to record their use and performance. Therefore, where it is necessary to use an "Other" code, sufficient information should be provided to identify what material or technique was used. A manufacturer or reference is highly desirable.

Data Sheets were to be filled out as completely as possible. It is recognized that some data elements or item may not be available. With this in mind, priority items have been indicated in bold face print with an asterisk (*). Every effort should be taken to obtain these data items. All remaining items should be acquired using a reasonable amount of effort. If any of these are unknown or unavailable, a "U" should be entered on the data sheet.

Data Source Identification

It is anticipated that SHRP/LTPP maintenance data will be collected from several sources of information. The source of this data or information should be considered when defining a relative level of confidence in the reported maintenance information.

The most reliable and desirable source of information was obtained from the data collection sheets completed in the field by a maintenance engineer or inspector. This would normally be accomplished at the actual time of treatment application. If this was impossible or impractical, then field notes or project diaries, related to each specific maintenance project, offered the next best alternative data source. These sources of data would more accurately reflect the actual materials and treatments placed on each monitoring site. It was strongly recommended that these "actual" sources be drawn from wherever possible.

If project diaries or field notes were not available, then maintenance, construction or as built plans were to be used to document the maintenance activities. If these existed, they could provide a relative idea of the maintenance activity but would more than likely only include typical cross sections or plan quantities. Since there was a potential for differences between actual field maintenance and the planned maintenance activity, this source was considered less desirable in defining maintenance.

Some of the parameters requested in the maintenance data collection guide were unavailable from plans and may not have even been recorded in a project diary. An example of this is the air content for a Portland Cement Concrete Mix. This value is usually a specification value defined by a SHA, AASHTO or industry standard. If no specific records of this type data were unavailable for a project, the likely source for this data would be an applicable specification. If it can be accepted that the mix was prepared in accordance with the specifications, then the specified air void values could nominally be considered representative of that found in the field.

Because this type of information is less specific to an individual monitoring site, it is also considered a less desirable source of information.

If all other data sources were considered but yielded no information, then the remaining method for obtaining this information would be a personal knowledge or judgement of personnel familiar with usual maintenance practices. However this approach is highly subjective and the reliability of the information would depend greatly on the knowledge and experience of each individual maintenance engineer or data collector. Therefore the use of the engineering knowledge and judgement as a data source was strongly discouraged and would be considered the least desirable data source since it may not reflect actual treatments or materials applied in the field.

Since the identification of data sources is an important element in the assessment of the overall quality of data collected, space was provided for the applicable items on the data collection sheets to indicate each source. This information helped to establish a level of confidence for the analyst/user and promoted proper use of the data.

To facilitate the reporting of the source of information, three categories were identified. These appear on the data collection sheets as "actual," "plans/specs," and "judgement." The definitions of these "sources" were described in previous paragraphs.

As maintenance data was collected and subsequent data sheets were completed and forwarded to the SHRP Regional Coordinating Office Contractor, it was imperative that the RCOC review these initial submissions. If sheets submitted from each State Highway Agency (SHA) appeared to be completed as described herein, then only spot checking of additional data by RCOCs was required. If problems in the data were obvious, then additional communication and coordination was required between the SHA's and RCOCs to resolve the questions.

Data Section Common for All Data Sheets

A common set of project identification data appear in the upper right hand corners of every data sheet. These data items are described below.

State Assigned ID - The State assigned ID is an identification number, assigned by the State Highway Agency (SHA), which is used solely to facilitate filing of the projects by the SHA. The ID may be cross-referenced with the construction project number. A State Highway Agency can use any system for assigning these identification numbers.

State Code - The State code is a number used to identify the state or Canadian province in which the pavement section is located. The codes are listed in Table 5.

SHRP Section ID - The SHRP section ID is a four-digit identification number assigned by SHRP. This number is used to facilitate the computer filing of the projects and will identify the section in the field. It will be cross-referenced with the State assigned ID.

Table 5 - Table of Standard Codes for States, District of Columbia, Puerto Rico, American Protectorates, and Canadian Provinces

State	Code	State	Code
Alabama	01	New York	36
Alaska	02	North Carolina	37
Arizona	04	North Dakota	38
Arkansas	05	Ohio	39
California	06	Oklahoma	40
Colorado	08	Oregon	41
Connecticut	09	Pennsylvania	42
Delaware	10	Rhode Island	44
District of Columbia	11	South Carolina	45
Florida	12	South Dakota	46
Georgia	13	Tennessee	47
Hawaii	15	Texas	48
Idaho	16	Utah	49
Illinois	17	Vermont	50
Indiana	18	Virginia	51
Iowa	19	Washington	53
Kansas	20	West Virginia	54
Kentucky	21	Wisconsin	55
Louisiana	22	Wyoming	56
Maine	23	American Samoa	60
Maryland	24	Guam	66
Massachusetts	25	Puerto Rico	72
Michigan	26	Virgin Islands	78
Minnesota	27	Alberta	81
Mississippi	28	British Columbia	82
Missouri	29	Manitoba	83
Montana	30	New Brunswick	84
Nebraska	31	Newfoundland	85
Nevada	32	Nova Scotia	86
New Hampshire	33	Ontario	87
New Jersey	34	Prince Edward Island	88
New Mexico	35	Quebec	89
		Saskatchewan	90

