SHRP-P-661

Manual for FWD Testing in the Long-Term Pavement Performance Program

PCS/Law Engineering and
Braun Intertec Pavement, Inc.

Strategic Highway Research Program
National Research Council
Washington, DC 1993

SHRP-P-661
Contract P-001

Program Manager: *Neil F. Hawks*
Project Manager: *Cheryl Allen Richter*
Production Editor: *Marsha Barrett*
Program Area Secretary: *Cynthia Baker*

August 1993

key words:
deflection testing
falling weight deflectometer
non-destructive testing
pavement evaluation
structural evaluation

Strategic Highway Research Program
National Academy of Sciences
2101 Constitution Avenue N.W.
Washington, DC 20418

(202) 334-3774

350/NAP/893

Acknowledgments

The research described herein was supported by the Strategic Highway Research Program (SHRP). SHRP is a unit of the National Research Council that was authorized by section 128 of the Surface Transportation and Uniform Relocation Assistance Act of 1987.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF TABLES

THIS PAGE INTENTIONALLY LEFT BLANK

Abstract

Non-destructive deflection testing with Falling Weight Deflectometers (FWDs) is a critical element of the pavement monitoring effort for the Long-Term Pavement Performance (LTPP) test sections of the Strategic Highway Research Program. Data obtained through this testing serves as the primary mechanism for assessing structural conditions within each LTPP test section.

For the LTPP deflection data to serve its intended purpose, the deflection testing unit must be conducted consistently with accurately calibrated FWDs. This report documents the procedures to be followed in the conduct of the LTPP deflection testing. It provides detailed testing programs for deflection testing within each of the LTPP experiments developed to date, as well as field quality assurance and data handling guidelines applicable to all deflection testing. In addition, the SHRP FWD Calibration Protocol, presented in Appendix A, provides the first generally applicable, independent procedure for verifying and refining the calibration of FWDs.

FOREWORD

Presently, no universally accepted comprehensive standard test procedures for falling weight deflectometer (FWD) testing exist. This manual was developed for use by personnel responsible for collecting deflection data on pavement test sections in the long-term pavement performance (LTPP) study. The manual discusses the role of deflection testing in the LTPP Study and provides field operational guidelines for data collection under the following headings:

(1) Falling Weight Deflectometer Field Test Procedures

(2) Data Acquisition and Handling

(3) Equipment Calibration, and

(4) Equipment Maintenance and Repair.

People involved with deflection testing are encouraged to discuss the contents of this Field Guide with the four Regional Coordination Offices (RCOs). The RCOs will keep LTPP staff in Washington, D.C. informed of necessary changes, and periodic reviews and necessary updates to this manual will help keep the FWD operational guidelines current and help maintain uniform test procedures between the four regions.

The test procedures recommended in this manual are a product of SHRP, its contractors, and the Deflection Testing and Backcalculation Expert Task Group. The manual was originally developed by Pavement Consultancy Services, a Division of Law Engineering (PCS/LAW), under contract to the Strategic Highway Research Program (SHRP), National Research Council. This second version of the manual was developed by PCS/LAW and Braun Intertec Pavement, Inc. under contract to the Federal Highway Administration (FHWA).

A special thanks to Lynne H. Irwin, Ph.D., SHRP consultant, who was responsible for the preparation of Appendix A, SHRP FWD Calibration Protocol, to the SHRP H-101 Contractor staff who were responsible for the preparation of the SPS-3 and -4 FWD Testing Guidelines contained in Appendix B, and to the Deflection Testing and Backcalculation Expert Task Group for their efforts in the development and review of the manual.

I. OVERVIEW OF THE LTPP PROGRAM

The SHRP Long-Term Pavement Performance (LTPP) study is one of four major technical research areas in the five-year, $150 million program. One of the primary objectives of the LTPP study is to improve prediction models for pavement behavior and pavement performance by collecting and analyzing pavement response and performance data on a broad spectrum of in-place pavement sections.

For data collection and coordination, the agencies from the United States and Canada participating in SHRP have been assigned to one of four Regional Coordination Offices (RCO). Boundaries for the four RCOs are shown in Figure 1.

The deflection response of the pavement to an applied load is an important indicator of structural capacity, material properties, and subsequent pavement performance. The LTPP Study uses Falling Weight Deflectometers (FWDs) to collect deflection data. The FWD applies an impulse load and measures deflection response at seven radial distances. The impulse load can be adjusted from 1,600 lbs. to 27,000 lbs. (7 kN to 120 kN).

The LTPP program has approximately 1000 in-service pavement sections in the General Pavement Study (GPS) area, and an increasing number of in-service pavement sections in the Specific Pavement Study (SPS) area. In addition, approximately 64 of the GPS sections are included in the Seasonal Monitoring program. Details specific to this program are contained in the "SHRP LTPP Seasonal Monitoring Program: Data Collection Guidelines for Core Experiment and State Supplements", December 1991.

Many details of the FWD testing on GPS, SPS, and Seasonal Monitoring sites are the same, and they are discussed in the body of this manual. Testing details specific to each of the currently identified SPS experiments are included in the Appendix.

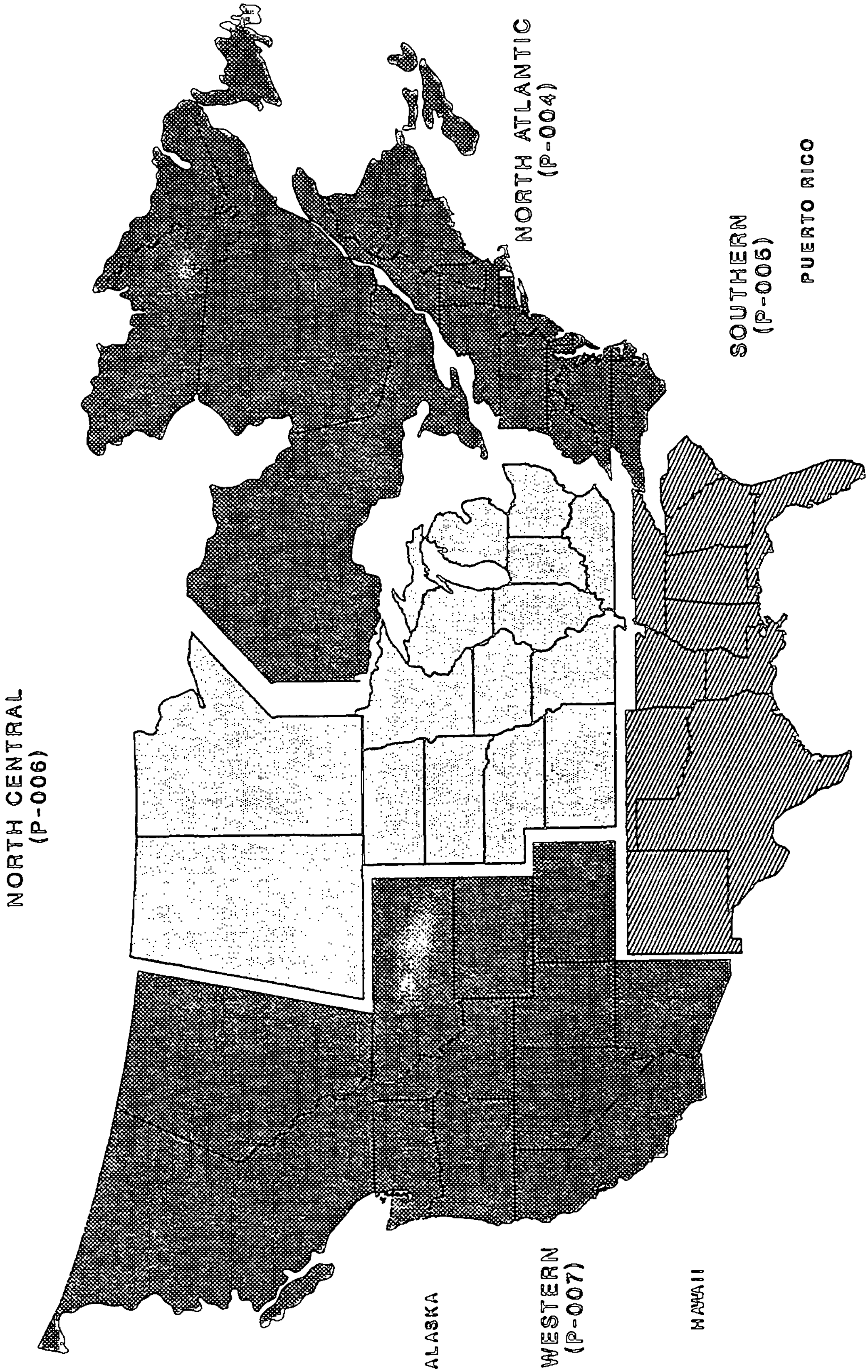


FIGURE 1 SHRP REGIONS

II. FWD FIELD TESTING

Background

Accurate measurement of deflection data with the Falling Weight Deflectometer (FWD) is a key element in the LTPP monitoring effort. Factors other than normal variation in the pavement cross-section (layer thickness, layer material type, material quality, and subgrade support) exist that influence the deflection response of a pavement. Each FWD operator needs a general knowledge of these factors so correct and meaningful deflection data is collected. In addition to pavement cross-section factors, there are three other sets of factors that significantly affect deflections;

- Environmental Factors,
- Pavement Discontinuities, and
- Variability in the Pavement Structure.

Environmental Factors

Temperature and moisture affect deflection response of both flexible pavements (asphaltic concrete) and rigid pavements (Portland Cement Concrete). The stiffness (rigidity) of asphalt concrete (AC) is very sensitive to temperature changes occurring over both long term (seasonal) and short term (hourly) periods. As the temperature of the pavement increases, the magnitude of deflection from a given impulse load will increase if all other factors remain the same. Therefore, deflections measured on a hot summer day will be larger than the deflections measured during a cooler period. Also, changes in temperature with depth (vertical temperature gradients) influence stresses in the AC layer. The influence of vertical temperature gradients becomes more pronounced as the thickness of the AC increases.

Portland Cement Concrete (PCC) pavement behavior is affected by temperature in two ways. First, long term (seasonal) variations in temperature cause panels to contract during cool periods and expand during warm periods. The expansion and contraction of panels influence the width of joints and cracks in the pavement and the degree of mechanical interlock between the panels. The deflection response at the joints and cracks is used to calculate the degree of interlock.

Secondly, short term (daily) variations in temperature cause vertical temperature gradients through the PCC that in turn cause differential expansion of materials with depth.

Differential expansion with depth causes the panels to "curl" in either a concave or convex form.

This curling action influences the deflection response of the PCC panels. For negative temperature gradients (surface cooler than the bottom of the PCC), the panels are concave with the panel edges lifted and the mid-panel resting on the base material. This condition normally occurs during early morning hours and normally results in higher deflections near the panel edges. For positive temperature gradients (surface warmer than the bottom of the slab), the panels are convex with the panel edges resting on the base material and the mid-panel lifted off the base material. This condition normally exists later in the day after the PCC has been exposed to the sun and results in higher deflection at the mid-panel locations.

In general, moisture in a pavement structure weakens the structure and causes deflections to increase. Moisture changes are normally long term, occurring over an annual cycle. However, pavement sections in areas with significant frost penetration can have extreme changes in deflection if significant moisture exists with fine grain soil. With the structure frozen, the deflections are small. In the spring as the structure thaws from the surface downward, moisture trapped between the surface and subgrade saturate the soils making them very weak and deflections very high.

FWD operators should recognize that pavement deflections vary on the same pavement section throughout the day and throughout the year from temperature and moisture changes. Thus, deflection readings taken at different times on a specific pavement section may not be the same. Deflection differences are considered normal and do not necessarily indicate equipment problems. In fact, the sections in the Seasonal Monitoring Study will help define the expected changes in deflection for temperature and moisture changes.

With the above background on environmental influences, FWD operators must insure the success of the LTPP program by;

1. making sure the correct local time is recorded on all forms and data sheets for a section (especially true for operators in regions spanning more than one time zone),

2. making sure air and pavement temperatures automatically recorded by the FWD are reasonable, and

3. making sure locations for vertical temperature gradient measurements are in representative areas and temperatures are properly recorded.

Pavement Discontinuities

A pavement section with surface discontinuities such as cracks and/or joints, or subsurface discontinuities such as voids below the pavement will generally have higher deflection readings than a pavement section without any discontinuities if all other factors are the same. The FWD testing plan in this manual provides specifics on deflection testing at joints and transverse cracks for PCC pavements. The testing plan also provides guidelines for recording any pavement distress near deflection tests.

It is important that FWD operators obtain typical deflection response data on each pavement section. FWD operators should not "bias" deflection readings by testing only crack-free areas or only cracked areas. More details on test point location and distribution are discussed later in this manual.

Variability in the Pavement Structure

For the GPS program, pavement sections as uniform as possible were selected. However, pavement deflection response will vary not only between drops at a given load level, but also between test points within the section.

Deflection variation at a given load level for a test point will generally be less than about 0.1 to 0.2 mils (3 to 5 microns), and is statistically accounted for by doing four drops at each load level. This variation occurs from limits on equipment repeatability for load and deflection measurement, and from material changes in the pavement structure from the load applications.

In contrast, deflection variation between test points within a section may be quite large; ranging from 15 percent to more than 60 percent. This variation reflects changes in layer thickness, material properties, moisture and temperature conditions, subgrade support, and contact pressure under the load plate. These are normal conditions, and FWD operators should not be concerned with deflection variations from changes in these conditions.

Also, some variation occurs from the test procedure; reduced load from warming of the FWD buffers, and changes in placement of deflection sensors relative to the edge of the pavement. FWD operators need to minimize these variations by conditioning the buffers prior to testing and by following test procedures in the manual.

No guideline on acceptable data variation at a test point can cover all potential conditions. However, variation checks in the software help screen data as it is collected so FWD operators can determine whether data at a test point is acceptable. These data checks are discussed in chapter three along with other quality control checks and criteria for accepting and rejecting data.

No data variation checks are used in the software to detect changes in deflection response over the length of a section, because the changes are considered normal and unknown before the data is collected. However, FWD operators should watch for large changes in deflection and try to identify possible causes and pass such information on to RCO engineers for further evaluation. Explanatory comments should be entered into the FWD data file using the F6 (comment) key, as appropriate.

Pavement Types

GPS Test Sections

The GPS portion of the LTPP program involves experiments on eight specific types of pavement cross sections. They are:

Experiment	Pavement Structure
1	AC Pavement Over Granular Base (AC/AGG)
2	AC Pavement Over Bound Base (AC/BND)
3	Jointed Plain Concrete Pavement (JPCP)
4	Jointed Reinforced Concrete Pavement (JRCP)
5	Continuously Reinforced Concrete Pavement (CRCP)
6	AC Overlay of AC Pavement (AC/AC)
7	AC Overlay of PCC Pavements (AC/PCC)
8	(not identified)
9	Unbonded PCC Overlay of PCC Pavements (PCC/PCC)

FWD Test Plans

The eight GPS experiments are divided by pavement characteristics into three specific FWD test plans as listed below, and details for the test plans are found in the rest of this chapter.

FWD Test Plan	GPS Experiment Number and Name
FLEX	(1) AC Pavement Over Granular Base (AC/AGG)
	(2) AC Pavement Over Bound Base (AC/BND)
	(6) AC Overlay of AC Pavement (AC/AC)
	(7) AC Overlay of PCC Pavement (AC/PCC)

JCP[1]	(3) Jointed Plain Concrete Pavement (JPCP)
	(4) Jointed Reinforced Concrete Pavement (JRCP)
	(9) Unbonded PCC Overlay of PCC Pavement (PCC/PCC)
CRCP	(5) Continuously Reinforced Concrete Pavement (CRCP)

Types of Deflection Tests

In the GPS study, two types of deflection tests are run:

1. Deflection Basin (DB) test and
2. Load Transfer (LT) test.

DB tests are used in all three test plans, while LT tests are used only in the JCP and CRCP test plans. DB tests are analyzed to estimate in-situ characteristics of the materials in the pavement structure.

In contrast, LT tests at joints and cracks in PCC pavements are analyzed to evaluate load transfer efficiency across the joints and cracks, and also to evaluate the possible existence of voids under the pavement.

In summary, the three major uses of deflection data are as follows:

Test	Data Analysis/Data Use
DB	Estimate Material Properties (Distribution)
LT	Joint/Crack Load Transfer Efficiency
LT	Void Detection

Deflection Sensor Spacing

The LTPP FWDs have seven deflection sensors placed at radial offsets from the center of the load plate to define the shape of the deflection basin. Deflection basin shape ranges significantly from steep basins for weak flexible pavements to shallow basins for stiff rigid

[1]This FWD test plan was referred to as RIGID in Version 1.0 of this manual.

pavements. The shape varies most significantly within three feet (0.9m) of the load plate for most highway pavements.

For any one pavement section, an optimal set of sensor spacings exists for defining the basin shape. However, only one set of sensor spacings is used for all DB tests to simplify data collection, decrease testing time, and minimize errors in sensor spacings. Figure 2a shows the sensor spacing used for all DB tests.

When LT tests are done, the set of sensor spacings shown in Figure 2b is used. The only difference between the spacings for the DB test and LT test is that sensor No. 2 at 8" (203mm) for the DB test is moved to -12" (-305mm) for LT test. Figure 2b-1 shows the load plate on the "approach" slab of a joint and Figure 2b-2 shows the load plate on the "leave" slab of the same joint; however, the sensor spacing does not change.

Load Sequence (Drop Heights)

The testing plans for FLEX, JCP, and CRCP have similar, but not identical drop sequences, and separate test setups need to be created and stored in the software for the testing plans. For the FLEX test plan, four drop heights are used with the target load and acceptable load range at each height as follows (1.0 kips = 1000 lbs.):

FLEX Testing Plan

Hgt.	Target Load (kips)	Acceptable Range (kips)
1	6.0 (26.7kN)	5.4 to 6.6 (24.0kN to 29.4kN)
2	9.0 (40.0kN)	8.1 to 9.9 (36.0kN to 44.0kN)
3	12.0 (53.3kN)	10.8 to 13.2 (48.1kN to 58.7kN)
4	16.0 (71.1kN)	14.4 to 17.6 (64.1kN to 78.3kN)

For the JCP and CRCP testing plans three drop heights are used with the target load and acceptable load range at each height as follows:

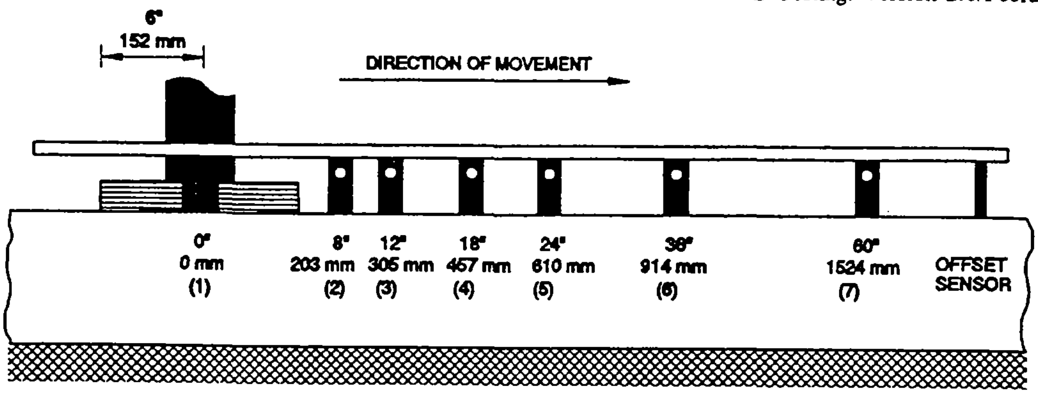


FIGURE 2A.
SENSOR CONFIGURATION FOR DEFLECITON BASIN TESTING

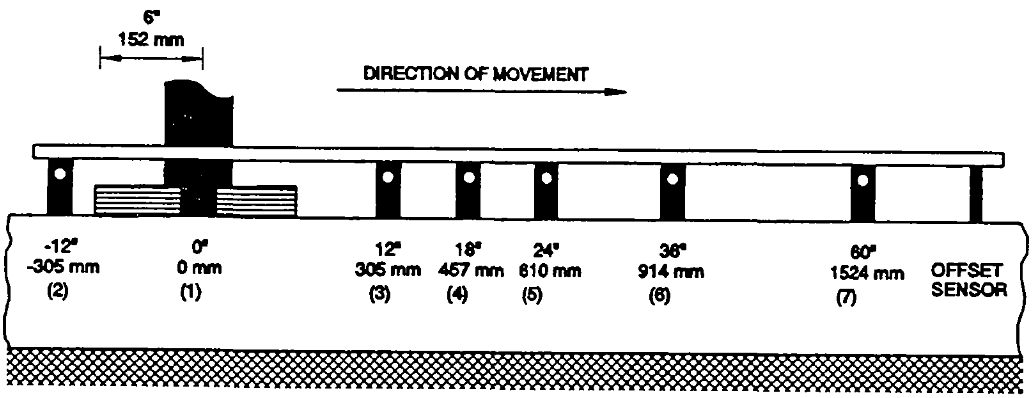


FIGURE 2B.
SENSOR CONFIGURATION FOR LOAD TRANSFER TESTING

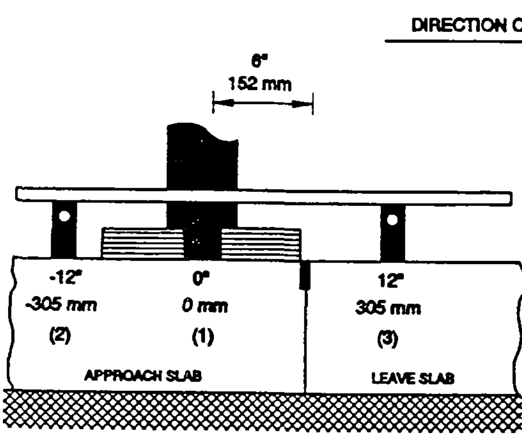


FIGURE 2B - 1.
APPROACH SLAB LOAD TRANSFER

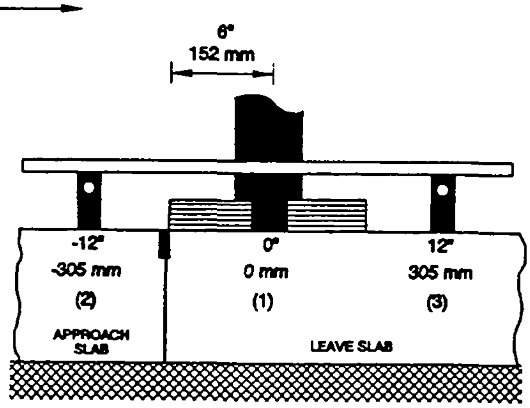


FIGURE 2B - 2.
LEAVE SLAB LOAD TRANSFER

FIGURE 2 - DEFLECTION SENSOR SPACING

JCP and CRCP Testing Plans

Hgt.	Target Load (kips)	Acceptable Range (kips)
2	9.0 (40.0kN)	8.1 to 9.9 (36.0kN to 44.0kN)
3	12.0 (53.3kN)	10.8 to 13.2 (48.1kN to 58.7kN)
4	16.0 (71.1kN)	14.4 to 17.6 (64.1kN to 78.3kN)

The impulse load induced (and measured) by the FWD is partially influenced by the pavement stiffness, and loads measured from one pavement to another will vary even if the distance the weight falls is the same. In addition, changes in the temperature of the rubber buffers (springs) on the FWD cause the measured load to change even though the distance the weight falls is the same. Typically, the rubber buffers increase in temperature when testing, and the measured loads decrease because the buffers are less stiff.

The FWD can generate the 6 kip to 16 kip (26.7 kN to 71.1 kN) load used for testing the GPS sections using only one combination of mass and rubber buffers. This combination uses three weights per side (total of six) and two rubber buffers per side (total of four), and is referred to as the 440lb. (200kg) package.

On occasion, it may be impossible to obtain the specified load for drop height one or four on certain pavements due to equipment limitations on minimum and maximum drop distance settings on the FWD. For these cases, the drop distance should be set to obtain loads as close to the target range as possible.

The recommended procedure for setting the drop distance for the four drop heights is as follows:

1. After arriving at a test section and before any test data is collected, select a point outside the 500 foot test section and run 64 drops to condition (warm up) the FWD buffers for ambient temperatures greater than 50°F (10°C) or 128 drops for lower temperatures.

2. Next, adjust the drop heights to obtain loads on the high side of the acceptable range (As a general rule, the recorded loads decrease during a typical testing day as the temperature of the rubber buffers continue to increase).

3. If a target load cannot be achieved within the normal range of drop distance for a given drop height on the FWD, set the drop distance to obtain a load as close to the target range as possible. Under no circumstance will the FWD mass/buffer combination be changed to achieve a target load.

4. Obtain loads as close to the 9 kip (40 kN) target load as possible (9 kips represents the load on one set of dual tires for a standard 18,000 lb. axle historically used for pavement design purposes).

5. After the drop heights are set, begin data collection on the section. The drop heights are not to be changed after data collection has started on the section, even if measured loads go outside the target ranges.

Drop Sequence

The drop sequence (drop heights and number of drops) for the three testing plans is as follows:

FLEX Testing Plan

No. of Drops	Drop Height	Data Stored
3	3	No [1]
4	1	Yes [2]
4	2	Yes [2]
4	3	Yes [2]
4	4	Yes [2]

JCP and CRCP Testing Plans

No. of Drops	Drop Height	Data Stored
3	3	No [1]
4	2	Yes [2]
4	3	Yes [2]
4	4	Yes [2]

1 No data stored, seating drop only. Deflection and load data is printed but not stored to a file.

2 Store deflection peaks for all four drops and a complete deflection-time history for the fourth drop only.

FWD Testing Plans

General

The differences in the FLEX, JCP AND CRCP testing plans used for the GPS experiment are as follows:

1. Longitudinal location of test points (spacing and stationing)
2. Lateral location of test points (distance from edge reference)
3. Type of deflection test (DB or LT test)
4. Drop sequence (drop heights and number of drops)

For longitudinal reference, all test point locations will be measured from station 0+00 using the distance measuring instrument (DMI) in the FWD tow vehicle. The DMI should be checked at stations 1+00, 2+00, 3+00, 4+00 and 5+00, and problems with the stationing for the section or the calibration of the instrument should be recorded.

For lateral reference, all FWD testing is done in the lane containing the test section. In general this will be the driving lane (truck lane) versus the passing lane of the highway. Within the lane tested, three lateral offsets measured from an edge reference are used to locate the test points (two offsets used on FLEX and three on JCP and CRCP).

In this guide, the edge reference is the lane-shoulder interface on a normal paving lane (usually a 12-foot wide lane) and the outside edge of the painted shoulder stripe on a wide paving lane (usually 13-foot wide lane or greater). If the outside edge of the painted shoulder stripe is over six inches inside the lane-shoulder interface, then use the outside edge of the painted shoulder stripe as the edge reference. If the lane-shoulder interface is inside the painted shoulder stripe, the interface should be used as the edge reference.

The three lateral offsets as measured from the edge reference towards the centerline of the roadway are as follows:

1. Mid Lane (ML) = 6.0'±0.5' (1.8m±0.15m)
2. Pavement Edge (PE) = 0.5'+0.25' (0.15m+0.08m)

    Note: With a 0.5' (0.15m) radius load plate, the load plate will be tangent to the edge reference when the center of the load plate is 0.5' (0.15m) from the edge, and the load plate will be 0.25' (0.08m) from the edge reference when the center of the load plate is 0.5'+0.25' (0.15m+0.08m) from the edge reference.

Note: The center of the load plate should never be less than 0.5' (0.15m) from the edge reference because this would place part of the load plate outside of the lane being tested. Also, the load plate and load cell could be damaged if the lane-shoulder interface is not level.

3. Outside Wheel Path (OWP) = 2.5'±0.25' (0.76m±0.08m) for nominal 12' (3.6 m) wide lanes.

   Note: On some sections, the OWP may be shifted from this location if the lane is either narrower or wider than normal. For these sections, the lateral offset for testing may have to be different than the 2.5'.

For the actual data collection, FWD tests are done at one lateral offset for each pass down the test section, and one type of deflection data is collected. When a pass is complete, the FWD returns to the beginning of the section to start on another lateral offset. The detailed testing plans later in the manual contain more information on the order of the passes and the type of data collected on each pass.

FWD test points need to be accurately located so future tests can be done in the same locations. For the longitudinal location, FWD operators only need to check that the DMI is calibrated, functioning properly, and accurately referenced to station 0+00. The lateral location will not be measured for any test points; however, excess deviation from the tolerances provided should be avoided, especially for the PE offset.

As long as these guidelines are followed, the general location of any test point can be identified in the field longitudinally within one foot and laterally within less than one foot. The test points do not need to be marked on the pavement.

Information on the spacing of test points, the type of deflection tests to run, and the drop height sequence are discussed later in the manual under the individual testing plans for FLEX, JCP and CRCP.

Test Pit (TP) Areas

At the TP areas, FWD testing and destructive material sampling are run sequentially to the extent possible in order to correlate the results from the two programs. At each GPS section, TPs for the sampling and testing study are located approximately at station 0-50 and 5+60. For TPs under the FLEX testing plan, deflection basin tests should be at station 0-50 and 5+60 regardless of the pavement condition. For the JCP testing plan, the TP are shifted to mid-slab and the new station recorded. And, for the CRCP testing plan, the station for the TP may have to be shifted slightly to keep the sampling between cracks and the new station recorded.

Typically, a 12 inch diameter core hole is located at station 0-50 in the OWP, and a four foot by six foot piece of pavement is removed at station 5+60. Unless informed otherwise by a RCO engineer, each GPS section will have FWD measurements in the OWP at these two potential TP areas.

When possible, FWD testing and field sampling are done on the same day. However, time delays may occur between the testing programs. If the field sampling is delayed, the FWD operator should mark the FWD test locations in the TP areas. The rest of this chapter gives details for TP, FLEX, JCP and CRCP testing plans.

TP Testing Plan

The first deflection tests done at a test section (excluding buffer conditioning) are in the TP areas. Regardless of the pavement category, all testing in the TP areas will have the following common characteristics:

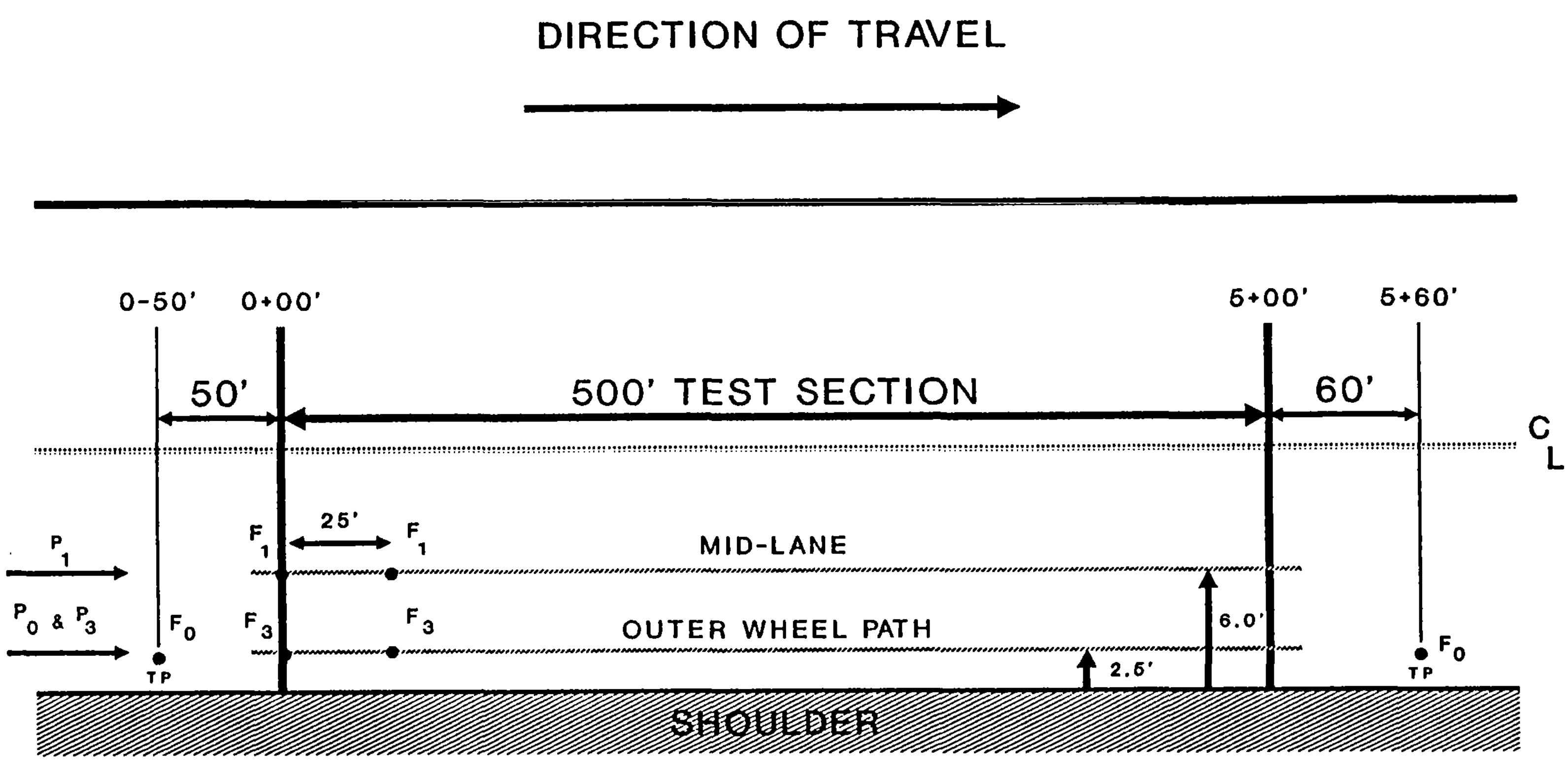
1. The first deflection tests at a section will be in the TP areas. However, TPs are only done during the first round of FWD testing and no additional testing is done in these areas for subsequent visits to the section.
2. The testing will be labeled as Pass Zero (P_o).
3. The lateral offset for the testing is the OWP.
4. Only DB tests will be run.
5. Only do one test point at each TP area for a total of two for the section.

FLEX Testing Plan

Figure 3 and Table 1 summarize the FLEX testing plan for GPS Experiments 1, 2, 6 and 7. All pavements covered under this plan have an AC surface. Two passes (not including the TP) are done; one at ML and the other in the OWP. On each pass, DB tests are done at 25' (7.6m) intervals for a total of 21 test points per pass and 42 total test points in the 500' section. At each test point, a sequence of 19 drops is used; 3 seating drops at height 3 and 4 drops each at heights 1, 2, 3 and 4.

JCP Testing Plan

Figure 4 and Table 1 summarize the JCP testing plan for GPS Experiments 3, 4 and 9. All pavements covered under this plan have jointed PCC pavement surfaces. Three passes are done; ML (P_1), PE (P_2) and OWP (P_3). For each panel tested, one DB test is done on the ML pass, two DB tests are done on the PE pass, and two LT tests are done on the OWP pass for a total of five test points per panel tested. At each test point, a sequence of 15 drops is used; 3 seating drops at height 3 and 4 drops each at heights 2, 3 and 4.



NOTE: FWD TESTS TO BE CONDUCTED AT TEST PIT LOCATIONS (TP) ON P_0 (FIRST SET OF TESTS).

NOTE: SEE TABLE 1 FOR FURTHER DETAILS.