Note: The U.S. codes are consistent with the Federal Information Processing Standards (FIPS) and HPMS

Maintenance Data for SPS Test Sections

The data collection and reporting process for SPS test sites required the completion of specific data sheets, including some extracted from the GPS Data Collection Guide for Long Term Performance Studies (Ref. 3), and other data sheets developed specifically for Specific Pavement Studies (SPS). The SPS project-specific-data sheets addressed construction data and special aspects of the materials sampling and testing activities. The various SPS experiments are listed in Table 6.

In general, data obtained from monitoring activities performed after construction was reported on data forms similar to those used for the GPS test section (Refs. 57 to 60). For the SPS-6 (Rehabilitation of Jointed Portland Cement Concrete Pavements), deflection measurements locations were modified in accordance with the FWD Test Plan developed for the SPS experiment (Ref. 60).

In contrast to the General Pavement Studies test section, each SPS site is composed of several test sections. Monitoring data on SPS sections, however, was recorded as section specific data.

All maintenance activities performed on these SPS test sections, after completion of construction, were recorded, on a test section basis, using appropriate data sheets contained in Chapter 6 of the SHRP-LTPP Data Collection Guide (Ref. 1).

All maintenance activities performed on the SPS-3 and SPS-4 test sections, subsequent to completion of construction, were recorded, on a test section basis, using appropriate SPS forms (Ref. 61). Surface preparation activities required for all SPS-3 and SPS-4 section (Ref. 61) with exception of the designated control section were conducted by the U.S. and Canadian highway agencies and recorded on appropriate data collection sheets from the Maintenance Data Collection Chapter of the SHRP-LTPP Data Collection Guide (Ref. 3).

Quality Control/Quality Assurance (QA/QC) Checks

Quality Control (QC) - The maintenance data was collected and reported by the individual highway agencies in a manner similar to the inventory data collection. In the process maintenance data was subjected to the following quality control (QC) checks.

1. Compliance with the designated SHRP data collection sheets and instructions (by the highway agency staff).

2. Review for acceptability for LTPP. The maintenance data sheets allow the entry of many different types of maintenance treatments; however, not all of these treatments are desirable for the SHRP-LTPP program. Therefore, the maintenance data sheets were reviewed by the RCOCs to determine if the test section was suitable for continued study.

Table 6 - Specific Pavement Studies Experiments

SPS-1 -	Structural Factors for Flexible Pavements
SPS-2 -	Structural Factors for Rigid Pavements
SPS-3 -	Preventative Maintenance Effectiveness of Flexible Pavements
SPS-4 -	Preventative Maintenance Effectiveness of Rigid Pavements
SPS-5 -	Rehabilitation of Asphalt Concrete Pavements
SPS-6 -	Rehabilitation of Jointed Portland Cement Concrete Pavements
SPS-7 -	Bonded Portland Cement Concrete Overlays of Concrete Pavements
SPS-8 -	Environmental Effects in Absence of Heavy Loads

3. SHRP Regional Contracting Office Contractors (RCOC) undertook a logical review of the maintenance data sheets submitted by the agency. The RCOCs checked the logical data relationships including, for example, checks to insure that the correct sheets were completed. This type of review is performed at the regional level, prior to entry in RIMS (Regional IMS Database). Discrepancies were resolved by the RCOCs with input from the States as necessary, prior to data entry. Internal IMS quality checks for allowable ranges were made in the RIMS as a part of the data quality assurance.

Quality Assurance (QA) - The following maintenance data quality assurance checks were established to ensure maintenance data quality and consistency before the data was transferred into the National Pavement Performance Database (NPPDB).

1. Internal IMS database quality checks are available in the LTPP regional database. Each data item on the maintenance sheets has been assigned a logical range of values. The range of values are based on prior engineering knowledge, specifications, and defined allowable codes. The range of values is utilized in the RIMS (Regional Information Management System) databases. When data are entered outside the allowable range, a message is displayed to the data entry person indicating an invalid entry. If the data item was improperly entered, the data entry person can correct it at this time. If the data item is actually out of range, the RCOCs should verify this number with the agency and revise the regional data range if necessary.

2. Distress information interpreted from the PASCO 35mm film was forwarded to the regions for direct entry into the database. If the distress photos and associated data displays evidence of maintenance work, then action were taken to insure that the corresponding maintenance data sheets had been completed. If not, the region worked with the States to resolve this problem. The regions reviewed manually-collected distress survey information in the same manner.

3. The information and data housed in regional databases is uploaded to the National Pavement Performance Database (NPPDB) for further QA/QC checks to investigate inter-regional consistency. The data is checked for consistency, reasonableness and reviewed for trends and differences across equipment, laboratories, and time, as well as, across regions. Any questionable data is identified by regions requiring a review by regional personnel. Any revised data is transmitted to the shadow database for completion of QA/QC checks.

4. QA analysis of the data. After all quality control and assurance procedures are satisfied, the data becomes available for preliminary analysis. If any inconsistencies are apparent at this time, all data is again re-evaluated by the regions and any problems resolved. The corrected database information is then

be transmitted to the National Pavement Performance Database maintained by the Transportation Research Board.

REHABILITATION

Objectives

The collection of rehabilitation data for the SHRP test sections is separated into two distinct before and after time periods. The rehabilitation data prior to acceptance as a SHRP section is gleaned from historical data on existing pavement sections. The data accumulated during SHRP-LTPP studies, on the other hand, is obtained through real time data collection activities. The entry of both historical and current data in the LTPP National Pavement Performance database (NPPDG) is essential because rehabilitation actions can significantly affect pavement performance of the test sections and impact monitoring data results.

Historical Rehabilitation Data

Historical rehabilitation data consists of the information collected on the test section from a time frame including the original construction to the time when the site-specific SHRP rehabilitation data collection activities are initiated. The historical data for GPS sections and SPS sections are recorded one time on Figure 12, Inventory Data Sheet 4, which is described in Chapter 2 of the Data Collection Guide for LTPP Studies (Ref. 1). The maintenance and work activities, reported as historical data, are presented in Table 7.

SHRP Accumulated Rehabilitation Data for GPS Test Sections

General Guidelines for Rehabilitation of GPS Test Sections - Rehabilitation of the approved GPS test sections was not permitted during the SHRP monitoring performance period, except when the condition of the test section dropped to a level that required a rehabilitative measure. In this event, the SHRP Regional Coordination Office Contractor (RCOC) coordinated the last round of evaluation measurements with the scheduled rehabilitation action. Since large amounts of information would already have been collected on these monitoring sites, it was highly desirable that these sections be continued in the LTPP program as part of a rehabilitated pavement study. Examples of such rehabilitation actions are:

- Extensive milling, grinding, grooving, or use of heater planer
- Undersealing
- Overlays (HMAC/PCC)
- Slab jacking
- Retro-fitting underdrains or edge drains
- Other specific types of activities that affect the structural response of the monitoring site.

	*STATE ASSIGNED ID	[_ _ _ _]
SHEET 4	*STATE CODE	[_ _]
INVENTORY DATA	*SHRP SECTION ID	[_ _ _ _]
LTPP PROGRAM		

AGE AND MAJOR PAVEMENT IMPROVEMENTS

* 1. DATE OF LATEST (RE)CONSTRUCTION (MONTH/YEAR) [_ _/_ _]

* 2. DATE SUBSEQUENTLY OPENED TO TRAFFIC (MONTH/YEAR) [_ _/_ _]

3. LATEST (RE)CONSTRUCTION COST PER LANE MILE (IN THOUSANDS OF DOLLARS)[1] _ _ _ _ _.

MAJOR IMPROVEMENTS SINCE LATEST (RE)CONSTRUCTION

* 4. YEAR	* 5. WORK TYPE CODE (TABLE A.17)	* 6. WORK QUANTITY (TABLE A.17 for units)	7. THICKNESS (INCHES)	8. TOTAL COST[1] (THOUSANDS OF DOLLARS PER LANE-MILE)
[_ _]	[_ _]	[_ _ _ _ _.]	_ _._	_ _ _.
[_ _]	[_ _]	[_ _ _ _ _.]	_ _._	_ _ _.
[_ _]	[_ _]	[_ _ _ _ _.]	_ _._	_ _ _.
[_ _]	[_ _]	[_ _ _ _ _.]	_ _._	_ _ _.
[_ _]	[_ _]	[_ _ _ _ _.]	_ _._	_ _ _.
[_ _]	[_ _]	[_ _ _ _ _.]	_ _._	_ _ _.

* 9. YEAR WHEN ROADWAY WIDENED [_ _]

*10. ORIGINAL NUMBER OF LANES (ONE DIRECTION) [_]

*11. FINAL NUMBER OF LANES (ONE DIRECTION) [_]

*12. LANE NUMBER OF LANE ADDED[2] [_]

NOTES: 1. Cost is to represent pavement structure cost. Non-pavement costs such as cut and fill work, work on bridges, culverts, lighting, and guard rails are to be excluded.

2. A lane created by roadway widening should not be used for SHRP LTPP unless the pavement structure under the entire lane was constructed at the same time and is uniform.