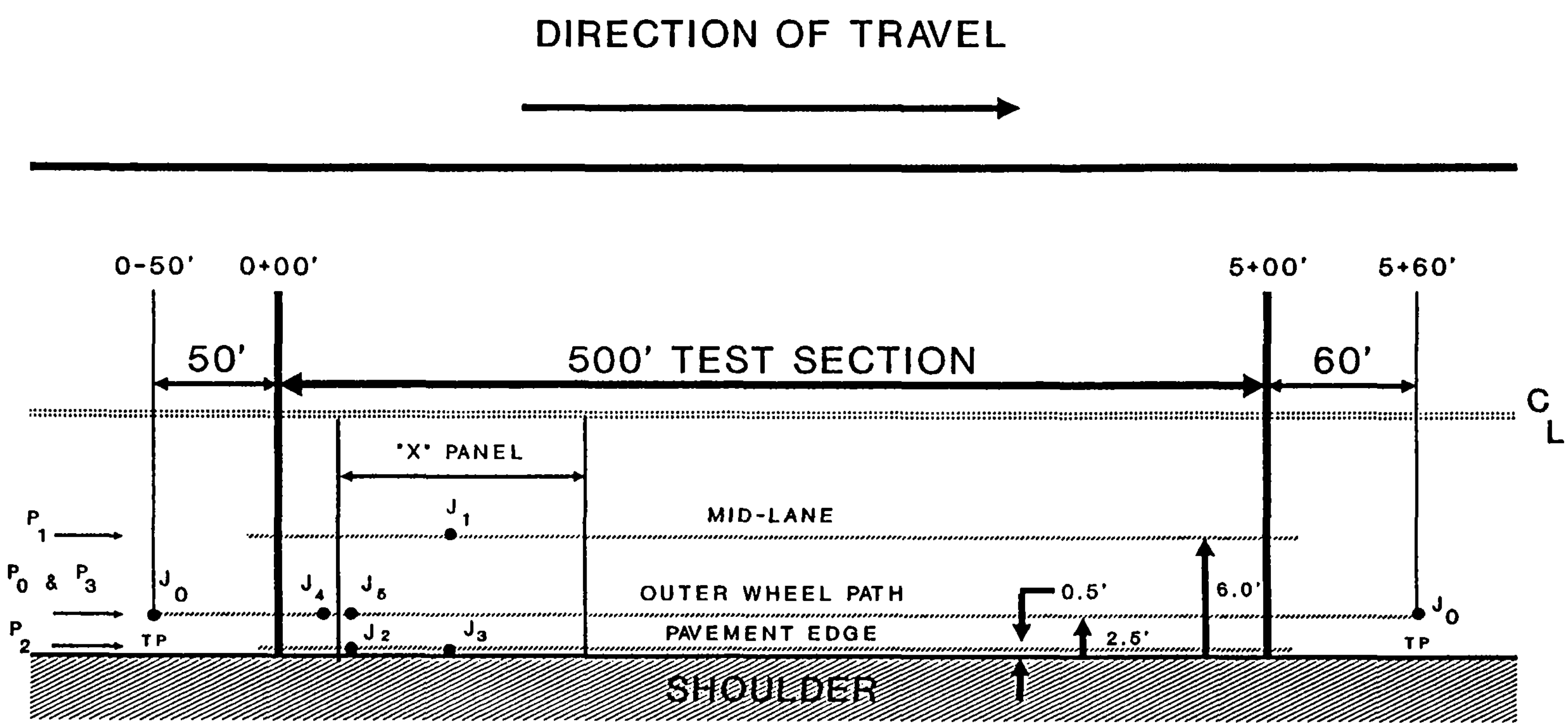
NOTE: LATERAL OFFSETS SHOWN REPRESENT NOMINAL DISTANCES.

FIGURE 3. FWD TEST PLAN (FLEX PAVEMENT CATEGORIES).

Table 1
FWD Test Plan Summary

Pavement Category	Test Point ID#	Pass No.	Location		Test Interval	Test Type	Sensor Configurations	Number of Test Points
			Transverse	Longitudinal				
FLEX	F0	P_0	OWP (Outer Wheelpath)	Test Pits	N/A	Basin	0, 8, 12, 18, 24, 36, 60	2
	F1	P_1	ML (Mid Lane)	—	25'	Basin	0, 8, 12, 18, 24, 36, 60	21
	F3	P_3	OWP (Outer Wheelpath)	—	25'	Basin	0, 8, 12, 18, 24, 36, 60	21
JCP	J0	P_0	OWP (Outer Wheelpath)	Test Pits	N/A	Basin	0, 8, 12, 18, 24, 36, 60	2
	J1	P_1	ML (Mid Lane)	Mid Panel	See Text	Basin	0, 8, 12, 18, 24, 36, 60	20[1]
	J2	P_2	PE (Pavement Edge)	Corner	See Text	Basin	0, 8, 12, 18, 24, 36, 60	20[1]
	J3	P_2	PE (Pavement Edge)	Mid Panel	See Text	Basin	0, 8, 12, 18, 24, 36, 60	20[1]
	J4, J5	P_3	OWP (Outer Wheelpath)	± Joint	See Text	Load Transfer	-12, 0, 12, 18, 24, 36, 60	40[1]
CRCP	C0	P_0	OWP (Outer Wheelpath)	Test Pits	N/A	Basin	0, 8, 12, 18, 24, 36, 60	2
	C1	P_1	ML (Mid Lane)	Mid Panel	~25'	Basin	0, 8, 12, 18, 24, 36, 60	20[1]
	C2	P_2	PE (Pavement Edge)	Centered on Crack	~25'	Basin	0, 8, 12, 18, 24, 36, 60	20[1]
	C3	P_2	PE (Pavement Edge)	Mid Panel	~25'	Basin	0, 8, 12, 18, 24, 36, 60	20[1]
	C4, C5	P_3	OWP (Outer Wheelpath)	± Crack	~25'	Load Transfer	-12, 0, 12, 18, 24, 36, 60	40[1]

NOTE: [1] Maximum number of tests per pass



NOTE: FWD TESTS (J_0) CONDUCTED AT TEST PIT LOCATIONS (TP) ON P_0 (FIRST SET OF TESTS). STATIONING WILL VARY TO LOCATE TP AT MIDPANEL.

NOTE: NUMBER OF PANELS AND PANEL LENGTH (X) WILL VARY DEPENDING UPON SPECIFIC JOINT SPACING, TRANSVERSE CRACK PATTERN AND PAVEMENT TYPE. OPERATOR SHOULD REFER TO TEXT AND TABLE 1 FOR FURTHER DETAILS. A MAXIMUM OF 20 EFFECTIVE SLABS (PANELS) SHOULD BE TESTED.

NOTE: LATERAL OFFSETS SHOWN REPRESENT NOMINAL DISTANCES.

FIGURE 4. FWD TEST PLAN (JCP PAVEMENT CATEGORIES).

The JCP test plan requires the most caution and judgment by FWD operators in the field to determine where to test. The reason is threefold;

1. panel lengths vary from less than 11' (3.3m) to greater than 50' (15.3m),

2. panels with large joint spacing generally have transverse cracks present near the middle of the original panels. For example, if an original panel has one transverse crack, FWD operators will view the original panel as two effective panels. Similarly, if there are two transverse cracks, the original panel will be viewed as three effective panels.

   Note: For LTPP purposes, an effective panel is defined as a continuous section of PCC pavement bound by two transverse breaks in the pavement. The two transverse breaks can be any combination of joints, cracks, or full width patches.

3. some JCP sections have non-uniform or random joint spacing intervals that repeat throughout the section (e.g., 10'-19'-17'-13' joint spacing pattern).

The number of effective panels can vary from as few as 9 or 10 to as many as 35 or more on a 500' (152m) section. Regardless of the total number of effective panels present no more than 20 effective panels are tested on a section. Thus, for JCP categories, a maximum of 100 deflection tests will be made within a 500' (152m) section.

Any effective panel tested must have all five test points for that panel located with reference to that same effective panel no matter how small or large the panel. On JCP sections, the five tests could be from 5' to more than 25' apart longitudinally.

In summary, FWD operators must determine the total number of effective panels in a JCP test section before testing begins. In addition, the effective panels to be tested (maximum of 20) should be marked for easy identification while testing.

When counting effective panels, panel No.1 should be identified as the first panel totally included within the section limits. This will prevent negative stationing for any of the 20 effective panels, and also provide consistency between operators on panel numbering. At station 5+00, any panel extending past station 5+00 should not be selected for testing for three reasons. First, the panel is not totally within the 500 foot section, so it is not protected from material sampling. Second, temperature holes are located in this location. Third, conflicts with equipment collecting material samples during the first round of FWD tests will be minimized.

The following examples of typical JCP joint/crack spacings will assist FWD operators in selecting effective panels to test.

Example 1:
A pavement has a 25' (7.6m) uniform joint spacing. A visual check finds no transverse cracks in the slabs. For the 500' (152m) test section, a total of 20 effective panels exist. Therefore, all 20 are tested.

Example 2:
A pavement has a random joint spacing pattern of 10'-19'-17'-13' (15' average). No transverse cracks are present. A total of 33 effective panels exist. However, only 20 of the 33 effective panels are tested. The actual effective panels to test must be selected by the FWD operator in the field. The FWD operator should not select the first 20 effective panels or the last 20 effective panels. Instead, approximately six slabs out of every ten should be selected.

One acceptable set of effective panel numbers to test is 1, 2, 4, 5, 7, 8, 11, 12, 15, 16, 18, 19, 21, 22, 25, 26, 29, 30, 32, and 33. However, other sets of effective panels to test will also work. In fact, it is desirable to test at least one or two groups of four adjacent panels to study the characteristics of random panel size on deflection response. For this case the following set of effective panel numbers to test may be 1, 2, 3, 4, 8, 9, 10, 11, 15, 16, 17, 18, 22, 23, 24, 25, 29, 30, 31 and 32.

Example 3:
A pavement has 40' (12.2m) uniform joint spacing with no mid-panel cracks for a total of 13 effective panels. With less than the 20 effective panels, all 13 are tested.

Example 4:
A pavement has 50' (15.2m) uniform joint spacing with transverse cracks near the middle of each original panel. As a result, the effective panel length is 50'÷2=25' (7.6m), and about 20 effective panels exist. Therefore, all 20 effective panels are tested. For this case, the effective panels are defined by a normal joint on one end and a transverse crack on the other end. The transverse crack is viewed as a working joint for FWD testing purposes, but comments in the field data should identify it as a transverse crack.

Example 5:
A pavement has 50' (15.2m) uniform joint spacing with transverse cracks near the third points of each original panel. As a result, the effective panel length is 50'÷3=16.7' (5.1m), and about 30 effective panels exist. However, only 20 of the 30 effective panels are tested. For this case, the effective panels are defined by (1) a normal joint on one end and a transverse crack on the other end or (2) a transverse crack on both ends. The actual effective panels to test must be selected by the FWD operator in the field. The FWD operator should not select the first 20 effective panels or the last 20 effective panels. Instead, approximately seven panels out of every ten should be selected.

The above examples do not cover all JCP conditions that exist, and FWD operators must use their best field judgment for selecting and documenting the effective panels tested using the following guidelines:

1. Avoid testing effective panels that extend outside the section limits from station 0+00 and 5+00.

2. Number effective panels with panel No.1 being the first panel completely in the test section limits at station 0+00.

3. Select a maximum of 20 effective panels to test based on the examples given above and conditions in the field.

4. Mark the "effective panels" with chalk or lumber crayon to avoid testing the wrong "effective panels".

5. Record the panel numbers tested on the Field Activity Sheet (discussed later in this manual), or document the "effective panels" tested using a sketch of the section showing joints and cracks and indicate the "effective panels" tested.

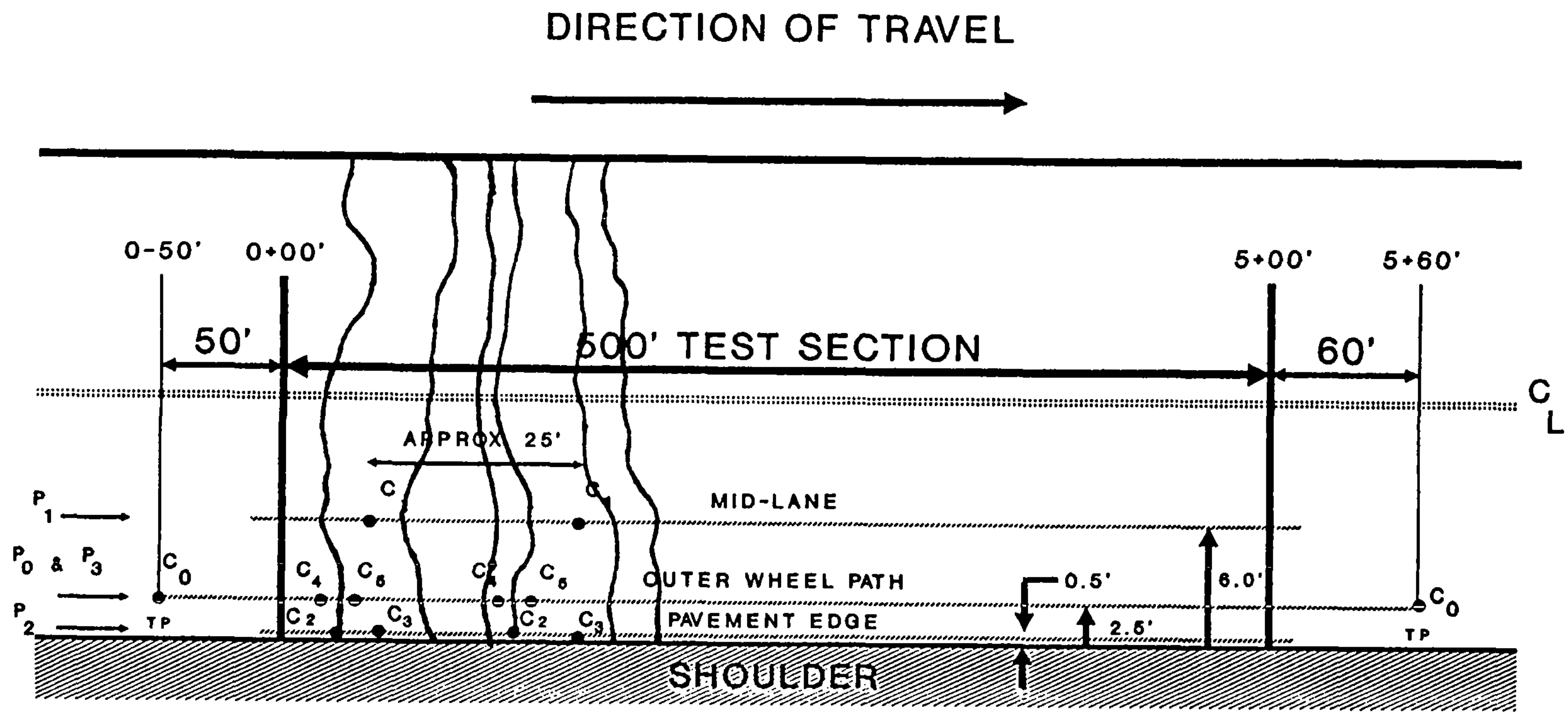
CRCP Testing Plan

Figure 5 and Table 1 summarize the CRCP FWD test plan for GPS Experiment 5. This plan is like the JCP plan with the major exception for the location of the load plate for Test Point ID No. C2. For the JCP plan, test point No. J2 is a corner load condition. However, for the CRCP plan, test point No. C2 has the load plate centered on the transverse crack defining the beginning of the effective panel being tested during the PE pass.

Effective panels for CRCP are defined by two adjacent transverse cracks typically at a spacing of 1' to 8' (0.3m to 2.5m). In general, the 20 effective panels tested should include stationing at 25'(7.6m) intervals starting from station 0+00; test effective panels at station 0+00, 0+25, 0+50, 0+75, 1+00, 1+25, 1+50, 1+75, 2+00, 2+25, 2+50, 2+75, 3+00, 3+25, 3+50, 3+75, 4+00, 4+25, 4+50, and 4+75 (no test at station 5+00).

Any effective panel tested must have all five test points for that panel located with reference to the same effective panel, no matter how small or large the panel. In fact, on CRCP pavements, it is possible to have all five test points no more than 1' (0.3 m) apart longitudinally.

FWD operators must not bias deflection data by deviating from the above stationing in order to test all large panels. However, in some cases field judgement will shift selection of effective panels from the above stations, because transverse cracks may not be fully developed or the effective panel may be wedge shaped and not extend the full width of the



NOTE: FWD TESTS CONDUCTED AT TEST PIT LOCATIONS (TP) ON P_0 (FIRST SET OF TESTS).

NOTE: SEE TABLE 1 FOR FURTHER DETAILS.

NOTE: LATERAL OFFSETS SHOWN REPRESENT NOMINAL DISTANCES.

FIGURE 5. FWD TEST PLAN (CRCP PAVEMENT CATEGORIES).

lane. Also, the first effective panel totally within the section at station 0+00 should be tested, and the actual station for the mid-panel will typically be at station 0+01 to 0+06.

With 20 effective panels for all CRCP sections, a total of 100 tests will be run in the 500 foot section; 60 DB tests and 40 LT tests. Similar to the JCP plan, the pass sequence in Figure 5 is used so the sensor spacing is only changed once on each section. At each test point, a sequence of 15 drops is used; 3 seating drops at height 3 and 4 drops each at heights 2, 3 and 4.

Other FWD Operator Field Measurements

General

For the analysis of FWD deflection data, pavement temperature gradients, pavement distress, and joint/crack width data that are not automatically measured and recorded in the FWD testing process are needed. This section of the manual describes the procedures for obtaining this data.

Temperature Gradient Measurements

The thermal gradient (temperature versus depth) through both bituminous and PCC layers is important for the analysis of deflection data. However, the automatic temperature sensors on the FWD only record ambient air temperature and pavement <u>surface</u> temperature. Therefore, FWD operators need to manually measure the temperature gradient in the pavement structure periodically during the deflection testing.

The specific field procedures for temperature gradient measurement are basically the same for all GPS experiments. The only exceptions are for: (1) GPS sections in Experiments 1 or 2 which use two temperature holes (at one-third points) <u>if</u> the existing AC surface layer is less than 2" (51 mm) thick, (2) GPS Experiment 7 (AC/PCC) which uses five temperature holes per set instead of the three holes per set used on the rest of the GPS experiments, and (3) GPS Experiment 9 (PCC/PCC) which uses three temperature holes, drilled into the top PCC layer only.

The steps for temperature gradient measurement are as follows:

1. Select one location at each end, just outside the test section limits in the OWP (typically near station 0-03 and 5+03). It is up to the FWD operator to make sure the locations are representative of sun exposure and wind conditions for the section. The locations selected should never be within the test section limits.

2. Estimate the thickness of all AC and/or PCC layers using available information for the pavement structure.

3. Determine the number and depth of temperature holes. See Figure 6 to determine whether to drill three or five holes at each location, and to what depth each hole should be drilled.

4. Mark locations for the holes in the OWP. There should be at least 18" (0.5m) between holes.

5. Drill 1/2" (13mm) diameter holes using a portable hammer drill to the depths determined in step 3.

6. Clear holes of cuttings and dust by blowing them out with a short piece of 1/4" (6mm) diameter plastic tubing.

7. Measure and record the depth of each hole to the nearest 0.1" (2 mm) on the Temperature Measurement Form; see Figure 7.

8. Fill the bottom of each hole with 1/2" (13mm) to 1" (25mm) of mineral oil (provides thermal conduction at the bottom of the hole to a temperature probe inserted in the hole).

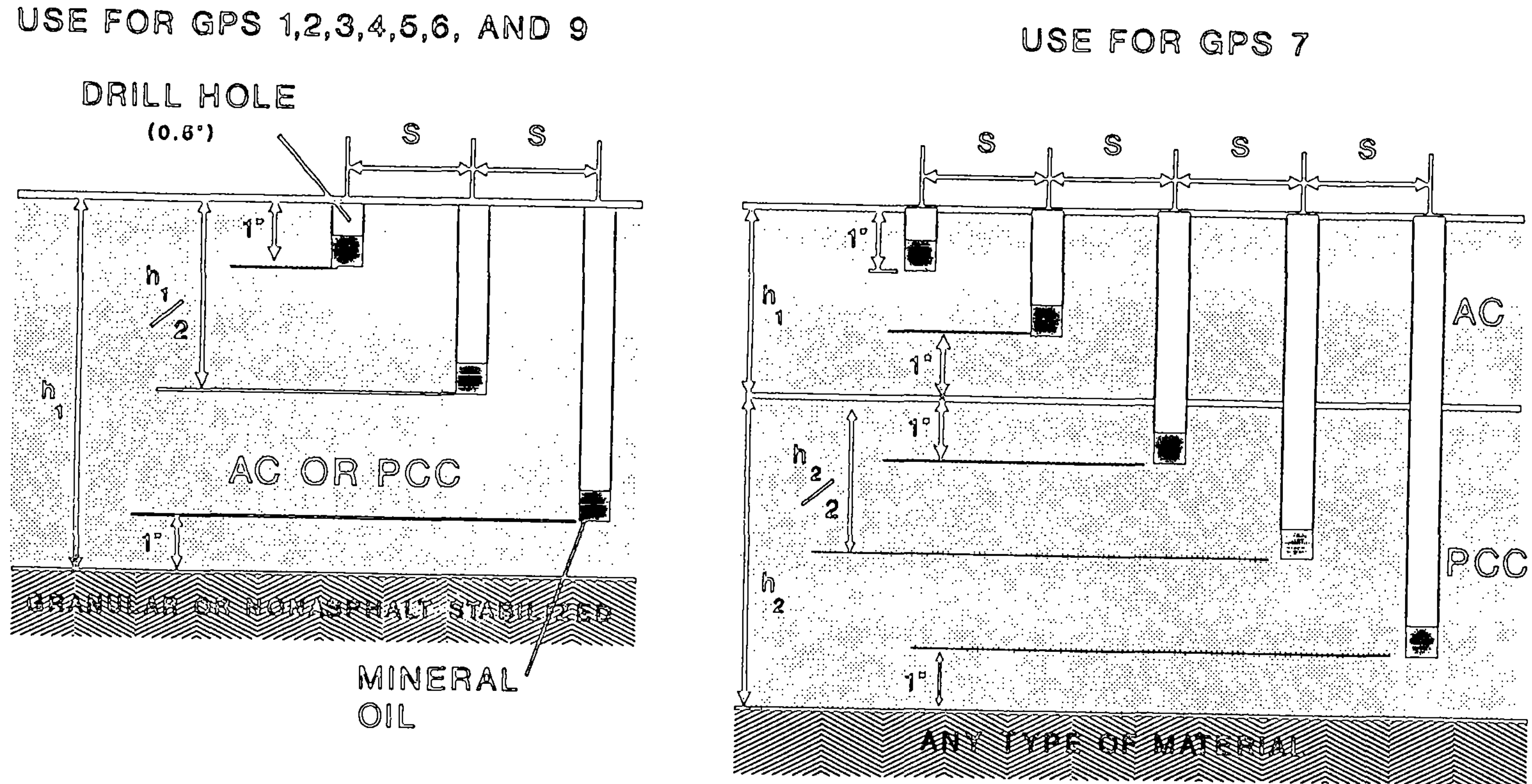
9. Cover each hole with a short piece of duct tape to prevent water and debris from entering the hole. The tape also prevents the sun from warming the oil in the 1" (25 mm) deep hole. A small incision or hole can be made in the tape for inserting the temperature probe.

10. Read temperatures to the nearest 0.1°F (0.05°C) each hour during FWD testing. The first temperature measurement should not be taken for at least 15 minutes after the oil is placed in the holes to allow heat from drilling to dissipate. After inserting the temperature probe in a hole, the reading should be allowed to stabilize for about one minute before recording the temperature. All temperatures should be recorded on the Temperature Measurement Form (Form F01). The last temperature measurement should be obtained immediately following the last FWD test.

11. Seal the holes after the last set of temperature measurements have been made. A sealant, such as silicon caulk, that can be drilled out for future testing without gumming up or binding the drill bit should be used.

The following equipment and material are needed for temperature gradient measurements:

1. A hand-held battery-powered digital temperature meter with resolution to 0.1°F (0.05°C) over the range 0°F to 140°F (-17°C to 60°C).



NOTE: DRILL HOLE SPACING (s) SHOULD BE 18" CC OR GREATER WITH ALL HOLES LOCATED IN THE OUTER WHEEL PATH.

NOTE: IF AC SURFACE LAYER IN GPS 1 OR 2 SECTIONS IS LESS THAN 2" THICK, DRILL TWO TEMPERATURE HOLES ONLY AT THE ONE-THIRD POINTS.

NOTE: IN GPS 9 SECTIONS, DRILL THREE TEMPERATURE HOLES INTO THE TOP PCC LAYER ONLY.

FIGURE 6. TYPICAL DRILLING PATTERNS FOR TEMPERATURE GRADIENT DATA MEASUREMENT IN GPS PAVEMENT SECTIONS.

SHRP REGION ______ STATE CODE ______ SHRP ASSIGNED ID ______

STATE ______ TESTING ______ DISTRICT ______

LTPP EXPERIMENT CODE ______ ROUTE/HIGHWAY NUMBER ______

TEMPERATURE MEASUREMENTS

TESTING DATE ______ SHEET NUMBER ______ FIELD SET NO. ______

LOCATION STATION ______

DEPTH	D_1 =	D_2 =	D_3 =	D_4 =	D_5 =	WEATHER CONDITIONS
TIME	T_1(°F)	T_2(°F)	T_3(°F)	T_4(°F)	T_5(°F)	

LOCATION STATION ______

DEPTH	D_1 =	D_2 =	D_3 =	D_4 =	D_5 =	WEATHER CONDITIONS
TIME	T_1(°F)	T_2(°F)	T_3(°F)	T_4(°F)	T_5(°F)	

NOTES:
1) D_i = DEPTH BELOW PAVEMENT SURFACE, INCHES
2) T_i = TEMPERATURE AT DEPTH i, °F
3) D_4 AND D_5 ONLY FOR GPS-7 IN ACCORDANCE WITH FIGURE 6 OF THE FWD MANUAL
4) USE ONLY THESE WEATHER TERMS: SUNNY, PARTLY CLOUDY, CLOUDY, RAIN, NIGHT

TEST COMPLETED

______ FWD OPERATOR ___/___/___ MONTH/DAY/YEAR ______ AFFILIATION

FORM F01/ISSUED 15 FEBRUARY 1993

FIGURE 7 - TEMPERATURE MEASUREMENT FORM

2. Two temperature probes, one at least 24" (0.6m) long with probe diameter not greater than 1/4" (6mm). The probes should be stainless steel with a thermocouple sealed in the tip and calibrated against NIST traceable standards by the manufacturer.

3. A gasoline-powered, portable, rotary-hammer drill for drilling holes.

    Note: the electrical power from the DC to AC inverter in the tow vehicle only provides about 4 amps of AC power (500 watts), which will not operate most electric hammer drills.

4. The following supplies need to be available and replenished as needed:

    - several 1/2" (13mm) diameter carbide tipped bits for the hammer drill. Lengths from 12" to 24" (0.3m to 0.6m) should handle all hole depths needed.

    - several 36" (0.9 m) pieces of 1/4" (6 mm) diameter plastic tube for blowing dust out of the temperature holes.

    - mineral oil and a bottle that can put a small volume of oil in the temperature holes without making a big mess.

    - duct tape for covering the temperature holes.

    - Temperature Measurement Form (Form F01).

    - several tubes of silicon caulk and a caulking gun for sealing the temperature holes after testing is complete.

For each set of temperature holes, the information requested on the Temperature Measurement Form (Form F01) must be properly and completely recorded by the FWD operator. Time entries for the temperature measurements are local time using a four-digit military time format (e.g., use 1615 for 4:15 PM and 0825 for 8:25 AM). The depth of temperature holes are <u>measured</u> and recorded to the nearest 0.1" (2 mm). Temperatures are measured and recorded to the nearest 0.1°F (0.05°C).

In addition to reading the temperature gradients, FWD operators should monitor the ambient air temperature and pavement surface temperatures automatically recorded to make sure the values recorded are reasonable (i.e., consistent with actual conditions or compared to hand-held meters used for temperature holes).

Pavement Distress

The type and severity of pavement distress influence the deflection response for a pavement. Therefore, FWD operators need to record any distress located from about one foot in front of geophone No. 7 to about three feet behind the load plate. This information should be recorded in the FWD file using the F6-Comment key in the field program immediately following the test. Abbreviations can be used for common distresses and L-, M-, and H- for (L)ow (M)edium and (H)igh severity (i.e., medium severity alligator cracking = M-ALLIG.CR.). FWD operators should refer to the "LTPP Distress Identification Manual" for information on distress type and severity.

When appropriate, the location of the distress relative to the geophones or load plate should be recorded. Abbreviations to make this easier include: OWP, ML, IWP, LP (load plate), and D1 to D7 for the geophones.

Examples: M-TRANS.CR. BETWEEN D4 AND D5
L-RUTTING OWP
L-PATCH UNDER LP

Other factors to document using the F6-Comment key include; data with nondecreasing deflections, data with variations, and unusual conditions or events. Unusual conditions or events could include items such as delays in testing due to break downs or weather, pavement changes within the section, moisture seeping out of cracks, or any other conditions that may help with or explain analysis results for the FWD data.

Joint/Crack Openings

Joint openings in rigid pavement systems affect deflection response and load transfer, and cracks in AC pavements affect pavement response. The following procedures are used for measuring joint/crack openings for the three FWD testing plans.

FLEX Crack Openings: For any GPS experiment under the FLEX testing plan, no crack opening measurements are made: however, the FWD operator still needs to record any pavement distress at the test point locations using the F6-Comment key as previously discussed.

JCP and CRCP Joint/Crack Widths: The GPS experiments under the JCP and CRCP testing plans have joint/crack opening measurements for at least 25% of the Load Transfer tests (see Figure 4 and Table 1): however, operators are encouraged to measure 100% of the joint/cracks tested for load transfer if time allows.

Vernier calipers with tapered jaws for measuring inside dimensions are used for measuring the openings. The vernier caliper scale should have a resolution of 0.01" (0.2 mm).

On transverse cracks, the goal is to measure the opening that extends through the pavement. If the cracks are spalled, the opening may have to be carefully estimated. On sawed joints, the goal is to measure the sawed opening (as opposed to the actual opening) through the pavement. It may be necessary to depress the joint sealant to measure the opening, especially if the joints are spalled.

Joint/crack openings should be measured at several points along the opening in the OWP, and the average value entered at the "condition request" prompt immediately following the LT test. The measurement is entered as an integer value between 5 and 99 (i.e., 0.50" is entered as 50).

Measurements less than 0.05" are hard to make with a vernier caliper because the caliper jaws will not enter the joint/crack. When this occurs, the operator should enter a "5" in the "condition request" data field. Measurements in excess of 0.99" should be entered as "99" because the "condition request" data field only accepts two characters.

For joints/cracks tested for load transfer where openings are not measured, FWD operators must clear the "condition request" data field, because the last entry in the field repeats until it is changed or the field is cleared.

Synthesis of Field Work Activity

The following list of field activities provide FWD operators with an overall perspective of a typical day at a test section, and it outlines the concepts and procedures presented in this Chapter. Further guidance is included in Chapter III and Chapter V.

<u>Field Activities at a Typical Test Section:</u>

Task 1: Arrive at Site

Task 2: Coordinate Personnel

- a: Traffic Control Crew
- b: Sampling and Testing Crew (Only for first round of tests)
- c: Other LTPP, State DOT and RCO Personnel

Task 3: Inspect Test Section

- a: Test Pit Locations (only for first round of tests)
- b: General Pavement Condition
- c: Test Section Limits

Task 4: Initiate Pavement Temperature Gradient Measurement

- a: Select and Mark Locations for Holes
- b: Prepare Temperature Holes and Record Depths
- c: Record Initial Temperature Measurements
- d: Record Temperature Measurements Every 60 Minutes after the Initial Readings.

Task 5: Prepare FWD Equipment

- a: Covers/trays off FWD
- b: Visual Check of Equipment
- c: Computer/Printer Setup
- d: Initiate FWD Field Program

Task 6: Check FWD Drop Heights

- a: Select Location Outside Test Section
- b: Condition Buffers
- c: Adjust Drop Heights to Obtain Loads Within Target Ranges

Task 7: Collect Deflection Data

- a: Run FWD Tests at Test Pit Locations, P_0 (See Chapter III)
- b: FWD Testing in Sequence of P_1, P_2, and P_3 (See Chapter III)

Task 8: Complete Data Collection and Data Backup

- a: Read Final Temperatures and Seal Holes
- b: Create Backup Data Disks and History Report (See Chapter V)
- c: Complete and Check Field Activity Form, and Temperature Form

Task 9: Prepare Equipment for Travel and Make Final Inspection

- a: Covers on FWD
- b: Computer and Printer Stored
- c: Final "Walk Around" Tow Vehicle and FWD

Operator Field Assistance

At a site, FWD operators need to carefully plan activities to make efficient use of time. Time is most critical for GPS experiments in the JCP and CRCP testing plans.

Personnel at the site other than the FWD operator are strictly prohibited from driving the tow vehicle or operating the FWD. These functions are the sole responsibility of the FWD operator. However, activities such as drilling temperature holes, recording temperatures, marking panels, and measuring joint/crack openings can be done by other personnel on the site (e.g., traffic control people, other RCO staff on site, etc.).

FWD operators should never directly ask personnel at the site for assistance. Instead, they should ask crew supervisors if volunteers are available to help. FWD operators should not imply that assistance is expected from others at the site.

III. DATA ACQUISITION AND HANDLING

General

The FWD operator's primary responsibility is FWD data collection. With data collected in the four regions by many operators, certain guidelines are needed to maintain uniform data collection. The guidelines are divided into the following three areas and described in detail:

1. Setting up the Software for Data Collection
2. Using the Software for Data Collection and Data Backup
3. Processing FWD and Related Data at the RCO

Setting up the Software for Data Collection

This section of the manual discusses setting up the software for collecting and backing up deflection data for GPS sections. Further details on the FWD Field Program for data collection are located in manuals from the FWD manufacturer.

Setting up the FWD Field Program

When the FWD Field Program is loaded, the Main Menu for the program displays the following choices:

1. Perform MEASUREMENTS with FWD S/N:
2. PRINT contents of FWD Data Files.
3. Set Printer, Disc and Road ID Options.
6. Check Deflectors against LVDT.
8. Calibrate/Install Optional Equipment (Temp. Sensors, DMI)
9. EXIT the Program and return to Operating System.

The first time the program is run, Option 3 should be selected to set printer and data storage options. The operator should set each item to the values shown in Figure 8. After all 12 options are set, hit the return key to save the changes and display the Main Menu. The new settings will be retained until they are manually changed. Operators should refer to the equipment operators manual for the FWD for explanation of Main Menu choices 2, 6, 8, and 9.

```
Select Option/Item number ([BLANK] to Quit):
□

1.  Page Length (in) ...: 11  = 279 mm.
2.  Line Spacing .......: 6  ( 8 ) per inch.
3.  Print Style ........: Data Processing (Enhanced)
4.  Printer Type .......: Think Jet (Microline, Epson)

5.  Data Drive .........: C:
6.  Working Directory ..: \FWD\DATA\
7.  Extension (JLN=date): .FWD
8.  File Width (English): 80  ( 32 )

9.  Roadway ID Template.: HWY.NO.,DIR.,DIST. AND DIR. TO CITY, STATE
10. File Naming Mask....:
11. Subsection Template.: SEC_ID

12. Peak Readings . . . : Direct        (Smoothed)
```

FIGURE 8 - PRINTER AND DATA STORAGE OPTIONS

To continue setting up the software select Main Menu choice 1. Continue through the prompts until the "TEST SETUP SCREEN" appears. If this is the first time through the software, setups for the FWD test plans, buffer conditioning, and equipment calibration need to be created, named, and stored. Screen prints of the setups with the proper settings are shown in Figures 9 through 17. Operators should create and save setups identical to these.

The setups for the three FWD testing plans have item 14 (Test Plots) activated for the last drop in a sequence. Test plots for any other drops will interrupt (delay) the test sequence. Operators should monitor the test plot from test point to test point for indications of changes in the pavements deflection response. In addition, the operator should visually scan the printed output for each test to assure no questionable data has been obtained.

Setting Up FastBack Plus® Backup Software

Each FWD unit has been supplied with the Fastback Plus® program for data backup. The following program options for the backup of FWD data collected in the field must be set as follows:

1. User level to **ADVANCED** (allows operator to set the other options noted below)
2. Data Compression to **SAVE DISKS** (reduces the required number of disks)
3. Format Mode to **ALWAYS FORMAT** (reduces the number of disks required for backup)
4. Overwrite Warning to **ANY USED DISK**
5. Error Correction to **ON** (for data security purposes)
6. Write Verify to **WRITE** (for best security, good use of extra time required)

The options selected above maximize the likelihood that the FWD data backed up using FastBack Plus® will arrive at the RCO in a readable form, but slightly increase the time required to perform the data backup. The data backup should take less than 30 minutes to make three complete backups, and FWD operators can typically use this time for completing other tasks between changing data disks.

```
Select Option/Item number ([BLANK] to Quit):
□

    "FLEX" BASIN TEST...........
 1. Test UNITS...: lbf,mil,inch     (kPa,mu,mm)
 2. Temperature..: Fahrenheit       (Centigrade)
 3. Stn.Request..: OFF              (ON)
 4. Test Checks..: RollOFF+Decr     (NONE, Decreasing dfls, Roll-Off)
 5. Reject prompt: OFF              (ON)
 6. Stationing...: Feet
 7. Temp.Request.: OFF              (ON)
 8. Cond.Request.: OFF              (ON)
 9. Variation :   0.38 psi   2.0%      0.08 mil   1.0%
10. Diameter of Plate: 11.8
11. Deflector distances : 8 12 18 24 36 60
                          1
12. Drop No.   : 1234567890123456789.........................................
13. Heights  . : CCC1111222233334444111111111111111111111111111111111111111111
14. Test Plots: ..................☆...........................................
15. Save Peaks: ...☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆
16. Load His. : ..............................................................
17. Whole His.: ......☆...☆...☆...☆..........................................

18. Load another TEST SETUP.
19. Store the CURRENT TEST SETUP.
```

FIGURE 9 - FLEX TEST SETUP

```
Select Option/Item number ([BLANK] to Quit):
■

    "JCP(RIGID)/CRCP" BASIN/EDGE TEST
 1. Test UNITS...: lbf,mil,inch     (kPa,mu,mm)
 2. Temperature..: Fahrenheit       (Centigrade)
 3. Stn.Request..: OFF              (ON)
 4. Test Checks..: Roll-Off         (RollOFF+Decr, NONE, Decreasing dfls)
 5. Reject prompt: OFF              (ON)
 6. Stationing...: Feet
 7. Temp.Request.: OFF              (ON)
 8. Cond.Request.: OFF              (ON)
 9. Variation :   0.38 psi   2.0%      0.08 mil   1.0%
10. Diameter of Plate: 11.8
11. Deflector distances : 8 12 18 24 36 60
                         1
12. Drop No.  : 123456789012345.............................................
13. Heights . : CCC222233334444111111111111111111111111111111111111111111111
14. Test Plots: ..............*.............................................
15. Save Peaks: ...*********************************************************
16. Load His. : ............................................................
17. Whole His.: ......*...*...*.............................................

18. Load another TEST SETUP.
19. Store the CURRENT TEST SETUP.
```

FIGURE 10 - JCP/CRCP DB TEST SETUP

```
Select Option/Item number ([BLANK] to Quit):
□

    "JCP(RIGID)/CRCP" JOINT/CRACK TEST
 1. Test UNITS...: lbf,mil,inch    (kPa,mu,mm)
 2. Temperature..: Fahrenheit      (Centigrade)
 3. Stn.Request..: OFF             (ON)
 4. Test Checks..: Roll-Off        (RollOFF+Decr, NONE, Decreasing dfls)
 5. Reject prompt: OFF             (ON)
 6. Stationing...: Feet
 7. Temp.Request.: OFF             (ON)
 8. Cond.Request.: ON              (OFF)
 9. Variation :   0.38 psi   2.0%      0.08 mil   1.0%
10. Diameter of Plate: 11.8
11. Deflector distances : 12 12 18 24 36 60
                                   1
12. Drop No.   : 123456789012345.............................................
13. Heights  . : CCC222233334444111111111111111111111111111111111111111111111
14. Test Plots: ..............☆.............................................
15. Save Peaks: ...☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆☆
16. Load His.  : ............................................................
17. Whole His.: ......☆...☆...☆.............................................

18. Load another TEST SETUP.
19. Store the CURRENT TEST SETUP.
```

NOTE: FWD SENSOR 2 IS SET AT -12", BUT SETUP HAS IT AT 12" SO TEST PLOT WILL WORK

FIGURE 11 - JCP/CRCP LT TEST SETUP

```
Select Option/Item number ([BLANK] to Quit):
■

    CONDITION BUFFERS FOR ASPHALT
 1. Test UNITS...: lbf,mil,inch      (kPa,mu,mm)
 2. Temperature..: Fahrenheit        (Centigrade)
 3. Stn.Request..: OFF               (ON)
 4. Test Checks..: NONE              (Decreasing dfls, Roll-Off, RollOFF+Decr)
 5. Reject prompt: ON                (OFF)
 6. Stationing...: Feet
 7. Temp.Request.: OFF               (ON)
 8. Cond.Request.: OFF               (ON)
 9. Variation :   0.38 psi   2.0%      0.08 mil   1.0%
10. Diameter of Plate: 11.8
11. Deflector distances : 8 12 18 24 36 60
                         1         2         3         4         5         6
12. Drop No.   : 123456789012345678901234567890123456789012345678901234567890
13. Heights .  : 123444441234444441234444444412344444123444444412344444441234
14. Test Plots: ............................................................
15. Save Peaks: ............................................................
16. Load His. : ............................................................
17. Whole His.: ............................................................

18. Load another TEST SETUP.
19. Store the CURRENT TEST SETUP.
```

FIGURE 12 - CONDITION BUFFERS FOR ASPHALT SETUP

```
Select Option/Item number ([BLANK] to Quit):
□

    CONDITION BUFFERS FOR CONCRETE
 1. Test UNITS...: lbf,mil,inch     (kPa,mu,mm)
 2. Temperature..: Fahrenheit       (Centigrade)
 3. Stn.Request..: OFF              (ON)
 4. Test Checks..: NONE             (Decreasing dfls, Roll-Off, RollOFF+Decr)
 5. Reject prompt: ON               (OFF)
 6. Stationing...: Feet
 7. Temp.Request.: OFF              (ON)
 8. Cond.Request.: OFF              (ON)
 9. Variation :   0.38 psi   2.0%       0.08 mil   1.0%
10. Diameter of Plate: 11.8
11. Deflector distances : 8 12 18 24 36 60
                                 1         2         3         4         5         6
12. Drop No.   : 1234567890123456789012345678901234567890123456789012345678901
13. Heights .  : 2344444234444423444442344444234444423444442344444234444423444
14. Test Plots: .............................................................
15. Save Peaks: .............................................................
16. Load His. : .............................................................
17. Whole His.: .............................................................

18. Load another TEST SETUP.
19. Store the CURRENT TEST SETUP.
```

FIGURE 13 - CONDITION BUFFERS FOR PCC SETUP

```
Select Option/Item number ([BLANK] to Quit):
■

    RELATIVE CALIBRATION @ HGHT. 3
 1. Test UNITS...: lbf,mil,inch     (kPa,mu,mm)
 2. Temperature..: Fahrenheit       (Centigrade)
 3. Stn.Request..: OFF              (ON)
 4. Test Checks..: NONE             (Decreasing dfls, Roll-Off, RollOFF+Decr)
 5. Reject prompt: OFF              (ON)
 6. Stationing...: Feet
 7. Temp.Request.: OFF              (ON)
 8. Cond.Request.: OFF              (ON)
 9. Variation :   0.38 psi   2.0%      0.08 mil   1.0%
10. Diameter of Plate: 11.8
11. Deflector distances : 8 12 18 24 36 60
                           1          2          3          4          5
12. Drop No.  : 12345678P9012345P6789012P3456789P0123456P7890123P4567890S...
13. Heights . : CCC33333PCC33333PCC33333PCC33333PCC33333PCC33333PCC33333S111
14. Test Plots: ............................................................
15. Save Peaks: ...*****...*****...*****...*****...*****...*****...*****.***
16. Load His. : ............................................................
17. Whole His.: ............................................................

18. Load another TEST SETUP.
19. Store the CURRENT TEST SETUP.
```

FIGURE 14 - RELATIVE CALIBRATION SETUP AT HEIGHT 3

```
Select Option/Item number ([BLANK] to Quit):
□

    RELATIVE CALIBRATION @ HGHT. 4
 1. Test UNITS...: lbf,mil,inch    (kPa,mu,mm)
 2. Temperature..: Fahrenheit      (Centigrade)
 3. Stn.Request..: OFF             (ON)
 4. Test Checks..: NONE            (Decreasing dfls, Roll-Off, RollOFF+Decr)
 5. Reject prompt: OFF             (ON)
 6. Stationing...: Feet
 7. Temp.Request.: OFF             (ON)
 8. Cond.Request.: OFF             (ON)
 9. Variation :   0.38 psi   2.0%      0.08 mil   1.0%
10. Diameter of Plate: 11.8
11. Deflector distances : 8 12 18 24 36 60
                                 1          2          3          4          5
12. Drop No.   : 12345678P9012345P6789012P3456789P0123456P7890123P4567890S...
13. Heights .  : DDD44444PDD44444PDD44444PDD44444PDD44444PDD44444PDD44444S111
14. Test Plots:  ............................................................
15. Save Peaks:  ...☆☆☆☆☆...☆☆☆☆☆...☆☆☆☆☆...☆☆☆☆☆...☆☆☆☆☆...☆☆☆☆☆...☆☆☆☆☆.☆☆☆
16. Load His.  : ............................................................
17. Whole His.:  ............................................................

18. Load another TEST SETUP.
19. Store the CURRENT TEST SETUP.
```

FIGURE 15 - RELATIVE CALIBRATION SETUP AT HEIGHT 4

```
Select Option/Item number ([BLANK] to Quit):
■

    REFERENCE CALIBRATION-GEOPHONES
 1. Test UNITS...: lbf,mil,inch     (kPa,mu,mm)
 2. Temperature..: Fahrenheit       (Centigrade)
 3. Stn.Request..: OFF              (ON)
 4. Test Checks..: NONE             (Decreasing dfls, Roll-Off, RollOFF+Decr)
 5. Reject prompt: OFF              (ON)
 6. Stationing...: Feet
 7. Temp.Request.: OFF              (ON)
 8. Cond.Request.: OFF              (ON)
 9. Variation :   0.38 psi   2.0%      0.08 mil   1.0%
10. Diameter of Plate: 11.8
11. Deflector distances : 8 12 18 24 36 60
                                  1                   2
12. Drop No.  : 123P4P5P6P7P8P9P0P1P2P3P4P5P6P7P8P9P0P1P2P3P4P5P6P7..........
13. Heights . : DDDP1P1P1P1P1P2P2P2P2P2P2P3P3P3P3P3P3P4P4P4P4P4P4111111111111
14. Test Plots: .............................................................
15. Save Peaks: ....*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.***********
16. Load His. : .............................................................
17. Whole His.: ............*...........*...........*...........*............

18. Load another TEST SETUP.
19. Store the CURRENT TEST SETUP.
```

FIGURE 16 - REFERENCE CALIBRATION FOR GEOPHONE SETUP

```
Select Option/Item number ([BLANK] to Quit):
□

    REFERENCE CALIBRATION-LOAD.
 1. Test UNITS...: lbf,mil,inch      (kPa,mu,mm)
 2. Temperature..: Fahrenheit        (Centigrade)
 3. Stn.Request..: OFF               (ON)
 4. Test Checks..: NONE              (Decreasing dfls, Roll-Off, RollOFF+Decr)
 5. Reject prompt: OFF               (ON)
 6. Stationing...: Feet
 7. Temp.Request.: OFF               (ON)
 8. Cond.Request.: OFF               (ON)
 9. Variation :   0.38 psi   2.0%      0.08 mil   1.0%
10. Diameter of Plate: 11.8
11. Deflector distances : 8 12 18 24 36 60
                               1                   2
12. Drop No.  : 123P4P5P6P7P8P9P0P1P2P3P4P5P6P7P8P9P0P1P2P3P4P5P6P7.........
13. Heights . : DDDP1P1P1P1P1P1P2P2P2P2P2P2P3P3P3P3P3P3P4P4P4P4P4P4111111111:
14. Test Plots: ............................................................
15. Save Peaks: ....☆.☆.☆.☆.☆.☆.☆.☆.☆.☆.☆.☆.☆.☆.☆.☆.☆.☆.☆.☆.☆.☆.☆.☆☆☆☆☆☆☆☆☆☆·
16. Load His. : ...........☆...........☆...........☆...........☆...........
17. Whole His.: ............................................................

18. Load another TEST SETUP.
19. Store the CURRENT TEST SETUP.
```

FIGURE 17 - REFERENCE CALIBRATION FOR LOAD CELL SETUP

Using the Software for Data Collection and Data Backup

Data Quality Checks in the FWD Data Collection Software

Research data must be valid and accurate. For the deflection data, the FWD software uses up to five quality control checks as the data is collected. The checks in use are selected in the setups and described below. Details on handling data failing any quality control checks are described later in this chapter in the section on "Rejecting tests".

1. Roll-off - electrical check that the magnitude of the deflections 60 milli-seconds after the trigger activated on FWD have decreased to less than 10% of the peak deflection readings. If this condition is not met, the 'REJECT' prompt appears and allows the operator to either (Q)uit the test sequence or continue.

   This check can "fail" if the pavement is close to bedrock, if the deflections are very low (frozen subgrade), or if a sensor is not properly seated on the pavement. If a sensor is suspect, the sequence should be (Q)uit and the sensor examined. If the check "fails" from bedrock or very low deflections, a comment should be included in the file using the F6-Comment key.

2. Decreasing Deflections - checks that deflections decrease with distance from the load. The check is used for DB tests only. If this condition is not met, the 'REJECT' prompt appears and allows the operator to (Q)uit the test sequence or continue.

   Most often the condition is not met when transverse cracks exist between the sensors, especially on full-depth asphalt. For this case the test should be continued, and the distress and failed check noted in the file using the F6-Comment key. This problem also occurs in JCP and CRCP DB tests, but no corrective action is necessary.

3. Out of Range - checks that deflections are less than the 80 mil (2000 micron) range of the sensors. The notation 'Out of Range' appears in the right margin next to drops which had deflections exceeding the allowable range. In addition to this warning, the 'REJECT' prompt appears and allows the operator to (Q)uit the test sequence or continue.

   If the condition is not met, the sensors and pavement surface should be checked for potential problems. If the deflections are large because the pavement is weak, the loads should not be changed. Comments should be included in the file using the F6-Comment key.

4. Load Variation - checks that the loads at a particular drop height are grouped within a specified tolerance. If the condition is not met, a "V" appears next to the load outside the acceptable range. A 'Reject' prompt appears at the end of the test sequence, and allows the operator to either reject or accept the data (See Section 10, under Field Data Collection Program on Rejecting tests.)

   The tolerance range for load is set as follows:

   X ± (40 lbs. + 0.02X) or
   X ± (2.5 kPa + 0.02X)

   Where X = average load for all drops at that height.

   For example, if the average load for four drops at drop height 1 is 6000 lbs. (377.3 kPa), the allowable load range would be 6000±(40+0.02*6000) or 5840 lbs. to 6160 lbs [377.3±(2.5+0.02*377.3) or 367.2 kPa to 387.4 kPa].

5. Deflection Variation - checks that the normalized deflections for an individual geophone at a particular drop height are grouped within a specified tolerance. If the condition is not met, a "V" appears next to the deflection outside the acceptable range. A 'Reject' prompt appears at the end of the test sequence, and allows the operator to either reject or accept the data (Section 10, under Field Data Collection Program on Rejecting tests.)

   Normalized deflections are the measured deflections (raw data) adjusted to a constant load magnitude.

   The tolerance range for deflections is set as follows:

   X ± (0.08 mils + 0.01X) or
   X ± (2 microns + 0.01X)

   Where X = average normalized deflection for a geophone for all drops at that height.

   For example, if the average normalized deflection for geophone 1 for four drops at drop height 1 is 20 mils (508 microns), the allowable normalized deflection range would be 20±(0.08+0.01*20) or 19.7 mils to 20.3 mils [508±(2+0.01*508) or 501 microns to 515 microns].

Field Data Collection Program

FWD operators must answer several prompts in the FWD Field Program for each pavement section tested. These prompts are described below.

1. Operator ID - FWD operators should enter their full name using the format:

   Last Name, First Name, Middle Initial.

2. Cancel automatic time of day recording? - **NO** (default setting is **NO** - <rtn> key), use automatic time of day recording to 'time stamp' all deflection data. Operators should make sure the internal computer clock/calendar is set to the correct local time.

3. Use existing file? - generally **NO** (default <rtn> = **NO**) unless testing was interrupted for some reason and a file was closed and must be opened to finish testing. In some cases, certain errors that occur during testing will exit the FWD Field Program and return to the operating system. In this case the existing file should be opened to continue testing.

   NOTE: A separate data file is used for each pass down the test section.

4. Roadway ID - Enter information using the following format: Highway classification and designation, direction of lane(s), distance reference to a large city, and state abbreviation.

   Examples: IH-94, EASTBOUND LANES, 1.2 MILES EAST OF ALBANY, MN

   US-2, EASTBOUND LANE, 5.0 MILES WEST OF GRAND RAPIDS, MN

   ST-15, NORTHBOUND LANE, 3.0 MILES SOUTH OF LAFEYETTE, MN

5. 5 day air temp - press <rtn> to cancel use of this option

6. Subsection ID - enter 6-digit SHRP section ID

7. Starting DMI - enter distance in feet for the load plate measured from station 0+00. The FWD load plate must be positioned at the station entered before the <rtn> key is hit to enter the DMI reading. The distance should be entered as follows:

   1. At the distance prompt, first clear the field using the F1 key,
   2. Enter "+" which sets the DMI to increase distance as the tow vehicle moves forward,
   3. Enter the polarity of the station (use "+" for station 0+00),
   4. Enter the distance in feet from station 0+00 without polarity.

For example the following key strokes would be used for station 0-50; (F1 Key) + - 50 <rtn>

NOTE: The display on the computer screen for distance should have the "-" next to the "50". If the "-" sign is left justified, the station was entered incorrectly, and the DMI reading will decrease (go more negative) as the tow vehicle moves forward (positive direction).

NOTE: Excessive changes in direction can accumulate significant error in the DMI reading, and operators should always check the DMI at stations 1+00, 2+00, 3+00, 4+00, and 5+00.

8. Lane specification - the entries for this field are two-digit codes that include information on the pavement type, test type (DB or LT test), and test point location. The codes are listed below according to the FWD testing plans, and include the pass number when the data is collected.

FLEX Testing Plan (see Figure 3)

F0	DB test at the test pits in the OWP (P_0)
F1	DB test from Sta.0+00 to 5+00 in the ML (P_1)
F3	DB test from Sta.0+00 to 5+00 in the OWP (P_3)

JCP Testing Plan (see Figure 4)

J0	DB test at the test pits in the OWP (P_0)
J1	DB test from Sta.0+00 to 5+00 in the ML at the mid-panel (P_1)
J2	DB test from Sta.0+00 to 5+00 in the PE at the panel corner (P_2)
J3	DB test from Sta.0+00 to 5+00 in the PE at mid-panel (P_2)
J4	LT test from Sta.0+00 to 5+00 in the OWP at joints/cracks with the load plate on approach slab (P_3)
J5	LT test from Sta.0+00 to 5+00 in the OWP at joints/cracks with load plate on leave slab (P_3)

CRCP Testing Plan (see Figure 5)

C0	DB test at the test pit in the OWP (P_0)
C1	DB test from Sta.0+00 to 5+00 in the ML at mid-panel (P_1)
C2	DB test from Sta.0+00 to 5+00 in the PE at with the load plate centered on the crack defining the beginning of the panel (P_2)

C3 DB test from Sta.0+00 to 5+00 in the PE at mid-panel (P_2)
C4 LT test from Sta.0+00 to 5+00 in the OWP at cracks defining the beginning of the panel with the load plate on approach slab (P_3)
C5 LT test from Sta.0+00 to 5+00 in the OWP at cracks defining the beginning of the panel with load plate on leave slab (P_3)

NOTE: Operators must change the lane specifications immediately before performing a test at a given location by using the F2 (Location) key in the FWD Field Program.

9. File naming convention - file names consist of eight characters using the following format:

- characters one thru six - SHRP six digit Section ID

- character seven - denote the number of times the section has been tested for the LTPP study

  Example: first test is 'A',
  second test is 'B', etc.

- character eight - pass number of the FWD on the section

  pass 0 (P_0) - OWP test pit locations
  pass 1 (P_1) - ML within the 500' section
  pass 2 (P_2) - PE within the 500' section
  pass 3 (P_3) - OWP within the 500' section

The extension ".FWD" is used to identify the file as raw deflection data. For example, **373807A1.FWD** is the file name for pass 1 of the first round of tests for SHRP Section 373807.

10. Rejecting tests - for the majority of cases, the REJECT prompt appears because load or deflection data exceeds variation limits; however, nondecreasing deflections or data exceeding the range of the geophones can also activate the REJECT prompt.

Operators should examine the data on the screen to determine the cause. A 'V' appears next to a deflection or load value if the data has failed the variance criteria (see Chapter II of this manual), and messages for nondecreasing deflections or out of range data are displayed if they occur.

For all cases, the operator has to decide whether to reject or accept the data. If the data is rejected the operator must repeat the test. In many cases, one load or deflection reading will be the problem, and a single repeat test is all that is needed.

The following guidelines will help decide what to do when the REJECT prompt occurs.

The normal procedure is to reject the test and re-test the location without moving the equipment.

> In many cases the data will meet variation criteria on the second test if it is an isolated problem (sensor may have been on a small stone and slipped off during the test, hydraulics settled if test delayed while mass up, truck passing in adjacent lane (especially on JCP), etc.).
>
> If variation occurs a second time at the location, the operator should check for equipment problems.
>
> > Operators should compare changes in deflection at a drop height with changes in load to see if the problem is with the load or a geophone.
> >
> > > If deflections at a given drop height are very consistent, but the load varies significantly, then the load reading is suspect.
> > >
> > > If the loads at a given drop height are very consistent, but a sensor has significant deflection variation, then that sensor is suspect.
> >
> > The following equipment checks should be done:
> >
> > - Check load cell and geophones electrically using the "drift" check in the auxiliary menu of the FWD Field Program. Very little if any noise should be present.
> > - Check magnetic coupling of the geophones in the holders.
> > - Check cables and connections.
> > - Check that the four targets for the drop heights are tight if load variations occur.

If no equipment problems are found, or if minor problems are found and corrected, the location is tested a third time.

If the data still fails the variation criteria, and it is at a crack/joint (J2, J4, J5, C2, C4, or C5 lane specification), the FWD can not be repositioned, and the third test with data variation is saved along with a comment (F6-Comment key) in the data file.

If the data still fails the variation criteria, and it is a DB test not adjacent to a joint/crack (F1, F3, J1, J3, and maybe C1 and C3 depending on the size of the panel), raise the load plate, move the FWD forward two feet, and test the new location. This set of data is saved regardless of load or deflection variation. However, the F6-Comment key should be used if the data failed the variation criteria.

Field judgement will be required by the operator if many variations occur, regardless of how much time is available for retests (it is more important to test all test points than to do repeat tests at all points with variations). If the operator can determine that a pavement condition is causing the variations and not a problem with the equipment, it may not be feasible to do more than a couple of repeat tests to verify that the problem or condition is inherent to the pavement structure. Some particular pavement conditions that can cause variations include:

- New overlay, leveling course, or patch compacting under the load plate.
- Uneven surface from rutting, patching, pavement repair, or roll-off at the pavement edge (PCC sections only) causing load variation from uneven contact pressure under the load plate.
- Unstable layer in the pavement structure which is altered by the load applications from the FWD. Such layers could be a distressed surface, stripped base, cement stabilized subgrade, saturated granular base, or a saturated subgrade.

For these conditions, at least one complete set of three repeat tests should be saved for analysis to determine what effect the repeat testing or "conditioning" of the pavement has on the results from analysis of the data.

11. Accidental Acceptance - if a reject test is accidentally accepted, the operator must take one of the following steps:

    1. If the error is caught before the next test is started or a comment is entered using the F6-comment key, the data set can be deleted using the

F5-File key and answering (Y)es to the prompt for "Repeat the last test". The last data set is erased from the file, and the message "Previous data set deleted!" is printed to the hardcopy.

2. Mark the data to delete from the file in the left margin on the printout with a RED pen, and use the F6-Comment key to include a note in the file that the data was accidentally accepted and should be removed from the data file at the RCO.

NOTE: If data for the test point is deleted, in most cases, the test point must be retested. If the data was deleted because the wrong location was tested, then the location does not need to be retested.

12. Crack/joint width measurements - crack/joint openings are measured to the nearest 0.01" and recorded in the two character field as hundredths of a inch.

Example: 3/4 inch = 0.75" is recorded as 75

If the joint/crack opening exceeds 0.99", enter 99

If the joint/crack opening is less than 0.05, enter 05

13. F6-Comment key - use this key to include comments about anything unusual that might affect the deflection data or its interpretation; pavement distress, data failing variation criteria, extreme temperature changes, delays in testing, etc.

Closing a Data File

The FWD data files must be closed properly at the end of each pass. This is done using the F5-File key if additional testing is done, or the Shift-F8-Exit key to close the last file for the day.

FWD Data and Field Program Backup Procedures

A backup copy of the FWD field program and configuration files should always be kept up to date. The field program informs operators when changes need to be saved to the backup disk. FWD operators should take a backup copy out of the tow vehicle when they are not with the equipment.

FWD operators also have the responsibility to safeguard the FWD data files by keeping copies of the data in more than one location. Without exception, all deflection data files must be backed up before leaving the site.

Three complete backup copies are made using FastBack Plus® software. The three copies are used as follows. Copy one is transmitted to the RCO along with the printed copy of the deflection data and a history report from FastBack Plus® of the files backed up. Copy two and three serve as backups if the copy sent to the RCO is lost or damaged. One of these copies must be removed from the tow vehicle whenever the FWD operator is not with the testing equipment.

Labelling Backup Diskettes for the Deflection Data Files

The format to use for the diskette labels is as follows:

Line 1:	'**xxxxxx**' where xxxxxx is the SHRP six digit section ID#
Line 2:	'**Volume x of y**' where x is the disk number within the set, and y is the total number of disks in the set
Line 3:	'**Copy x**' where x is the set number, usually 1 to 3
Line 4:	'**FWD SN xxx**' where xxx is the serial number of the FWD that tested the section
Line 5:	'**mm/dd/yy**' where mm/dd/yy is the date(s) the testing was performed

Operators should label each diskette as they are used by FastBack Plus®.

Specifics of FastBack Plus® Operation

FastBack Plus® has the option to backup individual files, directories, or entire hard disks. The actual FWD data files to backup can be selected individually or by directory (C:\FWD\DATA). If a directory, it should only contain the files to be backed up.

After the required directory or individual files have been selected for backup, select the 'Perform Backup'. Insert diskettes at the prompts until the backup is complete. Then print the History Report (available on the Options menu) to send to the RCO along with the diskettes.

Finally, perform the same backup two more times (acknowledging the warning message about identical backups) for a total of three copies of the FWD data.

Miscellaneous Supply Requirements

FWD operators should obtain adequate supplies before extended trips. While not complete, the following supplies are recommended.

1. 2000 pages of 8.5" x 11" (21.6cm x 27.9cm) ink jet compatible paper. Estimate using approximately 250 pages per week.

2. six ink cartridges. Estimate using one cartridge per week.

3. 200 3.5" (8.9cm) - 720 k diskettes. Estimate 45 to 50 diskettes per week.

   Note: The second and third set of the FWD data backups can be reused as soon as the RCO notifies the FWD operator that the first set of data disks has been restored, and that all the data was readable.

Data Handling at the RCO

Restoring Data

Fastbacked FWD data received at the RCO must be restored to its original format using the FastBack Plus® restore function. Once the data has been restored, and the RCO verifies the data files are complete, and in a readable form, the FWD operators can reuse the diskettes with the extra backup copies of this data.

RCO Deflection Data Evaluation

This field guide does not go into detail on the review and analysis of deflection data at the RCO. However, the steps are listed for processing the data before it is included in the LTPP-Information Management System (IMS) data base. They are:

1. All deflection data received at the RCO is restored using Fast Back Plus as described above.

2. Deflection data files are edited and stored. Editing is limited to header information (Station, lane specification, temperatures, etc.) and deleting of deflection data accidently stored.

3. The program FWDSCAN is used to check the data file format and operator input data, and also to create a separate file with only peak deflection data.

4. The program FWDCHECK is used to analyze the deflection data for reasonable and uniform data within the 500' section, and also to check that the TP data is representative of the rest of the section.

5. The deflection data are entered into the Regional Information Management System (RIMS).

6. The data in RIMS is periodically forwarded to the National Information Management System (NIMS), using the edited *.FWD files collected in the field.

THIS PAGE INTENTIONALLY LEFT BLANK

IV. FWD CALIBRATION

Background

Highly accurate deflection data are required if meaningful estimates of the structural characteristics of a pavement are to be derived from FWD data. For this reason, periodic calibration of any FWD collecting data for the LTPP study is required. The detailed procedures for FWD calibration are provided in Appendix A of this document. However, these procedures supplement, rather than replace, the manufacturer's calibration of the FWD measurement systems and are not intended to serve as the basic or initial calibration of the FWD.

The FWD calibration is a two-part procedure. The first part, referred to as <u>reference</u> (or occasionally, "absolute") calibration, involves calibration of the FWD load and deflection measurement systems against an independent reference system. Within the overall calibration procedure, reference calibration ensures that the FWD load and deflection measurement systems are unbiased with respect to independently calibrated reference systems traceable to National Institute of Standards and Technology (NIST) standards. The second part of the calibration procedure, referred to as <u>relative</u> calibration, involves calibration of the FWD deflection sensors against each other. This ensures that all sensors read the same with respect to each other. Also, relative calibration done on a monthly basis verifies the stability of the FWD deflection measurement system.

Calibration Requirements

As a minimum, any FWD collecting data for the LTPP study is required to undergo <u>full calibration</u> (including both reference and relative calibration) at least once per year. This calibration must be done at one of the four calibration centers established by SHRP (or equivalent as determined by the LTPP Division staff) following the procedures provided in Appendix A or subsequent versions of the SHRP FWD Calibration Protocol. <u>Full calibration</u> is also required immediately after replacement of a load cell, and as soon as possible after replacement of any major components of the FWD, such as deflection sensors, signal processing modules, etc.

In addition monthly <u>relative calibration</u> of the FWD deflection sensors is required. Under no circumstance should the time from the last relative calibration exceed 31 days when using an FWD for collecting data for the LTPP study.

Reporting Requirements

The FWD operator is responsible for sending copies of all calibration reports (for both annual calibration and monthly relative calibration) to the RCO and LTPP headquarters within seven working days after the calibration.

V. EQUIPMENT MAINTENANCE AND REPAIR

General Background

The extensive use of FWDs within LTPP makes good preventative maintenance practices especially important. The RCO's are responsible for preventative maintenance to keep the equipment dependable and minimize deterioration. The maintenance procedures in the manuals provided with each piece of equipment should be followed.

Coordination of schedules for traffic control, sampling and testing, and maintenance of the deflection testing equipment are critically important. Scheduled preventive maintenance ensures proper equipment operation and helps identify potential problems. Potential problems identified can be corrected to avoid costly delays or missing data that results if the equipment malfunctions while on site.

The testing requirements at a section usually prohibit FWD operators from doing more than initial checks and monitoring the operation of the equipment. Any maintenance must typically be done at the end of the day after the testing is complete, and should become part of the routine performed at the end of each test/travel day and on days when no other work is scheduled.

Equipment Maintenance and Repair

Routine Maintenance

Routine maintenance functions are performed easily with minimal disassembly and include procedures like checking the fluid levels in the tow vehicle, checking vehicle lights, etc. These basic and easily performed maintenance measures should be done each day prior to using the equipment.

The following partial list of BEFORE OPERATIONS CHECKS show the extent and detail required for preventative maintenance. These items are not to supersede manufacturer's minimum requirements for warranty compliance.

Tow Vehicle:

Under-hood	fluid levels (engine oil, brake fluid, power steering, windshield washer, engine coolant, transmission fluid); drive belt tension (water pump, alternator, a/c compressor); battery cable connections; general appearance (leaks, cracked hoses, cracked insulation).
Exterior	tires (inflation and condition); lights (headlights, signals, flashers, beacon, arrow board); glass (clean, no cracks); electrical connections (clean and corrosion free).
Interior	general appearance clean and uncluttered; equipment properly stowed; glass clean and view unobstructed; power inverter well ventilated and good electrical connections; computer in good condition; air conditioning functioning properly (operate monthly to keep compressor lubricated); temperature measuring equipment in good condition.

FWD:

Trailer	connection to van (ball tight, safety chains in place, breakaway cable for electric brakes in place); tires properly inflated and good condition; lights functioning properly (brake, turn signal); battery electrolyte level good and tight, clean connections; covers and latches good working condition; hydraulic oil proper level and viscosity; load plate swivel proper lubrication; general appearance clean and paint in good condition.
FWD	catch head lubricated; weight guide rollers clean and lubricated; weight guide shaft clean and dry lubrication; raise/lower bar cable not frayed, properly adjusted and positioned; geophone holder bases undamaged, free of corrosion, and silicon lube on foam guides; pressure switches rubber boots in good condition and full of grease; transport locks undamaged and functioning properly; raise/lower bar front guide mechanism undamaged and split pin in place when in transit; trailer connection box undamaged and properly latched.

FWD operators must indicate that the BEFORE OPERATION CHECKS were performed by initialing this item on the FWD FIELD ACTIVITY REPORT (Form F02).

Scheduled Major Maintenance

Scheduled major maintenance includes much more than routine checks. These services require some disassembly of equipment and services typically beyond the skill of FWD operators or RCO staff. The MAJOR MAINTENANCE/REPAIR REPORT form (Form F03) is used to record major repairs and keeps the RCO informed on the condition of the FWD and tow vehicle. Services in this category are engine tune-ups, tow vehicle brake work, drive belts, etc.

Refer to equipment owner's manuals for appropriate service intervals, unless instructed to do otherwise.

Equipment Problems/Repairs

Regardless of the maintenance program there will be equipment failures, and repairs must be done in a timely fashion. Repairs are easily handled when no testing is scheduled: however, if they occur during mobilization or testing, adjustments in the schedule will be needed to allow for repairs.

To minimize the impact of equipment problems, FWD operators should notify the RCO immediately, and any other agencies necessary. Sufficient spare parts should be kept in the tow vehicle to cover anticipated repairs. The length of time for repairs must be considered for rescheduling traffic control on future sites. Therefore, it is essential that maintenance be done in advance of field work, in order to minimize rescheduling of traffic control.

When emergency repairs are performed by an outside agency, FWD operators report this information using the MAJOR MAINTENANCE REPORT form as an UNSCHEDULED maintenance activity. Circumstances making the work necessary should be included in the report. Any repairs by FWD operators should be noted on the FWD FIELD ACTIVITY REPORT for that day, regardless of whether the report is for a testing day, travel day or just repairs.

Procedures

Maintenance of Records

FWD operators are responsible for keeping a file for FWD FIELD ACTIVITY REPORTS, MAJOR MAINTENANCE REPORTS, and RELATIVE CALIBRATION REPORTS. Copies of appropriate reports are forwarded to the RCO as needed to limit impacts on the testing schedule. LTPP Headquarters should be informed of major problems, but in general the RCO's are responsible for FWD operations.

Equipment Repairs

The RCOs are responsible for maintaining the FWDs. The decisions required for proper maintenance and repair should be based on the testing schedule, and expedited as necessary to prevent disruption of testing. Most services are provided by local agencies; however, annual FWD overhauls for four successive years will be performed by Dynatest as part of the maintenance contract.

Accidents

FWD operators will inform the RCOs and LTPP Headquarters as soon as practical after any accident. Details of any accident shall be reported in writing.

Records

FWD operators perform a great deal of work during a test day, and much information needs to be manually recorded. The following forms help organize this information without significantly adding to the work load.

The responsibility for equipment maintenance and repair rests with each RCO, and a copy of each record, form, or log need not be forwarded to LTPP Headquarters. Rather, the RCO should keep LTPP Headquarters informed as needed of any major problems concerning deflection testing equipment. Three types of records are required. These records should be up-to-date with one complete set kept in the tow vehicle, and another set on file at the RCO. The three forms/reports required are:

1. FWD Field Activity Report (Form F02)
2. Major Maintenance/Repair Activity Report (Form F03)
3. Calibration Reports

Field Activity Report

The FWD Field Activity Report (Form F02; see Figure 18) is used by FWD operators to record daily activities for the FWD and tow vehicle. On this report, the section information data, information related to productivity, and any conditions affecting deflection data not recorded in the FWD files should be recorded. The information required includes travel time and mileage to/from a site, length of time traffic control was in place, number of FWD tests performed, any down-time, and the names and agencies of both Field Sampling & Testing and Traffic Control personnel.

SHRP REGION __________ STATE CODE __________ SHRP ASSIGNED ID __________

STATE __________ TESTING __________ DISTRICT __________

LTPP EXPERIMENT CODE __________ ROUTE/HIGHWAY NUMBER __________

FWD FIELD ACTIVITY REPORT

TESTING DATE __________ SHEET NUMBER __________ FIELD SET NO. __________

FWD AND TOW VEHICLE BEFORE OPERATION CHECKS __________ (initial)

	TIME	ODOMETER
START TRAVEL	______	______
END TRAVEL	______	______
READY TO TEST	______	
TRAFFIC CONTROL READY	______	
BEGIN TESTING	______	
END TESTING	______	
START TRAVEL	______	______
END TRAVEL	______	______

DOWN TIME __________ HOURS REASON(S) __________

NUMBER OF TESTS:	BASIN	JT/CRACK
TP	______	
OWP	______	______
PE	______	
ML	______	

ADDITIONAL REMARKS REGARDING TESTING __________

FIELD SAMPLING AND TESTING CREW
NAMES: __________

TRAFFIC CONTROL CREW
AGENCY: __________
NAMES: __________

COPIES: RCO

FORM F02/ISSUED 15 FEBRUARY 1993

FIGURE 18 - FWD FIELD ACTIVITY REPORT FORM

The FWD Field Activity Report is filled out for all travel days, testing days, and any days the FWD operator performs maintenance on the FWD or tow vehicle. Reports for testing days must be completely filled out, while reports for travel days and maintenance days are only partially filled out including the section ID for which the travelling is done. For testing days, it is important to obtain the names of personnel on site in case of an accident.