Figure 12 - Inventory Data Sheet

Table 7 - Maintenance and Rehabilitation Work Type Codes

	Code
Crack Sealing (linear ft.)	01
Transverse Joint Sealing (linear ft.)	02
Lane-Shoulder, Longitudinal Joint Sealing (linear ft.)	03
Full Depth Joint Repair Patching of PCC (sq. yards)	04
Full Depth Patching of PCC Pavement Other than at Joint (sq. yards)	05
Partial Depth Patching of PCC Pavement Other than at Joint (sq. yards)	06
PCC Slab Replacement (sq. yards)	07
PCC Shoulder Restoration (sq. yards)	08
PCC Shoulder Replacement (sq. yards)	09
AC Shoulder Restoration (sq. yards)	10
AC Shoulder Replacement (sq. yards)	11
Grinding/Milling Surface (sq. yards)	12
Grooving Surface (sq. yards)	13
Pressure Grout Subsealing (no. of holes)	14
Slab Jacking Depressions (no. of depressions)	15
Asphalt Subsealing (no. of holes)	16
Spreading of Sand or Aggregate (sq. yards)	17
Reconstruction (Removal and Replacement) (sq. yards)	18
Asphalt Concrete Overlay (sq. yards)	19
Portland Cement Concrete Overlay (sq. yards)	20
Mechanical Premix Patch (using motor grader and roller) (sq. yards)	21
Manual Premix Spot Patch (hand spreading and compacting with roller) (sq. yards)	22
Machine Premix Patch (placing premix with paver, compacting with roller) (sq. yards)	23
Full Depth Patch of AC Pavement (removing damaged material, repairing supporting material, and repairing) (sq. yards)	24
Patch Pot Holes - Hand Spread, Compacted with Truck (no. of holes)	25
Skin Patching (hand tools/hot pot to apply liquid asphalt and aggregate) (sq. yards)	26
Strip Patching (using spreader and distributor to apply hot liquid asphalt and aggregate) (sq. yards)	27
Surface Treatment, single layer (sq. yards)	28
Surface Treatment, double layer (sq. yards)	29
Surface Treatment, three or more layers (sq. yards)	30
Aggregate Seal Coat (sq. yards)	31
Sand Seal Coat (sq. yards)	32
Slurry Seal Coat (sq. yards)	33
Fog Seal Coat (sq. yards)	34
Prime Coat (sq. yards)	35
Tack Coat (sq. yards)	36
Dust Layering (sq. yards)	37
Longitudinal Subdrains (linear feet)	38
Transverse Subdrainage (linear feet)	39

Table 7 - Maintenance and Rehabilitation Work Type Codes (Continued)

	Code
Drainage Blankets (sq. yards)	40
Well System	41
Drainage Blankets with Longitudinal Drains	42
Hot-Mix Recycled Asphalt Concrete (sq. yards)	43
Cold-Mix Recycled Asphalt Concrete (sq. yards)	44
Heater Scarification, Surface Recycled Asphalt Concrete (sq. yards)	45
Crack and Seat PCC Pavement as Base for New AC Surface (sq. yards)	46
Crack and Seat PCC Pavement as Base for New PCC Surface (sq. yards)	47
Recycled Portland Cement Concrete (sq. yards)	48
Pressure Relief Joints in PCC Pavements (linear feet)	49
Joint Load Transfer Restoration in PCC Pavements (linear feet)	50
Mill Off Existing Pavement and Overlay with AC (sq. yards)	51
Mill Off Existing Pavement and Overlay with PCC (sq. yards)	52
Other	53
Partial Depth Patching of PCC Pavement at Joints (sq. yards)	54

For the SHRP-LTPP program these measures should have been applied to the pavement within a minimum of the designated 1250 feet maintenance control zone (i.e., 500 feet prior to the test section, the 500 foot test section and 250 feet beyond the test section), as described in Chapter 7 of the SHRP-LTPP Data Collection Guide (Ref. 1).

If an activity was planned for the area outside of but not included within the maintenance control zone, a transition zone between the treatment and the control zone of sufficient length (recommended 200 feet in front of the beginning and at the end of the control zone was necessary) to ensure the monitoring site was influenced by the rehabilitative activity. If any of these types of treatments were planned for an area adjacent to a control zone, or for adjoining lanes or shoulders, the Regional Coordination Office Contractor (RCOC) was to be notified as soon as possible.

Guidelines for GPS Test Sections with Overlay Rehabilitation

1. Rehabilitation data was collected on <u>all</u> GPS test sections which required an asphalt concrete overlay. These overlaid sections were then reassigned to one of the following GPS experiments:

    - GPS-6B (Planned Asphalt Concrete Overlay of Asphalt Concrete Pavements)
    - GPS-7B (Planned Asphalt Concrete Overlay of Portland Cement Concrete Pavements)
    - Rehabilitation Data Sheets 3 through 9 (Ref. 1) would be completed for the test sections.

2. For test sections including <u>existing</u> asphalt concrete overlay, data pertaining to the overlay layer was collected using inventory data sheets 12-18 as a guide. The two existing asphalt concrete overlay experiments are:

    - GPS-6A (Existing AC Overlay of AC Pavements)
    - GPS-7A (Existing AC Overlay of PCC Pavements)

3. For a GPS-9 (PCC Overlay of PCC) test section, Rehabilitation Data Sheets 36-42 were completed if the PCC overlay was considered a planned activity and the overlay was constructed after inclusion in the SHRP-LTPP program. On the other hand, overlay information for those GPS-9 sections with an existing PCC overlay at time of entry in the SHRP-LTPP program would be recorded on Inventory Data Sheets 4 through 11.