A line is provided for FWD operators to initial indicating that routine maintenance was conducted prior to any FWD testing.

The original report is kept in the tow vehicle, and a copy is forwarded to the RCO along with the field data diskettes and a hardcopy of the data.

Equipment Maintenance Records

Equipment maintenance records include the FWD Field Activity Report (F02) and the Major Maintenance/Repair Activity Report (Form F03; see Figure 19). Any major maintenance or repair item that requires an outside agency is reported using Form F03. Routine maintenance, before operation checks, and minor repairs performed by FWD operators are reported on the FWD Field Activity Report (Form F02).

Calibration Reports

Results of both reference and relative calibration of the FWD are sent to the RCO and LTPP headquarters within seven working days after calibration. The calibration reports consist of printouts from the FWDCAL and FWDREFCL software, supplemented by print screens from the FWD data acquisition software as specified in Appendix A.

MAJOR MAINTENANCE/REPAIR ACTIVITY REPORT

REGION ______________________ DATE ______________________

EQUIPMENT ID

MAKE ________________ MODEL __________________ S/N _____________

ODOMETER ____________ (where applicable)

REASON FOR MAINTENANCE WORK (CHOOSE ONE ONLY)

SCHEDULED ___________ NON SCHEDULED ___________

DESCRIPTION OF MAINTENANCE AND REASON: ____________________________________

____

____

____

____

AGENCY PERFORMING MAINTENANCE COST ____________________________

NAME: ____

STREET ADDRESS: ____

CITY: ____

PHONE NUMBER: ____

CONTACT NAME: ____

DATE IN: ____

DATE OUT: ____

COPIES TO: RCO AND FHWA/LTPP HQ

FORM F03/ISSUED 15 FEBRUARY 1993

FIGURE 19 - MAJOR MAINTENANCE/REPAIR REPORT FORM

THIS PAGE INTENTIONALLY LEFT BLANK

VI. DEFINITIONS, ABBREVIATIONS, AND CONVERSIONS

Definitions

Deflection Basin (DB) test - a test with deflection sensors placed at radial offsets from the center of the load plate. The test is used to record the shape of the deflection basin resulting from an applied load. Information from this test is used to estimate material properties for a given pavement structure.

Effective Panel - continuous section of PCC defined by two adjacent transverse breaks in the pavement. The transverse breaks can be expansion joints, cracks, or construction joints. The transverse breaks are treated as working joints for FWD testing purposes, and all tests on an effective panel are done in relation to the two transverse breaks defining the panel.

Load Transfer (LT) test - a test, usually on PCC pavement, with deflection sensors on both sides of a transverse break in the pavement. The test is used to determine the ability of the pavement to transfer load from one side of the break to the other. Also, the test data can be used to predict the existence of voids under the pavement.

List of Abbreviations

AC - Asphaltic Concrete
CRCP - Continuously Reinforced Concrete Pavement
DB - Deflection Basin
DMI - Distance Measuring Instrument
FWD - Falling Weight Deflectometer
GPS - General Pavement Study
JCP - Jointed Concrete Pavement
JPCP - Jointed Plain Concrete Pavement
JRCP - Jointed Reinforced Concrete Pavement
LT - Load Transfer
LTPP - Long-Term Pavement Performance
ML - Mid Lane
OWP - Outside Wheel Path
PCC - Portland Cement Concrete
PE - Pavement Edge
RCO - Regional Coordination Office

SHRP - Strategic Highway Research Program
SPS - Specific Pavement Study
TP - Test Pit

English/Metric Conversions

Length	1.0 mil = 25.4 microns	1.0 micron = 0.039 mils
	1.0 ft. = 0.328 meters	1.0 meter = 3.048 feet
Force	1.0 lbf = 0.0044 kN	1.0 kN = 224.8 lbf
	1.0 kip = 4.45 kN	1.0 kN = 0.225 kips
Pressure	1.0 psi = 6.89 kPa	1.0 kPa = 0.145 psi

APPENDIX A

SHRP FWD CALIBRATION PROTOCOL

SHRP FWD CALIBRATION PROTOCOL

INTRODUCTION

This document describes the procedure for calibration of falling weight deflectometers (FWD) which was originally developed by the Strategic Highway Research Program (SHRP). This protocol is now administered by the Long Term Pavement Performance (LTPP) Division in the Federal Highway Administration.

The procedure is written primarily for use with the Dynatest falling weight deflectometer, however it can also be used with the KUAB FWD. Due to differences in the design of the KUAB certain details are not applicable. Special procedures for the calibration of KUAB FWDs are included in Appendix B. It may be possible to use the procedure for other types of FWDs with minor modifications of the hardware and of the data acquisition software. The procedure is not applicable to the calibration of cyclic loading and other types of pavement deflection testing equipment.

In this procedure, the deflection and load transducers from the FWD are first calibrated individually against independently-calibrated reference devices. This is called "reference calibration," and it is performed at a LTPP Regional Calibration Center, or any other properly equipped location. The calibration of the FWD deflection sensors is further refined by comparing them to each other in a process referred to as "relative calibration". Relative calibration is done as a final step that accompanies reference calibration, and it can also be carried out alone, at any suitable location. There is no corresponding relative calibration procedure for the load measurement system.

The procedure results in calibration factors which are entered into the FWD software as multipliers. When the FWD measurements are multiplied by the calibration factors the result is a measurement which has been corrected to agree with the calibration instrumentation. It is necessary that there be a place in the FWD software to enter the calibration factors. That is the responsibility of the FWD manufacturer.

To use this procedure Dynatest FWDs must have Version 10 or higher software. Earlier versions do not have the pause feature and do not allow programming the required number of drops in the test sequence. Furthermore, it is not possible to leave the load plate down, as is called for in this procedure. Thus, Dynatest FWDs must be upgraded to Version 10 or higher software *before* calibration.

FREQUENCY OF CALIBRATION

Reference calibration should be performed at least once per year, or as soon as possible after a sensor has been replaced on the FWD.

Relative calibration should be performed on the deflection sensors at least once per month. It should also be performed immediately after a deflection sensor is replaced.

PERSONNEL

FWD System Operator
Calibration System Operator

REFERENCE CALIBRATION PROCEDURE

Equipment Preparation

The FWD should be in good operating condition prior to performing reference calibration. Particular attention should be paid to cleaning the magnetic deflection sensor bases to insure that they seat properly. Also verify that the FWD load plate is firmly attached to the load cell. In the event that the load plate is loose, the lower bolts should be tightened to a torque of 7.5 lbf-ft and set with Locktite before proceeding. (**Note:** This torque requirement is applicable to the Dynatest FWDs. For non-Dynatest FWDs consult the manufacturer.) All electrical connectors should be inspected and, if necessary, cleaned and firmly seated.

The FWD should be at room temperature. If the FWD has been outdoors at a very low or a very high temperature, sufficient time should be allowed for it to equilibrate to room temperature. It is recommended that a series of warm-up drops be performed immediately prior to beginning calibration, to assure that the rubber buffers have been thoroughly warmed up.

Set the FWD mass and drop heights to produce loads within ± 10 percent of 6, 9, 12, and 16 kips (27, 40, 53, and 71 kN). For the Dynatest FWD, it is possible to be within this tolerance for the highest load, and yet to have the drop height set too high. *Before* placing the reference load cell under the load plate, and with the mass positioned at drop height four (the highest position), verify that there is at least a four inch clearance between the highest point on the mass subassembly and the underside of the brace between the two columns that surround the cylinders that raise and lower the load plate. If the clearance is too small, reposition the target for the fourth drop height to achieve the required clearance. This should assure that there will be adequate clearance when the reference load cell is in position under the load plate.

Before beginning any calibration work, and throughout the entire calibration period, it is necessary that there be no data filters in operation in the FWD. Verify that the "peak smoothing" processor has been turned off. This feature is accessed from the Dynatest Main Menu by selecting "Road Options" (item #3, followed by item #12), where "Peak Readings" should show "direct" and not "smooth".

General Procedure

The FWD load cell should be calibrated at least twice. Multiple calibration tests are performed on the load cell, and the results are averaged, since it is not possible to perform relative calibration on the load cell. Acceptance criteria based upon the repeatability of the calibration factor are identified in the load cell calibration procedure. If the results persist in failing the acceptance criteria, then the cause of the erratic results should be identified and corrected.

Each deflection sensor shall be calibrated once. Spare deflection sensors do not have to be calibrated until they are in active use. After all load and deflection sensors have been calibrated, the interim calibration factors shall be entered into the FWD computer before proceeding with relative calibration.

A sample reference calibration setup screen for the Dynatest FWD with version 10 or version 20 software is given in Figure 1. The information in Figure 1 can also be used as the basis for setup of Dynatest FWDs running version 25 and higher software.

A complete summary of the data to be recorded is given in Table 1. Before beginning to perform the calibrations, FWD-specific information should be recorded via printouts from the FWD data acquisition program screens (e.g., showing the deflection sensor serial numbers and calibration factors, load cell serial number, calibration factor, and sensitivity, and voltage screens from the Dynatest software), which have been annotated with the date and FWD identification information (i.e., FWD model and serial number).

Locate the calibration data acquisition system as close as possible to the FWD computer so that the two systems operators will be able to converse easily. Load the reference calibration software **FWDREFCL** into the reference system computer. Directions for performing reference calibration using this software are provided in the FWDREFCL User's Guide.

Before doing any calibrations, verify that the computers for the FWD and the reference data acquisition system are registering the correct date and time. If either is set incorrectly, correct it before proceeding.

```
    Reference Calibration
 1. Test UNITS...: lbf.mil.inch    (kPa.mu.mm)
 2. Temperature..: Fahrenheit      (Centigrade)
 3. Stn.Request..: OFF             (ON)
 4. Test Checks..: NONE            (Decreasing defls, Roll-Off, RollOFF+Decr)
 5. Reject prompt: OFF             (ON)
 6. Stationing...: [Doesn't matter]
 7. Temp.Request.: OFF             (ON)
 8. Cond.Request.: OFF             (ON)
 9. Variation : Load NOT Checked !  Deflections NOT Checked !
10. Diameter of Plate: 11.8
11. Deflector distances: [Doesn't matter.  Keep what you have.]
                                  1                   2
12. Drop No.  : 123P4P5P6P7P8P9P0P1P2P3P4P5P6P7P8P9P0P1P2P3P4P5P6P7S...........
13. Heights   : CCCP1P1P1P1P1P2P2P2P2P2P3P3P3P3P3P4P4P4P4P4P1111111111
14. Test Plots: ...............................................................
15. Save Peaks: ....*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*.*............
16. Load His. : ...............................................................
17. Whole His.: ...........*...........*...........*...........*...............

18. Load another TEST SETUP.
19. Store the CURRENT TEST SETUP.
```

Figure 1: Reference Calibration Test Setup for the Dynatest FWD

Equipment

As described in Appendix A.

FWD Load Cell Calibration Procedure

1. If the reference load cell has not been calibrated within the last 12 months, then it should be recalibrated in accordance with the procedure given in Appendix D.

2. Initialize the computer data acquisition program. This will include entry of operator names, FWD serial number, FWD load cell serial number, and its current calibration factor.

3. Position the FWD so that the load plate is near the center of the calibration test pad, or on any other stiff, smooth surface. Verify that there is no sand or other loose debris under the reference load cell.

4. Attach the cable from the signal conditioner/data acquisition system to the reference load cell. Position the reference load cell beneath the FWD load plate, making sure that the three guides are aligned around the plate. Zero the

Table 1 - FWD Calibration Data Reporting Requirements

Data Item	Mode of Entry	Source[1]
FWD Operator Name	Manual	Operator
Calibration System Operator Name	Manual	Operator
Date and Time of Calibration	Automatic	Computer Clock
FWD Serial/ID Number	Manual	Operator
FWD Manufacturer	Manual	Operator
FWD Owner	Manual	Operator
FWD Load Cell Serial Number	Manual	Transducer Setup and Gain Printout
FWD Deflection Sensor Serial Numbers	Manual	Transducer Setup and Gain Printout
Reference Load Cell Serial Number	Automatic	Configuration File[2]
Reference LVDT Serial Number	Automatic	Configuration File[2]
FWD Calibration Center Location	Automatic	Configuration File[2]
Current Calibration Factor for FWD Load Cell	Manual	Transducer Setup and Gain Printout
Current Cal. Factors for FWD Deflection Sensors	Manual	Transducer Setup and Gain Printout
Ref. Load Cell Calibration Constants	Automatic	Configuration File[2]
Ref. Load Cell Calibration Date	Automatic	Configuration File[2]
Ref. LVDT Calibration Constants	Computed	FWDREFCL Software
Ref. LVDT Calibration Date	Automatic	FWDREFCL Software
FWD Load Cell Readings (20 total)	Manual	FWD Computer
Ref. Load Cell Readings (20 total)	Automatic	Calibration Data Acquisition System
FWD Deflection Readings (20 per sensor)	Manual	FWD Computer
Ref. LVDT Readings (20 per sensor)	Automatic	Calibration Data Acquisition System
Interim Cal. Factors from Reference Calibration	Computed	FWDREFCL Software
FWD Relative Calibration Data	Automatic	Relative Calibration Data Files
Calibration Factors from Relative Calibration	Computed	FWDCAL2 Software
Final Calibration Factors	Manual	Final Gain Worksheet

[1]For SHRP FWDs. Source may be different for FWDs from other manufacturers.

[2]Reference calibration configuration file (FWDREFCL.CNF).

signal conditioner with the load plate high, so that there is no external load on the reference load cell.

Note: For accurate results it is critically important that the reference load cell be zeroed with the FWD load plate in the raised position. Also, the signal conditioner excitation and gain must be set exactly to the levels at which the reference load cell was calibrated.

5. Complete the following sequence of drops, as shown in Figure 1, for a single test:

   3 seating drops at height 3 (data not recorded), followed by a pause

   5 drops at height 1, with a pause after each drop

   5 drops at height 2, with a pause after each drop

   5 drops at height 3, with a pause after each drop

   5 drops at height 4, with a pause after each drop except the last

   Stop after the last drop (plate remains down)

   As shown in Figure 1, it is useful to program six drops at each height, rather than five, so that one can be considered a "spare" in case a drop is missed by the reference system instrumentation. If the first five drops are successfully recorded, then the data for the sixth drop can be discarded.

   The plate should not be raised at any time during the sequence. Data from both the FWD load cell and the reference system should be recorded for all drops except the three seating drops.

6. Perform the load cell reference calibration twice. If the two calibration factors agree within 0.003, then the results of the two tests shall be averaged. If they are outside this limit, then a third calibration of the load cell shall be performed. If the standard deviation of the three results is less than ± 0.003 (based on n - 1 degrees of freedom), then the three results shall be averaged. If the standard deviation exceeds ± 0.003, then all three calibration factors shall be discarded and the load cell calibration procedure should be repeated.

7. Upon completion of the calibration testing, raise the FWD load plate and remove the reference load cell.

The presence of any one or more of the following conditions invalidates the load cell calibration test results.

- Excessive noise messages for drop heights 2, 3, or 4. (For the low drop height (e.g., the 6000-pound load level) there is seldom enough free-fall time for the vibration caused by the release of the mass to attenuate before the mass strikes the plate. Thus excess noise messages at the low drop height may, in general, be disregarded.) The noise, due either to electrical noise or mechanical vibrations, is of concern only if it results in an erroneous zero value or an erroneous peak reading. The time history graphs provided by the **FWDREFCL** software should be viewed to determine if the noise is of concern before rejecting the calibration.

- Standard deviations for the five readings at any drop height that differ by more than a factor of three between the reference system data set and the FWD data set.

- Standard error of the adjustment factor (see Reference Calibration Data Analysis) in excess of ± 0.0020.

- Failure to satisfy the repeatability criteria for multiple calibration tests.

Should any of these conditions occur, the load cell calibration test procedure must be repeated after identifying the source of the problem and correcting it.

FWD Deflection Sensor Calibration Procedure

1. Initialize the computer data acquisition program. This would include entry of the operator names, FWD serial number, FWD deflection sensor serial number, and its current calibration factor.

2. Clean the spring-loaded tip of the LVDT. Use a non-lubricating contact cleaner in a pressurized can to spray cleaner into the bearing sleeve until the tip goes in and out without noticeable friction. Check by working the tip in and out. The stroke should be smooth, without "bumps." If the LVDT cannot be made to operate smoothly do not continue with the calibration.

3. Use the micrometer calibrator to calibrate the LVDT. To do this, the LVDT should first be positioned in the calibrator and set to the null point (zero voltage output), with the micrometer set to 5 mm. The micrometer should then be advanced slightly beyond 7 mm, and returned to the 7 mm mark. Verify that the MetraByte board reads within ± 30 bits of -2000 bits. If necessary, adjust the Gain knob on the 2310 signal conditioner in increments

of 0.1 (for instance, from a setting of 1.50 x1 to a setting of 1.40 x1) to achieve the required reading. The LVDT voltage output and the micrometer reading (7 mm) should be recorded.

The micrometer should be moved in 0.5 mm increments to a final reading of 3.0 mm, with the micrometer reading and LVDT voltage output recorded at each 0.5 mm step. Turn the barrel of the micrometer in one direction only, to avoid errors due to backlash.

Analyze the resulting data using a linear regression to determine the coefficient m in the equation $Y = m X + b$, where Y is the position of the LVDT tip in microns, as measured by the micrometer, and X is the corresponding voltage output in bits, as read by the computer data acquisition board. (The FWDREFCL software provides prompts for this entire process, reads and records the requisite data, and performs the computations.)

The slope m will be approximately -1.00 microns per bit. The standard error of the slope should be less than $\pm$0.0010. If a larger standard error is obtained, the LVDT calibration should be repeated.

4. Enter the LVDT calibration results into the computer data acquisition system. (This is handled automatically by the FWDREFCL software.) After the calibration results are entered, the signal conditioner gain must not be changed.

5. Secure the LVDT in its holder on the reference system aluminum beam, so that it is near the null point (eg., zero voltage output). Verify with a spirit level that the LVDT is vertical in its holder. If it is not vertical, adjust the position of the aluminum beam to attain verticality. This may require shimming the beam where it is bolted to the concrete block.

6. Position the FWD trailer so that the load plate is as close as possible to the deflection sensor holder. It is important, however, that the FWD should not come in contact with the beam or any other part of the reference system during the testing.

7. Remove the deflection sensors from their holders on the FWD beam, and verify that they are free of dirt and grime which would adversely affect their seating in the reference system deflection sensor holder. Run the magnetic base over a piece of fine-grained emery paper that is placed on a firm, flat surface (such as the upper flange of the aluminum beam), to assure that it is clean.

8. Place one deflection sensor in the sensor holder, and position the LVDT holder so that the LVDT and the FWD sensor are aligned.

9. Place a second deflection sensor on top of the LVDT holder, so that it will measure the movement of the end of the beam (and hence, of the LVDT housing).

10. Complete the following sequence of drops, as shown in Figure 1, for a single test:

    3 seating drops at height 3 (data not recorded), followed by a pause

    5 drops at height 1, with a pause after each drop

    5 drops at height 2, with a pause after each drop

    5 drops at height 3, with a pause after each drop

    5 drops at height 4, with a pause after each drop except the last

    Stop after the last drop (plate remains down)

    As shown in Figure 1, it is useful to program six drops at each height, rather than five, so that one can be considered a "spare" in case a drop is missed by the reference system instrumentation. If the first five drops are successfully recorded, then the data for the sixth drop can be discarded.

    The plate should not be raised at any time after the seating drops. One complete FWD time history plot should be studied for the fifth drop at each drop height, to verify that the calibration beam does not move during the test period.

The presence of any of the following conditions invalidates the calibration data.

- Movement of the calibration beam, as measured by the deflection sensor resting on the top of the beam, prior to, or simultaneous with, the peak deflection reading from the device under test. It is entirely possible that there will <u>ultimately</u> be some movement of the beam, as the deflection wave passes under the concrete inertial block. The important criterion is whether the beam moved <u>prior</u> to the time that the deflection sensor on the ground registered its peak reading. Beam movement can be determined by inspection of the FWD time history data files. At the moment when the sensor being calibrated shows its peak reading the sensor on the reference beam should show no more than ±0.08 mils (±2 microns) of displacement.

- Excessive noise messages for drop heights 2, 3, or 4. (For the low drop height (eg., the 6000-pound load level) there is seldom enough free-fall time for the vibration caused by the release of the mass to attenuate before the mass strikes the plate. Thus excess noise messages at the low drop height may, in general, be disregarded.) The noise, due either to electrical noise or mechanical vibrations, is of concern only if it results in an erroneous zero value or an erroneous peak reading. The time history graphs, provided by the FWDREFCL software, should be viewed to determine if the noise is of concern before rejecting the calibration.

- Standard deviations for the five readings at any drop height that differ by more than a factor of three between the reference system data set and the FWD data set.

- Standard error of the adjustment factor (see Reference Calibration Data Analysis) in excess of ±0.0020.

Should any of these conditions occur, the calibration test for the deflection sensor must be repeated after identifying the source of the problem and correcting it.

Reference Calibration Data Analysis

1. Analyze the data as follows (calculations are done automatically by the FWDREFCL software):

   a. Perform a least squares regression forced through zero for all of the data for each measurement device (i.e., 20 pairs of data per test -- 5 replicates at each of 4 load levels). The result of this regression will be the coefficient for an equation of the form $Y = m X$, where Y represents the response of the reference system, X represents the response of the FWD measurement device, and m is the slope of the regression line. Both X and Y should be measured in the same system of units.

   b. The coefficient, m, determined in step A, represents the adjustment factor for the calibration factor in the FWD Field Program. The new calibration factor is computed by multiplying the former calibration factor by the coefficient m from step A. This is listed as the new calibration factor on the FWDREFCL report.

c. The standard error of the adjustment factor should be less than ±0.0020. If a larger standard error is obtained for any sensor, the reference calibration for that sensor should be repeated.

2. Enter the new calibration factors for all sensors (load and deflection transducers) in the FWD Field Program before continuing with the relative calibration. The new calibration factor for the FWD load cell is a "final" calibration factor, while the new calibration factors for the deflection sensors are "interim" factors, which will be further refined by doing relative calibration.

RELATIVE CALIBRATION PROCEDURE

General Background

Relative calibration of the FWD deflection sensors is used to ensure that all sensors on a given FWD are in calibration with respect to each other. As such, it serves as the final step in the overall FWD calibration process, and as a quick means to periodically verify that the sensors are functioning properly and consistently.

Relative calibration uses the relative calibration stand supplied by the FWD manufacturer. The sensors are stacked vertically in the stand, one above another, so that all sensors are subjected to the same pavement deflection. Relative calibration assumes that the overall mean deflection, as determined from simultaneous measurements by the full set of deflection sensors, yields an accurate estimate of the true deflection. This assumption requires that the deflection sensors must have first been subjected to the reference calibration procedure.

Some FWDs have fewer than or more than seven active deflection sensors. If they do, these procedures should be modified to calibrate the actual number of active sensors in use on the FWD.

Equipment

FWD relative calibration stand with as many positions as the number of active deflection sensors. For purpose of illustration a seven-position stand is assumed herein.

FWD relative calibration software (FWDCAL2) and documentation.

General Procedure

The process involves rotation of the seven deflection sensors through the seven positions in the calibration stand. Each combination of sensors and levels is considered a "set," and thus there are seven sets of data. The test point is "conditioned" before beginning the calibration procedure to reduce the possibility that set will be significant in the data analysis. The required order of movement of the sensors is shown in Table 2. Spare deflection sensors do not have to be calibrated until they are in active use.

Table 2 - Relative Calibration Sensor Positions by Set

Level in Sensor Stand	Deflection Sensor Number in the Stand						
Set:	1	2	3	4	5	6	7
(Top)							
A	1	2	3	4	5	6	7
B	2	3	4	5	6	7	1
C	3	4	5	6	7	1	2
D	4	5	6	7	1	2	3
E	5	6	7	1	2	3	4
F	6	7	1	2	3	4	5
G	7	1	2	3	4	5	6
(Bottom)							

Note: The rotation must be done as prescribed above in order for the software (FWDCAL2) to work properly. For instance, for Set 2, move Sensor 2 to the position formerly occupied by Sensor 1, etc.

When done in conjunction with reference calibration, the relative calibration procedure shall be repeated twice. Acceptance criteria based upon the repeatability of the calibration factor are identified in the relative calibration procedure. If the results persist in failing the acceptance criteria, then the cause of the erratic results should be identified and corrected.

After the relative calibration is completed, the final calibration factors shall be entered into the FWD computer.

A sample relative calibration setup screen for the Dynatest FWD with version 10 or version 20 software is given in Figure 2. The information in Figure 2 can also be used as the basis for setup of Dynatest FWDs running version 25 and higher software.

```
   Relative Calibration
1. Test UNITS...: lbf.mil.inch      (kPa.mu.mm)
2. Temperature..: Fahrenheit        (Centigrade)
3. Stn.Request..: OFF               (ON)
4. Test Checks..: NONE              (Decreasing defls, Roll-Off, RollOFF+Decr)
5. Reject prompt: OFF               (ON)
6. Stationing...: [doesn't matter]
7. Temp.Request.: OFF               (ON)
8. Cond.Request.: OFF               (ON)
9. Variation : Load NOT Checked !  Deflections NOT Checked !
10. Diameter of Plate: 11.8
11. Deflector distances: [doesn't matter - keep what you have]
                         1         2         3         4
12. Drop No.   : 1234567P8901234P5678901P2345678P9012345P6789012P3456789S.......
13. Heights*   : CC44444PCC44444PCC44444PCC44444PCC44444PCC44444PCC44444S1111111
14. Test Plots: ................................................................
15. Save Peaks: ..*****...*****...*****...*****...*****...*****...*****........
16. Load His. : ................................................................
17. Whole His.: ................................................................

18. Load another TEST SETUP.
19. Store the CURRENT TEST SETUP.

*Note: Drop height should be adjusted to attain deflections within the specified
range.
```

Figure 2: Relative Calibration Test Setup for the Dynatest FWD

Relative Calibration of the Deflection Sensors

1. Remove all of the deflection sensors from their holders on the FWD. Make sure that the sensors are labeled (e.g., from 1 to 7, or 0 to 6) with respect to their normal position on the FWD. The center sensor is in position number "1" on the Dynatest FWD and in position number "0" on the KUAB FWD.

2. Label the seven levels on the sensor stand from "A" to "G." The top level is usually labeled "A."

3. Position the seven deflection sensors in the stand for the first of the seven sets.

4. Support the sensor stand in a vertical position. Mark the location where the stand rests so that it can be relocated precisely on the same spot. This may be done by gluing a washer to the pavement, or by making a small divot in the pavement with a chisel.

5. Select the FWD drop height and the distance from the loading plate to the sensor stand to yield deflections on the order of 400 to 600 microns (16 to 24

mils). If deflections in this range cannot be achieved, then it may be necessary to relocate the FWD to a different pavement. In general, a concrete pavement on a relatively weak subgrade will yield the required deflection. In most cases the reference calibration test pad should be usable for relative calibration.

6. Warm up the FWD rubber buffers and condition the test point by repeating a sequence of ten drops until the loads and deflections that are registered are nearly uniform. The deflections in a sequence of ten drops should not be showing a steadily increasing or decreasing trend. If liquefaction or compaction is indicated by the warm-up data, relocate the FWD to another pavement.

7. Lower the FWD loading plate. DO NOT raise the loading plate or move the FWD during the relative calibration testing. This will assure a constant distance between the center of the load plate and the base of the sensor stand.

8. For each set make two seating drops (no data recorded) followed by five replicate drops (for which data is recorded) while holding the stand in a vertical position. With seven sets and 5 replicate drops, data for a total of 35 drops is required (see Figure 2).

Relative Calibration Data Analysis

A three-way analysis of variance should be used to evaluate the data. This will partition the variance into four sources: (1) that due to sensor number, (2) that due to position in the calibration stand, (3) that due to set, and (4) that due to random error of measurement. This analysis is performed by the FWDCAL2 software. In this analysis, deflection is the dependent variable, and sensor number, position and set are the three main factors. The three hypotheses that may be tested are:

H_0: Sensor number is a significant source of error

H_0: Data set number is a significant source of error

H_0: Position in the stand is a significant source of error

Through the use of hypothesis testing it is possible to determine whether random error due to sensor number, due to position in the calibration stand, and due to set number are statistically significant. The only factor that should result in a change in the deflection sensor calibration factors is sensor number.

If the random error due to sensor number is found to be statistically significant, then the calculated adjustments in the calibration factors for each sensor should be made. If a change is made in the calibration factor for one sensor, then the calibration factors for all sensors should be changed in accordance with the calculations.

If position in the stand is statistically significant, it is likely that the stand was not held vertical throughout all of the sets during the test. Or a connection in the stand may have been loose. The problem should be corrected, and the test should be repeated.

If set is statistically significant, there may have been a systematic change in the properties of the pavement materials, for instance due to compaction or liquefaction. The test should be repeated after the testing site has been further "conditioned" according to the procedure. If the deflection readings do not become relatively constant during the conditioning, then another site should be selected for the testing.

The mere fact that either position or set, or both, are significant does not necessarily invalidate the relative calibration. Judgement must be used to assess whether or not these factors may be of sufficient physical significance (as opposed to statistical significance) to require that the relative calibration should be repeated or that a new test site should be selected.

The standard error of measurement (e.g., the square root of the mean square error due to error) should be on the order of ±0.08 mils (±2 microns) or less if the system is working properly and the calibration test was conducted carefully.

The analysis of the data obtained from the relative calibration procedure and the method used to determine revised calibration factors is as follows (calculations are done automatically within the **FWDCAL2** software):

1. Compute the mean deflection measurement, x_i, for each sensor (average for the seven sets) and the overall mean, x_o, for all of the sensors averaged together.

2. Compute the adjustment ratio, R_i, of the overall mean to the sensor mean for each sensor.

$$R_i = \frac{x_o}{x_i}$$

Adjustment of Calibration Factors

When relative calibration is conducted in conjunction with reference calibration, the procedure is repeated two times. If the two sets of calibration factors agree within 0.003 for each deflection sensor, then the results of the two tests shall be averaged. If they are outside the limit, then a third relative calibration shall be performed. If the standard deviation of the three results (based on n - 1 degrees of freedom) is less than ± 0.003, then the three results shall be averaged. If the standard deviation exceeds ± 0.003, the relative calibration procedure should be repeated.

An example of the calculations following this procedure is shown in Appendix C. The average final calibration factors should be computed, and the factor for each deflection sensor should be entered into the FWD computer software (e.g., the "FWD Field Program").

When relative calibration is done alone, typically on a monthly basis, then adjustment of the calibration factors in the FWD Field Program should be made only when those changes are both significant, and verified to be necessary. The following guidelines are to be used to evaluate the need for adjustment to the calibration factors.

1. Computed sensor adjustment ratios, R_i, between 0.997 and 1.003 inclusive are considered to be equivalent to a ratio of 1.000. In other words the required adjustments are trivial and need <u>not</u> be made.

2. Where the adjustment ratios for one or more sensors fall outside of the range 0.997 to 1.003, the calibration process should be repeated. If both sets of data agree within 0.003, the gains should be adjusted for <u>all</u> sensors.

3. The final calibration factor is calculated by multiplying the current calibration factor for a given sensor, i, by its adjustment ratio, R_i.

   According to the recommendations of the FWD manufacturers, a final calibration factor less than 0.98 or greater than 1.02 is possibly indicative of a damaged sensor, which should be repaired by the manufacturer, or replaced. Final calibration factors that are within this range should be entered into the FWD data collection software.

4. If any calibration factors are changed, the relative calibration process must be repeated to verify the accuracy of the final values. The resulting adjustment ratios should be within the range 0.997 to 1.003 for all sensors. If they are not, the test procedure should be repeated.

Reports

The full FWD calibration report shall consist of the following:

- Printouts of the following Dynatest FWD Field Program screens (or equivalent for non-Dynatest FWDs).

- Transducer Setup and Calibration Factors
- Voltages
- Load Cell Calibration

Each of the above printouts is to be annotated with the FWD unit identification (e.g., manufacturer's serial number or agency ID), and the calibration date.

- All printouts from the **FWDREFCL** software

- The final printouts from the **FWDCAL2** software for all relative calibration trials.

- The Final Calibration Computation worksheet (see Appendix C)

Distribution of this report shall be as follows:

- Original retained by FWD operator for submission to his agency (LTPP Regional Engineer for LTPP FWDs).

- One copy transmitted to LTPP Division Office within one week of calibration.

- One copy retained on file by calibration center for a period of at least three years.

The diskettes on which the reference and relative calibration data are stored should be kept in the FWD. It is recommended that labeled backup copies be kept on file with the calibration report at the office out of which the FWD is operated. For the LTPP FWDs, additional backup copies of the calibration diskettes are to be kept on file at the LTPP Regional Office.

When relative calibration is done alone (e.g., as a monthly calibration check), the relative calibration report will consist of all printouts from the **FWDCAL2** software, annotated as necessary to explain any problems which might have been encountered.

THIS PAGE INTENTIONALLY LEFT BLANK.

APPENDIX A: REFERENCE CALIBRATION EQUIPMENT AND FACILITIES

I. Facilities

Indoor space with:

- easy access for FWD and towing vehicle
- level floor large enough so that both the FWD trailer <u>and</u> the towing vehicle can sit level during the test and be enclosed indoors
- reasonably constant temperature (between 50 and 100 F) and humidity (40-90 percent), heated, but not necessarily air conditioned
- good security for calibration equipment

Test pad:

- 15 feet by 15 feet, with an 8-foot wide clear zone around perimeter (for maneuvering FWDs and the reference data acquisition system)
- smooth, crack-free portland cement concrete surface. A modest amount of hairline cracking is permissible. Should the test pad develop cracks which are visibly open (1/16 inch or more), it should be replaced.
- isolated (by impregnated felt bond breaker, or sawed and caulked joint) from the area where the concrete inertial block supporting the aluminum reference beam will rest
- slab deflection of at least 16 mils due to 16,000 lb load at the position of the deflection sensor holder when the FWD is in the specified position for calibration. The sensor holder should be located not closer than two feet from the edge of the test pad, but it is not required, nor is it possible, that the test pad should deflect uniformly across the entire area of the pad. Because the inertial block supporting the aluminum reference beam must be placed adjacent to, but not on the calibration test pad, the maximum possible distance from the sensor holder to the edge of the test pad will be about five feet.

Note: Fatigue calculations indicate that acceptable fatigue life can be achieved with a 5-inch-thick portland cement concrete slab resting on an 8-inch open-graded crushed stone base. A layer of filter fabric should be placed below the base to protect it from intrusion of subgrade fines. To achieve adequate deflections, the subgrade modulus should be less than 12,000 psi (80 MPa) with bedrock deeper than 25-30 feet. Where bedrock exists at depths of 15 to 25 feet, a subgrade modulus of 7,500 psi (50 Mpa) or less will be needed. Test pads located where bedrock is less than 15 feet deep are likely to be very sensitive to minor variations in subgrade moisture, and hence are not advisable.

II. Equipment

- concrete inertial block (4,000 lbs.)
- 5-foot aluminum reference beam
- Air-Cel low frequency rubber isolation pads for support of the concrete block
- LVDT mounting hardware
- deflection sensor holder assembly
- magnetic tip for LVDT
- Schaevitz Model GCD-121-125, 0.125-inch stroke DC LVDT with Cannon connector
- Schaevitz metric LVDT calibrator C-41M
- Measurements Group, Inc. Vishay Model 2310 signal conditioner, with factory modification for +15 VDC and -15 VDC excitation
- Keithley-MetraByte Model DAS-16G A/D data acquisition board, with STA-16 screw terminal board and C-1800 ribbon cable. The G2 version of the data acquisition board is recommended for IBM PC-XT and PC-AT computers, and compatibles; the G1 version is acceptable. A Model μDAS-16G board should be used with IBM PS/2 (microchannel bus) computers.
- connecting cables, Vishay to LVDT and Vishay to MetraByte
- FWD reference calibration software (FWDREFCL) and documentation
- custom built reference load cell (300 mm diameter, 40,000 lbs. capacity)
- connecting cable, Vishay to load cell

Note: Drawings of each of the special items of equipment, and cabling diagrams, are available from the Long-Term Pavement Performance (LTPP) Division at the Federal Highway Administration, Turner-Fairbank Highway Research Center, McLean, Virginia.

IBM PC-XT or PC-AT, or compatible, computer recommended; IBM PS/2 computer acceptable. Configuration:

- 80386 processor or higher
- 25 MHz or faster processor speed
- co-processor, if applicable
- 1 megabyte or more RAM
- 100 megabyte or more hard drive
- an 8-bit expansion slot for the MetraByte board

Monitor:

- Color monitor; monochrome not recommended
- VGA recommended; EGA acceptable

Graphics Printer:

- Laser printer recommended; dot matrix acceptable, but very slow

(Where both "recommended" and "acceptable" options are given in the above specifications, an effort has been made in the software development to accommodate both alternatives. However, since most of the testing has been done on computer hardware meeting the "recommended" specifications, installation of the calibration station will go more smoothly if those specifications are met. A demonstration version of the **FWDREFCL** software is available from the LTPP Division in the Federal Highway Administration (located at the Turner-Fairbank Highway Research Center, McLean, VA) which can be used to determine if the computer and peripherals will work satisfactorily with the program.)