Rehabilitation Data Sheets for GPS Test Sections

SHRP data was accumulated and recorded on the rehabilitation data sheets provided in Chapter 7 of Data Collection Guide (Ref. 1). The rehabilitation sheets are presented in the following order.

Description	Sheet(s)
Improvement Listing	1
Revised Layer Descriptions	2
Asphalt Concrete (AC) Overlay	3-10
Hot Mix Recycled Asphalt Pavement	11-22
Cold Mix Recycled Asphalt Pavement	23-34
Heater Scarification Surface Recycled Asphalt Pavement	35
Portland Cement Concrete (PCC) Overlay	36-43
Recycled PCC	44-52
Pressure Relief Joints in PCC Pavements	53-54
Subsealing PCC Pavement	55-56
Subdrainage (Retrofit) Data	57
Load Transfer Restoration Data	58-59
Crack and Seat PCC Pavement	60
Restoration of AC Shoulders	61
Restoration of PCC Shoulders	62-63
Milling and Grinding Data for Pavement Surfaces	64

Rehabilitation data sheets required for specific rehabilitation work type codes are listed in Table 8 (reproduced from Chapter 7 of the Data Collection Guide [Ref. 1]).

Rehabilitation Data for SPS Test Sections

The data collection and reporting process for SPS test sites required the completion of specific data sheets including some extracted from the Data Collection Guide for Long-Term Pavement Performance Studies (Ref. 1) which were developed for the General Pavement Studies (GPS) and other data sheets developed specifically for Specific Pavement Studies (SPS). The SPS project-specific data sheets addressed construction data and special aspects of the materials sampling and testing activities. Data obtained from monitoring activities performed after construction were reported on data forms similar to those used for the GPS test sections. In contrast to the General Pavement Studies test sections, each SPS site included several test sections. Monitoring data on SPS sections were recorded as section specific data (Refs. 62 to 65).

SPS-1 - Structural Factors for Flexible Pavements

Table 8 - Rehabilitation Data Sheets to be Completed

Rehabilitation Work Item	Work Type Code*	Data Sheets
PCC Shoulder Restoration	08	62-63
PCC Shoulder Replacement	09	62-63
AC Shoulder Restoration	10	61
AC Shoulder Replacement	11	61
Pressure Grout Subsealing	14	55-56
Slab Jacking Depressions	15	55-56
Asphalt Subsealing	16	55-56
Asphalt Concrete Overlay	19	3-10
Portland Cement Concrete Overlay	20	36-43
Longitudinal Subdrains	38	57
Transverse Subdrainage	39	57
Drainage Blankets	40	57
Well System	41	57
Drainage Blankets with Longitudinal Drains	42	57
Hot-Mix Recycled Asphalt Concrete	43	11-22
Cold-Mix Recycled Asphalt Concrete	44	23-34
Heater Scarification, Surface Recycled Asphalt Concrete	45	35
Crack and Seat PCC Pavement as Base for New AC Surface	46	60
Crack and Seat PCC Pavement as Base for New PCC Surface	47	60
Recycled Portland Cement Concrete	48	44-52
Pressure Relief Joints in PCC Pavements	49	53-54
Joint Load Transfer Restoration in PCC Pavements	50	58-59
Mill Off Existing Pavement and Overlay with AC	51	64**
Mill Off Existing Pavement and Overlay with PCC	52	64**

* Work Type Code from Table A.17
** Plus appropriate overlay data sheets

Note: Rehabilitation Sheets 1 and 2 should be completed for every rehabilitated test section.

SPS-5 - Rehabilitation of Asphalt Concrete Pavements
SPS-6 - Rehabilitation of Jointed Portland Cement Concrete Pavements
SPS-7 - Bonded PCC Overlays Test Section

All rehabilitation activities performed on the SPS test sections after completion of construction were recorded on a test section basis using the appropriate data sheets contained in Chapter 7 of the LTPP Data Collection Guide (Ref. 1).

Several data collection sheets from the GPS Rehabilitation Data Collection Chapter 7 of the Data Collection Guide were to be completed for the SPS-7 test section (Ref. 65). These include:

- REHABILITATION SHEET 39 PORTLAND CEMENT CONCRETE OVERLAY, MIXTURE DATA
- REHABILITATION SHEET 40 PORTLAND CEMENT CONCRETE OVERLAY, AGGREGATE DATA
- REHABILITATION SHEET 41 PORTLAND CEMENT CONCRETE OVERLAY, AGGREGATE DATA AND CONSTRUCTION DATA
- REHABILITATION SHEET 61 RESTORATION OF AC SHOULDERS
- REHABILITATION SHEET 62 RESTORATION OF PCC SHOULDERS
- REHABILITATION SHEET 63 RESTORATION OF PCC SHOULDERS

Rehabilitation Data Sheets 39, 40, and 41 were completed from project records and construction observations of the bonded portland cement concrete overlay. Rehabilitation Data Sheets 61, 62, and 63 were also completed to provide information on shoulder treatments.