THIS PAGE INTENTIONALLY LEFT BLANK.

APPENDIX B: SPECIAL PROCEDURES FOR TESTING THE KUAB FWD

Reference calibration of the KUAB FWD can be carried out in a manner very similar to the procedure outlined for the Dynatest FWD. However, because the KUAB has its load plate forward of the deflection sensor beam (i.e., toward the towing vehicle), it will be necessary to place the trailer on an angle with respect to the test pad, so that the load plate can be positioned as close as possible to the LVDT and the deflection sensor holder. The end of the aluminum beam holding the LVDT should be just behind the trailer wheels, near the place where the "foot" of the KUAB A-frame rests on the floor.

KUAB FWDs must have operational program SFWD version 4.0 or higher to perform reference calibrations. This version can be obtained from the manufacturer.

Before the reference calibration procedure is performed, the FWD Operator should first conduct a static calibration of the deflection sensors. The KUAB software will automatically file the static calibration factors. The manufacturer recommends that the dynamic calibration factors be entered as 1.05 for all sensors. These values should not be changed during or after the reference calibration.

Due to the larger distance between the center of the load plate and the seismometer holder it may not be possible to achieve the specified deflection of 16 mils at 16,000 pounds. The deflection should be as large as possible.

To achieve the specified load levels the manufacturer recommends using Load Mode 3 (9+9 small buffers, 2 stack weights). Adjust the drop height endswitches as necessary to be within the load tolerances.

In general the KUAB will be tested with the 17-millisecond rubber buffers installed. The reference data acquisition system and the **FWDREFCL** software allow for calibration using the 25-millisecond buffers, but the movement of the aluminum beam should be checked carefully to assure that there is no motion before the ground deflection peaked out.

The **FWDREFCL** software contains an number of special features to accommodate the KUAB, and thus in initializing the software, the FWD type should be set for "KUAB." The deflection sensor that is mounted through the load plate (i.e., the center sensor) is called sensor number zero on the KUAB, and it is in position number 0 as far as **FWDREFCL** is concerned.

KUAB FWDs with version 4.0 software are able to pause during the drop sequence, prior to releasing the mass. This is achieved by entering the letter "P" after the drop height position code during programming of the drop sequence. For example, the required reference calibration drop sequence would be entered as follows (drop height, number of drops):

333(1P,6)(2P,6)(3P,6)(4P,6)

The pause occurs with the mass elevated, ready to drop. The mass will not be released until the FWD operator strikes a key.

To repeat the drop sequence without raising the load plate from the ground, strike the ESC key twice immediately following the final drop. This will interrupt the initial drop sequence, allowing a second drop sequence to be started without raising the plate.

Because the top of the reference load cell is 300 millimeters in diameter, it will only be possible to calibrate the small (300 mm) load plate on the KUAB. If the KUAB is outfitted with the large (450 mm) load plate, it should be replaced with the 300 millimeter load plate in order to attain accurate results.

A special holder is provided for mounting the KUAB seismometer under the LVDT. The Dynatest geophone holder should be removed and the KUAB holder bolted down in its place. The LVDT mounting plate that attaches to the end of the aluminum beam should be removed from its position under the beam and reinstalled on top of the beam. The KUAB deflection sensors will be slid upward off the two rods that hold them in position on the sensor beam in the trailer. Remove the tripod foot by loosening its holding screw, and then slip the deflection sensor over the peg on the holder under the LVDT. Tighten the holding screw firmly.

Conducting load plate calibration is particularly difficult on the KUAB, because it is hard to detect when the FWD mass has been released. To make this easier, a double layer (or thicker) of "duct tape" should be wrapped around the guide post (down which the runners under the falling mass roll), located an inch or two above the bottom of the stroke. The proper position for the tape can be found when the mass is at its lowest drop height. Adjust the KUAB load sensitivity in the reference system computer to a value of 5 to 10 bits. Remove the tape after completion of the reference calibration.

Enter the new calibration factors for the deflection sensors as the "SHRP Calibration Factors" under the Calibrate menu in the KUAB operational program. The calibration factor for the 300 mm load plate is entered in the same manner. The calibration factor for the large (450 mm) load plate should remain unchanged.

Most KUAB FWDs do not have a calibration stand for performing relative calibration. Thus it will not be possible to perform the relative calibration procedure as described herein. Limited experience in the calibration of KUAB FWDs has shown that the combination of static calibration and dynamic calibration may be adequate to yield a satisfactory calibration and accurate final calibration factors. However, relative calibration further refines the reference calibration factors, and it allows a monthly check of the accuracy of the deflection sensors. Thus it is highly recommended that a means of performing relative calibration with the KUAB FWD be developed.

APPENDIX C: SAMPLE COMPUTATION OF FINAL CALIBRATION FACTORS

Sensor	Final Calibration Factors From Relative Calibration Trial 1	Trial 2	Trial 3	Average Final Calibration Factors	Standard Deviation
1	1.014	1.011	1.015	1.013	0.0035
2	1.010	1.007	1.012	1.010	0.0035
3	1.012	1.010	1.013	1.011	0.0035
4	1.016	1.020*	1.012	1.016	0.0035
5	1.017	1.018	1.018	1.018	0.0035
6	1.008	1.012*	1.011	1.010	0.0035
7	1.012	1.012	1.009	1.011	0.0035

Notes:

1. If the results from the first two trials agree within 0.003 for each deflection sensor, then it is not necessary to perform a third test. Average the results of the first two trials, and enter the average final calibration factors in the FWD computer. In the example above, after Trial 2 the data marked (*) did not meet this criterion.

2. If three trials are performed, compute the mean and the standard deviation of the three results for each deflection sensor. If the standard deviations (based on n - 1 degrees of freedom) are all less than ±0.003, enter the average final calibration factors in the FWD computer. If any of the standard deviations exceed ±0.003, repeat the entire relative calibration test.

THIS PAGE INTENTIONALLY LEFT BLANK.

APPENDIX D: REFERENCE LOAD CELL CALIBRATION PROCEDURE

Introduction

The reference load cell is a precision instrument, capable of measuring loads within ±0.3 percent or better. Such a high degree of precision can be attained, however, only if this calibration procedure is followed exactly. It is essential that the reference load cell be calibrated using a universal testing machine that is properly maintained and accurately calibrated.

Frequency of Calibration

Calibration of the reference load cell should be performed at least once per year. It should also be performed immediately after any of the six Allen head screws that attach the load measurement links to the upper or lower plates of the reference load cell are loosened. Calibration would also be necessary if the load cell fails to pass the unbalanced zero test (within ±5 percent) as detected by the **FWDREFCL** program.

Equipment

- Universal testing machine. A static testing machine, hydraulic or screw-powered, with a load capacity of 120,000 pounds or more should be used for the reference load cell calibration. Although the reference load cell will only be calibrated to a capacity of 20,000 pounds, the higher capacity of the testing machine assures that the test frame will be adequately rigid. The testing machine should have several load ranges, among them a 0 - 20,000 pound range (slightly higher ranges, such as 0 - 24,000 pounds, etc., would be acceptable). Care must be taken to avoid overloading the reference load cell during its calibration.

  Note: Do not use a servo-controlled, closed-loop testing system such as a MTS machine for this purpose. In general such equipment does not provide the high degree of accuracy that is required for this calibration.

- Bearing blocks: special wood/aluminum bearing blocks.

- Measurements Group, Inc. Model 2310 Signal Conditioner. This should be the same signal conditioner that will be used in the reference calibration procedure.

- Keithley-MetraByte DAS-16G data acquisition board, installed in the same computer that is used for reference calibration.
- Push-button trigger for activating the data acquisition system.

The reference load cell and its cable, and the associated signal conditioner, data acquisition board and computer should be considered a system of instruments, which should be calibrated together and used together.

Calibration of Equipment

The universal testing machine should be calibrated according to ASTM procedure E-74 within twelve months prior to conducting this procedure. The device(s) used to calibrate the universal testing machine should be certified to be traceable to the National Institute for Science and Technology (NIST - formerly the National Bureau of Standards) calibration(s). The certificate of calibration provided for the universal testing machine should be used to develop an adjustment algorithm which will correct the indicated load on the universal testing machine to the NIST load. It is highly recommended that the reference load cell be calibrated soon after the universal testing machine is calibrated.

The MetraByte board should be calibrated according to the procedure described in the manufacturer's instruction manual. Its accuracy should be verified using a reference voltage source such as a 1.350 volt mercury cell (eg., camera battery in new condition).

The 2310 signal conditioner amplifier should be balanced according to the procedure described in the manufacturer's instruction manual. With the signal input terminals shorted together, at gain 100 the ac noise on the ±10 volt output terminals should be 1 millivolt or less.

Equipment Preparation

Inspect the reference load cell carefully before calibration. Verify that the cable and the Amphenol connectors are making proper contact in their sockets (eg., fitting and locking tightly). Make a continuity check to verify that there are no breaks in the wires. Verify that the Allen screws on the load cell are tight.

Note: The six Allen screws on the top and the bottom of the load cell were torqued to 100 lb.-in. and set with Locktite during assembly. These screws should not be loosened unless it is absolutely necessary. If any of the screws are loosened, they should be removed one at a time and their threads cleaned. Locktite should be reapplied to their threads, and they should be torqued to precisely 100 lb.-in.

Verify that the three steel pads on the bottom of the reference load cell are in good condition. Verify that one of the wood/aluminum bearing blocks has a ribbed rubber pad cemented to it. If the edges of the rubber pad are loose, use rubber cement to reattach it.

Install a spherically-seated bearing block in the cross head of the universal testing machine.

Make the following settings on the front panel of the 2310 signal conditioner:

- Excitation Voltage set to 10 volts
- Filter set to 1000 Hz
- AC IN button fully extended (eg., out)
- Gain set to 5.5 x100
- Auto Balance switch OFF

Verify that the Tape Playback switch on the rear panel of the signal conditioner is OFF. Position the signal conditioner and the computer several feet apart near the testing machine and attach them to ac line power.

Computer Preparation

Use the same computer system for reference load cell calibration that is used for FWD calibration. A graphics printer must be available.

Load the software **LDCELCAL** into the reference system computer. This program should be located in the same subdirectory with **FWDREFCL.EXE** and **FWDREFCL.CNF.** A disk with the files **REFLCCAL.WK1** and **REFLCCAL.FMT** on it should be inserted in drive A. The computer must be running under **DOS** and not under **WINDOWS** during the calibration.

The computer program **LDCELCAL** is designed to interact with a Lotus 1-2-3, version 2.3, spreadsheet to accomplish the data analysis. The subdirectory containing the 1-2-3 program must be on the PATH in order for the two programs to work together successfully. The **WYSIWYG** add-in utility should be installed according to the Lotus directions. Defaults in Lotus 1-2-3 should be set as follows.

- Default directory: A:\
- Auto-execute macros: on

- Auto-attach add-in #1: C:\LOTUS\WYSIWYG

See the Lotus User's Manual for instructions regarding setting the defaults. If the program is correctly installed and set up, the data analysis will be run, a listing of the data will be produced, and graphical output will be printed automatically. A demonstration version of LDCELCAL is available to use with Lotus 1-2-3 to verify that your computer system can interact properly with the program.

Calibration Procedure

1. Attach the cable from the signal conditioner to the reference load cell, turn on the signal conditioner, and allow the system to warm up for at least 15 minutes. Attach the cables connecting the signal conditioner to the computer. Attach the push-button trigger in the blue terminal box of the MetraByte data acquisition system. Turn on the computer and the printer. If an hydraulic universal testing machine is used, turn the pump on and allow it to warm up for 15 minutes.

2. Place a wood/aluminum bearing block with no rubber pad in the center of the testing machine platen.

3. Place the reference load cell on top of the bearing block with the three steel pads down (i.e., in contact with the top surface of the lower bearing block).

4. Place the second bearing block on top of the load cell with the cemented rubber pad down (i.e., in contact with the top surface of the load cell).

5. Carefully align the edges of the load cell and the two bearing blocks, and center the system under the upper loading block of the universal testing machine.

6. Set the testing machine on a range equal to or slightly larger than 20,000 pounds. Apply a nominal load of 20,000 pounds to the reference load cell three times. Apply the load at a rate in the range of 5,000 to 20,000 pounds per minute.

7. Temporarily remove the upper wood/aluminum bearing block. Set the Auto Balance switch on the 2310 signal conditioner to OFF. Read and record the unbalanced zero voltage. If this voltage is in excess of ±5 volts the load cell has been damaged by yielding and it should be returned to the manufacturer for repair.

8. Push down the Auto Balance switch on the signal conditioner to the RESET position and release it to the ON position. Adjust the Trim knob until the MetraByte board reads 0 bits.

9. Replace and align the upper bearing block, rubber pad down. Verify that the three guide fingers do not come in contact with the upper bearing block.

10. Apply a load of 20,000 pounds, and while it is held relatively constant verify that the MetraByte board reads within ±30 bits of -2000 bits. If necessary, adjust the Gain knob on the 2310 signal conditioner in 0.1 increments (for example, from a setting of 5.50 x100 to 5.40 x100) to achieve the required reading. Release the load. Record the gain setting.

    Note: When the load is released the MetraByte board will not read exactly zero because it was zeroed without the upper bearing block in place. Do not rezero the signal conditioner at this point.

11. Apply load at a rate no faster than 1,000 pounds per minute. Record the MetraByte board readings at 1,000 pound intervals up to a maximum load of 20,000 pounds. While releasing the load, record a reading at 10,000 pounds and at zero load.

12. Remove the upper bearing block and, if necessary, adjust the Trim knob on the signal conditioner until the MetraByte board reads 0 bits. Push and hold the Cal switch in the +B position and record the reading. Repeat for the -B position. Set the Auto Balance switch to OFF and again record the unbalanced zero voltage. This reading should be within three bits of the earlier reading. If it is not, repeat the calibration procedure from step 4 (be sure that the load cell is centered in the testing machine, and be sure to repeat the 20,000-pound preloading procedure in step 6).

Data Analysis

Using a spreadsheet utility program such as Lotus 1-2-3, enter the results of the calibration. In column A enter the nominal loads registered by the universal testing machine (i.e., 0, 1000, 2000, etc.). In column B correct these loads to the NIST traceable loads, based on the certificate of calibration for the testing machine. In column C subtract the tare weight of the upper bearing block from the loads in column B. In column D enter the MetraByte board readings in bits. Note that the readings are negative. In columns E, F, G and H calculate V^2, V^3, V^4, and V^5, respectively (where V represents the readings in column D).

Use the spreadsheet regression utility to calculate a linear regression of corrected load (as the Y-variable) versus bits (as the X-variable). The regression should be forced through zero, yielding an equation of the form $Y = m V$, where Y is the corrected load (column C), V is the voltage (column D), and m is the slope of the line of best fit. The coefficient m should be approximately -10 pounds per bit.

Use the regression utility to calculate a fifth degree polynomial regression of the form:

$$Y = A_1 V + A_2 V^2 + A_3 V^3 + A_4 V^4 + A_5 V^5$$

where the coefficients A_i are determined by the regression. Evaluate the polynomial solution according to the following criteria.

1. The standard error of the Y estimate should be less than ±50 pounds.

2. The standard error of each of the coefficients should be small with respect to the coefficient. Generally speaking the coefficient should be at least a factor of ten larger than its standard error. For instance, if the coefficient A_2 is -0.15, its standard error should be ±0.015 or smaller. If this is not the case, the regression coefficient is not significant.

If the standard error any of the coefficients is too large (eg., not significant), repeat the regression using a fourth degree polynomial of the form:

$$Y = A_1 V + A_2 V^2 + A_3 V^3 + A_4 V^4$$

Again evaluate the polynomial according to the criteria in 1 and 2 above. When the evaluation criteria are satisfied, and all of the coefficients are significant (usually this will happen with either a fourth degree polynomial or a third degree polynomial), record the regression coefficients.

Enter the Regression Coefficients in FWDREFCL

The regression coefficients should be entered in the data acquisition program FWDREFCL. Instructions for doing this can be found in the Load Cell Setup section of the FWDREFCL User's Guide. Any of the unused higher order terms should have their coefficients entered as 0.0.

When the regression coefficients are entered in FWDREFCL, the unbalanced zero, the +B and -B calibration factors, the load cell signal conditioner gain factor, and the date of calibration should also be entered.

APPENDIX B

FWD TESTING GUIDELINES FOR SPS EXPERIMENTS

Appendix B-1
FWD TESTING GUIDELINES
FOR SPECIFIC PAVEMENT STUDIES (SPS) EXPERIMENT 1
STRATEGIC STUDY OF STRUCTURAL FACTORS
FOR FLEXIBLE PAVEMENTS

INTRODUCTION

This appendix provides guidelines and information specific to Falling Weight Deflectometer (FWD) testing at individual test sites for the Long Term Pavement Performance (LTPP) study experiment SPS-1, "Strategic Study of Structural Factors for Flexible Pavements". The intent of this document is to establish the specific testing requirements for SPS-1 sites based on a uniform set of assumptions. It is recognized that not all sites will conform to all assumptions contained herein. However, the objectives and approach to deflection data collection must be consistent so data obtained can be analyzed in a consistent manner. For deflection testing details not specifically addressed in the appendix, refer to the general guidelines in this manual.

The objective of the SPS-1 experiment is to define the relative influence of structural factors affecting performance of flexible pavements. The primary structural factors addressed include pavement subsurface drainage, base type, and pavement layer thickness. The study will help determine the influence of environmental conditions and soil type on these factors. Results of the SPS-1 experiment will improve design and construction of new and reconstructed flexible pavements. Characterization of materials and environmental conditions between test sections is required to explain performance differences and provide a basis for improved flexible pavement design.

In contrast to the LTPP General Pavement Studies (GPS), SPS has controlled construction of multiple test sections at a single site. On a SPS-1 site, there are 12 test sections. Experiment sites should conform to criteria contained in "Specific Pavement Studies Guidelines for Nomination and Evaluation of Candidate Projects for Experiment SPS-1, Strategic Study of Structural Factors for Flexible Pavements", February 1990. The site characteristic affecting FWD testing is the number of test sections.

LTPP test sections in a SPS-1 experiment are tested the same after construction regardless of cross section. Location of test sections should avoid cut/fill transitions, bridges, culverts, and side hill fills to limit the potential for variability of subgrade soils. Unlike other GPS and SPS experiments, no TPs are excavated for SPS-1 since a thorough quality control program is performed during construction.

FWD TEST PLAN

General

FWD testing for SPS-1 is performed during construction (labelled as "DURING"), 3 to 6 months after construction (labelled as "AFTER"), and annually more than 6 months after construction (labelled as "LONG TERM"). The "AFTER" testing verifies material properties of the as-built pavement for evaluating the effectiveness and long term performance of the section. "LONG TERM" testing evaluates the effect of temperature, moisture changes and traffic loading on pavement deflections and performance.

The specific FWD test plan for SPS-1 is similar to the Flex Testing Plan for GPS. The factors inherent within this test plan are:

1. Test Point ID (F1 and F3)
2. Lane for Each FWD Pass (Transverse Location)
3. Test Interval (Longitudinal Location)
4. Test Type (Basin)
5. Deflection Sensor Spacing
6. Drop Sequence (Load Levels/Number of Drops)

All FWD testing is done in the driving lane at two lateral offsets. The two lateral offsets are the ML and OWP as defined in the GPS portion of this manual. For a given lateral offset, a single pass through the test section is made to collect a particular type of deflection data. When finished with a particular pass, the FWD returns to the beginning of the section to start another pass. <u>All</u> testing uses station 0+00 of the <u>test section</u> (not the SPS project site) as the distance reference so FWD test point locations can be located for future testing.

Naming Scheme/Data Storage

A unique 6 digit code identifies the individual test sections at an SPS-1 site (similar to that for the GPS sections), with the fourth character being "1" for SPS-1.

The computer filenames are identical to those used in the GPS testing, with the 6 character test section code followed by two characters indicating the times a section has been tested and the number of the pass within the section. The "times tested" (character #7) is a single letter which corresponds to the number of times the section has been tested. Characters A and B are reserved for "BEFORE" and "DURING" construction testing on SPS experiments (<u>not used in SPS-1 testing</u>); all SPS testing uses letter C as the first "AFTER" construction testing; and, letter D as the first "LONG TERM" testing. The "pass" (character #8) is 1 for ML testing and 3 for OWP testing as used for GPS testing. For example, files from "AFTER" FWD testing of section 2 at an SPS-1 site in Iowa would be: 190102C1 and 190102C3.

Test Pit Areas

The SPS-1 experiment has no test pits. Therefore, pass P_0 testing is <u>not</u> performed in SPS-1.

Test Point Identification

FWD operators must properly record longitudinal distances with the distance measuring instrument relative to 0+00 station reference for each section, and follow the guidelines for lateral offset for the OWP and ML passes, so all FWD testing can be repeated in the same general location.

Detailed Test Plan (Test Sections)

For SPS-1 test sections, FWD testing procedures do not vary between "AFTER" and "LONG TERM" testing.

"AFTER" and "LONG TERM" Testing: All sections in SPS-1 are tested similar to the GPS FLEX Testing Plan except that the number of tests is reduced.

The test plan includes 11 FWD tests on each pass down the test section for both the ML and the OWP. Deflection Basin tests begin at station 0+00 and continue to station 5+00 at 50' intervals. Tests at ML use the lane specification F1 and tests in the OWP use the lane specification F3. Figure B-1.1 indicates the test locations for a section. Each section has 22 test points for a total of 264 test points for a project. At a rate of 20 points per hour, the FWD testing will take about 13 hours. With about 30 minutes per section for temperature gradient measurements, the total time for all tasks will be approximately 19 hours.

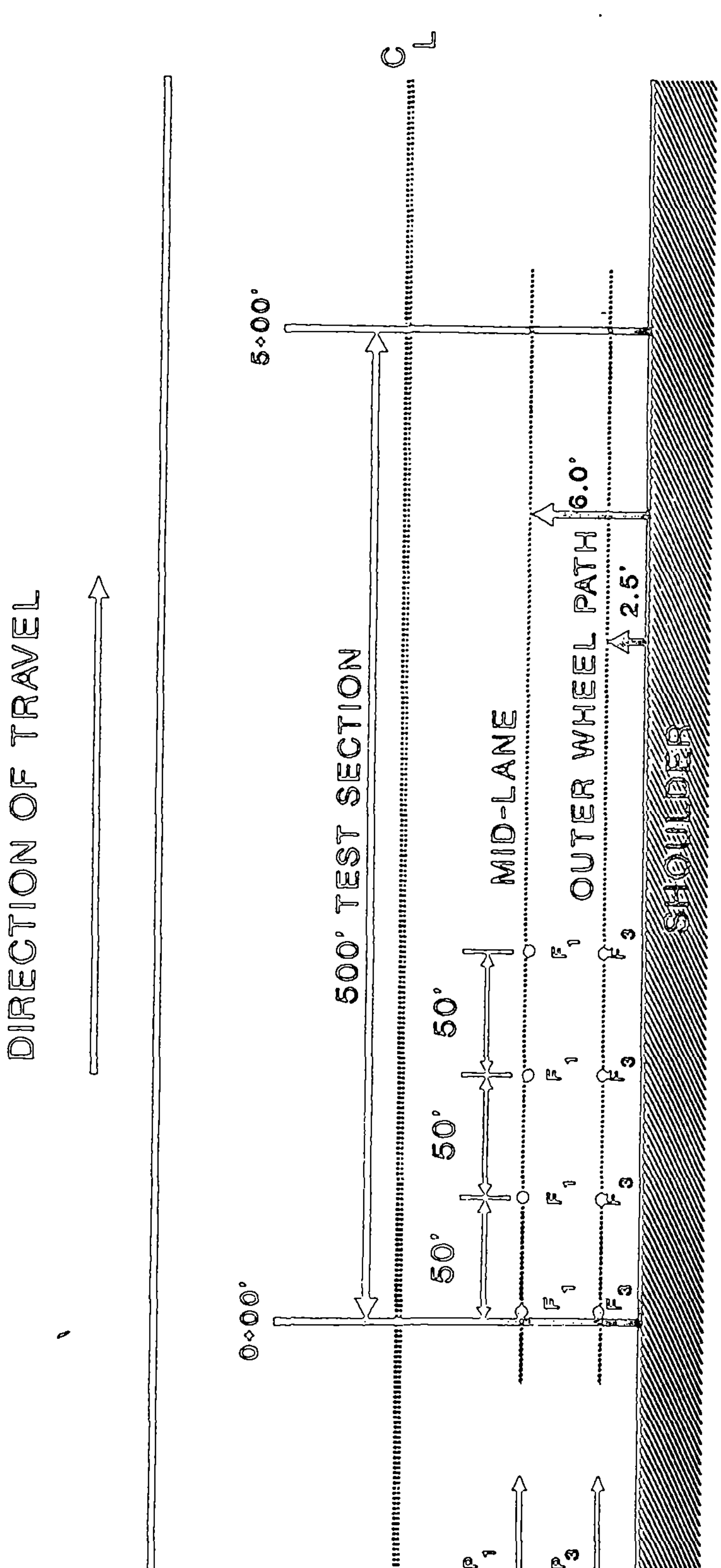
FWD operators must use their best judgement and carefully note any abnormal conditions or unique situations encountered in the field. However, only 22 points should be tested on a given section.

Other FWD Operator Field Measurements

Temperature Gradient Measurements

Temperature gradient measurements for SPS-1 sites are obtained similar to that for GPS sections, with the two exceptions below.

> Measurements are obtained at only one location for each test section. It is up to the FWD operator to assess variations in sun exposure and wind conditions to select the most representative location adjacent to the section limits for temperature measurements.



NOTE: LATERAL OFFSETS SHOWN REPRESENT NOMINAL DISTANCES.

FIGURE B - 1.1 FWD TEST PLAN FOR SPS-1 SECTIONS.

Temperature readings at SPS-1 sites are obtained at 30 minute intervals, with the first readings prior to starting FWD testing on the section and the last readings after completion of the FWD testing the section.

Crack Widths

For any SPS-1 site, no crack opening measurements are made; however, FWD operators must record pavement distress at test point locations as described in guidelines for GPS testing using the F6-Comment key.

THIS PAGE INTENTIONALLY LEFT BLANK

Appendix B-2
FWD TESTING GUIDELINES
FOR SPECIFIC PAVEMENT STUDIES (SPS) EXPERIMENT 2
STRATEGIC STUDY OF STRUCTURAL FACTORS
FOR RIGID PAVEMENTS

INTRODUCTION

This appendix provides guidelines and information specific to Falling Weight Deflectometer testing at individual test sites for the Long Term Pavement Performance (LTPP) study experiment SPS-2, "Strategic Study of Structural Factors for Rigid Pavements." The intent of this document is to establish the specific testing requirements for SPS-2 sites based on a uniform set of assumptions. It is recognized that not all sites will conform to all assumptions contained herein. However, the objectives and approach to deflection data collection must be consistent so data obtained can be analyzed in a consistent manner. For deflection testing details not specifically addressed in the appendix, refer to the general guidelines in this manual.

The objective of the SPS-2 experiment is to define the relative influence of structural factors affecting performance of rigid pavements. The primary structural factors addressed include pavement subsurface drainage, base type, concrete strength and thickness, and lane width. Secondary factors addressed in the study include load transfer, joint orientation, and steel reinforcement. The study will determine the influence of environmental conditions and soil type on these factors. Results of the study will improve design and construction of new and reconstructed rigid pavements. Characterization of materials and environmental conditions between test sections is required to explain performance differences between test sections and provide a basis for improved rigid pavement design.

In contrast to the LTPP General Pavement Studies (GPS), SPS has controlled construction of multiple test sections at a single site. The main SPS-2 experiment has jointed plain concrete with 15 foot joint spacings, supplemental experiment SPS-2A has jointed plain concrete using undoweled skewed joints at variable spacings, and supplemental experiment SPS-2B has jointed reinforced concrete with 30 foot joint spacings. The main SPS-2 experiment has 12 test sections, SPS-2A has 6 sections, and SPS-2B has 8 sections. The supplemental experiments are built in conjunction with the main experiment site, and are never constructed as individual projects. Therefore, SPS-2 projects have a minimum of 12 sections and up to 18 or 26 sections if one or both of the supplemental experiments are constructed.

Experiment sites should conform to criteria contained in "Specific Pavement Studies Guidelines for Nomination and Evaluation of Candidate Projects for Experiment SPS-2, Strategic Study of Structural Factors for Rigid Pavements", April 1990. The project characteristic affecting FWD testing is the number of test sections.

LTPP test sections in a SPS-2 experiment are tested the same regardless of cross section. Location of test sections should avoid cut/fill transitions, bridges, culverts, and side hill fills to limit the potential for variability of subgrade soils. Unlike other GPS and SPS experiments, no Test Pits are excavated for SPS-2 since a thorough quality control program is performed during construction.

FWD TEST PLAN

General

FWD testing for SPS-2 is performed during construction (labelled as "DURING"), 3 to 6 months after construction (labelled as "AFTER"), and annually more than 6 months after construction (labelled as "LONG TERM"). The "AFTER" testing verifies material properties of the as-built pavement for evaluating the effectiveness and long term performance of the section. "LONG TERM" testing evaluates the effect of temperature, moisture changes and traffic loading on pavement deflections and performance.

Deflection Basin tests as well as Load Transfer tests will be used in the SPS-2 testing. The specific FWD test plan for SPS-2 is similar to the JCP Testing Plan for GPS. The factors inherent within this test plan are:

1. Test Point ID Number (J1, J2, J3, J4, J5, J7, and J8)
2. Lane for Each FWD Pass (Transverse location)
3. Test Interval (Longitudinal location)
4. Test Type (Basin or Load transfer)
5. Deflection Sensor Spacing
6. Drop Sequence (Load Levels/Number of Drops)

All FWD testing is done in the driving lane at three lateral offsets. For each lateral offset, a single pass through the test section is made to collect a particular type of deflection data. When finished with a particular pass, the FWD returns to the beginning of the section to start another pass. All testing uses station 0+00 of the test section (not the SPS site) as the distance reference so all FWD test point locations can be located for future testing.

Three lateral (transverse) testing passes will be employed for 12 foot lanes, with one additional pass for sections having a 14 foot lane. For SPS-2 a "Pavement Edge" is the shoulder-pavement interface for 12 foot lanes and the outer edge of the painted shoulder stripe on 14 foot lanes (widened pavement lanes). For widened lane construction a "Widened Lane Edge" is defined as the outer edge of the pavement slab. The four passes are:

1. ML (Mid Lane) - located 6.0' ± 0.5' (1.8 m ± 0.15 m) from the edge reference
2. OWP (Outer Wheel Path) - located 2.5' ± 0.25' (0.76 m ± 0.08 m) from the edge reference
3. PE (Pavement Edge) - Edge of load plate should be less than 3" (76 mm) from the edge reference
4. WLE (Widened Lane Edge) - Edge of load plate should be less than 3" (76 mm) from the outside edge of the slab. (Notes: (1) This pass applies only to sections built with 14 foot lane width, (2) FWD tests at the WLE are actually on the shoulder and not the driving lane.)

FWD operators must insure that the tests are located within the above tolerances. The FWD operators are not expected to measure the position of each test point, but excessive deviations must be avoided, particularly for pavement edge and corner testing.

Testing widened lane construction in SPS-2 includes WLE testing, in addition to PE testing. Pass 4, P_4, has been assigned for WLE testing on sections with 14 foot lane width for doing one corner test and one mid-panel test on this pass. The following list of lane specifications are used to identify the type and location of tests performed.

"JPC" Category Pavements

J0	NOT USED ON SPS-2
J1	all tests in the mid-lane pass (P_1)
J2	corner tests in the pavement edge pass (P_2)
J3	mid-panel tests in the pavement edge pass (P_2)
J4	approach slab tests in the outer wheel path pass (P_3)
J5	leave slab tests in the outer wheel path pass (P_3)
J7	corner tests in the widened lane edge pass (P_4)
J8	mid-panel tests in the widened lane edge pass (P_4)

Lane specifications J7 and J8 are on the shoulder, outside the edge stripe.

Naming Scheme/Data Storage

A unique 6 digit code identifies the individual test sections at an SPS-2 site (similar to that for the GPS sections), with the fourth character being "2" for SPS-2.

The computer filenames are identical to those used in the GPS testing, with the 6 character test section code followed by two characters indicating the times a section has been tested and the number of the pass within the section. The "times tested" (character #7) is a single letter which corresponds to the number of times the section has been tested. Characters A and B are reserved for "BEFORE" and "DURING" construction testing on SPS experiments (<u>not used in SPS-2 testing</u>); all SPS testing uses letter C as the first "AFTER" construction testing; and, the letter D as the first "LONG TERM" testing. The "pass" (character #8) is 1 for ML testing, 2 for PE testing, 3 for OWP testing, and 4 for WLE testing as used for GPS testing. For example, files from "AFTER" FWD testing of section 3 (14 foot lane) at an SPS-2 site in Iowa would be: 190203C1, 190203C2, 190203C3 and 190203C4.

Test Pit Areas

The SPS-2 experiment has no test pits. Therefore pass P_0 testing is not performed in SPS-2.

Test Point Identification

FWD operators must properly record longitudinal distances with the distance measuring instrument relative to 0+00 station reference for each section, and follow the guidelines for lateral offsets for the WLE, PE, OWP and ML passes, so all FWD testing can be repeated in the same general location.

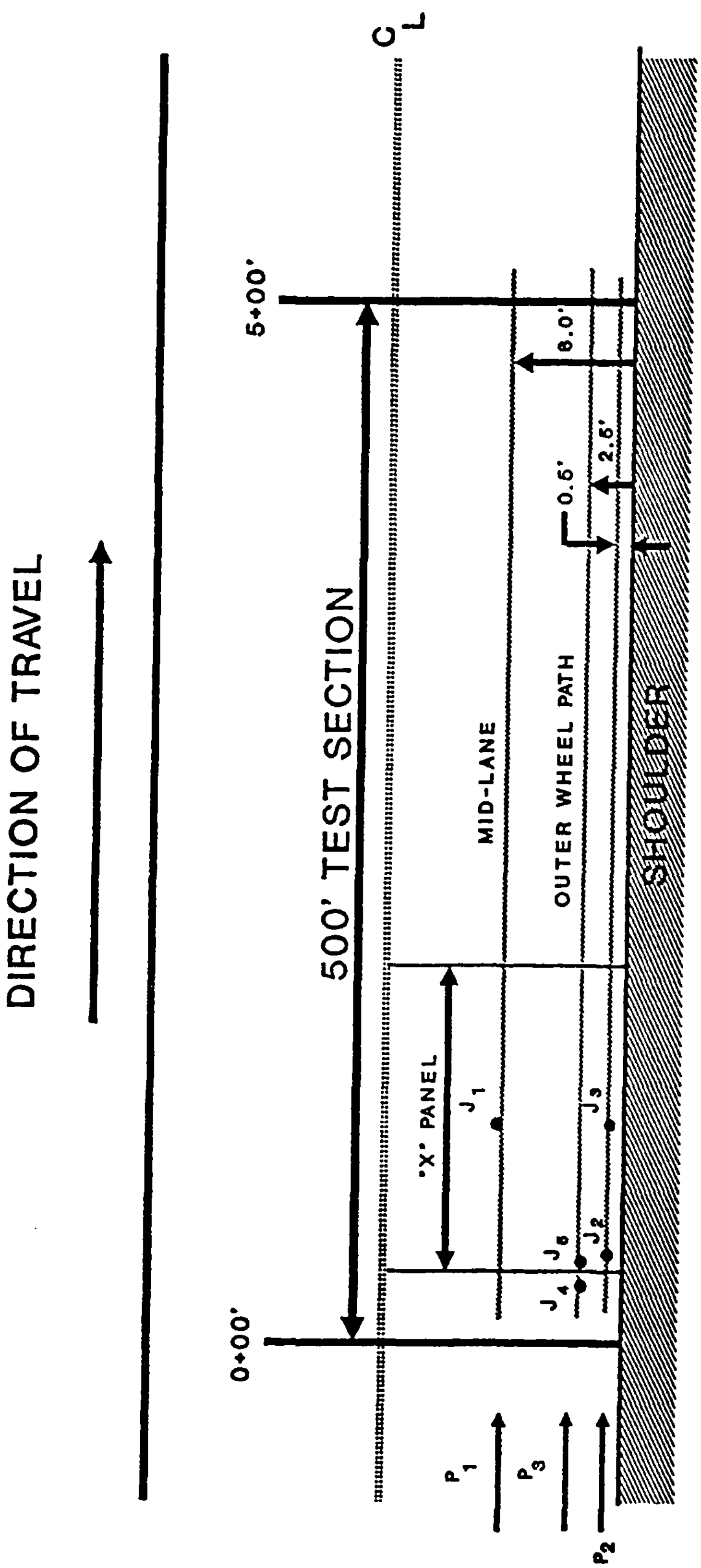
Detailed Test Plan (Test Sections)

For SPS-2 test sections, FWD testing procedures do not vary between "AFTER" and "LONG TERM" testing.