Quality Control/Quality Assurance (QA/QC) Checks

Quality Control (QC) - The rehabilitation data were collected and reported by the individual highway agencies in a manner similar to the inventory data collection (Refs. 66 to 68). In the process rehabilitation data were subjected to the following quality control (QC) checks.

1. Compliance with the designated SHRP data collection sheets and instructions (by the highway agency staff).

2. Review for acceptability for LTPP. The rehabilitation data sheets allow the entry of many different types of rehabilitation treatments; however, not all of these treatments are desirable for the SHRP-LTPP program. Therefore, the rehabilitation data sheets would be reviewed by the RCOCs to determine if the test section is suitable for continued study. The GPS-6B and GPS-7B experiments involve test sections with planned overlays; therefore, rehabilitation sheets are required for these test sections. The same requirements apply to a planned PCC overlay section within the GPS-09 experiment. The remaining rehabilitated test sections were reviewed by the RCOCs on a case-by-case basis to determine their acceptability for continued study.

3. SHRP Regional Coordination Office Contractors (RCOC) undertook a logical review of the rehabilitation data sheets submitted by the agency. The RCOCs were to check the logical data relationships, including, for example, checks to insure that the correct sheets are completed (e.g. if a AC overlay is placed, Rehabilitation Sheets 3 through 10 are completed). This type of review was performed at the regional level, prior to entry in RIMS (Regional IMS Database). Discrepancies were resolved by the RCOCs with input from the States as necessary, prior to data entry. Internal IMS quality checks for allowable ranges were made in the RIMS as a part of the data quality assurance.

Quality Assurance (QA) - The following rehabilitation data quality assurance checks were established to ensure rehabilitation data quality and consistency before the data is transferred into the National Pavement Performance Database (NIMS).

1. Internal IMS database quality checks are included in the LTPP regional database. Each data item on the rehabilitation sheets has been assigned a logical range of values. The range of values are based on prior engineering knowledge, specifications, and defined allowable codes. The range of values is utilized in the IMS databases. When data are entered outside the allowable range, a message is displayed to the data entry person indicating an invalid entry. If the data item was improperly entered, the data entry person can correct it at this time. If the data item is actually out of range, the RCOCs were to verify this number with the agency and revise the regional data range if necessary.

2. Distress information interpreted from the PASCO 35mm film was forwarded to the regions for direct entry into the database. If the distress photos and associated data displayed evidence of rehabilitation work, then action was taken to insure that the corresponding rehabilitation data sheets were completed. If not, the region worked with the States to resolve this problem. The regions reviewed manually-collected distress survey information in the same manner.

3. The information and data housed in regional databases was uploaded to the National Pavement Performance Database for further QA/QC checks to investigate inter-regional consistency. The data was checked for consistency, reasonableness and reviewed for trends and differences across equipment, laboratories, and time, as well as across regions. Any questionable data was identified by regions requiring a review by regional personnel. Any revised data were to be transmitted to the shadow database for completion of QA/QC checks.

4. QA analysis of the data. After all quality control and assurance procedures were satisfied, the data was then available for preliminary analysis. If any inconsistencies were apparent at the time, all data was again re-evaluated by the regions and any problems resolved. The corrected database information was then transmitted to the National Pavement Performance Database maintained by the Transportation Research Board.

REFERENCES

1. Strategic Highway Research Program: Data Collection Guide for Long-Term Pavement Performance Studies, Operational Guide No. SHRP-LTPP-OG-001, Strategic Highway Research Program, January 1990.

2. LTPP Overview, Fifth Year Report, Volume 1, Texas Research and Development Foundation, August, 1993.

3. Strategic Highway Research Program: Distress Identification Manual for the Long-Term Pavement Performance Studies, Strategic Highway Research Program, June 1989.

4. Strategic Highway Research Program: Permanent Distress Record Collection and Transverse Profile Analysis using PASCO USA's Roadrecon Survey Systems, Strategic Highway Research Program, May 1992.

5. Strategic Highway Research Program: Distress Interpretation from 35mm Film for the LTPP Experiments, Strategic Highway Research Program, June 1992.

6. Strategic Highway Research Program: Manual for Distress Surveys, Strategic Highway Research Program, May 1992.

7. Strategic Highway Research Program: Manual for Dipstick Profile Measurements: Operational Field Guidelines, Version 1.1, Strategic Highway Research Program, January 1991.

8. Strategic Highway Research Program: Manual for Faultmeter Measurements: Operational Field Guidelines, Version 1.1, Strategic Highway Research Program, June 1991.

9. Strategic Highway Research Program: Accreditation of Manual Distress Survey Raters, Strategic Highway Research Program, June 1992.

10. Strategic Highway Research Program: Materials Characterization, Fifth Year Report, Volume 5, Texas Research and Development Foundation, August 1993.

11. Strategic Highway Research Program: Seasonal Monitoring Program: Data Collection Guidelines for Core Experiment with State Supplements, Strategic Highway Research Program, December 1991.

12. Strategic Highway Research Program: Manual for FWD Testing: Operational Field Guidelines, Version 1.0, Strategic Highway Research Program, January 1989.

13. Strategic Highway Research Program: FWD Test Plan for Experiment SPS-1: Strategic Study of Structural Factors for Flexible Pavements, Strategic Highway Research Program, April 1992.

14. Strategic Highway Research Program: FWD Test Plan for Experiment SPS-2: Strategic Study of Structural Factors for Rigid Pavements, Strategic Highway Research Program, April 1992.

15. Strategic Highway Research Program: FWD Test Plan for Experiment SPS-5: Rehabilitation of Asphalt Concrete Pavements, Strategic Highway Research Program, April 1992.

16. Strategic Highway Research Program: FWD Test Plan for Experiment SPS-6: Rehabilitation of Jointed Portland Cement Concrete Pavements, Strategic Highway Research Program, April 1992.

17. Strategic Highway Research Program: FWD Test Plan for Experiment SPS-7: Bonded Portland Cement Concrete Overlays, Strategic Highway Research Program, April 1992.

18. Strategic Highway Research Program: FWD Test Plan for Experiment SPS-8: Study of Environmental Effects in the Absence of Heavy Loads, Strategic Highway Research Program, April 1992.

19. Strategic Highway Research Program: Analysis of Data Filtering Results from the North Carolina Pilot Study, Strategic Highway Research Program, March 1989.

20. Strategic Highway Research Program: Analysis of Data Filtering Results from the North Carolina Pilot Study, Strategic Highway Research Program, April 1989.

21. E.O. Lukanen, "Buffer Effects on Falling Weight Deflectometers Loadings with Deflections," paper accepted for publication in the Transportation Research Records, Washington, D.C., July 1991.

22. Strategic Highway Research Program: FWD Calibration Protocol, Strategic Highway Research Program, October 1991.

23. Strategic Highway Research Program: Reference Calibration of Falling Weight Deflectometers - FWDREFCL, Version 3.2 A&B - Software User's Guide and Instructional Manual, Strategic Highway Research Program, October 1991.

24. Strategic Highway Research Program: Relative Calibration Analysis - FWDCAL, Version 1.0, Strategic Highway Research Program, December 1989.

25. Strategic Highway Research Program: Analysis of Within Drop (Replicate) Error of Load Cell and Sender Responses of the FWD, Strategic Highway Research Program, January 1989.

26. Strategic Highway Research Program: FWD Data Readability and Completeness - FWDSCAN, Version 1.30 - Program Background and User's Guide, Strategic Highway Research Program, April 1992.

27. Strategic Highway Research Program: Analysis of Section Homogeneity, Non-Representative Test Pit and Section Data, and Structural Capacity - FWDCHECK, Version 2.00, Strategic Highway Research Program, April 1992.

28. Strategic Highway Research Program: Procedure for Temperature Correction of Maximum Deflections, Strategic Highway Research Program, February 1992.

29. Strategic Highway Research Program: Layer Moduli Backcalculation Procedure - Software Selection, Strategic Highway Research Program, July 1991.

30. Strategic Highway Research Program: Layer Moduli Backcalculation Procedure - Rules and Guidelines, Strategic Highway Research Program, January 1992.

31. Strategic Highway Research Program: SHRP-LTPP Manual for Profile Measurements, Operational Field Guidelines Version 2.0, Strategic Highway Research Program, Fall 1992.

32. Strategic Highway Research Program: SHRP-LTPP Manual for Profile Measurements: Operational Field Guidelines Version 1.0, Strategic Highway Research Program, December 1989.

33. Strategic Highway Research Program: SHRP-LTPP Manual for Dipstick® Profile Measurements: Operational Field Guidelines Version 1.0, Strategic Highway Research Program, September 1990.

34. Strategic Highway Research Program: SHRP-LTPP PROFQUAL User Documentation Version 1.4, Pavement Management Systems Limited.

35. "Strategic Highway Research Program Research Plans," Final Report, May 1986, Technical Research Area 2, Long-Term Pavement Performance, Prepared for the Strategic Highway Research Program, January 1986.

36. "The SHRP Traffic Data Requirements," Mark Hallenbeck and Kris Gupta, August 1991.

37. "Framework for Traffic Data Collection at GPS Test Locations," SHRP, January 1989.

38. SHRP Traffic Data Collection and Analysis Expert Task Group meeting notebook, compiled by TRDF, May 1992.

39. "Guidelines for Traffic Data Collection Plans," SHRP-LTPP, John L. German, Texas Research and Development Foundation (TRDF), October 1991.