"AFTER" and "LONG TERM" Testing: All sections in SPS-2 are tested similar to the GPS JCP Test Plan except that the number of tests is reduced.

There are 5 FWD tests performed in each slab tested on 12 foot lanes. An additional 2 FWD tests are required in each slab for the widened lanes (a total of 7 tests). These include three Deflection Basin tests -- one in the center of the slab (J1), one at the leave slab corner (J2) and one at midslab at the edge of the pavement (J3) -- and two Load Transfer tests -- one on the approach side of the joint (J4) and one on the leave side of the joint (J5). For widened lanes two additional Deflection Basin tests are taken -- one along the approach corner (J7) and one midslab at the physical edge of the slab (J8). Figures B-2.1 and B-2.2 show the position of the test locations for the 12 and 14 foot lane widths, respectively. Each test section will have 10 slabs tested for a total of 50 FWD points for 12 foot lanes and 70 for the widened lanes. For the main SPS-2 experiment this totals 720 test points. At a rate of 20 points per hour, the FWD testing will take about 36 hours. With about 30 minutes per section for temperature gradient measurements, the total time for all tasks will be about 42 hours. FWD testing and temperature measurements for SPS-2A would add an additional 360 test points (about 21 hours), while SPS-2B would add 480 test points (about 28 hours).

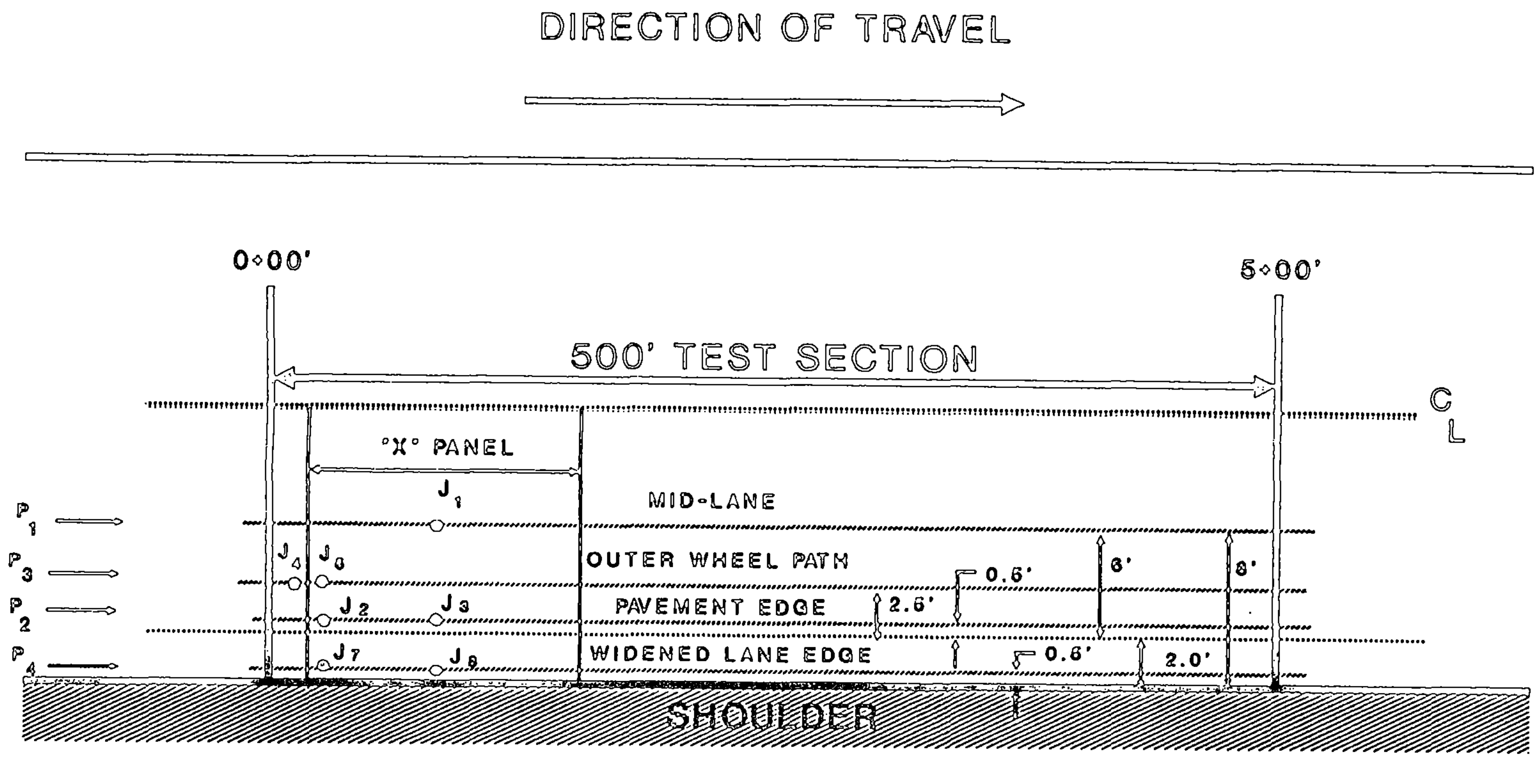
FWD operators must use their best field judgement in the slab selection process and carefully note any abnormal conditions or unique situations encountered in the field. However, only 10 slabs should be tested on a given test section.



NOTE: FIVE TEST POINTS PER PANEL DONE IN THREE PASSES.

NOTE: TEN PANELS SHOULD BE TESTED ON ALL SECTIONS.

FIGURE B - 2.1 FWD TEST PLAN FOR TESTING - 12 FT. LANE.



NOTE: TEN PANELS SHOULD BE TESTED ON ALL SECTIONS.

NOTE: SEVEN TEST POINTS PER PANEL DONE IN FOUR PASSES.

NOTE: LANE SPECIFICATIONS J_7 AND J_8 ARE ON SHOULDER.

NOTE: LATERAL OFFSETS SHOWN REPRESENT NOMINAL DISTANCES.

FIGURE B - 2.2 FWD TEST PLAN FOR ALL TESTING - 14 FT. LANE.

Other FWD Operator Field Measurements

Temperature Gradient Measurements

Temperature gradient measurements for SPS-2 sites are obtained similar to that for GPS sections, with the two exceptions below.

> Measurements are obtained at only one location for each test section. It is up to the FWD operator to assess variations in sun exposure and wind conditions to select the most representative location adjacent to the section limits for temperature measurements.
>
> Temperature readings at SPS-2 sites are obtained at 30 minute intervals, with the first readings prior to start of FWD testing on the section and the last readings ending after completion of the FWD testing on the section.

Joint/Crack Widths

Joint and crack opening measurements for SPS-2 sites are obtained as defined in the JCP Testing Plan for GPS.

THIS PAGE INTENTIONALLY LEFT BLANK

Appendix B-3
FWD TESTING GUIDELINES
FOR SPECIFIC PAVEMENT STUDIES (SPS) EXPERIMENT 3
PREVENTIVE MAINTENANCE EFFECTIVENESS
OF FLEXIBLE PAVEMENTS

INTRODUCTION

This appendix provides guidelines and information specific to Falling Weight Deflectometer testing at individual test sites for the Long Term Pavement Performance (LTPP) study experiment SPS-3, "Preventive Maintenance Effectiveness of Flexible Pavements." The intent of this document is to establish the specific testing requirements for SPS-3 sites based on a uniform set of assumptions. It is recognized that not all sites will conform to all assumptions contained herein. However, the objectives and approach to deflection data collection must be consistent so data obtained can be analyzed in a consistent manner. For deflection testing details not specifically addressed in the appendix, refer to the general guidelines in this manual.

The objective of the SPS-3 experiment is to compare the effectiveness and mechanisms by which selected maintenance treatments preserve or extend pavement service life, driver safety and ride quality on asphaltic concrete pavements. The impact of materials or construction process is not a part of this study. In addition, the overall goal is to compare the performance of treated sections to untreated sections. The impact of a preventive maintenance treatment is based on the process or type of treatment; e.g., a slurry seal. Process parameters for material, design, and construction specification known to work reasonably well in each individual climatic zone were selected.

The primary factors addressed in the experimental design include moisture and temperature conditions, subgrade type, and traffic loading. The secondary factors include the individual treatments: crack sealing, chip seal, slurry seal, and thin overlays. Other second level factors include pavement condition at the time the treatment is placed and the structural capacity of the pavement for the traffic loads applied to the pavement.

FWD TEST PLAN

General

The LTPP test sections in an SPS-3 experiment are tested the same before and after maintenance regardless of treatment. The site characteristic affecting FWD testing is the number of sections.

FWD testing is performed 0 to 3 months prior to application of the maintenance treatment (labelled as "BEFORE"), 3 to 6 months after application of the maintenance treatment (labelled as "AFTER"; not required), and biannually more than 6 months after the application of the maintenance treatment (labelled as "LONG TERM"). In addition, sections should be tested just prior to removal of the section from the experiment.

The specific FWD test plan to be implemented will be similar to the GPS Operational Category FLEX. The factors inherent within this test plan are:

1. Test Point ID (F1, F3)
2. Lane for Each FWD Pass (Transverse Location)
3. Test Interval (Longitudinal Location)
4. Test Type (Basin)
5. Deflection Sensor Spacing
6. Drop Sequence (Load Levels/Number of Drops)

All FWD testing is done in the driving lane at two lateral offsets. The two lateral offsets are the ML and OWP as defined in the GPS portion of this manual. For a given lateral offset, a single pass through the test section is made to collect a particular type of deflection data. When finished with a particular pass, the FWD returns to the beginning of the section to start another pass. <u>All</u> testing uses station 0+00 of the <u>test section</u> (not the SPS project site) as the distance reference so FWD test point locations can be located for future testing.

Naming Scheme/Data Storage

A unique 6 digit code identifies the individual test sections of an SPS-3 site (similar to that for the GPS sections), with the fourth character being "3" for SPS-3.

The computer filenames are identical to those used in the GPS testing, with the 6 character test section code followed by two characters indicating the times a section has been tested and the number of the pass within the section. The "times tested" (character #7) is a single letter which corresponds to the number of times the section has been tested. Character A is reserved for "BEFORE" construction testing on SPS experiments; B refers to SPS "DURING" construction testing (<u>not used in SPS-3 testing</u>); all SPS testing uses letter C as the first "AFTER" construction testing for a section (<u>not required in SPS-3 testing</u>); and, the letter D as the first "LONG TERM" testing. The "pass" (character #8) is 1 for ML testing and 3 for OWP testing as used for GPS testing. For example, files from "BEFORE" FWD testing of section 1 at an SPS-3 site in Iowa would be: 19A301A1 and 19A301A3. When performed, the FWD testing "AFTER" have the following filenames: 19A301C1 and 19A301C3 (test time "B" is skipped for SPS-3 as there is no testing during construction). Files representing data collected for "LONG TERM" testing will have a "D" or higher as the seventh character.

Drop Sequence

The drop sequence (load levels and number of drops) for SPS-3 testing is similar to the FLEX Testing Plan for GPS, except the number of drops is reduced from four to three.

SPS-3 Testing Plan - Drop Sequence

No. of Drops	Drop Height	Data Stored
3	3	No [1]
3	1	Yes [2]
3	2	Yes [2]
3	3	Yes [2]
3	4	Yes [2]

[1] No data stored, seating drop only. Deflection and load data is printed but not stored to a file.

[2] Store deflection peaks for all three drops and a complete deflection-time history for the third drop only.

Operators should use the FWD Field Program (Main Menu choice 1) to create, name and store the SPS-3 FWD test plan setup. This setup will be similar to the FLEX Testing Plan for GPS (Figure 9 in main text), except as follows:

```
13.  Heights:          CCC111222333444
14.  Test Plots:       .....*..*..*..*
15.  Save Peaks:       ...************
16.  Load His.:        ...............
17.  Whole His.:       .....*..*..*..*
```

Test Pit Areas

The SPS-3 experiment has no test pits. Therefore, pass P_0 testing is <u>not</u> performed in SPS-3.

Test Point Identification

FWD operators must properly record longitudinal distances with the distance measuring instrument relative to 0+00 station reference for each section, and follow the guidelines for lateral offset for the OWP and ML passes, so all FWD testing can be repeated in the same general location.

Detailed Test Plan (Test Sections)

For SPS-3 test sections, FWD testing procedures do not vary between "BEFORE", "AFTER" and "LONG TERM" testing. For all test sections in SPS-3 experiments, testing is similar to the FLEX Testing Plan for GPS except that the number of tests is reduced.

The test plan includes 6 FWD tests on each pass down the test section for both the ML pass (P_1) and the OWP pass (P_3). Deflection Basin tests are at 100 foot intervals beginning at station 0+00 and continuing to station 5+00. Figure B-3.1 indicates the test locations for a section. Each test section has 12 deflection basin test points for a total of 36 to 72 test points for a project, depending on the number of treatments used. At a rate of 20 points per hour, the FWD testing will take about 2 to 4 hours. With about 30 minutes per section for temperature gradient measurements, the total time for all tests should be approximately 4 to 7 hours.

FWD operators must use their best judgement and carefully note any abnormal conditions or unique situations encountered in the field. However, only 12 points should be tested on a given section.

Other FWD Operator Field Measurements

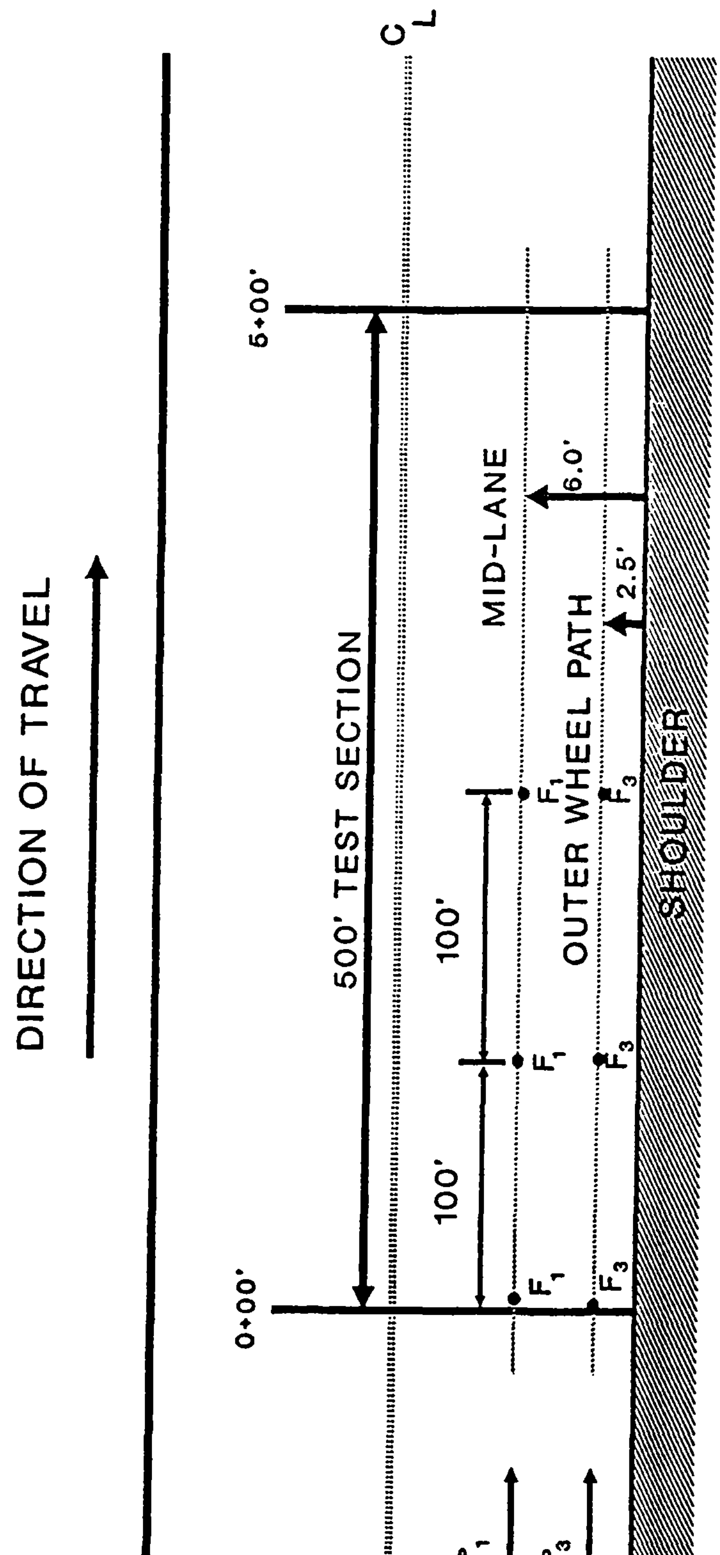
Temperature Gradient Measurements

Temperature gradient measurements for SPS-3 sites are obtained similar to that for GPS sections, with the one exception below.

> Temperature measurements are taken as usual for the GPS section (i.e., at each end) and at two additional locations for the treatment sections, throughout the duration of FWD testing at the site. It is up to the FWD operator to assess variations in sun exposure and wind conditions to select the most representative location adjacent to the section limits for temperature measurements.

Crack Widths

For any SPS-3 site, no crack opening measurements are made; however, FWD operators must record pavement distress at test point locations as described in guidelines for GPS testing using the F6-Comment key.



NOTE: LATERAL OFFSETS SHOWN REPRESENT NOMINAL DISTANCES.

FIGURE B - 3.1 FWD TEST PLAN FOR SPS-3 SECTIONS.

THIS PAGE INTENTIONALLY LEFT BLANK

Appendix B-4
FWD TESTING GUIDELINES
FOR SPECIFIC PAVEMENT STUDIES (SPS) EXPERIMENT 4
PREVENTIVE MAINTENANCE EFFECTIVENESS
OF RIGID PAVEMENTS

INTRODUCTION

This appendix provides guidelines and information specific to Falling Weight Deflectometer (FWD) testing at individual test sites for the Long Term Pavement Performance (LTPP) study experiment SPS-4, "Preventive Maintenance Effectiveness of Rigid Pavements." The intent of this document is to establish the specific testing requirements for SPS-4 sites based on a uniform set of assumptions. It is recognized that not all sites will conform to all assumptions contained herein. However, the objectives and approach to deflection data collection must be consistent so data obtained can be analyzed in a consistent manner. For deflection testing details not specifically addressed in the appendix, refer to the general guidelines in this manual.

The objective of the SPS-4 experiment is to compare the effectiveness and mechanisms by which selected maintenance treatments preserve or extend pavement service life, driver safety and ride quality on portland cement concrete pavements. The impact of materials or construction process is not a part of this study. In addition, the overall goal is to compare the performance of treated sections to untreated sections. The impact of a preventive maintenance treatment is based on the process or type of treatment; e.g., undersealing. Process parameters for material, design, and construction specification known to work reasonably well in each individual climatic zone were selected.

The primary factors addressed in the experimental design include moisture and temperature conditions, subgrade type, and traffic loading. The secondary factors include the individual treatments: crack/joint sealing and undersealing. Other second level factors include pavement condition at the time the treatment is placed and the type of subbase.

FWD TEST PLAN

General

The LTPP test sections in an SPS-4 experiment are tested the same before and after maintenance regardless of treatment. The site characteristic affecting FWD testing is the number of sections. FWD testing is performed 0 to 3 months prior to application of the maintenance treatment (labelled as "BEFORE"), 3 to 6 months after application of the maintenance treatment (labelled as "AFTER"; not required), and biannually more than 6 months after the application of the maintenance treatment (labelled as "LONG TERM"). In addition, sections should be tested just prior to removal of the section from the experiment.

Deflection Basin tests as well as Load Transfer tests are used in the SPS-4 testing. The specific FWD test plan is similar to the JCP Testing Plan for GPS. The factors inherent within this test plan are:

1. Test Point ID (J4, J5, and J6)
2. Lane for Each FWD Pass (Transverse Location)
3. Test Interval (Longitudinal Location)
4. Test Type (Basin and Load Transfer)
5. Deflection Sensor Spacing
6. Drop Sequence (Load Levels/Number of Drops)

All FWD testing is done in the OWP of the driving lane, located 2.5' ± 0.25' (0.76 m ± 0.08 m) from the edge reference defined for GPS testing. All testing uses station 0+00 of the test section (not the SPS site) as the distance reference so FWD test point locations can be located for future testing.

FWD operators must insure tests are located within the above tolerances. FWD operators are not expected to measure the position of each test point, but excessive deviations must be avoided.

The GPS load transfer sensor configuration (-12", 0", 12", 18", 24", 36", and 60") is used for all tests done on the single pass down the section. The following list of lane specification codes identifies the type and location of tests performed.

"JCP" Category Pavements

J4 approach slab tests in the OWP pass (P_3)
J5 leave slab tests in the OWP pass (P_3)
J6 mid-panel tests in the OWP pass (P_3)

Lane Specification J6 uses the load transfer sensor configuration so FWD operators do not have to move the D2 Sensor for each panel tested.

Naming Scheme/Data Storage

A unique 6 digit code identifies the individual test sections of an SPS-4 project (similar to that for the GPS sections), with the fourth character being "4" for SPS-4.

The computer filenames are identical to those used in the GPS testing, with the 6 character test section code followed by two characters indicating the times a section has been tested and the number of the pass within the section. The "times tested" (character #7) is a single letter which corresponds to the number of times the section has been tested. Character A is reserved for "BEFORE" construction testing on SPS experiments; B refers to SPS "DURING" construction testing (not used in SPS-4 testing); all SPS testing uses letter C as the first "AFTER" construction testing for a section (not required in SPS-4 testing); and, the letter D as the first "LONG TERM" testing. The "pass" (character #8) is OWP testing as used for GPS testing. For example, computer file from "BEFORE" FWD testing of section 1 at an SPS-4 site in Iowa would be: 19A401A3. When performed, the FWD testing "AFTER" has the filename 19A401C3 (test time "B" is skipped for SPS-4 as there is no testing during construction). Files representing data collected for "LONG TERM" testing will have a "D" or higher as the seventh character.

Drop Sequence

The drop sequence (load levels and number of drops) for joint/crack sealing test sections and underseal test sections is the same as the JCP Testing Plan for GPS when FWD testing is done alone. However, for underseal test sections, the drop sequence is as follows when testing is done with other equipment for void detection (i.e. Benkelman Beam):

SPS-4 Loss of Support Testing Plan - Drop Sequence (Used Only with Other Equipment Present)

No. of Drops	Drop Height	Data Stored
3	3	No [1]
3	1	Yes [2]
3	2	Yes [2]
3	3	Yes [2]

[1] No data stored, seating drop only. Deflection and load data is printed but not stored to a file.

[2] Store deflection peaks only.

Operators should use the FWD Field Program (Main Menu choice 1) to create, name and store the SPS-4 FWD test plan setup for use in conjunction with Benkelman Beam for loss of support testing. This setup will be similar to that for GPS Operational Category JCP (see Figure 10 in main text), except as follows:

```
13.  Heights . : CCC111222333
14.  Test Plots: .....*..*..*
15.  Save Peaks: ...*********
16.  Load His. : ............
17.  Whole His.: ............
```

This setup is only used on underseal sections, and only when Benkelman Beam testing is done at the same time. The reduced drop sequence lets the FWD keep up with the Benkelman Beam.

Test Pit Areas

The SPS-4 experiment has no test pits. Therefore pass P_0 testing is not performed in SPS-4.

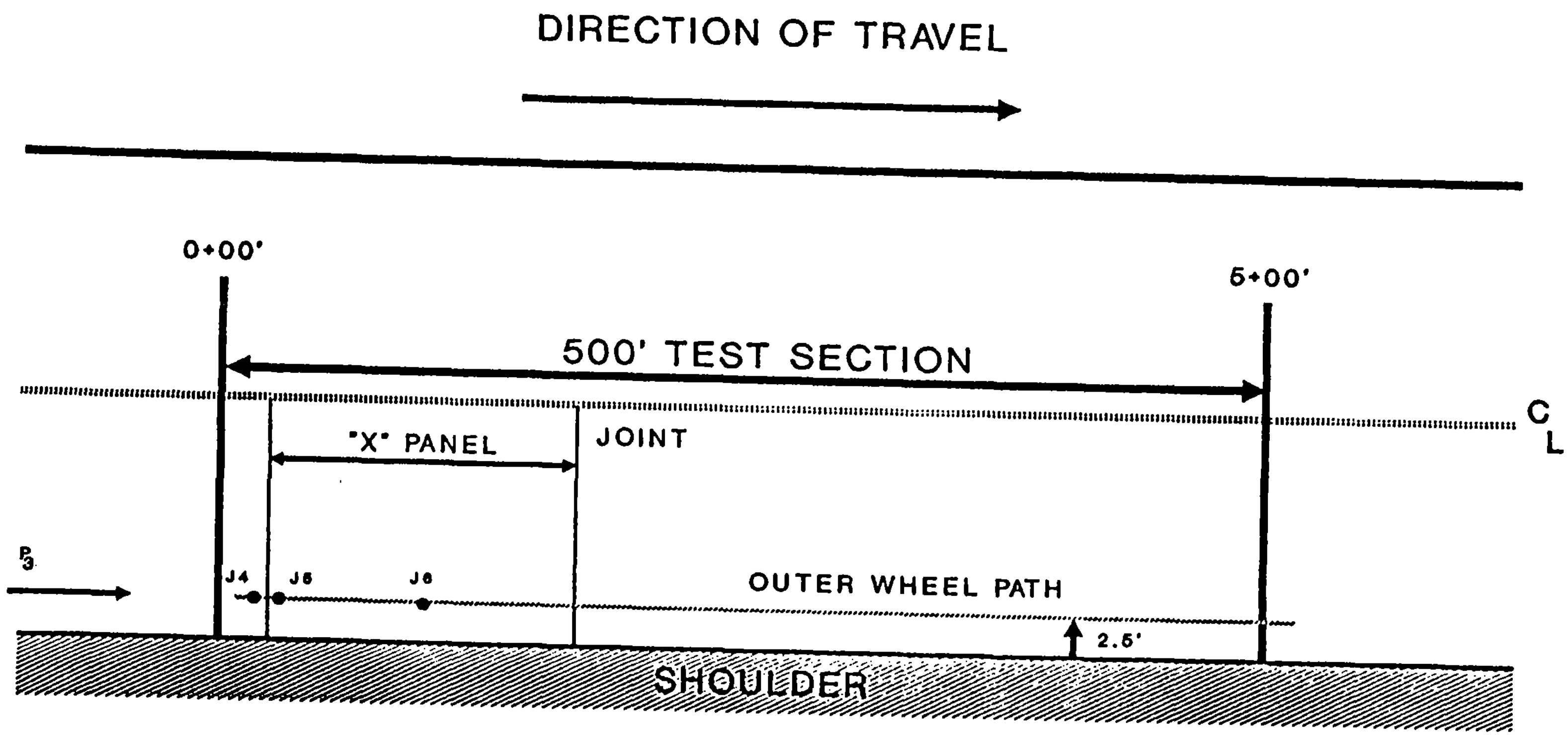
Test Point Identification

FWD operators must properly record longitudinal distances with the distance measuring instrument relative to 0+00 station reference for each section, and follow the guidelines for lateral offset for the OWP pass, so all FWD testing can be repeated in the same general location.

Detailed Test Plan (Test Sections)

For SPS-4 test sections, the type of FWD testing performed varies between "BEFORE", "AFTER" and "LONG TERM" testing, only if testing is done in conjunction with Benkelman Beam for loss of support testing. Deflection testing always consists of a single pass in the OWP. Tests are done on each side of the joint and/or crack and at the mid-slab, as shown in Figure B-4.1, using the GPS load transfer test sensor configuration. The standard test procedure for joint and crack sealing test sections, control sections, and state test sections is to test the first joint and the center of the first slab and every third joint and slab thereafter. Any transverse crack within the slabs is also tested. For the underseal test sections, all slabs in the sections are tested. The total number of test points and hence time requirements for SPS-4 sections will depend on the slab size, number of cracks present, number of supplemental agency sections, and whether loss of support testing is done in conjunction with Benkelman Beam.

Conditions encountered in the field may present unique and unanticipated situations. For these situations, FWD operators must use their best judgement in slab selection and carefully record any abnormal conditions using the F6-Comment key or by making notes on the FWD Field Activity Report.



NOTE: PANEL LENGTH "X" WILL BE VARIABLE DEPENDING UPON SPECIFIC JOINT SPACING, TRANSVERSE CRACK PATTERN AND PAVEMENT TYPE.

NOTE: TEST ALL PANELS ON UNDER SEAL SECTIONS AND EVERY THIRD PANEL ON REMAINING SECTIONS.

NOTE: LATERAL OFFSETS SHOWN REPRESENT NOMINAL DISTANCES.

FIGURE B - 4.1 FWD TEST PLAN FOR SPS-4 TEST SECTIONS.

Other FWD Operator Field Measurements

Temperature Gradient Measurements

Temperature gradient measurements for SPS-4 sites are obtained similar to that for GPS sections, with one exception as noted below.

> Temperature measurements are taken as usual for the GPS section (i.e., at each end) and at two additional locations for the treatment sections, throughout the duration of FWD testing at the site. It is up to the FWD operator to assess variations in sun exposure and wind conditions to select the most representative location adjacent to the section limits for temperature measurements.

Joint/Crack Widths

Joint and crack opening measurements for SPS-4 sites are obtained as defined under the JCP Testing Plan. However, FWD operators are encouraged to measure all joints/cracks tested.

Appendix B-5
FWD TESTING GUIDELINES
FOR SPECIFIC PAVEMENT STUDIES (SPS) EXPERIMENT 5
REHABILITATION OF ASPHALT CONCRETE PAVEMENTS

INTRODUCTION

This appendix provides guidelines and information specific to Falling Weight Deflectometer (FWD) testing at individual test sites for the Long Term Pavement Performance (LTPP) study experiment SPS-5, "Rehabilitation of Asphalt Concrete Pavements." The intent of this document is to establish the specific testing requirements for SPS-5 sites based on a uniform set of assumptions. It is recognized that not all sites will conform to all assumptions contained herein. However, the objectives and approach to deflection data collection must be consistent so data obtained can be analyzed in a consistent manner. For deflection testing details not specifically addressed in the appendix refer to the general guidelines in this manual.

The objective of the SPS-5 experiment is to investigate the performance of selected asphalt concrete (AC) pavement rehabilitation treatments. A variety of rehabilitation techniques can be applied to AC pavements to restore condition and extend service life. The techniques included in this experiment include a combination of types and thicknesses of AC overlay using either virgin or recycled AC mixes. Another variable examined is the extent of surface preparation. Characterization of the materials and their variation between test sections is required to explain performance differences and provide a basis for improved rehabilitation design.

In contrast to the LTPP General Pavement Studies (GPS), SPS has controlled construction of multiple test sections at a single site. On a SPS-5 site, there are 8 test sections and one control section. All sections have either two or five inch AC overlays, using either virgin or recycled AC mixes and either minimum or intensive pre-overlay surface preparation.

Experiment sites should conform to criteria contained in Specific Pavement Studies Guidelines for Nomination and Evaluation of Candidate Projects for experiment SPS-5, "Rehabilitation of Asphalt Concrete Pavements", November 1989. The site characteristic affecting FWD testing is the number of sections.

Table B-5.1 lists the LTPP test sections contained in an SPS-5 experiment. Criteria for selection limit the sites to a single structural cross section, constructed of the same materials throughout, under a single contract. Location of test sections should avoid cut/fill transitions, bridges, culverts, and side hill fills to limit the potential for variability of subgrade soils. A minimum of three Test Pits are used on the total site.

Table B-5.1 - SPS-5 Test Section Numbering Scheme

SPS-5 Section No.	Surface Preparation	Overlay Material	Overlay Thickness, inches
1	Routine Maintenance		0
2	Minimum	Recycled AC	2
3	Minimum	Recycled AC	5
4	Minimum	Virgin AC	5
5	Minimum	Virgin AC	2
6	Intensive	Virgin AC	2
7	Intensive	Virgin AC	5
8	Intensive	Recycled AC	5
9	Intensive	Recycled AC	2

FWD TEST PLAN

General

FWD testing for SPS-5 is performed 0 to 3 months prior to overlay construction (labelled as "BEFORE"), 3 to 6 months after overlay construction is completed (labelled as "AFTER"), and annually more than 6 months after the completion of overlay construction (labelled as "LONG TERM"). The preconstruction phase is used to characterize the existing pavement structure, and provide a baseline for comparison of the various rehabilitation techniques. Post construction testing is directed at verifying material properties and the as-built pavement section for use in evaluating the effectiveness and long term performance of the rehabilitations. "LONG TERM" FWD testing is performed to evaluate the effects of temperature, moisture changes and traffic loading on pavement deflection and performance.

Only deflection basin tests are used in the SPS-5 testing. The specific FWD test plan to be implemented for SPS-5 is similar to the FLEX Testing Plan for GPS. The factors inherent within each test plan are:

1. Test Point ID (F10, F1, F3)
2. Lane for Each FWD Pass (Transverse Location)
3. Test Interval (Longitudinal Location)
4. Test Type (Basin)
5. Deflection Sensor Spacing
6. Drop Sequence (Load Levels/Number of Drops)

All FWD testing is done in the driving lane at two lateral offsets. The two lateral offsets are the ML and OWP as defined in the GPS portion of this manual. For a given lateral offset, a single pass through the test section is made to collect a particular type of deflection data. When finished with a particular pass, the FWD returns to the beginning of the section to start another pass. <u>All</u> testing uses station 0+00 of the <u>test section</u> (not the SPS site) as the distance reference so FWD test point locations can be located for future testing.

Naming Scheme/Data Storage

A unique 6 digit code identifies test sections at an SPS-5 site (similar to that for the GPS sections), with the fourth character being "5" for SPS-5.

The computer filenames are identical to those used in the GPS testing, with the 6 character test section code followed by two characters indicating the times a section has been tested and the number of the pass within the section. The "times tested" (character #7) is a single letter which corresponds to the number of times the section has been tested. Character A is reserved for "BEFORE" construction testing on SPS experiments; B refers to SPS "DURING" construction testing (<u>not used in SPS-5 testing</u>; all SPS testing uses the letter C as the first "AFTER" construction testing; and, letter D as the first "LONG TERM" testing. The "pass" (character #8) is 0 for TP testing, 1 for ML testing, and 3 for OWP testing, as used for the GPS testing. For example, files from "BEFORE" FWD testing of section 1 at an SPS-5 site in Iowa would be: 190501A0, 190501A1, and 190501A3. FWD testing "AFTER" results in the following files: 190501C0, 190501C1, and 190501C3 (test time "B" is skipped for SPS-5 as there is no during construction testing). Files representing data collected for "LONG TERM" testing will have a "D" or higher as the seventh character.

Test Pit Areas

As in the GPS testing, efforts are made to "link" the material sampling/testing program and FWD test results on all SPS-5 sites. At each SPS-5 experiment site, test pits (TP) are located approximately 50' (15.2m) to 60' (18.3m) from a particular test section. Due to the length of the SPS-5 sites, test pits are not located adjacent to every test section. As a rule, a minimum of three test pits are used at every SPS-5 site. Each potential test pit location has FWD measurements taken in the OWP pass. Subject to traffic control restrictions, this pass (P_0) is completed for the entire SPS-5 test site prior to testing of pass P_1 on any section. There may be occasions where time delays of days or weeks occur between FWD testing and sampling, and FWD operators must mark the location of the FWD tests in the TP areas. Also, pass P_0 testing is only performed for the "BEFORE" time period.

Test Point Identification

FWD operators must properly record all longitudinal distances with the distance measuring instrument relative to 0+00 station reference for each section, and follow the guidelines for lateral offset for the OWP and ML passes, so all FWD testing can be repeated in the same general location.

Detailed Test Plan (Test Pit Areas)

TP areas are tested identical to the procedures outlined for GPS testing in the main part of this manual.

Detailed Test Plan (Test Sections)

For all SPS-5 test sections, FWD testing procedures are identical for "BEFORE", "AFTER", and "LONG TERM" testing. The procedure used is similar to the FLEX Testing Plan for GPS except the number of test points is reduced.

The test plan includes 11 FWD tests on each pass down the test section for both the ML and the OWP. Deflection Basin tests begin at station 0+00 and continue to station 5+00, at 50' intervals. Figure B-5.1 indicates the test locations for a section. Each section has 22 test points for a total of 198 test points (not including Test Pit locations) for a project. At a rate of 20 points per hour, the FWD testing will take approximately 10 hours. This does not include the time for testing Test Pit locations or the temperature gradient measurements. The total time for all tasks should be approximately 16 hours.

FWD operators must use their best judgement in the testing process and carefully note any abnormal conditions or unique situations encountered in the field. However, only 22 points should be tested on a given section (exclusive of test pits located adjacent to the section).

Other FWD Operator Field Measurements

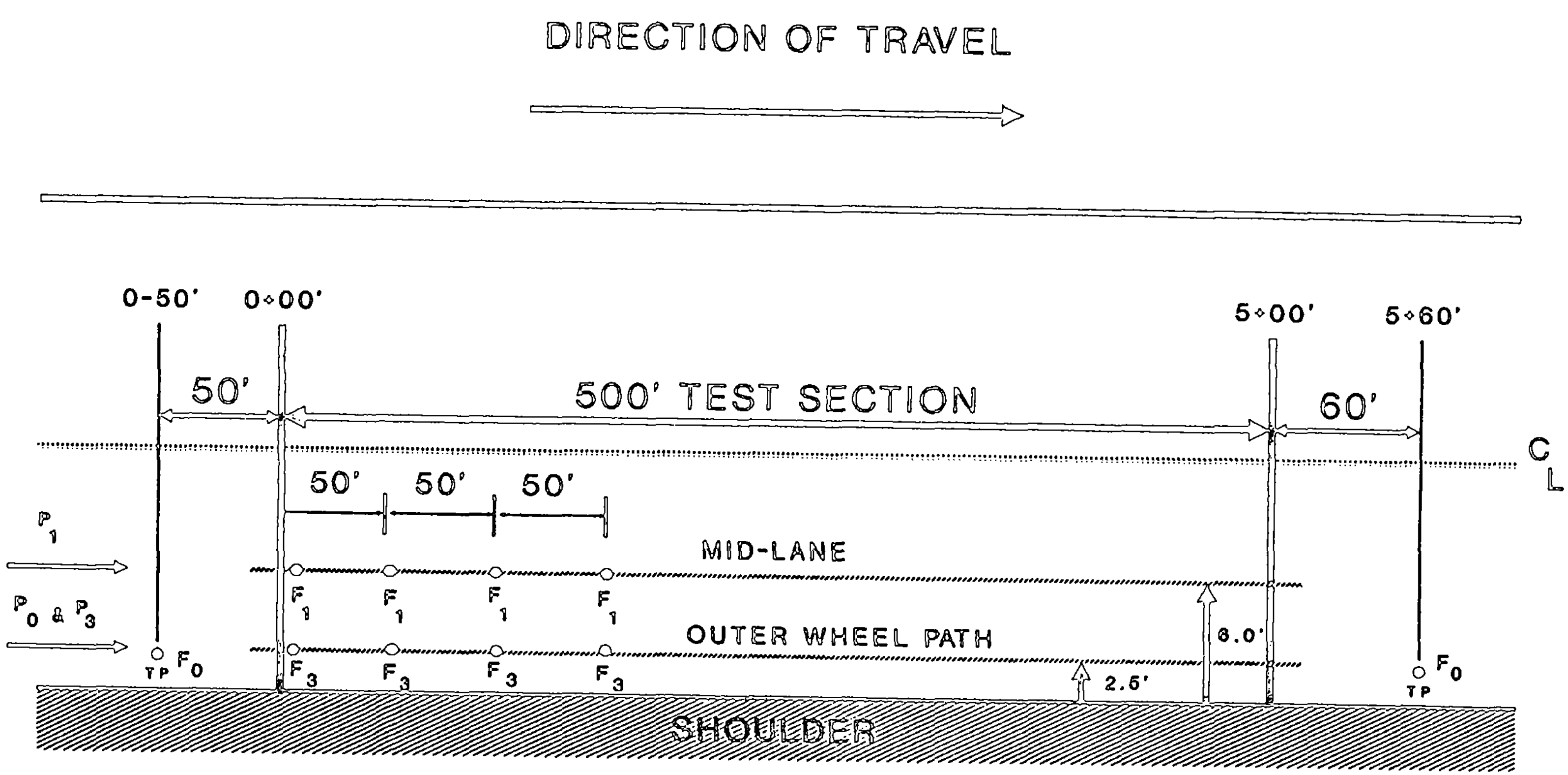
Temperature Gradient Measurements

Temperature gradient measurements for SPS-5 sites are obtained similar to that for GPS sections, with the three exceptions below.

> Temperature measurements are required at 2 depths (at one-third points) if the existing bituminous surface layer is less than 2 inches thick. Otherwise, three depths are always used just like normal GPS testing. Figure B-5.2 illustrates the drilling patterns to use for temperature gradient data.
>
> Measurements are obtained at only one location for each SPS-5 section. It is up to the FWD operator to assess variations in sun exposure and wind conditions to select the most representative location adjacent to the section limits for temperature measurements.
>
> Temperature readings are obtained at 30 minute intervals, with the first readings prior to starting FWD testing on a section and the last readings after completion of the FWD testing on the section.

Crack Widths

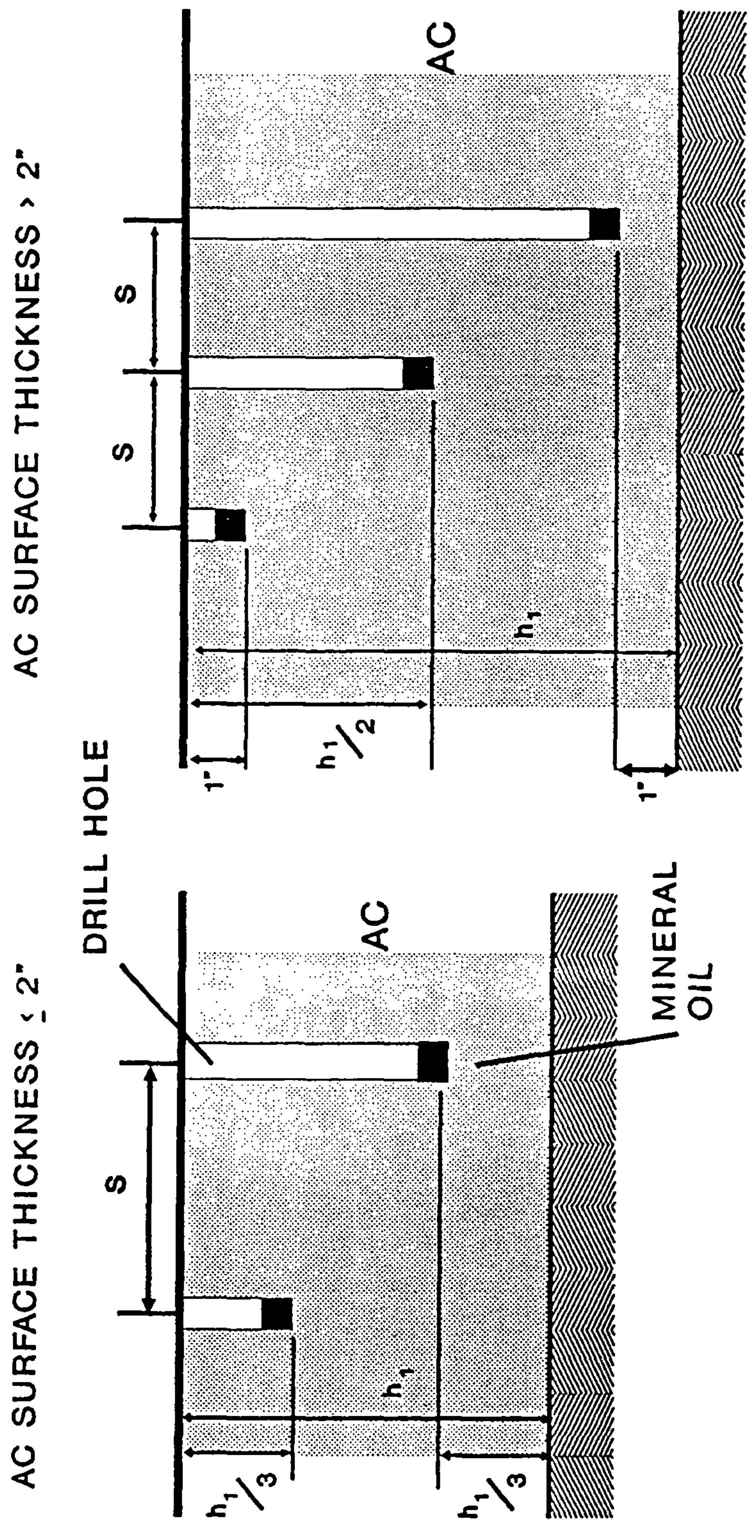
For any SPS-5 site, <u>no</u> crack opening measurements are made; however, FWD operators must record pavement distress at test point locations as described in guidelines for GPS testing using the F6-Comment key.



NOTE: FWD TESTS RAN AT TEST PIT LOCATIONS (TP) ON P_0 AS FIRST SET OF TESTS.

NOTE: LATERAL OFFSETS SHOWN REPRESENT NOMINAL DISTANCES.

FIGURE B - 5.1 FWD TEST PLAN FOR SPS-5 TEST SECTIONS.



NOTE: DRILL HOLE SPACING (s) SHOULD BE 18" CC OR GREATER.

FIGURE B - 5.2 TYPICAL DRILLING PATTERNS FOR TEMPERATURE GRADIENT DATA.

THIS PAGE INTENTIONALLY LEFT BLANK

Appendix B-6
FWD TESTING GUIDELINES
FOR SPECIFIC PAVEMENT STUDIES (SPS) EXPERIMENT 6
REHABILITATION OF JOINTED
PORTLAND CEMENT CONCRETE PAVEMENTS

INTRODUCTION

This appendix provides guidelines and information for Falling Weight Deflectometer (FWD) testing at individual test sites for the Long Term Pavement Performance (LTPP) study experiment SPS-6, "Rehabilitation of Jointed Portland Cement Concrete Pavements." The intent of this document is to establish the specific testing requirements for SPS-6 sites based on a uniform set of assumptions. It is recognized that not all sites will conform to all assumptions contained herein. However, the objectives and approach to deflection data collection must be consistent so data obtained can be analyzed in a consistent manner. For deflection testing details not specifically addressed in the appendix, refer to the general guidelines in this manual.

The objective of the SPS-6 experiment is to investigate the performance of selected rehabilitation treatments for jointed portland cement concrete (PCC) pavements. A variety of rehabilitation techniques can be applied to jointed PCC pavements to restore condition and extend service life. The techniques included in this experiment include a combination of types of pavement preparation ranging from minimal treatment to full "Concrete Pavement Restoration" (CPR) as well as cracking/breaking and seating. AC overlays of different thicknesses are included depending on the type and extent of pavement preparation. Characterization of materials and environmental conditions between test sections is required to explain performance differences and provide a basis for improved rehabilitation design.

In contrast to the LTPP General Pavement Studies (GPS), SPS has controlled construction of multiple test sections at a single site. On a SPS-6 site, there are 7 test sections and one control section. Five of the experimental sections have AC overlays. Experiment sites should conform to criteria contained in Specific Pavement Studies Guidelines for Nomination and Evaluation of Candidate Projects for experiment SPS-6, "Rehabilitation of Jointed Portland Cement Concrete Pavements", November 1989. The site characteristic affecting FWD testing is the number of sections.

Table B-6.1 lists the LTPP test sections in an SPS-6 experiment site. Criteria for selection limit the sites to a single structural cross section, constructed of the same materials throughout, under the same contract. Location of test sections should avoid cut/fill transitions, bridges, culverts, and side hill fills to limit the potential for variability of subgrade soils. A minimum of three Test Pits are used at a site.

Table B-6.1 - SPS-6 Test Section Numbering Scheme

SPS-6 Section No.	Preparation	Other Treatments	AC Overlay Thickness, Inches
1	Routine Maintenance		0
2	Minimum Restoration		0
3	Minimum Restoration		4
4	Minimum Restoration	Saw and Seal Joints in AC Overlay	4
5	Maximum Restoration		0
6	Maximum Restoration		4
7	Crack/Break and Seat		4
8	Crack/Break and Seat		8

FWD TEST PLAN

General

FWD testing for SPS-6 is performed 0 to 3 months prior to rehabilitation (labelled as "BEFORE"); immediately following cracking and seating of the PCC surface in sections 7 and 8, but before placement of the AC overlay (labelled as "DURING"); 3 to 6 months after rehabilitation is completed (labelled as "AFTER"); and annually more than 6 months after the completion of rehabilitation (labelled as "LONG TERM"). The "BEFORE" testing is used to characterize the existing pavement structure and provide a baseline for comparison of the various rehabilitation techniques. Testing "DURING" construction is used to characterize the strength of the cracked and seated PCC layer. The "AFTER" testing is directed at verifying material properties and the as-built pavement section for use in evaluating the effectiveness and long term performance of the rehabilitations. "LONG TERM" testing is performed to evaluate the effects of temperature, moisture changes, and traffic loading on pavement deflection and performance.

Deflection Basin tests and Load Transfer tests are used in the SPS-6 testing. The specific FWD test plan to be implemented for SPS-6 is similar to the JCP and FLEX (modified) Testing Plan for GPS. Table B-6.2 contains the FWD Operational Categories corresponding to SPS-6 "BEFORE", "DURING", "AFTER", and "LONG TERM" testing periods. The factors inherent within each test plan are:

1. Test Point ID (J0, J1, J2, J3, J4, and J5; F1, F3, F4, and F5)
2. Lane for Each FWD Pass (Transverse Location)
3. Test Interval (Longitudinal Location)
4. Test Type (Basin or Load Transfer)
5. Deflection Sensor Spacing
6. Drop Sequence (Load Levels/Number of Drops)

All FWD testing is done in the driving lane at several lateral offsets. For a given lateral offset, a single pass through the test section is made to collect a particular type of deflection data. When finished with a particular pass, the FWD returns to the beginning of the section to start another pass. <u>All</u> testing uses station 0+00 of the <u>test section</u> (not the SPS site) as the distance reference so FWD test point locations can be located for future testing.

The testing of joint load transfer efficiency for the saw and seal treatment, Test Section Number 4, requires additional lane specification codes to properly identify the location of the testing. The sawed joints will be tested in the OWP both on the approach and the leave side of the joint. The lane specification for the approach side shall be "F4," and for the leave side "F5" which correspond to the "J4" and "J5" specifications in "JCP." The following table briefly summarizes the lane specification codes for the "FLEX" category, as modified for SPS-6 rehabilitation treatments.

Table B-6.2 - SPS-6 FWD Testing Periods and Appropriate FWD Operational Category

SPS-6 SECTION No.	"BEFORE"	"DURING"	"AFTER"
1	JCP	none	JCP
2	JCP	none	JCP
3	JCP	none	FLEX
4	JCP	none	JCP/FLEX (see text)
5	JCP	none	JCP
6	JCP	none	FLEX
7	JCP	FLEX	FLEX
8	JCP	FLEX	FLEX

Note: See additional text on modifications to FLEX Testing Plan.

"FLEX" Category Pavements

F0 basin tests at both TP sites
F1 all tests in the ML (P_1)
F3 all basin tests in the OWP (P_3)
F4 approach slab LT tests in the OWP (P_5)
F5 leave slab LT tests in the OWP (P_5)

The GPS load transfer sensor configuration (-12", 0", 12", 18", 24", 36", and 60") is used for lane specifications F4 and F5 in pass P_5.

Naming Scheme/Data Storage

A unique 6 digit code identifies the individual test sections at an SPS-6 site (similar to that for the GPS sections), with the fourth character being "6" for SPS-6.

The computer filenames are identical to those used in the GPS testing, with the 6 character test section code followed by two characters indicating the times a section has been tested and the number of the pass within the section. The "times tested" (character #7) is a single letter which corresponds to the number of times the section has been tested. Characters A and B are reserved for "BEFORE" and "DURING" construction testing; all SPS testing uses letter C as the first "AFTER" construction testing; and, the letter D as the first "LONG TERM" testing. The "pass" (character #8) is 0 for TP testing, 1 for ML testing, 2 for PE pass corner and mid-panel edge testing, and 3 or 5 for OWP load transfer testing, as used for GPS testing. For example, files from "BEFORE" FWD testing of section 1 at an SPS-6 site in Iowa would be: 190601A0, 190601A1, 190601A2 and 190601A3. Files representing data collected "DURING" construction (for sections 7 and 8 only) would contain a "B" in the seventh character position 190607B1 and 190607B3. The "AFTER" testing will result in filenames with a "C" in the seventh position, while "LONG TERM" testing will have a "D" or higher.

Test Pit Areas

As in the GPS testing, LTPP plans to "link" the material sampling/testing program and FWD test results on all SPS-6 sites. At each SPS-6 experiment site, test pits (TP) are located approximately 50' (15.2m) to 60' (18.3m) from a particular test section. Due to the length of the SPS-6 sites, test pits are not located adjacent to every test section. As a rule, a minimum of three test pits are used at every SPS-6 site. Each potential test pit location has FWD measurements taken in the OWP pass. Subject to traffic control restrictions, this pass (P_0) is completed for the entire SPS-6 test site prior to testing of pass P_1 on any section. There may be occasions where time delays of days or weeks occur between FWD testing and sampling, and FWD operators must mark the location of the FWD tests in the TP areas. Also, pass P_0 testing is only performed for the "BEFORE" time period.

Test Point Identification

FWD operators must properly record all longitudinal distances with the distance measuring instrument relative to 0+00 station reference for each section, and follow the guidelines for lateral offset for the PE, OWP and ML passes, so all FWD testing can be repeated in the same general location.

Detailed Test Plan (Test Pit Areas)

TP areas are tested identical to the procedures outlined for GPS testing in the main part of this manual.

Detailed Test Plan (Test Sections)

For SPS-6 test sections, FWD testing performed varies between "BEFORE," "DURING," and "AFTER", depending on the rehabilitation for the section.

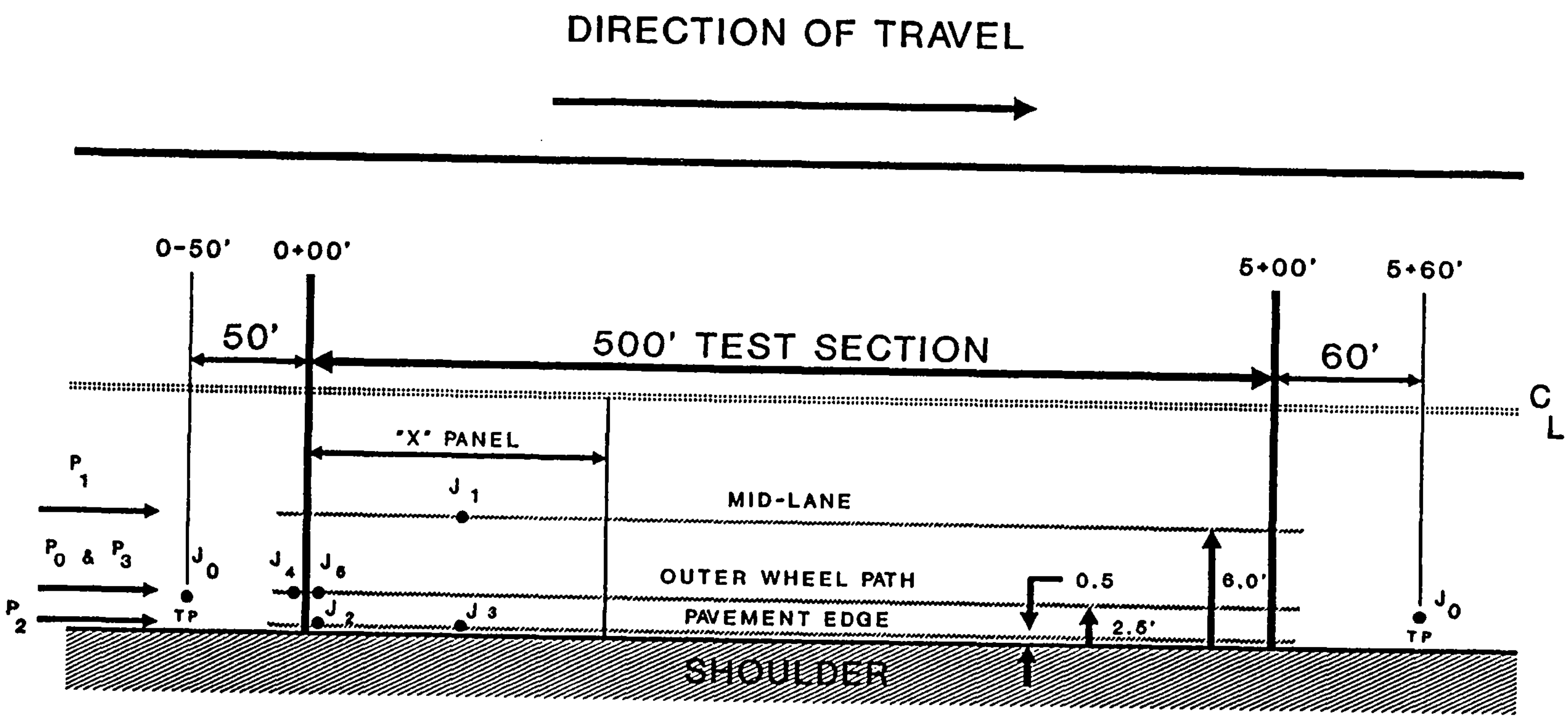
"BEFORE" Rehabilitation Testing: For all SPS-6 sections, the testing "BEFORE" rehabilitation is similar to that outlined for JCP pavement sections (see Table B-6.2), except the number of tests is reduced. Figure B-6.1 illustrates the "BEFORE" testing pattern for all sections and the "AFTER" testing pattern for Sections 1, 2 and 5. For all sections except Section 2 and 5, 10 effective slabs are tested (the concept of "effective slab" is defined previously in this manual). For Sections 2 and 5, which are 1000 feet long, 20 effective slabs are tested. The "BEFORE" test plan includes three passes along each section; (P_1) Mid-lane, (P_2) Pavement edge and (P_3) Outer wheel path. A preliminary pass (P_0) will also be made to evaluate the test pit locations where applicable.

FWD operators must consider "end conditions" (joints, cracks, and patches) of the effective slabs when selecting slabs to test. The proportion of end conditions will determine the slabs tested. For example, if 24 total effective slabs are present with the following distribution:

6 terminated by a joint at one end and a joint at the other
6 terminated by a joint at one end and a patch at the other
6 terminated by a joint at one end and a crack at the other
6 terminated by a patch at one end and a crack at the other

two or three of each type of effective slab should be tested while attempting to get both types of end conditions in each category above (e.g. 1 or 2 with a joint at the approach end and a patch at the leave end, and 1 or 2 with a patch at the approach end and a joint at the leave end).

Five FWD tests are performed in each effective slab tested. These include a Deflection Basin test in the center of the slab (J1) on P_1, a Deflection Basin test along the approach corner (J2) and edge of the slab (J3) on P_2, and two load transfer tests at the joints (J4 and J5) on P_3.



NOTE: FWD TESTS CONDUCTED AT TEST PIT LOCATIONS (TP) ON P_0 (FIRST SET OF TESTS, NOT FOR "AFTER" REHABILITATION).

NOTE: TEN (10) PANELS SHOULD BE TESTED ON ALL 500 FT. SECTIONS, AND 20 PANELS ON ALL 1,000 FT. SECTIONS.

NOTE: TEST SECTIONS 2 AND 5 ARE 1000' IN LENGTH.

NOTE: LATERAL OFFSETS SHOWN REPRESENT NOMINAL DISTANCES.

FIGURE B- 6.1 FWD TEST PLAN FOR ALL TESTING "BEFORE" REHABILITATION AND FOR SECTIONS 1,2 AND 5 "AFTER" REHABILITATION.

Figure B-6.1 indicates the positions of the test locations for a given effective slab. Each test section should have 10 effective slabs (20 in Sections 2 and 5) for a total of 450 FWD points (not including TP locations). At a rate of 20 points per hour, the entire process (all eight test sections) will take approximately 23 hours. This does not include the time for testing TP locations or taking temperature gradient measurements. The total time for all tasks should be approximately 30 hours.

"DURING" Rehabilitation Testing: For test sections 7 and 8 (crack and seal sections), testing is performed "DURING" the construction process, on the cracked PCC surface. The FWD test pattern used "DURING" rehabilitation is the same as that for FLEX Testing Plan for GPS except the stations for the points should correspond to the J1 tests from the ML tests (P_1) performed "BEFORE" rehabilitation. The testing pattern for these sections is illustrated in Figure B-6.2. No tests are conducted at the PE and no Load Transfer tests are performed.

"AFTER" Rehabilitation Testing: For test sections 1, 2 and 5, the test plan for the "AFTER" rehabilitation testing is the same as that for "BEFORE" rehabilitation testing, and the same effective slabs are tested.

The remaining sections all have an AC overlay and the test plan is different. Only Deflection Basin tests are performed for test sections 3, 6, 7 and 8. These are performed in both the pass P_1 and pass P_3 for each effective slab tested "BEFORE" rehabilitation. The stations for F1 and F3 must correspond to the stations for J1 tests performed "BEFORE" rehabilitation. The testing pattern for these sections is illustrated in Figure B-6.2. No tests are conducted at the PE and no Load Transfer tests are performed.

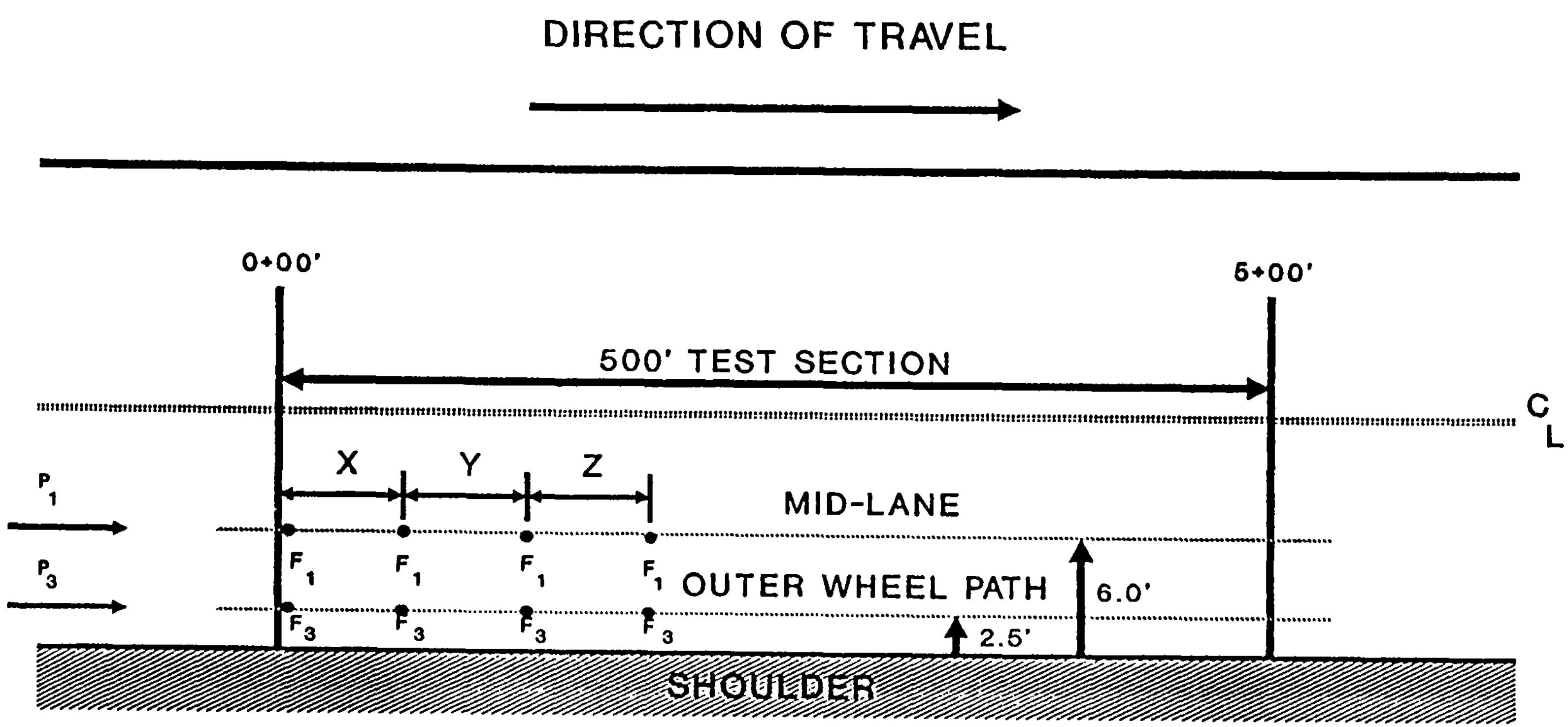
Test section 4 has the same Deflection Basin test plan as sections 3, 6, 7 and 8. In addition, Load Transfer tests are performed at the sawed and sealed joint locations corresponding to the J4 and J5 locations in the "BEFORE" testing. The sawed joints must correspond with the slab joints, transverse cracks and patches which were used to define the original effective slabs. Figure B-6.3 illustrates the testing pattern for this particular test section.

FWD operators must use their best judgement in the slab selection process and carefully note any abnormal conditions or unique situations encountered in the field. However, only 10 effective slabs should be tested within a given section, except for sections 2 and 5 where 20 slabs are tested.

Other FWD Operator Field Measurements

Temperature Gradient Measurements

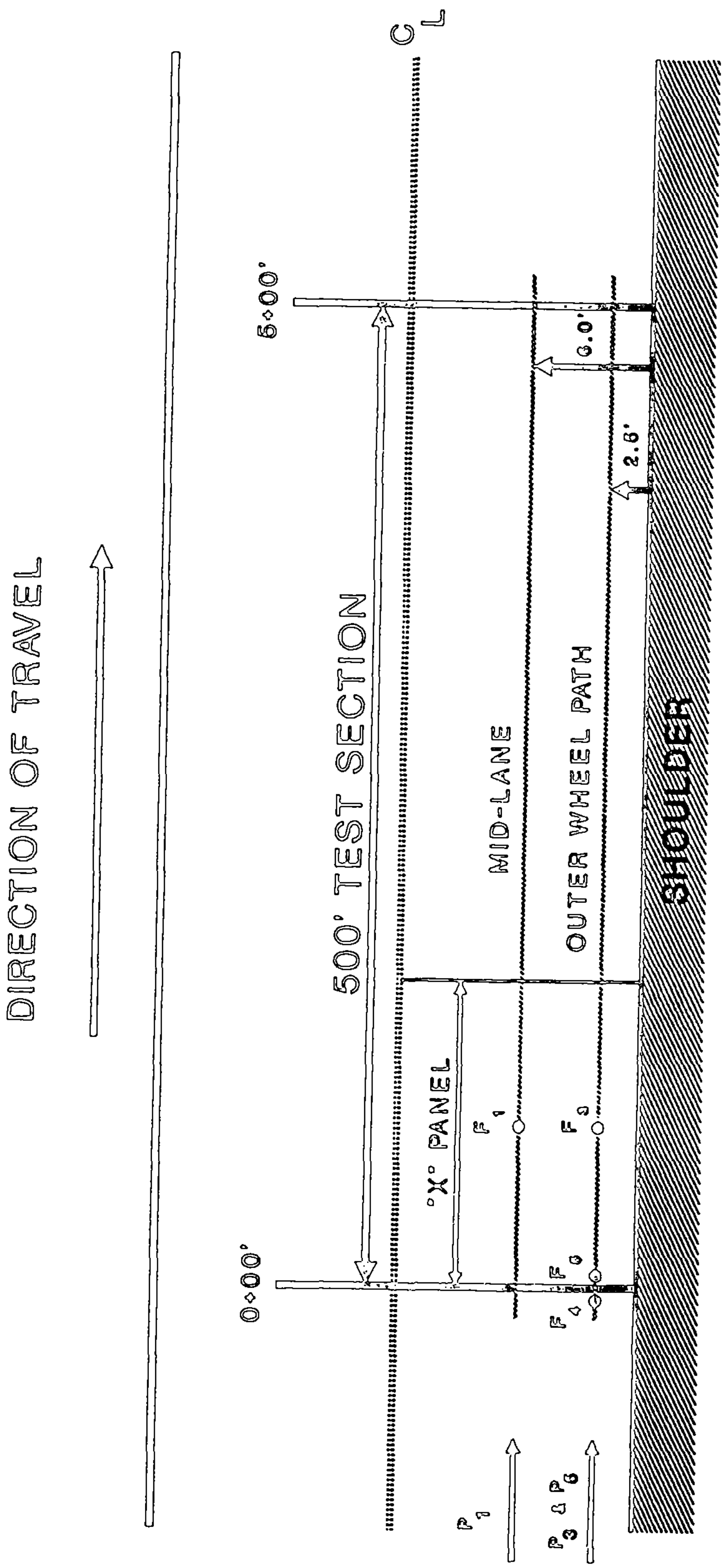
Temperature gradient measurements for SPS-6 sites are obtained similar to that for GPS sections, with three exceptions as noted below.



NOTE: TEST POINT INTERVALS (X, Y, Z) VARY TO MATCH UP TEST POINT LOCATIONS TESTED PREVIOUSLY.

NOTE: LATERAL OFFSETS SHOWN REPRESENT NOMINAL DISTANCES.

FIGURE B - 6.2 FWD TEST PLAN FOR SECTIONS 7 AND 8 "DURING" REHABILATION AND SECTIONS 3, 6, 7 AND 8 "AFTER" REHABILITAITON (F_1, F_3).



NOTE: PASS 6 FOR LOAD TRANSFER TESTS AT SAWED JOINT AND PASS 3 FOR DEFLECTION BASIN TESTS IN OWP AT MID-PANEL LOCATIONS.

NOTE: LATERAL OFFSETS SHOWN REPRESENT NOMINAL DISTANCES.

FIGURE B- 6.3 FWD TEST PLAN FOR SECTION 4 "AFTER" REHABILITATION.

For the "BEFORE" testing, temperature gradient measurements are required at 3 depths. Temperature gradient measurements are not required for the "DURING" construction testing. For temperature gradients measured "AFTER" and "LONG TERM", either 3 or 5 depths are used depending on whether or not an AC overlay is present. For sections with an AC overlay on an unbroken PCC layer (sections 3, 4, and 6), five depths per section are required. For sections 1, 2, and 5, three depths per section are used. Test sections 7 and 8, the cracked and seated PCC with AC overlay, have three depths all in the AC overlay ONLY. Figures B-6.4 and B-6.5 illustrate the drilling patterns used for obtaining the temperature gradient data.

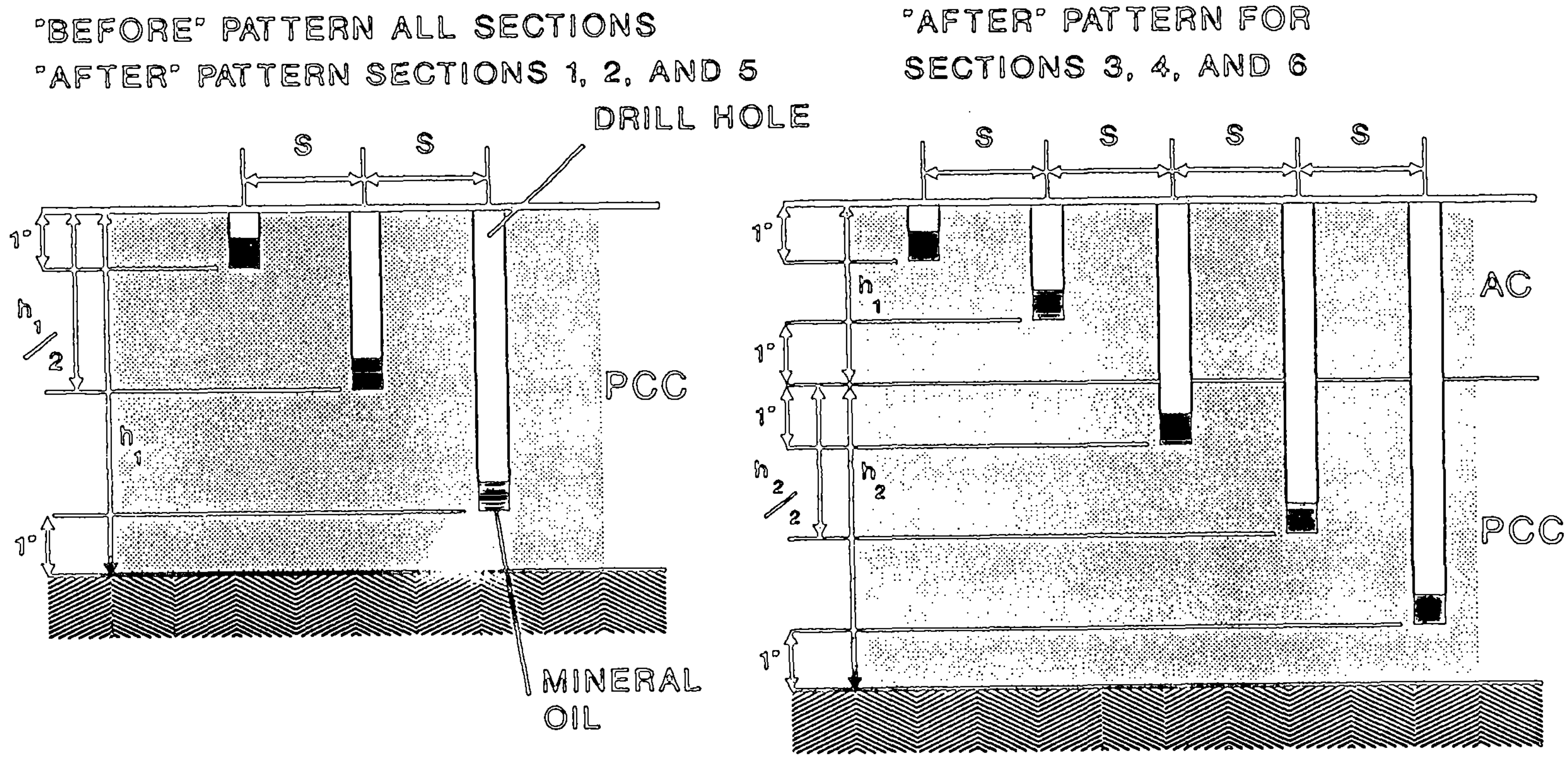
Measurements are obtained at only one location for each section. It is up to the FWD operator to assess variations in sun and wind exposure to select the most representative location adjacent to the section limits for temperature measurements.