40. "The SHRP Traffic Database: What it Really is?" SHRP-LTPP, Paper prepared by mark Hallenbeck for SHRP Mid Term Conference in Denver, August, 1990.

41. SHRP-LTPP Data Collection Guide, Proposed Final Chapter 4, "Traffic Data Collection for GPS Sections," April 1992.

42. "SHRP-LTPP Traffic Database Design," Mark Hallenbeck, August 1990.

43. "Procedures for Manipulating SHRP-LTPP Traffic Data," SHRP-LTPP, Mark Hallenbeck, August 1990.

44. "Traffic Monitoring Guide," U.S. DOT FHWA, June 1985.

45. "SHRP National Traffic Database: Description of the Required Computer System," SHRP-LTPP, Mark Hallenbeck, August 1990.

46. "SHRP-LTPP International Traffic Data Collection Handbook," SHRP-LTPP, John L. German, TRDF, September 1991.

47. "Status of LTPP Traffic Data Collection," SHRP-LTPP, John L. German, TRDF, April 1992.

48. "Skid Data Collection for SHRP Test Sections," SHRP, (TRDF Reference Number MG0014), May 5, 1989.

49. "Quality Control Plan for Skid Data." TRDF Technical Memorandum AU-75, August 24, 1989.

50. Strategic Highway Research Program: Collection of Ground Truth Weather Data for GPS Sections, Strategic Highway Research Program, June 1992.

51. Strategic Highway Research Program: LTPP Seasonal Monitoring Program - Core Experiment and State Supplements, Strategic Highway Research Program, December 1991.

52. Strategic Highway Research Program: LTPP Seasonal Monitoring Program - Instrumentation Needs for Core Experiment and State Supplements, Strategic Highway Research Program, May 1991.

53. Strategic Highway Research Program: Seasonal Testing Instrumentation Pilot - GPS 361011, IH 481S.B., E. Syracuse, New York, Strategic Highway Research Program, October 1991.

54. Strategic Highway Research Program: Seasonal Instrumentation Pilot Study - Instrumentation Installation, Section 163023 in Idaho, Strategic Highway Research Program, April 1992.

55. "SHRP Guidelines for Maintenance of General Pavement Studies (GPS) Test Sections," Strategic Highway Research Program, Operational Memorandum SHRP-LTPP-OM-001, July, 1988.

56. Elkins, Gary E., "Policy for Pavement Maintenance on GPS Sections," Texas Research and Development Memorandum T-001, May 26, 1988.

57. "Specific Pavement Studies Data Collection Guidelines for Experiment SPS-1, Study of Structural Factors for Flexible Pavements," Strategic Highway Research Program, Operational Memorandum No. SHRP-LTPP-OM-026, December 1991.

58. "Specific Pavement Studies Data Collection Guidelines for Experiment SPS-2, Study of Structural Factors for Rigid Pavements," Strategic Highway Research Program, Operational Memorandum No. SHRP-LTPP-OM-028, February 1992.

59. "Specific Pavement Studies Data Collection Guidelines for Experiment SPS-5, Rehabilitation of Hot Mix Asphalt Concrete Pavements," Strategic Highway Research Program, Operational Memorandum No. SHRP-LTPP-OM-015, October 1990.

60. "Specific Pavement Studies Data Collection Guidelines for Experiment SPS-6, Rehabilitation of Jointed Portland Cement Concrete Pavements," Strategic Highway Research Program, Operational Memorandum No. SHRP-LTPP-OM-023, May 1991.

61. *SHRP-LTPP Fifth Year Report*, Volume 3, Texas Research and Development Foundation, August 1992.

62. "SPS Data Collection Guidelines for Experiment SPS-1, Strategic Study of Structural Factors for Flexible Pavements," Strategic Highway Research Program (SHRP), Operational Memorandum No. SHRP-LTPP-OM-026, December 1991.

63. "SPS Data Collection Guidelines for Experiment SPS-5, Rehabilitation of Asphalt Concrete Pavements," Strategic Highway Research Program (SHRP), Operational Memorandum No. SHRP-LTPP-OM-015, October 1991.

64. "SPS Data Collection Guidelines for Experiment SPS-6, Rehabilitation of Jointed Portland Cement Concrete Pavements," Strategic Highway Research Program (SHRP), Operational Memorandum No. SHRP-LTPP-OM-023, May 1991.

65. "SPS Data Collection Guidelines for Experiment SPS-7, Bonded Portland Cement Concrete Overlays," Strategic Highway Research Program (SHRP), Operational Memorandum No. SHRP-LTPP-OM-024, July 1991.

66. "Quality Control Plan for Rehabilitation Data Collection," Texas Research and Development Foundation (TRDF) Technical Memorandum AU-30, September 26, 1989.

67. "Quality Control for Rehabilitation Data," Texas Research and Development Foundation (TRDF) Technical Memorandum AU-115 (Revised), March 23, 1990.

68. "IMS Intra Checks Rehabilitation," Texas Research and Development Foundation (TRDF) IMS Development Message Number TRDF-57, April 29, 1991.