Temperature readings are obtained at 30 minute intervals with the first reading prior to starting FWD testing on a section and the last readings after completion of the FWD testing on the section.

Joint/Crack Widths

Joint and crack opening measurements for SPS-6 sites are obtained the same as for GPS sections, with one exception as noted below:

> For Test Section 4, "AFTER" (after saw and seal), the width of the sealed sawcuts are measured and recorded for 25% of the sawcuts tested for load transfer efficiency.

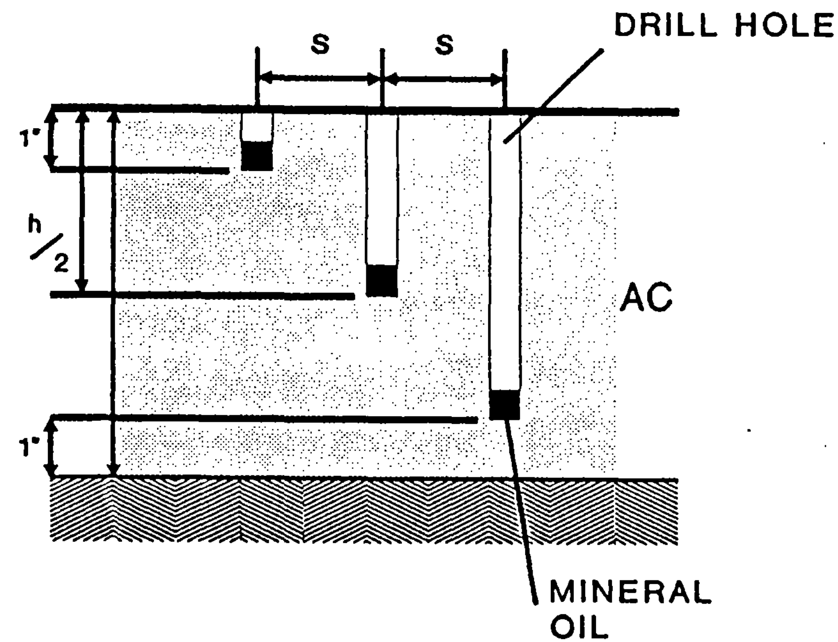


NOTE: DRILL HOLE SPACING (s) SHOULD BE 18" CC OR GREATER.

NOTE: SEE FIGURE B-6.5 FOR SECTIONS 7 AND 8.

FIGURE B - 6.4 TYPICAL DRILLING PATTERNS FOR TEMPERATURE GRADIENT DATA.

"AFTER PATTERN FOR SECTIONS 7 AND 8



NOTE: DRILL HOLE SPACING (s) SHOULD BE 18" CC OR GREATER.

NOTE: NO TEMPERATURE MEASUREMENTS IN BROKEN PCC (SECTIONS 7 AND 8).

FIGURE B - 6.5 TYPICAL DRILLING PATTERNS FOR TEMPERATURE GRADIENT DATA - SECTIONS 7 AND 8 "AFTER".

THIS PAGE INTENTIONALLY LEFT BLANK

Appendix B-7
FWD TESTING GUIDELINES
FOR SPECIFIC PAVEMENT STUDIES (SPS) EXPERIMENT 7
BONDED PORTLAND CEMENT CONCRETE OVERLAYS

INTRODUCTION

This appendix provides guidelines and information for Falling Weight Deflectometer (FWD) testing at individual test sites for Long Term Pavement Performance (LTPP) study experiment SPS-7, "Bonded Portland Cement Concrete Overlays." The intent of this document is to establish the specific testing requirements for these sites based on a uniform set of assumptions. It is recognized that not all sites will conform to all assumptions contained herein. However, the objectives and approach to deflection data collection must be consistent so data obtained can be analyzed in a consistent manner. For deflection testing details not specifically addressed in this appendix, refer to the general guidelines in this manual.

The objectives of the SPS-7 experiment are to measure the additional pavement life from bonded concrete overlays, to evaluate the effectiveness of surface preparation techniques prior to overlay, and to investigate the environmental influence on the performance of bonded concrete overlays. The experiment includes overlays on jointed plain (JPCP), jointed reinforced (JRCP) and continuously reinforced (CRCP) concrete pavements. The factors addressed in this experiment include surface preparation, use of bonding grout, and overlay thickness. Analysis of data from this experiment will provide improved tools for evaluating the effectiveness of bonded concrete overlays as a rehabilitation technique for existing concrete pavements.

In contrast to the LTPP General Pavement Studies (GPS), SPS has controlled construction of multiple test sections at a single site. On a SPS-7 site, there are 8 test sections and one control section. Four of the test sections have a 3 inch thick concrete overlay and four have a 5 inch overlay. Combinations of surface preparation, milling or shot blasting, and grout or no-grout cover the construction factors investigated in this experiment. Complete data records starting from construction, and multiple test sections constructed on similar subgrade and subjected to similar traffic and environmental conditions will allow for comparison of the experimental factors. Substantial deflection testing is required to evaluate the relative performance of the different sections.

Experiment sites should conform to criteria contained in "Specific Pavement Studies Guidelines for Nomination and Evaluation of Candidate Projects for Experiment SPS-7, Bonded Portland Cement Concrete Overlays", June 1990. The site characteristic affecting the FWD testing is the number of sections.

Table B-7.1 details the LTPP test sections in an SPS-7 experiment site. Criteria for selection limit the sites to a single structural cross section, constructed of the same materials throughout, under the same contract. Location of test sections should avoid cut/fill transitions, bridges, culverts, and side hill fills to limit the potential for variability of subgrade soils. A minimum of three Test Pits are used at a site.

FWD TEST PLAN

General

FWD testing for SPS-7 is performed in multiple phases, 0 to 3 months prior to rehabilitation (labelled as "BEFORE"), 3 to 6 months after overlay construction (labelled as "AFTER"), and annually more than 6 months after the completion of rehabilitation (labelled as "LONG TERM"). The "BEFORE" testing is used to characterize the existing pavement structure, and provide a baseline for comparison of the various construction factors. The "AFTER" testing is directed at verifying material properties and the as-built pavement section for use in evaluating the effectiveness and long term performance of the rehabilitations. "LONG TERM" testing is performed to evaluate the effects of the temperature, moisture changes and traffic loading on pavement deflections and performance.

Deflection Basin tests and Load Transfer tests are used in the SPS-7 testing. The specific FWD test plan to be implemented is similar to the JCP or CRCP Testing Plan for GPS. The factors inherent within the test plan are:

1. Test Point ID (J0, J1, J2, J3, J4, and J5 <u>or</u> C0, C1, C2, C3, C4, and C5)
2. Lane for Each FWD Pass (Transverse Location)
3. Test Interval (Longitudinal Spacing)
4. Test Type (Basin or Load Transfer)
5. Deflection Sensor Spacing
6. Drop Sequence (Load Levels/Number of Drops)

All FWD testing is in the driving lane at three lateral offsets. The three lateral offsets are the ML, PE, and OWP as defined in the GPS portion of this manual. For a given lateral offset, a single pass through the test section is made to collect a particular type of deflection data. When finished with a particular pass, the FWD returns to the beginning of the section to start another pass. <u>All</u> testing uses station 0+00 of the <u>test section</u> (not the SPS site) as the distance reference so FWD test point locations can be located for future testing.

Table B-7.1 - SPS-7 Test Section Numbering Scheme

Section Number	Surface Preparation	Cement Grout	Overlay Thickness (inches)
01	Control Section	-	-
02	Milling and Sand Blasting	Yes	3
03	Milling and Sand Blasting	No	3
04	Shot Blasting	No	3
05	Shot Blasting	Yes	3
06	Shot Blasting	Yes	5
07	Shot Blasting	No	5
08	Milling and Sand Blasting	No	5
09	Milling and Sand Blasting	Yes	5

Naming Scheme/Data Storage

A unique 6 digit code identifies the individual test sections at an SPS-7 site (similar to that for the GPS sections), with the fourth character being "7" for SPS-7.

The computer filenames are identical to those used in the GPS testing, with the 6 character test section code followed by two characters indicating the times a section has been tested and the number of the pass within the section. The "times tested" (character #7) is a single letter which corresponds to the number of times the section has been tested. Character A is reserved for "BEFORE" construction testing on SPS experiments; B refers to SPS "DURING" construction testing (not used in SPS-7 testing); all SPS testing use letter C as the first "AFTER" construction testing; and, letter D as the first "LONG TERM" testing. The "pass" (character #8) is 0 for TP testing (C0 or J0), 1 for ML testing (J1 or C1), 2 for PE testing (J2 and J3 or C2 and C3), or 3 for OWP testing (J4 and J5 or C4 and C5) as used in GPS testing. For example, files from "BEFORE" FWD testing of section 1 at an SPS-7 site in Minnesota would be: 270701A0, 270701A1, 270701A2 and 270701A3. The "AFTER" testing would have filenames with a "C" in the seventh position, while "LONG TERM" testing would have a "D" or higher.

Test Pit Areas

As in the GPS testing, efforts are made to "link" the material sampling/testing program and FWD test results on all SPS-7 sites. At each experiment site, test pits (TP) are located approximately 50' (15.2m) to 60' (18.3m) from a particular test section. This distance varies due to site conditions. Due to the length of the project sites, test pits are not located adjacent to every test section. As a rule, a minimum of three test pits are located at every site. Each potential test pit location has FWD measurements taken along the OWP pass (P_o). This pass is completed for the entire test site prior to testing of pass P_1 on any section. There may be occasions where time delays of days or weeks occur between the testing programs and FWD operators must mark the location of the FWD tests in the TP (Test Pit) areas. Also, pass P_0 testing is only performed for the "BEFORE" time period.

Test Point Identification

FWD operators must properly record all longitudinal distances with the distance measuring instrument relative to 0+00 station reference for each section, and follow the guidelines for lateral offset for the PE, OWP and ML passes, so all FWD testing can be repeated in the same general location.

Detailed Test Plan (Test Pit Areas)

TP areas are tested identical to the procedures outlined for GPS testing in the main part of this manual.

Detailed Test Plan (Test Sections)

For SPS-7 test sections, the type of FWD testing does not vary between "BEFORE" and "AFTER" rehabilitation testing.

"BEFORE" Rehabilitation Testing

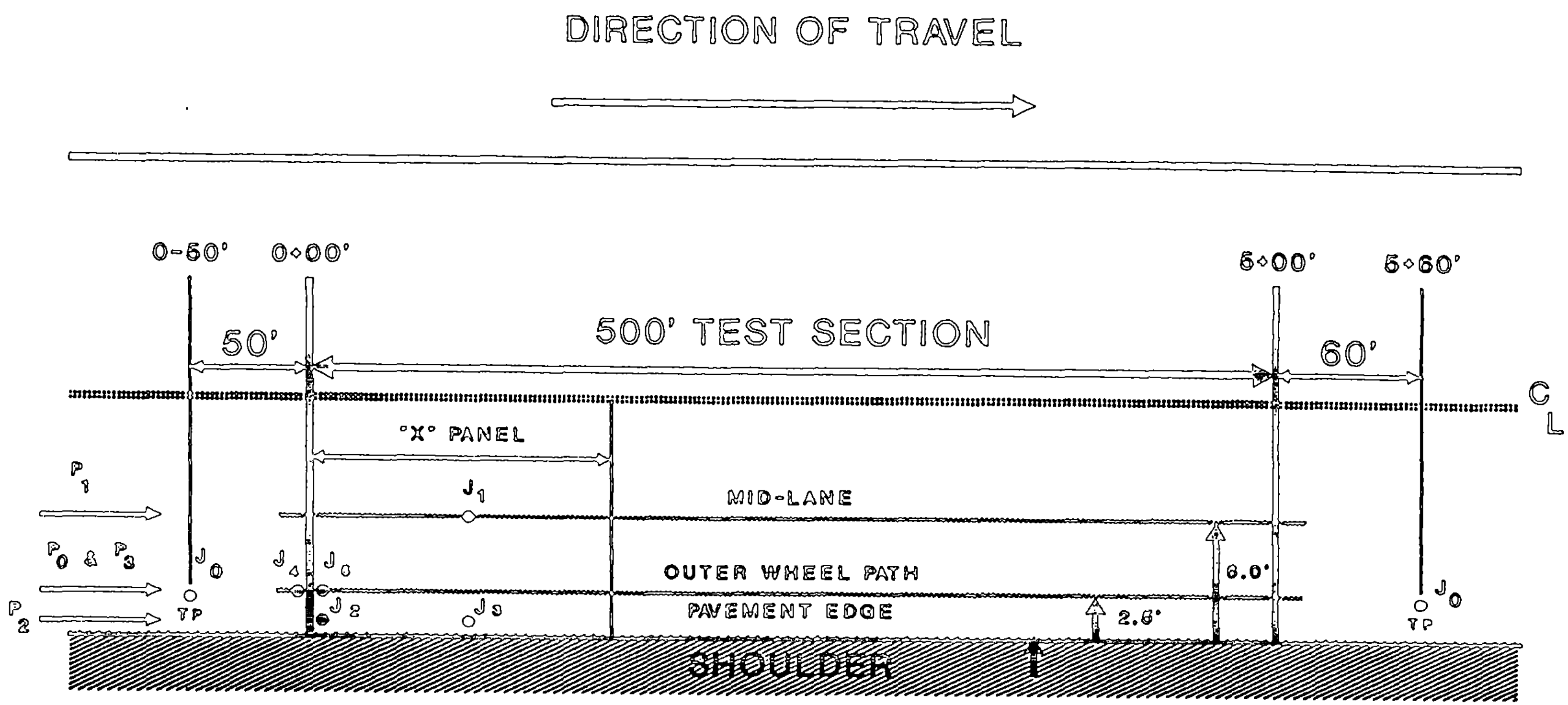
Jointed Pavements - For all SPS-7 sections, the testing "BEFORE" rehabilitation is similar to that outlined in the JCP Testing Plan for GPS, except the number of tests is reduced. The concept of "effective slab" is as defined previously. Figure B-7.1 illustrates the testing pattern for all "BEFORE" and "AFTER" testing. For all test sections, 10 effective slabs are tested. The "BEFORE" and "AFTER" test plan includes three passes along each section; (P_1) Mid-lane, (P_2) Pavement edge and (P_3) Outer wheel path. A preliminary pass (P_0) is also made in "BEFORE" testing to evaluate the test pit locations when appropriate.

FWD operators must consider the "end conditions" (joints, cracks, and patches) of the effective slabs when selecting slabs to test. The proportion of end conditions will determine the slabs tested. For example, if 24 total effective slabs are present with the following distribution:

6 terminated by a joint at one end and a joint at the other
6 terminated by a joint at one end and a patch at the other
6 terminated by a joint at one end and a crack at the other
6 terminated by a patch at one end and a crack at the other

two or three of each type of effective slab should be tested while attempting to get both types of end conditions in each category above (e.g. 1 or 2 with a joint at the approach end and a patch at the leave end, and 1 or 2 with a patch at the approach end and a joint at the leave end).

Five FWD tests are performed in each effective slab tested. These include a Deflection Basin test in the center of the slab (J1) on P_1, a Deflection Basin test along the approach corner (J2) and edge of the slab (J3) on P_2 and the two Load Transfer tests (J4 and J5) on P_3. Figure B-7.1 indicates the positions of the test locations for a given effective slab. Each test section has 10 effective slabs for a total of 450 FWD points (not including Test Pit locations). At a rate of 20 points per hour, the entire process (all eight test sections) will take approximately 23 hours. This does not include the time for testing Test Pit locations or taking temperature gradient measurements. The total time for all tasks should be approximately 30 hours.



NOTE: FWD TESTS AT TEST PIT LOCATIONS (TP) ON P_0 ("BEFORE" TESTING ONLY).

NOTE: TEN PANELS (EFFECTIVE SLABS) TESTED ON ALL SECTIONS.

NOTE: TEST PIT STATIONING MAY VARYTO CENTER (TP) IN PANEL.

NOTE: LATERAL OFFSETS SHOWN REPRESENT NOMINAL DISTANCES.

FIGURE B - 7.1 FWD TEST PLAN FOR ALL TESTING "BEFORE" AND "AFTER" REHABILITATION ON JCP PAVEMENTS.

CRCP Pavements - The pattern for testing SPS-7 CRCP is similar to the CRC Testing Plan outlined in the GPS portion of this manual, except the number of tests is reduced. Figure B-7.2 illustrates the testing pattern for all "BEFORE" and "AFTER" testing. Panels (slabs between transverse cracks) should be tested at approximate 50'(15.2m) intervals so 10 panels are obtained. The test pattern is the same regardless of the crack spacing (typically 1'-8' or 0.3m-2.4m).

"AFTER" Rehabilitation Testing: For all test sections originally having JCP, the test plan for "AFTER" rehabilitation testing is the same as "BEFORE" rehabilitation testing and the same effective slabs are tested. This includes both Deflection Basin and Load Transfer tests in the same manner and locations as were done previously.

For CRCPs, transverse cracks which defined the panels tested in "BEFORE" testing may not ever reflect through the overlay. Edge tests (C3) and deflection basin tests (C1) are performed at the same stations as "BEFORE". Load transfer (C4 and C5) and "corner" tests (C2) are performed at the first transverse crack behind the deflection basin test.

"LONG TERM" Rehabilitation Testing: For all SPS-7 sections, the plan for the "LONG TERM" rehabilitation testing follows the same logic as that for the "AFTER" rehabilitation testing. The same effective slabs are tested as were tested previously. (Note: the location of CRCP test points, especially C2, C4, and C5, may change as additional cracks reflect through the overlay.)

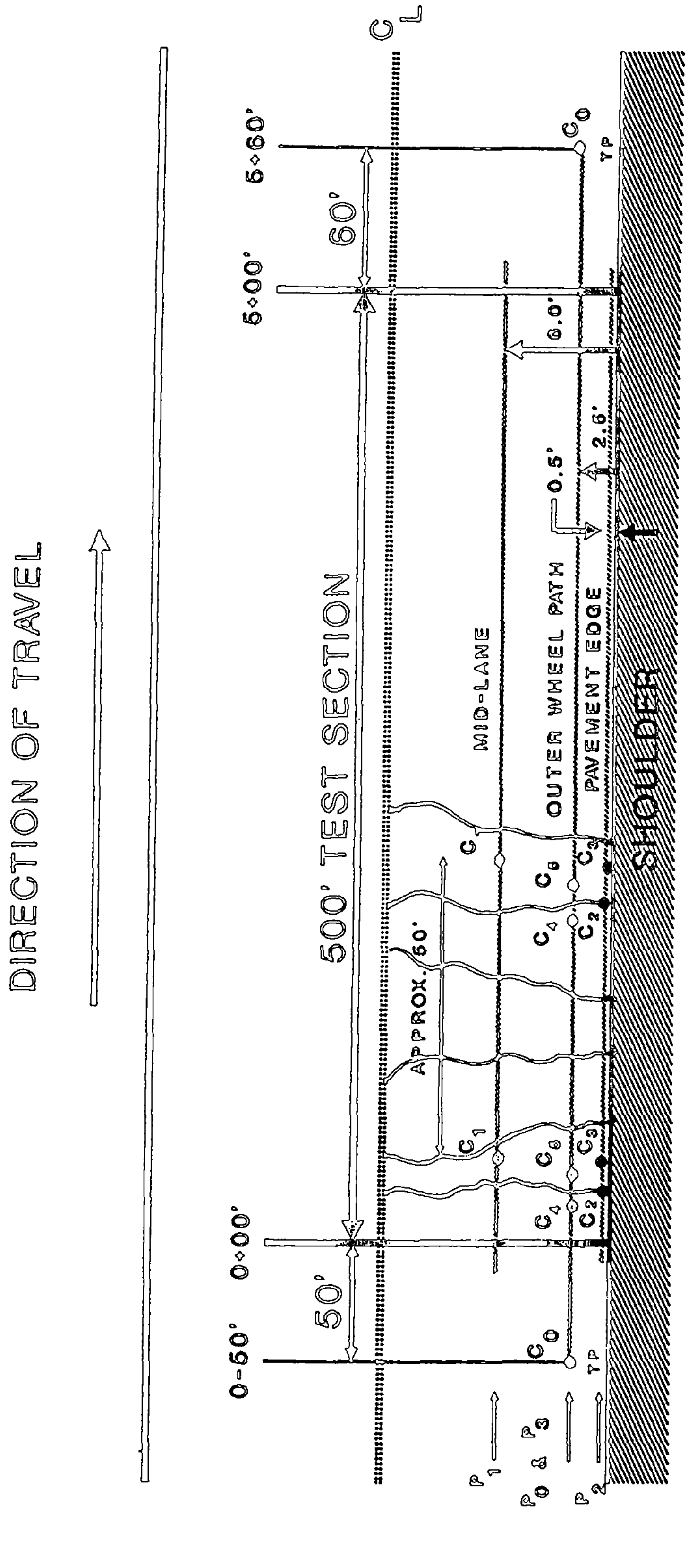
FWD operators must use their best judgement in the slab selection process and carefully note any abnormal conditions or unique situations encountered in the field. However, only 10 effective slabs should be tested on a given section.

Other FWD Operator Field Measurements

Temperature Gradient Measurements

Temperature gradient measurements for SPS-7 sites are obtained similar to that for GPS sections, with three exceptions as follows.

> For all testing ("BEFORE", "AFTER", and "LONG TERM"), temperature gradients measured at 3 depths are required, as illustrated in Figure B-7.3.
>
> Measurements will be obtained at only one location for each section. It is up to the FWD operator to assess variations in sun and wind exposures to and select the most representative location adjacent to the section limits for temperature measurements.



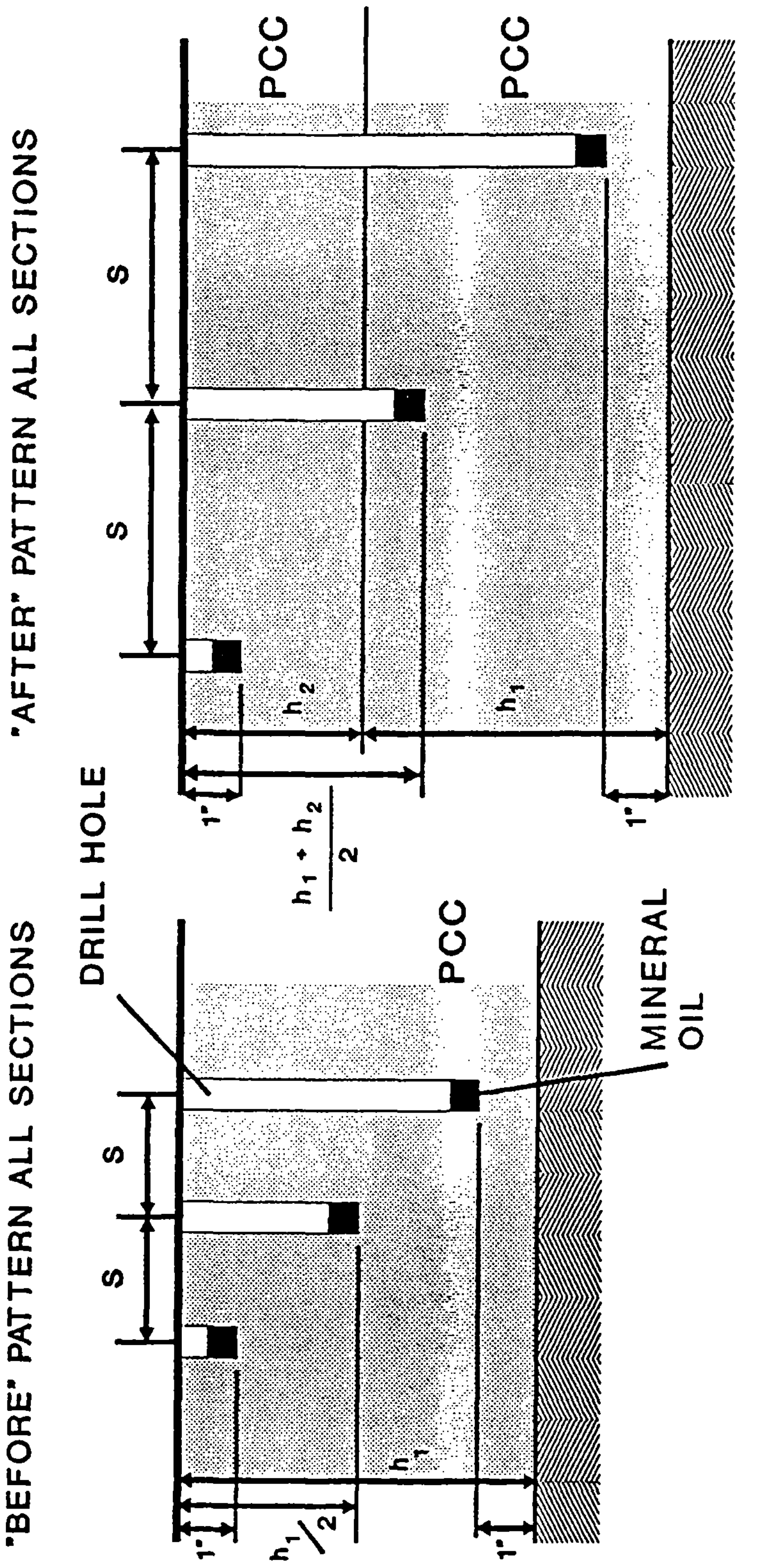
NOTE: FWD TESTS AT TEST PIT LOCATIONS (TP) ON P_0 ("BEFORE" TESTING ONLY).

NOTE: TEN PANELS (EFFECTIVE SLABS) TESTED ON ALL SECTIONS.

NOTE: TEST PIT STATIONING MAY VARY TO CENTER (TP) IN PANEL.

NOTE: LATERAL OFFSETS SHOWN REPRESENT NOMINAL DISTANCES.

FIGURE B - 7.2 FWD TEST PLAN FOR ALL TESTING "BEFORE" AND "AFTER" REHABILITATION ON CRCP PAVEMENTS.



NOTE: DRILL HOLE SPACING (s) SHOULD BE 18" CC OR GREATER.

FIGURE B - 7.3 TYPICAL DRILLING PATTERNS FOR TEMPERATURE GRADIENT DATA.

Temperature readings are obtained at 30 minute intervals, with the first readings prior to starting FWD testing on a section and the last readings after completion of the FWD testing on the section.

Joint/Crack Widths

Joint and crack width measurements for SPS-7 sites are obtained the same as for GPS sections under the JCP and CRCP Testing Plans.

Appendix B-8
FWD TESTING GUIDELINES
FOR SPECIFIC PAVEMENT STUDIES (SPS) EXPERIMENT 8
STUDY OF ENVIRONMENTAL EFFECTS
IN THE ABSENCE OF HEAVY LOADS

INTRODUCTION

This appendix provides information for Falling Weight Deflectometer (FWD) testing at individual test sites for the Long Term Pavement Performance (LTPP) study experiment SPS-8, "Study of Environmental Effects in the Absence of Heavy Loads." The intent of this document is to establish the testing requirements for SPS-8 sites based on a uniform set of assumptions. It is recognized that not all sites will conform to all assumptions contained herein. However, the objectives and approach to deflection data collection must be consistent so data obtained can be analyzed in a consistent manner. For deflection testing details not specifically addressed in this appendix, refer to the general guidelines in this manual.

The objective of the SPS-8 experiment is to measure the deterioration in pavement performance in the absence of heavy traffic loads. The proposed experiment encompasses both flexible and rigid pavement structures built on conventional, non-drained base materials over subgrades of coarse, inactive fine grained and active fine grained soils. The factors addressed are pavement type, layer thickness, and subgrade soil type across a factorial of temperature and moisture conditions. The analysis of data from this experiment will provide improved design of rigid and flexible pavements for environmental effects.

Experiment sites should conform to criteria contained in "Specific Pavement Studies Guidelines for Nomination and Evaluation of Candidate Projects for Experiment SPS-8, Study of Environmental Effects in the Absence of Heavy Loads", August 1991. Project sites may be included as part of new construction or reconstruction of flexible pavements or may be constructed as part of SPS-1 or SPS-2 projects.

FWD TEST PLAN

FWD testing for SPS-8 is performed in two phases, "AFTER" and "LONG TERM". The "AFTER" testing (3 to 6 months after construction) verifies material properties of the as-built pavement section for evaluating the effectiveness and long term performance of the section. "LONG TERM" testing (annually more than 6 months after construction) is used to evaluate the effect of temperature and moisture changes and traffic loading on pavement deflections and performance.

The pavement types in SPS-8 are flexible (asphalt concrete on a granular base) and rigid (jointed plain concrete on a granular base). These pavements are built on the same or separate projects. Deflection testing is done according to the FWD test plans developed for the SPS-1 and SPS-2 experiments. Table B-8.1 indicates the SPS FWD Plan applicable to testing of each SPS-8 pavement type.

For SPS-8 test sections, the type of FWD testing performed depends on the pavement type and appropriate test plan in Table B-8.1. Table B-8.2 summarizes the number of test points and approximate time requirements for each pavement type, including the time for the temperature gradient measurements (30 minutes per location).

FWD operators must use their best judgement and carefully note any abnormal conditions or unique situations encountered in the field. However, no more than 22 points on a given flexible section or 50 points on a rigid section are tested.

Table B-8.1 - FWD Test Plan by Pavement Type

Pavement Type	SPS FWD Plan	
	AFTER	LONG TERM
Flexible	SPS-1	SPS-1
Jointed Plain Concrete	SPS-2	SPS-2

Table B-8.2 - Number of Test Locations and Time Estimates

Pavement Type	AFTER			LONG TERM		
	PLAN	Number of Points	Time Estimate	PLAN	Number of Points	Time Estimate
Flexible	SPS-1	22 per section	3 hrs per section	SPS-1	22 per section	3 hrs per section
Jointed Plain Concrete	SPS-2	50 per section	5 hrs per section	SPS-2	50 per section	5 hrs per section

THIS PAGE INTENTIONALLY LEFT BLANK

Appendix B-9
FWD TESTING GUIDELINES
FOR SPECIFIC PAVEMENT STUDIES (SPS) EXPERIMENT 9
VALIDATION OF SHRP ASPHALT SPECIFICATIONS
AND MIX DESIGN
AND INNOVATIONS IN ASPHALT PAVEMENTS

INTRODUCTION

This appendix provides information for Falling Weight Deflectometer (FWD) testing at individual test sites for the Long Term Pavement Performance (LTPP) study experiment SPS-9, "Validation of SHRP Asphalt Specifications and Mix Design and Innovations in Asphalt Pavements." The intent of this document is to establish the testing requirements for SPS-9 sites based on a uniform set of assumptions. It is recognized that not all sites will conform to all assumptions contained herein. However, the objectives and approach to deflection data collection must be consistent so data obtained can be analyzed in a consistent manner. For deflection testing details not specifically addressed in this appendix, refer to the general guidelines in this manual.

The objective of the SPS-9 experiment is to compare the performance of asphalt pavements using specifications and mix design procedure developed by the SHRP Asphalt Research group to current participating agency specifications and procedures. The primary factors addressed are mix design method and asphalt concrete materials. Also, the study includes a detailed climatic factorial experiment. Accomplishing these objectives will provide improved tools for the design and construction of new and reconstructed flexible pavements and rehabilitation of rigid and flexible pavements using asphalt concrete overlays. FWD and laboratory testing will be used to characterize the materials and the variation within and between test sections to provide a basis for comparing the performance of the different sections at a site.

Experiment sites should conform to criteria contained in "Specific Pavement Studies Guidelines for Nomination and Evaluation of Candidate Projects for Experiment SPS-9, Validation of SHRP Asphalt Specification and Mix Design and Innovations in Asphalt Pavements", February 1992. Project sites are included as part of new construction on AC and/or PCC or reconstruction of flexible pavements or may be constructed as part of the rehabilitation of existing flexible, jointed concrete (JCP), or continuously reinforced (CRCP) pavements.

FWD TEST PLAN

FWD testing for SPS-9 is performed in multiple phases. For project sites on existing pavements, testing is conducted 0 to 3 months prior to overlay construction (labelled as

"BEFORE"), 3 to 6 months after construction (labelled as "AFTER"), and annually more than 6 months after construction (labelled as "LONG TERM"). Projects constructed as part of new or reconstruction of flexible pavements only "AFTER" and "LONG TERM" testing will be performed. The "BEFORE" testing assesses the condition of the existing pavement structure. The "AFTER" testing verifies material properties of the as-built pavement section for evaluating the effectiveness and long term performance of the section. "LONG TERM" testing is performed to evaluate the effect of temperature and moisture changes and traffic loading on pavement deflections and performance.

The pavement types included in an SPS-9 project are summarized in Table B-9.1, along with the required FWD testing. Table B-9.2 presents the SPS FWD Plan to use for each pavement type. Table B-9.3 summarizes the number of test points and time requirements for each pavement type, including the time for the temperature gradient measurements (30 minutes per location).

Each SPS plan referenced in Table B-9.2 has test locations, layouts and other information presented in terms of the time of testing relative to construction of the overlay, i.e. "BEFORE", "AFTER", and "LONG TERM" testing. On rehabilitation projects, Test Pits may be excavated, based on the policy of the participating agency. Therefore, pass P_0 testing included in the SPS-5 and SPS-6 FWD plans, will depend entirely on the agency's policy for Test Pit excavation.

Table B-9.1 - Required FWD Testing by Pavement Type

Existing Pavement Type	FWD Testing Required		
	BEFORE	AFTER	LONG TERM
New or Reconstructed Flexible	No	Yes	Yes
Flexible	Yes	Yes	Yes
AC Overlay of Flexible	Yes	Yes	Yes
AC Overlay of Rigid	Yes	Yes	Yes
Jointed Concrete	Yes	Yes	Yes
Continuously Reinforced	Yes	Yes	Yes

Table B-9.2 - FWD Test Plan by Pavement Type

Existing Pavement Type	SPS FWD Test Plan		
	BEFORE	AFTER	LONG TERM
New Construction or Reconstruction	N/A	SPS-1	SPS-1
Rehabilitation of Flexible	SPS-5	SPS-5	SPS-5
Rehabilitation of Jointed Concrete	SPS-6	SPS-6 (1)	SPS-6 (1)
Rehabilitation of Continuously Reinforced	SPS-7	SPS-6 (2)	SPS-6 (2)

(1) FWD test plan is identical to SPS-6 test plan for sections 3 and 6.
(2) FWD test plan is similar to SPS-6 test plan for sections 3 and 6, except testing is done at previously tested C1 locations.

Table B-9.3 - Number of Test Locations and Time Estimates

Pavement Type	BEFORE			AFTER			LONG TERM		
	PLAN	Number of Points	Time Est.	PLAN	Number of Points	Time Est.	PLAN	Number of Points	Time
New or Reconstruction	SPS-1	N/A	N/A	SPS-1	22 per section	3 hrs per site	SPS-1	22 per section	3 hrs per site
Flexible	SPS-5	22 per section	3 hrs per site	SPS-5	22 per section	3 hrs per site	SPS-5	22 per section	3 hrs per site
Rehabilitation of Flexible	SPS-5	22 per section	3 hrs per site	SPS-5	22 per section	3 hrs per site	SPS-5	22 per section	3 hrs per site
Rehabilitation of Jointed	SPS-6	50 per section	5 hrs per site	SPS-6 (1)	20 per section	3 hrs per site	SPS-6 (1)	20 per section	3 hrs per site
Rehabilitation of CRC	SPS-7	50 per section	5 hrs per site	SPS-6 (2)	20 per section	3 hrs per site	SPS-6 (2)	20 per section	3 hrs per site

(1) FWD test plan is identical to SPS-6 test plan for sections 3 and 6.

(2) FWD test plan is similar to SPS-6 test plan for sections 3 and 6, except testing is done at previously tested C1 locations.